IRRIGATION SCHEDULING AND WATER STRESS MITIGATION STRATEGIES IN UPLAND RICE (*Oryza sativa* L.)

GRITTA ELIZABETH JOLLY

(2017-21-031)

DEPARTMENT OF AGRONOMY

COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM - 695 522

KERALA, INDIA

2021

IRRIGATION SCHEDULING AND WATER STRESS MITIGATION STRATEGIES IN UPLAND RICE (*Oryza sativa* L.)

by

GRITTA ELIZABETH JOLLY

(2017-21-031)

THESIS

Submitted in partial fulfillment of the

requirements for the degree of

DOCTOR OF PHILOSOPHY IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF AGRONOMY
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM - 695 522
KERALA, INDIA
2021

DECLARATION

I, hereby declare that this thesis entitled **"Irrigation scheduling and water stress mitigation strategies in upland rice (*Oryza sativa* L.)"** 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.

Vellayani

Date: 02-09-2021

Gritta Elizabeth Jolly

(2017-21-031)

CERTIFICATE

Certified that this thesis entitled **"Irrigation scheduling and water stress mitigation strategies in upland rice (*Oryza sativa* L.)"** is a record of research work done independently by Ms. Gritta Elizabeth Jolly (2017-21-031) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Vellayani
Date: 02-09-2021

Dr. T. Sajitha Rani
(Major Advisor, Advisory Committee)
Professor and Head
Instructional Farm
College of Agriculture, Vellayani

CERTIFICATE

We, the undersigned members of the advisory committee of Ms. Gritta Elizabeth Jolly (2017-21-031), a candidate for the degree of **Doctor of Philosophy in Agriculture** with major in Agronomy agree that this thesis entitled **"IRRIGATION SCHEDULING AND WATER STRESS MITIGATION STRATEGIES IN UPLAND RICE (*Oryza sativa* L.)"** may be submitted by Ms. Gritta Elizabeth Jolly, in partial fulfillment for the degree.

Dr. T. Sajitha Rani
(Chairman, Advisory Committee)
Professor (Agronomy) and Head,
Instructional Farm
College of Agriculture, Vellayani

Dr. Shalini Pillai. P
(Member, Advisory Committee)
Professor and Head (Agronomy)
College of Agriculture, Vellayani

Sri. V. Jayakrishnakumar,
(Member, Advisory Committee)
Associate Professor (Agronomy)
College of Agriculture, Vellayani

Dr. Usha C. Thomas
(Member, Advisory Committee)
Associate Professor (Agronomy)
AICRP on forage crops and utilization
College of Agriculture, Vellayani

Dr. Roy Stephen
(Member, Advisory Committee)
Professor (Crop Physiology) and ADR,
RARS (SZ),
College of Agriculture, Vellayani

EXTERNAL EXAMINER
Dr. S Sunitha
Principal Scientist (Agronomy)
Central Tuber Crops Research Institute
Sreekariyam, Thiruvananthapuram
Kerala

ACKNOWLEDGEMENT

First of all, I bow my head before the Almighty God for making me confident and optimistic throughout my journey and enabled me to complete the thesis work successfully on time.

With immense pleasure, I wish to express my sincere gratitude and indebtedness to ***Dr. T. Sajitha Rani,*** *Professor and Head, Instructional Farm, College of Agriculture, Vellayani and Chairperson of my Advisory Committee for her valuable suggestions, constant support and diligent assistance and co-operation throughout the investigation. This work would not have been possible without her valuable help and support. It was her sincerity, dedication and perfectionism which influenced me deeply to improve myself in all aspects. I feel proud of myself in confessing that it has been a unique privilege for me being one of her students.*

I am indebted to ***Dr. Shalini Pillai. P,*** *Professor and Head, Department of Agronomy, College of Agriculture, Vellayani, and member of Advisory Committee, for her valuable advice, extreme patience and whole hearted approach for the successful completion of the thesis.*

I am extremely thankful to ***Dr. Roy Stephen,*** *Professor and Associate Director, RARS (SR), Department of Crop Physiology, College of Agriculture Vellayani, and a member of Advisory Committee for the support, constant criticism and valuable suggestions rendered throughout the period of research work and course of study.*

With great pleasure, I express my gratitude to ***Dr. Usha. C. Thomas,*** *Assistant Professor, AICRP on forage crops and utilization, College of Agriculture, Vellayani and a member of Advisory Committee for her encouragement, wholehearted help and support throughout the period of my research work.*

My heartiest and esteem sense of gratitude and indebtedness to ***Sri.V. Jayakrishnakumar,*** *Associate Professor, Department of Agronomy, College of Agriculture, Vellayani for his prudent suggestions, advisement and critical assessment right from the beginning.*

I owe my heartfelt gratitude to Dr. V. M. Bhale, Vice Chancellor, Dr. PDKV, Akola and Dr. M. R. Deshmukh, Associate Professor, Dept. of Agronomy, Dr. PDKV, Akola, for their valuable advices and support.

I extend my thankfulness and respect to all the faculty members of Department of Agronomy for their constant encouragement and support throughout my course work. Words are scarce to express my deep sense of gratitude to the all the non teaching staff of our department for their timely help and support during the lab work.

*Words would fail to express my thanks to my juniors **Vijay, Sandra, Sanika and Merin** for their love and support. I also thank my roommates Greeshma and Thasni for their constant and loving support which energized me in taking up the challenges faced during the course programme positively. I will always remember the love and support given by my dear juniors Arunjith, Mubi, Pooja, Elso and Chippy. I duly acknowledge the encouragement, help, love and moral support by my dear class mates **Lekshmi Sekhar, Dhanalakshmi and Anjana.** The love and support of my batchmates Kari, Nihala, Pinkymol, Amruthap, Chinju, Mithra, Nithish, Elizabeth and Reshma Murugan are also remembered with sincere thanks.*

The care, support and valuable advice given by Dr. Nimmy Jose, Professor and Head, RRS Moncompu will always be cherished gratefully. The advice and support of Dr. Reena Mathew and the love and support of Dr. Rani. B, Dr.Aparna and Dr. S. Anil kumar are gratefully acknowledged. I also thank all the faculties of Lovely Profssional University, especially Dr. Chandra Mohan Mehta, Head (Department of Agronomy), Dr. Sandip Menon, Dr. Rubeena Gill, Dr. Prasanna Kumar and Gayatrikumari. Words would not be enough to express my gratitude to my students Lokesh, Christy, Hari and Pavan for their constant support and love.

I am grateful to all the labourer chettans for their support throughout the thesis work, especially during the lockdown period. I sincerely thank Manikandan chettan, Savitha chechi, Laalan, Sumesh chettan, Shibu chettan, Laalan chettan, Shaju chettan and Bindhu chechi for their love and care.

All my family members especially Ammachi, Uncle, Jolly aunty, Appu, Mariammanty, Kochanty, Valyanty, Valyauncle, Kochuncle, Kochanty, Kochuchettay, Deepu, Valyettay, Dona, Reeja, Keerthy, Rinku, Sosanty, Appus, Ashu, Ichi, Saji uncle, Antichen uncle who stood by me during the Ph. D programme is remembered with love and gratitude. The support of Fr. Thomas Kocheleyachankalam, Fr. Antony Thuruthy, Sr. Anit, Neha sister, Dolly sister, Poonam sister are also sincerely acknowledged.

I am also indebted to express my thanks to Reni, Silpa, Abuji, Gopan, Anjana, Dundu, Jesma, Shana

Ishrath, Kari, Greeshma, Sandra, Amla Mary, Amruthap, Nihala, Pinkymol and Chinju, Sutty, Susoo and Liz for their hearted support throughout my research work.

At this moment, I recall with love, cooperation and caring extended by ***Reshma Gopi*** *who stood with me during all hardships I passed through and kept me encouraged and happy throughout the course of work. Words are inadequate to express my thanks to my beloved friends* ***Arya, Thomaskutty, Tony, Miya, Anjana, Meldy, Shamna, Mili, Staphy*** *and for their constant support, love, care and for the happiest moments we cherished together.*

Mere words cannot express my profound indebtness to my belovd grandmother ***Smt. Ealikkutty Alexander,*** *my beloved father* ***Sri. Jolly Mathew*** *my dearest mother* ***Smt. Daisamma P. Antony*** *and my beloved sister* ***Kumari Greeshma Rose Jolly*** *for their unconditional love, sacrifices and support bestowed on me during my hard periods.*

I once again express my sincere gratitude to all those who helped me in one way or another in the successful completion of this venture.

Gritta Elizabeth Jolly

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABBREVIATIONS

%	Per cent
@	At the rate of
ºC	Degree Celsius
$	Dollars
ºN	Degree North
ºE	Degree East
µ	Micro
µ moles g^{-1}	Micro moles per gram
₹	Rupees
ANOVA	Analysis of Variance
AWD	Alternate Wetting and Drying
B: C	Benefit Cost
BD	Bulk density
BSSH	Bright sunshine hours
Ca	Calcium
$CaCO_3$	Calcium carbonate
CGR	Crop Growth Rate
cm	centimeter
CD	Critical difference
cfu	Colony forming unit
CPE	Cumulative pan evaporation
D	Depth

DAS	Days after sowing
DMSO	Dimethyl Sulfoxide
E_{pan}	Pan evaporation
ET	Evapotranspiration
et al.	Co- workers/Co-authors
FC	Field capacity
Fe	Iron
$g\ g^{-1}\ d^{-1}$	Gram per gram per day
$g\ cc^{-3}$	Gram per centimeter cube
HYV	High yielding varieties
IARI	Indian Agricultural Research Institute
ICAR	Indian Council of Agricultural Research
i.e.	That is
INCID	Indian National Committee on Irrigation and Drainage
IW	Irrigation water
KAU	Kerala Agricultural University
kg	Kilogram
$kg\ ha^{-1}$	Kilo gram per hectare
$kg\ ha^{-1}cm^{-1}$	Kilo gram per hectare per centimeter
$kg\ ha^{-1}mm^{-1}$	Kilogram per hectare per millimeter
$kg\ m^{-3}$	Kilogram per meter cube
K	Potassium
KUE	Potassium use efficiency
L	Litre

L ha^{-1}	Litres per hectare
LAI	Leaf area index
LAR	Leaf area ratio
m^{-2}	Per Meter square
mg	Milligram
Mg	Mega gram
mg g^{-1}	Milligram per gram
mm	Millimeter
mm d^{-1}	Millimeter per day
M ha	Million hectare
mL	Milli litre
MO	Moncompu
N	Nitrogen
NABARD	National Bank for Agriculture and Rural Development
NAR	Net Assimilation Rate
NH_4	Ammonium
NMMI	National Mission on Micro Irrigation
NS	Not significant
P	Phosphorous
PE	Pan Evaporation
PGR	Plant Growth Regulators
pH	Power of Hydrogen
PI	Panicle initiation

PPFM	Pink Pigmented Facultative Methylotrophs
ppm	Parts per million
PWP	Permanent wilting point
q	Quintal
q ha^{-1}	Quintal per hectare
RGR	Relative Growth Rate
RLWC	Relative leaf water content
SAP	Super absorbent polymer
SE	Standard Error
SMD	Soil moisture deficit
SPAD	Soil Plant Analysis Development
SRI	System of Rice Intensification
SLW	Specific leaf width
t	Tonnes
t ha^{-1}	Tonnes per hectare
viz.	Namely
WUE	Water Use efficiency
Z	Root zone depth
Zn	Zinc

APPENDICES

1. INTRODUCTION

Agriculture consumes about 85 per cent of the total water used worldwide in various human activities (Jury and Vaux, 2007). Most of the agricultural consumptive use is from rainfall (80 %), while the rest originates from water withdrawals that are diverted for irrigation. The surface area under rainfed agriculture largely exceeds the area devoted to irrigation; in fact, only 18 per cent of the cultivated land in the world is irrigated. However, the value of irrigated production is over 45 per cent of the total, indicating the importance that irrigated agriculture has for feeding the world now and in the future (Molden, 2007). Because of the increasing demands for food production caused by population growth, it is anticipated that irrigation water demand will continue to increase in the foreseeable future, albeit at a slower rate than that experienced in the past decades (Jury and Vaux, 2007). The difficulties in developing additional irrigation water supplies to meet the anticipated demand increase will lead to a scenario of increased water scarcity in the foreseeable future. Therefore, most efforts should concentrate on how to increase the efficiency of water use in irrigation, or on how to increase water productivity beyond the present values. The challenge ahead is to improve productivity while minimising waste and at the same time, achieving a high level of sustainability. Faced with uncertainty about their water needs, farmers always tend to avoid risk by staying on the safe side and applying excessive irrigation water. This approach is not only becoming unacceptable, but it is not even feasible in water-scarce areas. Farmers will have to produce more with less irrigation water, a path that has already been taken in recent but that has to be more vigorously pursued worldwide. Considering irrigation efficiency and environmental issues, microirrigation, which is the precise application of water on or below the soil surface at low pressure using small devices like spray, mist, sprinkler or drip water, is becoming more attractive (Hla and Scherer, 2003). Microirrigation provides a constant supply of water in the crop zone and has been proven to provide a higher crop yield and increased water use efficiency over conventional irrigation methods.

Rice is the staple food for half of the world's population, and rice farming is a livelihood for millions of farmers in Asia. In India, it provides an individual with 32 per cent of the total calorie requirement and 24 per cent of the total protein requirement daily (Zimmermann and Hurrell, 2002). This crop is mostly grown in puddled soil by transplanting, and flood irrigation is practised by farmers. Water or irrigation input to transplanted rice typically ranges from 1000 to 2000 mm depending upon the growing season, climatic condition, soil type and hydrological conditions. Facing water scarcity and climate change, reducing the water requirement of this crop is a challenge. Out of 42.75 million hectares (m ha) rice area, only 25.12 m ha is under irrigation (Mandal *et al*., 2019). Regarding water resources, depletion of groundwater is alarming in the North Indian states. On the other hand, it is under-utilized in Eastern India. Microirrigation, *i.e.*, sprinkler and drip methods have been used to minimize water use and enhance water use efficiency of rice.

Several strategies are being pursued to reduce rice water requirements, such as saturated soil culture, alternate wetting and drying, system of rice intensification (SRI) and aerobic rice. In addition, an emerging water-saving technique is the use of micro-irrigation (sprinkler and drip irrigation).

The major limitation with the cultivation of upland rice is that the yield potential of upland rice cultivars is far less as compared to that of the wetland rice cultivars, which limits its cultivation in most of the dryland tracts. The quality rice cultivars are also rare in the upland conditions. And also, the quality and trust of upland cultivars are been preferred by elite group in the market. It is necessary to identify the best suitable upland rice varieties suited to a particular region.

Another strategy to ensure better yield and productivity of the upland rice is the proper scheduling of irrigation. Many scientific approaches for scheduling irrigation have been utilized, *viz*., IW/CPE method, soil moisture depletion method and critical growth stage approach. The major problem associated with upland rice during the summer season is moisture stress. Numerous water stress mitigation strategies are being adopted to mitigate the stress caused by water shortage like application of hydrogel polymer and spraying of pink pigmented facultative methylotrophs (PPFM), which can ensure reasonable yield during water scarce situations by reducing the water requirement by the crop. The hydrogel can retain water and plant nutrients and release it to the plants when surrounding soil near the root zone of plants start to dry up (Abobatta, 2018). The methanol consumed by methylobacterium are released as a by-product via the leaf stomata and contributes to the epiphytic fitness of the organism. These PPFMs are especially abundant on leaves of field-grown crops averaged about 106 cfu of PPFMs per leaflet, and typically less than 80 per cent of the viable bacteria recovered from leaves were PPFMs, which helps in mitigating the water stress to a great extent. In light of the above facts, the present study was undertaken with the following objectives:

- to identify a suitable variety and irrigation method for upland rice
- to standardize irrigation scheduling and
- to assess the effect of moisture stress mitigation strategies on the growth, yield and economics of upland rice

2. REVIEW OF LITERATURE

Several strategies are being pursued to reduce rice water requirements, such as saturated soil culture (Borell, 1997), alternate wetting and drying (Tabbal *et al*., 2002, Li and Barker, 2001), system of rice intensification (SRI) (Stoop *et al*., 2002, Thakur *et al*., 2014) and aerobic rice (Bouman *et al*., 2006, Mandal *et al*., 2013). The most recent approach is micro-irrigation which includes sprinkler and drip irrigation, aiming at minimizing water use and enhancing water use efficiency (WUE) by crops. The reviews pertaining to the importance of microirrigation, varietal differences, various approaches of scheduling irrigation and the moisture stress mitigation strategies have been furnished below:

2.1 IMPACT OF METHODS OF IRRIGATIONS AND IRRIGATION LEVELS ON THE GROWTH AND YIELD

2.1.1. Impact of Sprinkler Irrigation on the Growth Parameters, Yield Attributes, Soil Moisture Parameters and Economics

2.1.1.1. Influence of Sprinkler Irrigation on Growth Parameters of Crops

In a study by Shahanila *et al*. (2015), with four irrigation levels *viz*., sprinkler irrigation at 75 per cent pan evaporation, 100 per cent pan evaporation, 125 per cent pan evaporation and life saving irrigation at 5cm depth at required stages, sprinkler irrigation at 125 per cent pan evaporation resulted in significantly higher plant height and tiller numbers per hill in rice.

Senthil Kumar *et al*. (2018), while studying the effect of sprinkler irrigation levels on the performance of rice genotypes under aerobic condition with three levels of irrigation I_1 - surface irrigation method, I_2 - sprinkler irrigation at 125 per cent pan evaporation, I_3 - sprinkler irrigation at 150 per cent pan evaporation, have observed that 150 percentage pan evaporation registered higher plant height over lower levels.

2.1.1.2 Impact of Sprinkler Irrigation on the Yield Attributes and Yield

Studies during the 1980s addressed sprinkler irrigation of rice in Louisiana (Westcott and Vines, 1986) and Texas (McCauley, 1990), and reported large yield reductions in rice due to sprinkler irrigation compared with flooded rice production.

In Coimbatore, higher seed cotton yield (23.3 q ha^{-1}) was recorded consuming only 316 mm water through sprinkler, whereas, basin system recorded the lowest yield of 18.5 q ha^{-1}, consuming 610 mm. While at Madurai, similar trend in groundnut was observed with sprinkler irrigation over surface irrigation (Sivanappan, 1987).

According to a survey by Padhye (1990), the percentage increase in the yields of coconut, coffee, sugarcane and vegetables, using sprinkler method was 14%, 17%, 11% and 9-30% respectively. Considerable amount of water saving and yield improvement has been observed in many crops. Water saving of 9.03 cm and yield improvement of 3.78 q ha^{-1} were registered among food grain crops, while, it was 18.01 cm and 3.51 q ha^{-1} among oilseed crops.

Average incremental yield in maize and wheat was 4.45% and 6.95%, respectively at Udaipur, Rajasthan due to adoption of sprinkler irrigation over flood irrigation (Acharyna *et al*., 1993). Mehta (1993) reported about 17 percentage improvement in groundnut yield and 40 percentage improvement in water use efficiency in summer groundnut at Dharwad, Karnataka.

A study revealed that the sprinkler irrigation method is used mainly for irrigating *rabi* crops, though it was used sparingly for *kharif* crops like bajra in case of monsoon failure (NABARD, 1997).

An experimental study by Kundu *et al*. (1998) suggested that sprinkler irrigation can be used successfully for cultivating paddy crop. Vories *et al*. (2002) compared furrow irrigation of rice with conventional flooding and reported consistently lower yields.

Based on two years pooled data, Ramanjaneyulu *et al*. (2013) further reported 31.7%, 50.2% and 17.5 to 32.4% higher yield in cotton, redgram and castor crops with two times sprinkler irrigation vis-à-vis rainfed crop. However, they could not find much difference between one flood irrigation and two sprinkler irrigations with regard to economic yield of these crops.

About 30 percentage of productivity gain due to sprinkler irrigation vis-a-vis conventional method of irrigation was observed for winter maize in Gujarat showing the superiority of sprinkler irrigation over flood irrigation method (Shirazi *et al*., 2014).

2.1.1.3 Soil Moisture Studies

Datta (1973) compared sprinkler irrigation with furrow irrigation for potato crop and found that the application and water use efficiency were higher with sprinkler irrigation. Further, he reported 35 percentage water saving over furrow irrigation.

Agrawal and Agrawal (1977) compared sprinkler irrigation with surface irrigation and found that there was increase in the total irrigated area from 8 to 140 %. Besides, the time required for each irrigation was reduced by 30 to 50 % by the use of sprinkler irrigation.

Sharma (1984) compared sprinkler irrigation with surface method for various crops and calculated water savings by individual crops and reported that the available water can be used to the maximum benefit with sprinkler irrigation and he has also reported that the application of water through sprinklers has improved on-farm irrigation efficiency up to 80 percentage under the prevailing climatic conditions in Indian sub continent.

At Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, studies indicated that the efficiency of the sprinkler system is higher than the border method of irrigation. The overall application efficiency is estimated to be 60-70% in surface irrigation, whereas the same comes to 70-80 % for sprinkler and 90% for drip irrigation method (Sivanappan, 1987).

In South Gujarat, about 20.3% water saving and 47.6% water use efficiency were recorded with mini sprinkler in safflower as compared to conventional methods of irrigation (Abrol and Sharma, 1990). He also reported that the water use efficiency was to be higher in all schedules of sprinkler irrigation and 9.6 to 53.9% of irrigation water could be saved when compared to surface irrigation method in groundnut crop. The net income per mm water used was found to be more under all the sprinkler irrigation schedules vis-a-vis surface irrigation.

Sugarcane, a water-intensive crop, did not show any impressive result in terms of water saving and yield gain due to sprinkler irrigation. Similarly, cotton crop also did not show substantial gain (INCID, 1998).

According to Perry *et al*. (2009) switching from flood or furrow irrigation to low-pressure sprinkler systems reduces water use by an estimated 30%. Ramanjaneyulu *et al*. (2013) reported that farm pond water can be safely and efficiently utilized for scheduling life saving irrigation to dry land crops like cotton, red gram and castor especially to avert mid season or terminal dry spell.

2.1.1.4 Economics of Sprinkler Irrigated Upland Rice

An evaluation study carried out in Rajasthan using a sample data of 56 farmers showed that the sprinkler system helps increasing the area devoted to remunerative crops like HYV wheat and mustard in *rabi* seasons. The increased irrigated area also generated additional income to the adopters of sprinkler irrigation, besides substantially increasing wage employment. The study further underlines that the benefits could have perhaps been higher and the power supply been available for a longer duration during the cropping seasons (NABARD, 1989). On the same line, an another study carried out in Barmer district of Rajasthan also indicates that the adoption of sprinkler irrigation increases the gross irrigated area, cropping intensity and helps farmers to switch over to cash crops like cumin, isabgol, mustard, etc.

Acharyna *et al*. (1993) reported 29% water saving along with 35% yield increase in fenugreek crop based on a three year trail in North Gujarat. Further, net income per mm of water used rose from ₹ 2.80 with surface irrigation to ₹ 9.57 with sprinkler method of irrigation in farmer's fields.

Kumar and Senseba (2008) have reported that the highest benefit cost ratio (2.03) was found in sprinkler irrigation and drip irrigation (2.02) , followed by flood irrigation (1.80), furrow irrigation (1.74) and lowest was found in control (1.10), when a comparative analysis of different methods of irrigation methods in broccoli in terms of monetary returns was carried out.

2.1.2. Impact of Drip Irrigation on the Growth Parameters, Yield Attributes, Physiological Parameters, Soil Moisture Parameters and Economics

2.1.2.1. Influence of Drip Irrigation on the Growth Parameters

Rao *et al.* (2016) assessed the effects of drip irrigation system for enhancing rice yield under system of rice intensification management and revealed that the growth parameters like plant height, number of tillers, SPAD and root length were significantly higher in drip irrigation in which emitters were placed at a spacing of 20 cm which gave more even distribution of water to the plants, followed by emitters spaced at 40 cm, compared to the conventional method of irrigation.

Sharma *et al.* (2016), in a study conducted in okra which consisted of three levels of nitrogen fertilizers *i.e.*, F_1-60%, F_2-80% and F_3-100% of recommended dose of fertilizer N and three drip irrigation levels I_1-60%, I_2-80% and I_3-100% of cumulative pan evaporation, plant population after 40, 80 and 120 days of sowing was maximum in F_2I_2 treatment with 96.1%, 86.7% and 82.2% respectively. Plant height after 40, 80 and 120 days of sowing was maximum in F_2I_2 treatment 48.73

cm, 98.07 cm and 145.07 cm respectively. Days to first flowering were minimum in F_2I_2 treatment (39.97 days), days to fruit initiation and days to fruit maturity were minimum in F_3I_2 treatment (45.49 days 48.1 days respectively).

2.1.2.2 Influence of Drip Irrigation on the Yield and Yield Attributes

The experiment carried out by Cetin *et al.* (2002) showed that the average fruit yield of fresh market tomatoes irrigated by drip was 132.2 tones ha^{-1} while the yield was 54.8 tones ha^{-1} under conventional irrigation and local conditions of Eskişehir.

Paul *et al*. (2013) conducted an experiment to evaluate the yield, water-use efficiency and economic feasibility of capsicum grown under drip and surface irrigation with non-mulch and black linear low density poly ethylene (LLDPE) plastic mulch. The study indicated better plant growth, more number of fruits $plant^{-1}$ and enhancement in the yield under drip irrigation system with LLDPE mulch. The highest yield (28.7 t ha^{-1}) was recorded under 100% net irrigation volume with drip irrigation (VD) and plastic mulching as compared to other treatments.

The effects of drip irrigation system for enhancing rice (*Oryza sativa* L.) yield under system of rice intensification management was studied by Rao *et al*. (2016) and reported that among treatments, T_1: conventional paddy cultivation under continuous flooding, T_2: System of Rice Intensification (SRI) methods which include alternate wetting and drying, T_3: SRI methods with drip-irrigation, the emitters being spaced at 20 cm, T_4: SRI methods with drip emitters spaced at 30 cm, and T_5: SRI methods with drip emitters spaced at 40 cm, yield and yield-contributing parameters like productive tillers m^{-2}, number of grains $panicle^{-1}$, average panicle length and weight, average grain yield (7 t ha^{-1}), and harvest index were significantly higher in T_3 treatment as compared with conventional practice T_I.

Sharda *et al.* (2016) in an experiment on rice variety 'PR-115' with drip at 1.5, 2.25 and 3.0 times pan evaporation (PE), grain yield obtained was 7.34–8.01 and 6.63–7.60 tonne ha^{-1} respectively, with 860 and 1455 mm water in drip and flood irrigation respectively.

Kumar *et al.* (2017), in a study on the effect of different irrigation methods on yield attributes of chickpea and coriander intercropping observed the highest yield (11.78 q ha^{-1}) in drip irrigation system followed by sprinkler irrigation (10.75 q ha^{-1}), furrow irrigation (9.93 q ha^{-1}), flood irrigation (9.86 q ha^{-1}) and lowest yield found in control (5.22 q ha^{-1}).

Bansal *et al*. (2018) conducted an experiment on on-farm drip irrigation in rice for higher productivity and profitability in Haryana, India with three different irrigation methods *viz.* drip, sprinkler and flood irrigation methods and found out that rice grain yield (6950 kg ha^{-1}) was significantly increased by drip irrigation method, compared to flood irrigation (6225 kg ha^{-1}) method.

According to Sarkar *et al*. (2018), among the treatments (i) T_1- conventional irrigation with 5 cm of water in each irrigation after disappearance of water, (ii) T_2-0.8 E pan under drip irrigation @ 4 l h^{-1} at 3 days interval, (iii) T_3-1.0 E pan under drip irrigation @ 4 l h^{-1} at 3 days interval and (iv) T_4-1.2 E pan under drip irrigation @ 4 l h^{-1} at 3 days interval, the average yield at T_1, T_2, T_3 and T_4 treatments were 2.29 t ha^{-1}, 3.10 t ha^{-1}, 2.44 t ha^{-1} and 2.54 t ha^{-1} respectively, indicating that the average yield was more under the drip system in comparison to the conventional system.

2.1.2.3. Soil Moisture Studies in Drip Irrigation

The studies on cotton in Harran Plain of Turkey showed that water requirement could be 1113 mm (Kanber *et al*., 1993) and 937 mm (Cetin and Bilgel, 2002) by furrow irrigation. Cetin and Bilgel (2002) also reported that water requirement of cotton could be 619 mm by drip irrigation in order to obtain approximately same yield. Accordingly drip irrigation resulted in not only higher cotton yield but also considerable water savings.

Postel (2002) claims that drip irrigation has the potential to double the crop yield per unit of water in most vegetables, cotton, sugar cane and orchard and vineyard crops.

According to Medley and Wilson (2005), a 58 percent saving of irrigation water was observed in drip irrigation, compared to flood irrigation with rive var. ‘Cocodrie’.

A collection of research results from various Indian research institutes indicates typical water use reductions with drip irrigation of 30-60% and typical yield increase of 20-50% for a variety crops, including cotton, sugarcane, grapes, tomatoes, and bananas (Kooij *et al*., 2013).

Kumar *et al*. (2016) has observed an increase in water use efficiency for drip irrigation system in brinjal variety Pant Samrat. Among the drip irrigation levels, the highest field water use efficiency (6148.31 kg ha^{-1} cm^{-1}) was found at 65% irrigation level, indicating comparatively more efficient use of irrigation water with a possibility of water saving of 35 percentage.

Kumar *et al.* (2017) in a study on effect of different irrigation methods on yield attributes and economics of chickpea and coriander intercropping in *Vertisol* of Chhattisgarh plains, compared five different irrigation methods *viz.* flood irrigation, furrow irrigation, sprinkler irrigation, drip irrigation and control and reported that water use efficiency was the highest in drip irrigation (4.71 kg ha^{-1} mm^{-1}) followed by sprinkler irrigation (4.30 kg ha^{-1} mm^{-1}), furrow irrigation (3.97 kg $ha^{-1}mm^{-1}$), flood irrigation (3.94 kg ha^{-1} mm^{-1}) and minimum was recorded under flood control (2.08 kg ha^{-1} mm^{-1}).

In a study by Bansal *et al.* (2018) on on-farm drip irrigation in rice for higher productivity and profitability in Haryana, India, in which three different irrigation methods *viz*. drip, sprinkler and flood irrigation methods were adopted, drip irrigation method of paddy cultivation has recorded considerably higher water use efficiency (17.1 kg ha mm^{-1}) followed by sprinkler method (11.5 kg ha mm^{-1}).

In an experiment on the evaluation of drip irrigation system for water productivity and yield of rice, Parthasarathy *et al*. (2018) has observed twice the water productivity in drip irrigated aerobic rice, compared to that of the conventional aerobic rice production system.

In a study conducted by Sarkar *et al*. (2018), with the objectives to determine the water requirements of summer rice under drip irrigation and to compare the water requirements of summer rice under drip and conventional (flooding) irrigation and yield of summer rice cultivation under drip irrigation, it was observed that the water requirements under drip irrigation for all the treatments were less as compared to conventional (flooding) irrigation. This indicated that the WUE was more under the drip system compared to conventional system.

Soman *et al.* (2018) has reported a water saving of 40 percentage in drip irrigated rice, as compared to that in conventional, flood irrigated system while evaluating the effect of drip irrigation and fertigation on the performance of several rice cultivars in different rice ecosystems in India.

2.1.1.4 Economics of Drip Irrigation

According to Paul *et al.* (2013), 100% net irrigation volume with drip irrigation and plastic mulching increased the yield and net seasonal income by 57 percentage and 54 percentage respectively as compared to conventional surface irrigation without mulch with a benefit cost ratio of 2.01. The benefit cost ratio was found to be the highest (2.44) for the treatment VD without mulch. Drip irrigation system could increase the yield by 28 percentage over surface irrigation even in the absence of mulch.

The findings of the study by Rao *et al*. (2016) indicated that the highest net return (\$ 2442 ha^{-1} $year^{-1}$) and B:C ratio 3.23 can be obtained under SRI management with drip irrigation emitters spaced at 20 cm, followed by SRI with drip irrigation emitters spaced at 30 cm. The lowest net return (\$ 853 ha^{-1} $year^{-1}$) and lowest benefit: cost (2.18) ratio was obtained with conventional practice of paddy cultivation. Based upon his research in Hungary, he also reported that optimal water use using drip technology can enhance returns from system of rice intensification with enhanced labour productivity and far higher net income than the traditional methods of cultivation of rice.

Kumar *et al.* (2017) has reported that the highest benefit cost ratio (2.03) was found in sprinkler irrigation and drip irrigation (2.02), followed by flood irrigation (1.80), furrow irrigation (1.74) and lowest was found in control (1.10), when a comparative analysis of different methods of irrigation methods in terms of monetary returns was carried out.

2.1.3 IMPACT OF MICROIRRIGATION OVER CONVENTIONAL IRRIGATION METHODS

According to Maadramootoo and Rigby, (1991), in addition to farm productivity (crop yield and output), farmer income and food security are also increased with microirrigation. With earlier harvests, labour costs are reduced. Improvements in drip irrigated crop quality have also been observed.

Continuous submergence of the plots increases the rate of seepage and percolation and consequently increases the amount of water use (Borrell *et al.*, 1997).

The loss components of a puddled rice field are evaporation, transpiration (combined as evapotranspiration, ET), percolation and seepage. Typically, ET from rice fields is 4–5 mm d^{-1} during wet months and 6–7 mm d^{-1} during dry months; this can be as high as 10–11 mm d^{-1} in subtropical regions. It was estimated that about 30–40% of ET is due to evaporation (Bouman *et al*., 2005, Tabbal *et al*., 2002).

Gleick (2002) reported that “shifting from conventional surface irrigation to drip irrigation in India has increased overall water productivity by 42-255 percentage for crops as diverse as banana, cotton, sugar cane and sweet potato”. Due to its high water use efficiency, micro-irrigation is increasingly being used as a strategy to address water scarcity and poverty.

Losses through seepage and percolation account for 1–5 mm d^{-1} in heavy clay soils and 25–30 mm d^{-1} in sandy and sandy loam soils. The combined losses through seepage and percolation may be 25–50 percentage of total water loss in heavy soils with shallow groundwater table (20–50 cm depth) and 50–85 percentage of total water loss in coarse textured soils with groundwater table. (Chaudhury *et al*., 2007, Cabangon *et al*., 2004 and Dong *et al*., 2004).

An impact study report by the National Mission on Micro-irrigation, Government of India, clearly indicates that the overall efficiency of micro-irrigation (50–90%) is much higher than surface irrigation (30–35%) (NMMI, 2014).

2.2 IMPACT OF DIFFERENT VARIETIES OF RICE ON GROWTH, YIELD ATTRIBUTES AND YIELD

2.2.1 Influence of Irrigation Levels and Methods on Growth, Yield Attributes and Yield of Rice Varieties

Mohammad *et al*. (2002) asserted that plant height of rice is controlled by both environmental conditions and genetic makeup of the plant. This finding is in conformity with Garba *et al*. (2013) and Gagandeep and Gandhi (2015) who reported that vegetative growth of rice is significantly influenced by the type of varieties used.

Akinbile (2010) in a study on the behavioural pattern of upland rice agronomic parameters to variable water supply in Nigeria, concluded that maximum plant height (89.0 and 100.3 cm), total tillers (14 and 12) and leaf length (36.9 and 38 cm) maximum root depth (22.1 and 23.8 cm), panicle diameter (3.9 and 4.5 cm), panicle length (26.1 and 25.7 cm), leaf area index (3.27 and 3.95) were observed for NERICA 2 and NERICA 4 varieties, respectively.

Garba *et al*. (2013) and Getachew and Birhan (2015) observed that grain yield and yield components of rice were significantly influenced by the varieties used.

Sokoto and Muhammad (2013) conducted a pot experiment to study the responses of rice varieties to water stress (FARO 44, NERICA 2 and FARO 15). The results indicated that there are significant differences among the genotypes. FARO 44 differed significantly from others in plant height, number of leaves per plant and total biomass.

Kate *et al*. (2015) studied the growth of three rice cultivars under upland conditions with different levels of water supply in which he found that with a cultivar regime interaction in total dry matter at maturity, with adequate water supply, cultivar 'Nipponbare' had the highest total dry matter production compared to cultivar Yumeno-hatamochi.

In a study by Harish *et al*. (2017) on the effect of promising rice (*Oryza sativa* L.) varieties and nutrient management practices on growth, development and crop productivity in eastern Himalayas using three varieties Shahsarang-1, Lumpnah and Megha semi-aromatic-2, it was observed that Shahsarang-1 produced significantly highest grain yield (3.86 t ha^{-1}) followed by Lumpnah (3.60 t ha^{-1}) and Megha SA2 (3.19 t ha^{-1}), respectively. Similar trend was also observed for biological yield.

2.2.2 Moisture Studies of Different Rice Varieties

Akinbile *et al.* (2010) in their experiment on crop water use responses of upland rice found that the water use efficiency in NERICA 2 decreased from 0.0165 tha^{-1} mm^{-1}(A) to 0.0152 t $ha^{-1}mm^{-1}$ (B) to 0.0099 t $ha^{-1}mm^{-1}$ (C) to 0.0044 t $ha^{-1}mm^{-1}$ (D) and in NERICA 4, it was 0.0175 t $ha^{-1}mm^{-1}$ (A), 0.0154 t $ha^{-1}mm^{-1}$ (B), 0.0110 t $ha^{-1}mm^{-1}$ (C) and 0.0087 t $ha^{-1}mm^{-1}$ (D).

Hassan *et al*. (2015), in an experiment on the response of three rice cultivars to the intermittent irrigation in Southern Iraq with three varieties, Anber 33, Yasamin, and Furat-1 found that Furat-1 and Yasamin varieties manifested higher water compared with Anber 33. Water productivity of Furat-1 and Yasamin were 0.6108 kg m^{-3} and 0.5667 kg m^{-3} respectively.

In a study by Anning *et al*. (2019) on the effect of irrigation management methods on growth, grain yield and water productivity of three rice varieties *viz*., Agra, Ex Baikha and a hybrid variety and five irrigation management methods *viz*., continuous submergence (I_1), alternate wet and dry soil condition (AWD) from transplanting to panicle initiation (PI) then submergence to harvest (I_2), AWD from transplanting to booting then submergence to harvest (I_3), AWD from transplanting to flowering then submergence to harvest (I_4), and continuous AWD (I_5), it was observed that the hybrid variety had the highest water use efficiency.

2.2.3 Impact of Different Varieties on the Physiological Parameters of Rice

An experiment was conducted at Iran Rice Research Institute-Deputy of Mazandaran in 2007, to study the physiological and morphological indices of different rice varieties by Nicknejad *et al*. (2009) using three varieties Tarom, Neda, Shafagh and Najr in which it was observed that the maximum CGR was observed in the variety Shafagh (25.18 g m^{-2} d^{-1}) and the RGR was also found the highest in the same variety.

The performance of three rice varieties RNR 2354, RNR 2458 and JGL 384 in relation to crop growth, yield, physiological parameters and agrometeorological indices under different dates of transplanting was studied by Meena *et al*. (2015) and it was observed that the CGR, RGR and NAR were significantly different among the three varieties.

Rajput *et al*. (2017) conducted a study on the physiological parameters of different rice varieties and revealed that the CGR, RGR and NAR were influenced by varietal differences. At 0-30, 30-60 and at harvest, CGR were found to be significantly different among the varieties, whereas at 60-90 DAS, it was observed to be non-significant. The relative growth rate were significantly different at all the stages of the crop, whereas the net assimilation rate was non-significant at 60-90 DAS.

2.3. IMPACT OF VARIOUS APPROACHES OF SCHEDULING OF IRRIGATION

2.3.1. Irrigation Scheduling by Using IW/CPE Ratio

2.3.1.2 Influence of IW/CPE Ratios on the Yield and Yield Attributes

A field experiment at Pudukkottai, Tamil Nadu, was conducted by Ramamoorthy *et al.* (1998) on sandy clay loam, direct-sown upland rice, showed a marked reduction in grain yield under the lower moisture regime (1.00 IW/CPE ratio) (1.61 t ha^{-1}) compared with the higher moisture regime (IW/CPE ratio of 2.00) (3.01 t ha^{-1}). However, the medium moisture regime (IW/CPE ratio of 1.50) saved about 13 per cent of irrigation water and gave higher water-use efficiency compared with a higher moisture regime (2.00 IW/CPE ratio).

Jadhav *et al.* (2000) conducted a similar comprehensive study on basmati rice and irrigated the crop at critical growth stages and at IW/CPE ratios of 0.8, 1.2 or 1.6. Yield increased with increasing irrigations, with the highest yield at 1.6 IW/CPE ratio (2.53 t ha^{-1}) from 396 mm irrigation water applied.

Jadhav *et al.* (2003) conducted a field experiment in Parbhani, Maharashtra to determine the effect of irrigation on the yield of rice cv. Basmati-370. The treatments comprised of irrigation at critical growth stages (I_1), 0.8 (I_2), 1.2 (I_3), and 1.6 (I_4) IW/CPE ratio. The treatment I_4 registered the highest grain yield (2.26 t ha^{-1}).

Parihar and Tiwari (2003) conducted a field experiment on the effect of irrigation and nitrogen level on yield, nutrient uptake and water use of late sown wheat and reported that the irrigation applied at 1.2 IW/CPE ratio gave significantly higher grain yield than that with 0.6 and 0.9 ratios.

Shekara *et al.* (2010) reported that the irrigation scheduled at IW/CPE ratio of 2.5 produced higher grain yield of 6.21 t ha^{-1} and 6.58 t ha^{-1} during first and second year, respectively as compared to IW/CPE ratio of 1.0. A field experiment was conducted in Coimbatore by Maheswari *et al.* (2008) to ascertain the optimum irrigation schedule to enhance aerobic rice (*Oryza sativa* L.) productivity and found that irrigation at 1.2 IW/CPE ratio recorded significantly higher crop growth rate and yield with no moisture stress as compared to IW/CPE ratio of 0.8 and 1.0.

Murthy and Reddy (2013) in a study conducted on irrigation and weed management effect on aerobic rice found that scheduling the irrigation with IW/CPE of 1.2 produced significantly higher stature of yield attributes *viz.*, total number of panicles m^{-2}, total number of grains and number of filled grains and grain (4702 and 4547 kg ha^{-1}) and straw yield respectively and were distinctly superior to IW/CPE of 0.8 and 1.0.

Thomas *et al.* (2014) studied the response of upland rice to different levels of irrigation, nutrients and seed priming in which the results revealed that the levels of irrigation and nutrients exerted significant influence on yield attributes *viz.*, number of productive tillers $hill^{-1}$, length of panicle, weight of panicle, number of spikelets per panicle, number of filled grains per panicle, chaff percentage and test weight. Irrigating the crop at an IW/CPE ratio of 1.5 recorded the highest value for all yield attributing characters.

2.3.1.3 Soil Moisture Studies

Shekara *et al.* (2010) conducted an experiment on the effect of irrigation schedules on growth and yield of aerobic rice with IW/CPE ratios of 2.5, 2.0, 1.5 and 1.0, with irrigation water of 5 cm in which, IW/CPE ratio 1.0 recorded the highest water use efficiency.

2.3.1.4 Impact of IW/CPE Ratios on the Quality Aspects of Grain

Jadhav *et al.* (2003) conducted a field experiment in Parbhani, Maharashtra to determine the effect of irrigation on the yield and quality of rice cv. Basmati-370. The treatments comprised of irrigation at critical growth stages (I_1), 0.8 (I_2), 1.2 (I_3), and 1.6 (I_4) IW/CPE ratios. I_4 showed the highest kernel length and breadth and cooked kernel length while the highest head rice recovery was obtained with I_1. The highest amylose content was obtained with I_2 and I_1 in first and second year, respectively.

Maheswari *et al.* (2008) conducted a field experiment on irrigation regimes and nitrogen levels and revealed that biochemical parameters like chlorophyll content and soluble protein contents increased significantly under irrigation at IW/CPE ratio of 1.2, followed by 1.0, 0.8 and micro sprinkler system.

Kachhadiya *et al*. (2010) in an experiment on the effect of irrigation, mulch-es and antitranspirants reported that I_3 (IW/CPE= 1.0) registered significantly highest value of protein content, compared to I_2 (IW/CPE=0.8) and I_1 (IW/CPE=0.6).

.

2.3.4 Irrigation Scheduling using Soil Moisture Depletion Method

2.3.4.1 Soil Moisture Depletion and Growth Characteristics

At Mohanpur, results revealed that irrigation up to field capacity resulted in significantly higher growth of wheat over the depleted levels of irrigation (Saren and Jana, 2001)

At Karagpur, results showed that when the irrigation was scheduled at a depletion level of less than or equal to 45 percentage soil moisture depletion, there was not much change in the leaf area index. However, a reduction in the leaf area index was noticed when the irrigation was scheduled at 65 to75 percentage soil moisture depletion (Panda, 2003).

2.3.4.2 Soil Moisture Depletion on Yield and Yield Attributes

Ahmed *et al.* (1996) reported that increasing soil moisture depletion from 50 to75 percentage resulted in a marked decrease in straw yield. Weston (1996) reported that crop gave significantly higher straw yield by 4.29 q ha^{-1} at 41 percentage soil moisture depletion.

Results from Bursa has revealed that an alternative to full irrigation during the entire growing season, the irrigation at the rate of deficit irrigation of 75 percentage can be recommended as optional level because it achieved water saving of 25 percent, an increase of 16 percent in forage yield, irrigation water use efficiency, satisfactory plant morphological characters and an acceptable net income with an yield loss of only approximately 7 percent compared to full irrigation (Kirda and Kanber, 1999).

An experiment was conducted by Mahmood and Ahmad (2005) to determine water requirement and response of some wheat cultivars to irrigation at different soil moisture depletion (SMD) levels. Four wheat genotypes *viz*., AS2002, SH2002, Inqlab 91 and Uqab 02 were subjected to irrigation at 50% and 70% SMD levels. Results indicated that grain yield, harvest index and water use efficiency were greater when irrigation was applied at 50% SMD and was reduced at 70% SMD. SH2002 was the top yielder among the four cultivars tested at each level of irrigation.

Increasing moisture depletion levels decreased the dry matter, evapotranspiration, biomass yield and water use efficiency for biomass of bread wheat. Irrigating wheat crop when 50 percentage available soil moisture is depleted produced highest yield than other treatments (Badel *et al*., 2013).

2.3.4.3. Impact of Critical Growth Stage Approach for Scheduling Irrigation

Sarvestani *et al.* (2008) asserted that water stress at flowering stage signifi cantly reduced grain yield. This outcome is in line with previous studies (Borrell *et al.*, 1997, Vories *et al.*, 2005) that, practicing AWD throughout the plant cycle reduces grain yield significantly due to reduced soil moisture.

2.4 INFLUENCE OF VARIOUS MOISTURE STRESS MITIGATION STRATEGIES

2.4.1 Impact of Hydrogel Polymer on Various Characters

2.4.1.1 Impact of Hydrogel Polymer on Various Growth Parameters

Kramer (1998) has reported that the application of superabsorbent polymer could conserve water, thereby increasing the soil's capacity for water storage, ensuring more available water, relative water content in leaves and plant growth increased even under water stress conditions.

Huttermann *et al*. (1999) reported an increased root and plant growth with a 0.4% hydrophilic polymer, w/w, and application with Aleppo Pine. Viero *et al*. (2000) under similar conditions found only an increase in seedling growth when hydrogel was applied in combination with irrigation.

According to Koupei *et al.* (2004) hydrophilic polymer significantly reduced the number of irrigation frequency in tomato by increasing water holding capacity of soil which is in accordance with the results observed in Cupressus. Leaf area indicates good idea of the photosynthetic capacity of the plant and decreased leaf area is an early response to water deficit. With an increase in hydrophilic polymer, there was significant increase in leaf area.

In a study by Yangyuuoru *et al.* (2006), it was revealed that he amended soil with natural and synthetic polymers improved maize yields by 36 percentage and 31percentage, and improved dry matter yields by 92% percentage and 81percentage respectively, than those of the control.

Chen *et al.* (2007) studied the effect of hydrogel (Stokosorb K 410) on growth and ion relationships of salt resistant woody species, *Populus euphratica*, and stated that by the addition of 0.6% hydrogel to saline soil, there was an improved seedling growth (2.7 fold higher biomass) during a period of 2 years. Root length and surface area of treated plant was 3.5 fold more than those grown in untreated soil.

Mangold and Sheley (2007) in a study on the effects of soil texture, watering frequency and hydrogel, on the emergence and survival of coated and uncoated crested wheatgrass seeds have revealed that the incorporation of hydrogel into the potting medium aided the emergence (20.4 seedlings pot^{-1}) and survivorship (80-100%) of crested wheat grass seedlings as compared to control with 13.0 seedlings pot $^{-1}$ emergence.

According to Yazdani *et al*. (2007), leaf area indicates good idea of the photosynthetic capacity of the plant and decreased leaf area is an early response to water deficit. With an increase in hydrophilic polymer, there was significant increase in leaf area. Hydrophilic polymer increases the turgor pressure inside the cells by maintaining sufficient amount of water as per crop requirement and thus causing increase in leaf area and other related growth parameters.

Hydrophilic polymer increases the turgor pressure inside the cells by maintaining sufficient amount of water as per crop requirement and thus causing increase in leaf area and other related growth parameters (Yazdani *et al*., 2008).

Hardy and Shafi (2009) in a study on the physio-bio-chemical properties of the sandy soil, conditioned with acrylamide hydrogels after cucumber plantation found out that soil incorporation of hydrogel (1 g plant^{-1}) with 2 kg compost increased dry weight of tomato as compared to soil treated with 2g hydrogel (43.7 g plant^{-1}) or 2 kg compost (35.0 g plant^{-1}) separately or control (19.2 g plant^{-1}). The beneficial effects of mixtures of organic matter and hydrogel exceeds that of each conditioner when solely added. Similarly, coating of pearl millet seed with 10 and 20 g of hydrogel kg^{-1} of seed resulted in the production of significantly higher effective tillers and ear length compared to control and water soaking treatment, according to Spanu *et al*. (2009).

The effect of hydrogel on the performance of aerobic rice sown under different techniques was studied by Rehman *et al.* (2011) and reported that the application of water absorbents results in significantly higher emergence count (180 m^{-2}), plant height (79 cm) and effective tillers (264 m^{-2}), of aerobic rice as compared to control.

2.4.1.2 Impact of Hydrogel Polymer on the Yield Attributes and Yield

Silberbush *et al.* (1993) tested the Agrosoak hydrogel for cabbage (*Brassica oleraceae* L.). They reported that Agrosoak increased water availability, which indeed contributed to the increase in the yield of the crop irrigated with saline water.

Waly *et al.* (2004) conducted an experiment on rice, which clearly indicated that the treatment with 1 percentage hydrogel was superior among all the treatments in all the yield attributes. Treatment with 1 percentage hydrogel produced the highest number of grains panicle^{-1} (90.00), the heaviest panicle (2.24 g), the highest grain yield pot^{-1} (9.89 g), the highest biological yield pot^{-1} (50.00 g), the highest harvest index (19.78%) and the highest protein content in grains (10.88%).

Yazdani *et al*. (2007) in a study on the impact of superabsorbent polymer on yield and growth analysis of soybean (*Glycine max* L.) under drought stress condition found out that the grain yield obtained was 1.77, 3.47, 4.98 and 6.41 q ha^{-1} with application of super absorbent polymer @ 0, 75, 150 and 225 kg ha^{-1} respectively.

An increase in yield and yield related attributes could be because of sufficient availability of water and indirectly nutrients, supplied by the SAP to the plants under water stress condition, which in turn lead to better translocation of water, nutrients and photosynthates and finally better plant stand and yield (Hardy *et al*., 2009).

The results obtained from farmers field demonstration conducted by ICAR at different locations in Uttar Pradesh evidenced that soil application of hydrogel @ 5 kg ha^{-1} along with three irrigations in different wheat varieties, is able to produce grain yield equivalent to irrigating wheat crop five times without hydrogel application. It indicates that soil application of hydrogel can save two irrigations in wheat without reducing the grain yield. Application of 65 percentage cow manure and 35 percentage superabsorbent polymer (26 t ha^{-1} cow manure + 70 kg ha^{-1} super absorbent polymer) increased grain yield by 16.2 percentage as compared to control (Khadem *et al*., 2010).

Islam *et al*. (2011) has reported that maize yield increased slightly following superabsorbent polymer application by 11.2 percentage under low and 18.8 percentage under medium dose, but significantly at high and very high doses by 29.2 and 27.8 percentage, with only half amount (150 kg ha^{-1}) of fertilizer as compared to control, which received conventional standard fertilizer dose (300 kg ha^{-1}).

Rehman *et al.* (2011) observed that application of hydrogel improved soil moisture content in all the three sowing techniques (flat, ridge, and bed sowing) as compared to soil without hydrogel. Yield of rice was higher in hydrogel amended soil in all sowing techniques as compared to without hydrogel. Hydrogel application improved 1000-kernel weight of rice crop. The 1000 grain weight depends on length and rate of seed filling period.

Alekhya (2020) reported a significantly higher productive tillers m^{-2}, grain weight panicle^{-1}, number of spikelets panicle^{-1}, percentage of filled grains panicle^{-1}, 1000 grain weight, grain yield ha^{-1} and straw yield ha^{-1} in hydrogel polymer treated plots, compared to non-treated plots.

2.4.1.3 Impact of Hydrogel Polymer on Soil Moisture Characters

Huttermann *et al.* (1999) reported that hydrogel application in sandy soil promoted an increase in water retention capacity and plant water potential while in loamy and clay soils the effect may be negligible. They also reported that the hydrogel allowed 19 days drought tolerance.

Sendurkumaran (2001) reported the influence of hydrophilic polymer (HP) on root characteristics in tomato. Hydrophilic polymer significantly reduced the irrigation frequency in tomato by increasing water holding capacity of soil which is in accordance with the results of Sivalapan *et al.* (2001) in soybean.

According to Frantz *et al*. (2005), the application of high levels of Superab A 200 addition @ 2, 4, 6 and 8 g kg^{-1} enhanced available water content by about 1.8, 2.2 and 3.2 fold in sandy loam, loamy and clay soils respectively, as compared to that of the control and there were marked responses in the number of days to permanent wilting point as a result of polymer application. They concluded that the application of 4 g kg^{-1} soil of Superab A 200 had a proper performance in Arizona cypress (*Cupressus arizonica*) and reduced the water requirement to about 1/3 of the control. So, application of hydrogel increased the soil water content during growth period and reduced the irrigation requirement.

Koupaei and Jafar (2006) observed the effects of hydrogel (Superab A 200) on the field performance of ornamental plant (*Cupressus arizonica*) under reduced irrigation regimes and concluded that the hydrogel (6g kg^{-1} soil) increased the number of days (22 days) to reach permanent wilting point (PWP), as compared to control (12 days).

Rahim *et al*. (2007) reported that hydrogel increases the water holding capacity, for agricultural applications. They further reported that application of 0.6 percentage hydrogel prolonged the time of water loss from the soil by about 66 percentage and the seedlings grown in 0.6 percentage hydrogel mixed soil survived three times as long as those grown in the control soil.

Hardy *et al*. (2009), while assessing the physio-bio-chemical properties of the sandy soil, conditioned with acrylamide hydrogels after cucumber plantation proved that hydrogels applied to sandy loam soils increased the amount of available moisture in the root zone and water holding capacity resulting in longer intervals between irrigations. The water holding capacity (33.75%, 27.10%, 23.05% and 20.15%) and available moisture (12.47%, 10.62%, 7.70% and 4.82%) were recorded when hydrogel was applied @ 4, 3, 2 and 0 g hydrogel per plant pit respectively. They also reported that application of hydrogel at 2.5 kg ha^{-1} improved the soil moisture content of the soil and the moisture recorded were 12.78%, 13.20%, 12.21%, 12.87%, 11.03%, 13.10%, 12.83% and 13.31% at 21, 28, 35, 42, 53, 60, 77 and 84 DAS respectively.

Agaba *et al.* (2011) reported the effect of hydrogel amended at 0.4%, 0.2% and a control (no hydrogel) on *Agrostis stolonifera* seeds. The 0.4% hydrogel amendment in sand increased the water use efficiency of grass eight fold with respect to the control.

Moghadam *et al*. (2013) reported that the hydrogel at 7% concentration was able to reduce the destructive effect of water deficiency, by absorbing and preserving water and improving several agronomic characters and recorded increased yield and its components and decreasing plant water requirement in six oilseed rape genotypes. They also studied the effect of super absorbent polymer on growth, yield components and seed yield of wheat grown under irrigation withholding at different stages revealed that hydrogel application in irrigation withholding at different growth stages had a positive effect on all the attributes, except for protein percentage in wheat crop and further reported that with attention to increased yield and its components and decreasing plant water need, using this material is acceptable.

Shahid and Ram (2016) in a study on the grain yield, nutrient uptake and water-use efficiency of wheat (*Triticum aestivum*) under different moisture regimes, nutrient and hydrogel levels found out that consumptive use of water increased with the increase in irrigation levels while increase in hydrogel level decreased the consumptive use of water. With three irrigations using 2.5 and 5.0 kg ha^{-1} hydrogel, water-use efficiency is similar but significantly higher than without hydrogel.

2.4.1.3 Impact of Hydrogel Polymer on the Physiological Parameters of the Crop

The decrease in photosynthetic pigment content under stress conditions, might be attributed to reduced synthesis of the main pigment complexes (Nikolaeva *et al.*, 2010), or to destruction of the pigment protein complexes which protect the photosynthetic apparatus, or to oxidative damage of chloroplast lipids and proteins, therefore formation of photosynthetic pigment decreases. In this regard Akca and Samsunlu (2015) reported that the negative effects of abiotic stress on photosynthetic pigments could be due to the inhibition of chlorophyll biosynthesis or increase of its degradation by chlorophyllase enzyme.

High levels of proline enabled the plant to maintain low water potentials. Proline accumulation in drought-stressed plants may play a role as osmolyte to maintain the organelles, resulting in the greenish leaf when exposed to water deficit condition (Safarnejad, 2008). By applying natural polymers, a reduced proline accumulation was found in sunflower (Nazarli *et al*., 2011).

Ahmed and Fahmy (2019) in a work on the applications of natural polysaccharide polymers to overcome water scarcity on the yield and quality of tomato fruits with four treatments; without polymer as a control and with different polymers (cellulose and cellulose/starch composite) under three levels of irrigation (100, 75 and 50%), have revealed that use of all natural polymers (cellulose, starch and cellulose/starch) in soil with different water stress condition (100, 75, and 50% FC) increased leaf chlorophyll content.

2.4.2 Impact of Pink Pigmented Facultative Methylotrophs on Stress Mitigation

Nalayani *et al*. (2014) have reported that the microbial consortia containing different strains of Bacillus, Pseudomonas, and Azospirillum with PPFM and foliar spray of PPFM applied to seeds and soil with recommended N and P fertilizers could be used as a potent bioinoculant to increase yield of cotton.

An experiment was conducted at the Cardamom Research Station, Kerala Agricultural University, Pampadumpara, Idukki, Kerala during 2017 summer (February-May) by Sathyan *et al*. (2017), to evaluate the response of small cardamom crop to the foliar application of PPFM and synthetic materials under drought situation and it was observed that the chlorophyll stability index of PPFM was significantly higher than the control and can be a good choice for the organic cardamom growers under drought situation.

In a pot culture experiment carried out by Sivakumar *et al*. (2017) in tomato variety PKM 1 and foliar spray with different plant growth regulators like brassinolide (1 ppm), salicylic acid (100 ppm), benzyl amino purine (100 ppm) and gibberellic acid (10 ppm) and PPFM (1%), PPFM (2%) and PPFM (3%) under drought condition created based on field capacity of soil, it was observed that the PPFM and PGRs could be effective in improving drought tolerance capacity of tomato crop under drought. Among the PGRs and different concentrations of PPFM used, PPFM (2%) was found to be superior in improving RLWC, photosynthetic rate, SPAD value and proline content. The antioxidant enzyme, catalase activity was enhanced by PPFM (2%) and salicylic acid (100 ppm) treatments which has the ability to protect the plant under abiotic stress by nullifying oxidative damage. Foliar spray of salicylic acid (100 ppm) was found effective in improving the NR activity followed by 2 per cent PPFM. The soluble protein content was maintained by brassinolide followed by PPFM (2%) under drought.

Sivakumar *et al*. (2018) assessed the impact of Pink Pigmented Facultative Methylotrophs and plant growth regulators on alleviating the drought stress effects on tomato through estimating leaf water potential, leaf temperature, stomatal conductance, net assimilation rate, relative growth rate and yield. Pot culture experiment was carried out in tomato variety PKM 1 with foliar spray of PPFM (1%), PPFM (2%), PPFM (3%) and growth regulators like brassinolide (1 ppm), salicylic acid (100 ppm), benzyl amino purine (100 ppm) and gibberellic acid (10 ppm) under drought condition. Among the PGRs and different concentrations of PPFM used, 2% PPFM was found to be superior in improving drought tolerance. The highest fruit yield of 552.9 g was maintained by PPFM (2%) followed by brassinolide (509.4) under drought.

2.5 INFLUENCE OF IRRIGATION METHODS, IRRIGATION LEVELS, VARIETIES AND STRESS MITIGATION STRATEGIES ON THE PHYSIOLOGICAL PARAMETERS

It was observed that increase in duration of water stress can reduce significantly the total chlorophyll content as well as chlorophyll a/b ratio (Nilsen and Orcutt, 2007). Guerfel *et al*. (2009) reported that water stress posed significant effects on total cholorophyll in `Chemlali' and `Chetoui'; olives, and the amount of reduction of total chlorophyll were 29 percentage and 42 percentage for in `Chemlali' and `Chetoui' olives respectively under water stress.

In a study by Zhang *et al.* (2009), on the effects of different water conditions on rice growth at the seedling stages, they have observed that the free proline in rice increased as water potential decreased.

Mojaddam *et al.* (2012) in a study on the effect of irrigation ending date on physiological growth parameters and yields of sunflower hybrids with irrigation treatments (I) complete irrigation (I_1), irrigation until heading stage (I_2) and irrigation until grain formation(I_3), the results indicated that dry matter accumulation trend and physiological indices (CGR, RGR, NAR, LAI) declined in water ending treatments (irrigation until grain formation and irrigation until heading stage) compared to the desirable treatment.

Jabasingh and Saravana (2013) estimated the proline content of rice under water stress with three treatments namely, Treatment A (watered daily), Treatment B (watered once in 3 days) and Treatment C (watered weekly once) and found that proline level increased in the rice leaves in response to water stress. Proline content was higher in Treatment C compared to Treatment A and B.

The experiment conducted by Jasbir and Kumar (2015) to study the influence of nitrogen levels, irrigation regimes and planting methods on growth attributes and yield of spring maize with combinations of planting methods (bed and ridge) and irrigation regimes (IW/ CPE ratio of 0.9, 1.2 and 1.5) in main plots and nitrogen levels (0, 100, 125 and 150 kg N ha^{-1}) has revealed that the crop growth rate, relative growth rate and net assimilation rate though statistically similar in bed and ridge planted crop, irrigation scheduling at 1.2 and 1.5 IW/ CPE resulted in similar grain yield, growth attributes and crop growth rate and were significantly more than that in 0.9 IW/CPE.

The effect of various water regimes on rice production in lowland irrigation was studied by Khairi *et al*. (2015) and observed that chlorophyll content was reduced under decreased water levels.

Arsa *et al*., (2016) while evaluating the grain yield and aroma of upland rice (Pare Wangi Var.), in response to soil moisture and salinity have revealed that the proline content at 50% FC soil moisture was significantly higher than other soil moisture levels. The proline content at 75% FC soil moisture tend to be higher than 100% and 125% FC.

Pascaul and Wang (2016) in their study on the impact of water management on rice varieties, yield and water productivity under the system of rice intensification in Southern Taiwan have found out that the leaf chlorophyll content varied according to irrigation regimes. At heading, the SPAD values for leaf chlorophyll content was the lowest under continuous flooded irrigation, whereas statistically comparable results were observed for intermittent irrigation of three and seven-day intervals.

A study on the physiological parameters of some upland rice genotypes under moisture stress condition by Timung *et al.* (2017) has revealed a reduction in the total chlorophyll by of about 3.008 percentage in drought condition, as compared to irrigated condition.

Silva *et al*. (2018) studied the effect of sowing date and water availability on growth of plants of chia (*Salvia hispanica* L) and found out that greater water availability increased RGR by 60 percentage, compared to stressed plants and LWR, NAR, CGR and SLW were affected by sowing date and water availability.

2.6 INFLUENCE OF IRRIGATION LEVELS, IRRIGATION METHODS, VARIETIES AND STRESS MITIGATION STRATEGIES ON THE QUALITY PARAMETERS

Ferguson and Gilmore (1977) found statistically similar hulled rice recovery, milled rice recovery, length-breadth ratio and amylose content, in rice grains produced by two different irrigation regimes *viz*. irrigation after two (I_2) and four (I_4) days after drainage of applied water but, head rice recovery and protein content were statistically higher in I_2 than in I_4.

Jadhav *et al.* (2003) conducted a field experiment in Parbhani, Maharashtra to determine the effect of irrigation on the yield and quality of rice cv. Basmati-370. The treatments comprised of irrigation at 0.4 (I_1), 0.8 (I_2), 1.2 (I_3) and 1.6 (I_4)

IW/CPE ratios and I_4 showed the highest kernel length and breadth while the highest amylose content was obtained with I_2.

In a field experiment on rice, Huang *et al*. (2008) studied three irrigation regime, *i.e,* well-watered (WW), moderate dry-wet alternate irrigation(MD): soil was rewatered when the soil-water potential reached -20 KPa and severe dry-wet alternate irrigation (SD: soil was re-watered when the soil-water potential reached -40 kPa). The treatments were imposed from 7 days after heading up to maturity and it was found that compared with WW, MD significantly increased, whereas SD significantly reduced, brown rice rate, milled rice rate and head rice rate.

Maheswari *et al.* (2008) conducted a field experiment on irrigation regimes and nitrogen levels and revealed that biochemical parameters like chlorophyll content and soluble protein contents increased significantly under irrigation at IW/CPE ratio of 1.2, followed by 1.0, 0.8 and micro sprinkler system.

Kachhadiya *et al*. (2010) in an experiment on the effect of irrigation, mulches and antitranspirants reported that I_3 (IW/CPE=1.0) registered significantly the highest value of protein content, compared to I_2 (IW/CPE=0.8) and I_1 (IW/CPE=0.6).

Esmailian *et al*. (2011), Farhad *et al*. (2013) and Aydinsakir *et al*. (2013) who worked on different irrigation water levels and different maize cultivars also reported that the grain protein contents were significantly influenced by different irrigation levels.

In a study by Karasu *et al.* (2015), on the effect of different irrigation water levels on grain yield, yield components and some quality parameters of silage maize, the effect of different irrigation water amounts was not statistically important for crude protein content and the crude protein content ranged from 7.8 to 8.6 percentage. Similarly, Vartanli and Emeklier (2007) reported that crude protein content of some maize cultivars were between 6.21 and 8.65%. Conversely, Ertek and Kara (2013) who worked with the similar subjects on sugar maize reported that deficit irrigation levels affected the content of crude protein, which vary in their study, between 10.63 - 11.25 %.

2.7 INFLUENCE OF IRRIGATION LEVELS, IRRIGATION METHODS, VARIETIES AND STRESS MITIGATION STRATEGIES ON THE NUTRIENT UPTAKE

Magalhaes *et al.* (1987) found higher retention of NH_4, K, Ca, Mg, Zn, and Fe in an oxisol treated with gel-polymers as compared to untreated soil. In addition, a higher shoot growth as well as N, K, and Fe uptake in radish was found in soils amended with gel-polymers.

A study on the nitrogen management with drip and sprinkler irrigation was conducted by Sivapalan (1987) and revealed that with either sprinkler or drip irrigation, it is possible to control the amount of water applied to match crop evapotranspiration. It is also much easier to split the nitrogen applied into small doses during the irrigation season. Consequently, the nitrogen use efficiency may be substantially different with sprinkler and drip irrigation systems.

Bredenkamp (2000) reported that hydrogel improves macro and micro nutrient uptake, especially nitrogen, potassium and phosphorus as Aqua-Soil TM retained up to 400 percentage more nitrogen and 300 percentage more potassium than standard quick and slow release fertilizers.

Eissa and Negim (2018) assessed the nutrient uptake and water use efficiency of drip irrigated maize under deficit irrigation, in which maize plants were irrigated with 100, 80, or 60 percentage of water requirements. Maize growth was negatively affected by the lower water supply and the total uptake of N, P, and K by maize irrigated with I_{100} increased by 21, 25, and 21 percentage compared to that irrigated with I_{60}. NPK requirements of drip irrigated maize under deficit irrigation are less than those irrigated by full water supply thus help to sustain the environmental ecosystem and increased the economic returns.

In a study on the effect of irrigation regimes and soil texture on the potassium utilization efficiency of rice by Hamoud *et al*. (2019), the rice plants were grown in three soils, with clay contents of 40%, 50%, and 60%, irrigation regimes at 100%, 90%, and 70% of saturated soil water content. Results showed that the responses of the roots and shoots and the potassium accumulation and the KUE of rice were significantly affected by the water regimes. Under the same soil type, 100% saturated soil water was the optimal water management practice for growing rice and the 70% saturated soil water treatment showed the lowest KUE, which was 13.8%.

Xiang *et al*. (2019), while studying the effect of irrigation level and irrigation frequency on the growth of mini Chinese cabbage and residual soil nitrate nitrogen with conventional border irrigation with adequate water supply as a control (CK), three irrigation levels (WH: 160% crop evapotranspiration (ETc), WM: 120% ETc and WL: 80% ETc) and three irrigation frequencies (intervals of F_2: 2 days, F_4: 4 days, and F_8: 8 days) have observed that, at the same irrigation level, the total N content of the plants increased in the order $F_8 < F_2 < F_4$. The total N uptake in the WMF_4 treatment was 79.2% higher than that in the CK treatment, and the N loss in the WMF_4 treatment was 46.3% lower than that in the CK treatment.

3. MATERIALS AND METHODS

The investigation entitled "Irrigation scheduling and water stress mitigation strategies in upland rice" was carried out with the objectives of identifying a suitable variety and irrigation method for upland rice, to standardize irrigation scheduling and to assess the effect of moisture stress mitigation strategies on the growth, yield and economics of upland rice. The study was conducted as two field experiments (1). Identification of suitable variety and standardization of irrigation method (2). Standardization of irrigation scheduling and moisture stress mitigation strategies for upland rice. The materials used and the methods followed for the study are detailed below:

3.1 MATERIALS

3.1.1 Experimental Site

The first and second experiments were carried out in the Instructional Farm, College of Agriculture, Vellayani during the summer season of 2019 and 2020 respectively. The field was located at 8.5° N latitude and 76.9° E longitude at an altitude of 29 m above sea level.

3.1.2 Climate

The experimental site has a humid tropical climate. Data on weather parameters *viz*. temperature, rainfall, relative humidity and bright sunshine (BSS) hours were recorded for the standard weeks during the cropping period. The mean values of weather parameters recorded during the cropping periods are given in Appendix I a and I b and graphically presented in Fig 1a and 1b respectively.

3.1.3 Cropping Season

The first experiment was conducted during 16th January 2019 to 23rd May 2019 (*summer*) and the second experiment was carried out during 19th January 2020 to 27th April 2020.

3.1.4 Soil

The experimental site was fairly levelled and uniform in depth and topography. To know the physico-chemical properties of the experimental site, the soil samples from 30 cm depth were randomly collected from different locations of the experimental field before the start of the experiment and a composite sample was prepared and analyzed for physical and chemical properties of the soil. The soil in the experimental field was observed to be sandy clay loam. The procedures followed for soil analysis are furnished in Table 1 and data on mechanical composition and physico-chemical properties are presented in Table 2 and Table 3 respectively.

3.1.5 Cropping History of the Field

After raising upland rice crop during *kharif* of 2016, rice bean was raised and was kept fallow prior to layout of the experiment.

3.1.6 Crop Variety

The rice varieties used in the first experiment were Uma (MO-16) and Prathyasa (MO-21) which were released from Rice Research Station, Moncompu, Kerala Agricultural University.

Uma is a non-lodging variety, resistant to brown plant hopper and gall midge, which is suited to three seasons, especially to additional *virippu* crop season of Kuttanad, whereas Prathyasa is a non-lodging, photo-insensitive, semi-tall variety, which is resistant to gall midge, brown plant hopper, sheath blight and sheath rot.

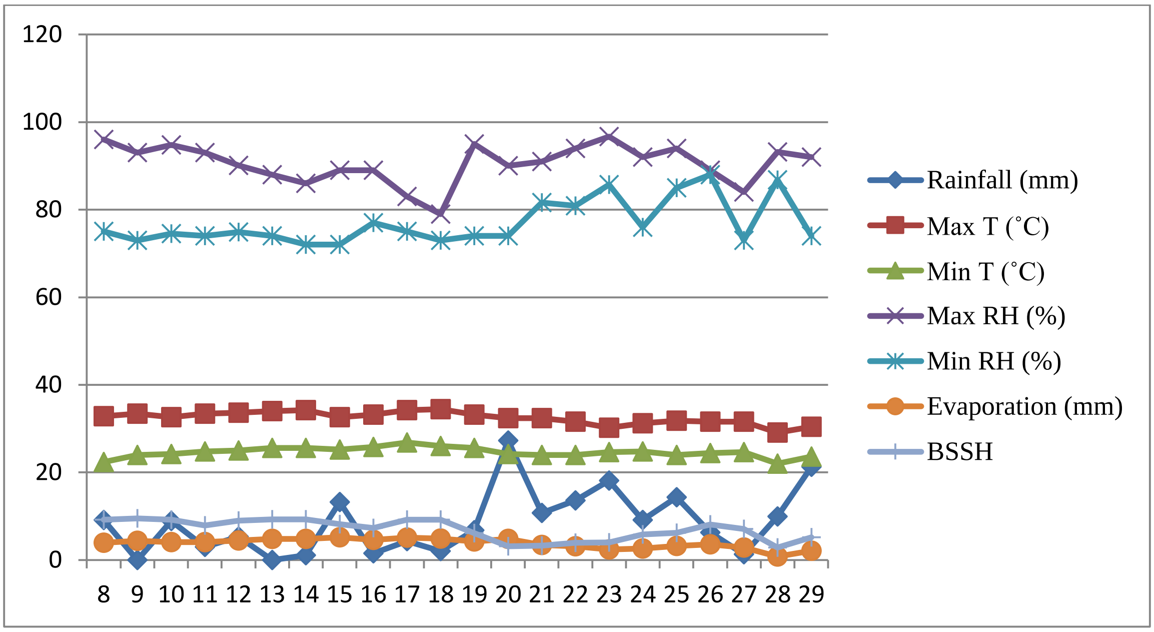

Fig. 1. Weather parameters during the cropping season in standard weeks (January 16 to May 23)

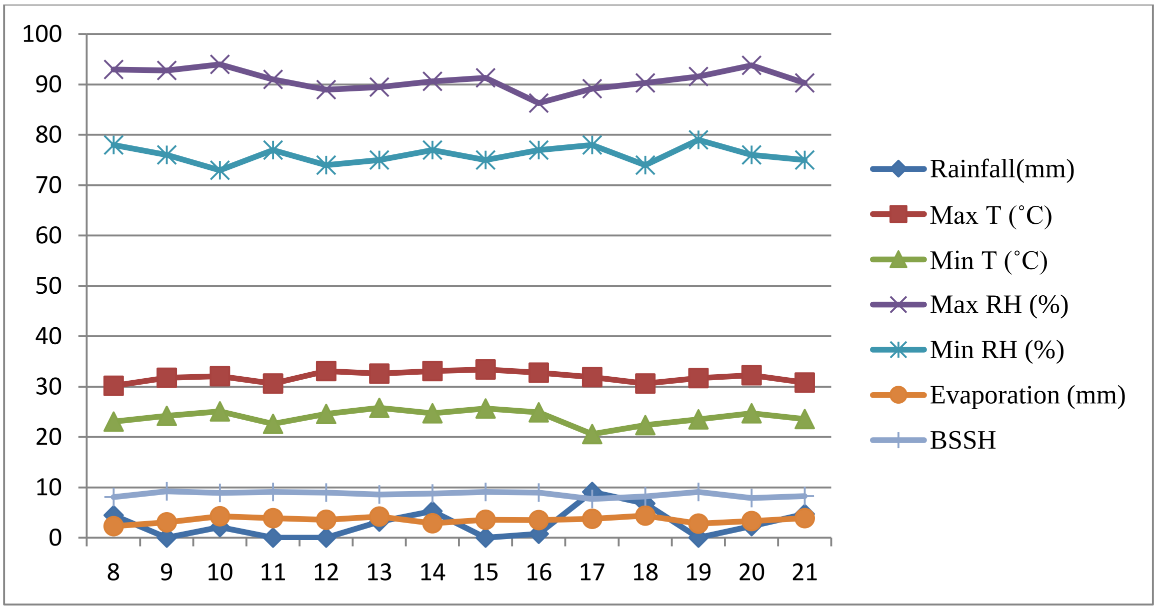

Fig. 2. Weather parameters during the cropping season in standard weeks (January 19 to April 27)

Table 1. Procedures followed for soil analysis

Soil parameter	Procedure of analysis	Instrument used	Reference
Mechanical composition	Bouyoucos hydrometer method		Bouyoucos (1962)
pH	Soil water suspension (1:1)	pH meter	Jackson (1973)
Organic carbon	Chromic acid wet oxidation method	Titration	Walkley and Black(1934)
Available N	Alkaline permanganate method	Titration	Subbiah and Asija (1956)
Available P	Bray No.1 extraction and photoelectric colorimetry	Spectro photometer	Jackson (1973)
Available K	Neutral ammonium acetate extraction	Flame photometer	Jackson (1973)
Field capacity (0-60 cm layer)	Pressure plate method	Pressure plate membranous apparatus	Richards and Weaver (1943)
Permanent wilting point (0-60 cm layer)	Pressure plate method	Pressure plate membranous apparatus	Richards and Weaver (1943)
Bulk density (g cc^{-3}) (0-60 cm layer)	Core sampler method	Core sampler	Blake (1965)

Table 2. Mechanical composition of the soil of the experimental site

Soil fractions	Content in soil
Coarse sand (%)	16.86
Fine sand (%)	30.47
Silt (%)	23.82
Clay (%)	26.97
Texture	Sandy clay loam

3. Physico-chemical properties of the soil before the experiment

a. Physical properties

Bulk density (Mg m^{-3})	1.47
Porosity (%)	41.24
Water holding capacity (%)	20.11

b. Chemical properties

Soil parameters	Unit	Content	Rating
pH		5.2	Strongly acidic
Organic carbon	%	0.82	Low
Available N	kg ha^{-1}	226.80	Low
Available P	kg ha^{-1}	16.02	Medium
Available K	kg ha^{-1}	268.80	Medium

3.1.7 Soil Ameliorants

Lime was used as a soil ameliorant for correcting the soil acidity. The results of chemical analysis of the liming materials are furnished in Table 4.

Table 4. Chemical analysis of the liming material

Liming material	Nutrient content, %				
	P	K	Ca	Mg	Si
Lime	-	-	31.35	-	-

3.1.8 Manures and Fertilizers

Urea, rajphos and muriate of potash containing 46% N, 20% P_2O_5 and 60% K_2O respectively were used as the sources of N, P and K for soil application.

3.1.9. Hydrogel and PPFM

For the field application of hydrogel polymer gel, PUSA hydrogel (CUMI jal), developed by Indian Agricultural Research Institute (IARI), Delhi, which is biodegradable, eco-friendly and non-toxic was used.

For PPFM spray, PPFM culture from Tamil Nadu Agricultural University, Coimbatore was used.

3.2 METHODS

3.2.1 Design, treatments and layout

3.2.1.1 Experiment I- Identification of Suitable Variety and Standardization of Irrigation Method

Design : Split plot design

Main plot treatments : 5

Subplot treatments : 2

Replications : 4

Plot size : 4m x 4m

Spacing : 20 cm x 10 cm

Season : *Summer*, 2019 (January –May)

Treatments

Main plot : Methods of irrigation (M)

m_1 : Sprinkler irrigation at 100% PE

m_2 : Sprinkler irrigation at 75% PE

m_3 : Drip irrigation at 100% PE

m_4 : Drip irrigation at 75% PE

m_5 : Hose irrigation (Farmer's practice-irrigation given thrice in a week)

(PE - Pan evaporation)

Sub-plot : Varieties (V)

v_1 : Prathyasa

v_2 : Uma

The best method of irrigation and the best performing variety from experiment I are selected for experiment II

3.2.1.2 Experiment II- Standardization of Irrigation Scheduling and Moisture Stress Mitigation Strategies for Upland Rice

Design : Split plot

Main plot treatments : 4

Sub plot treatments : 5

Replication : 5

Plot size : 4 m x 4 m

Season : Summer, 2020 (January to April)

Spacing : 20 cm x 10 cm

Treatments

Main plot: Approaches of scheduling irrigation (I)

i_1 : IW/CPE (0.8)

i_2: Critical growth stage approach (irrigation at seedling, maximum tillering, panicle initiation and grain filling stages to a depth of 2 cm)

i_3 : Irrigation to maintain soil moisture at 100% FC

i_4 : Irrigation to maintain soil moisture at 75 % FC

FC- field capacity

Sub-plot : Moisture stress mitigation strategies (S)

s_1 : Field application of hydrogel polymer (2.5 kg ha^{-1})

s_2 : Seed treatment with hydrogel polymer (10 g kg^{-1})

s_3 : Field application + seed treatment (S_1+S_2)

s_4 : Foliar application of Pink Pigmented Facultative Methylotrophs (PPFM) (foliar application 1% at 30 and 45 DAS) (9 x 10^5 CFU ml^{-1})

s_5: Absolute control

Layout plan of experiment I and II are given in Fig. 2 and Fig. 3 respectively. General view of the experimental field during 2019 and 2020 is presented in Plate 1 and 5 respectively.

3.2.2 Details of Cultivation

3.2.2.1 Land Preparation

The experimental field was tilled, levelled and laid out as per the design for experiment I and experiment II. Bunds were constructed across the main plots and were separated by 1m.

3.2.2.2 Irrigation

The experimental set up for providing irrigation by drip, sprinkler and hose were provided, as shown in the plate 3 and 4.

Details of irrigation treatments for experiment I

The pan evaporimeter reading for the entire duration of the crop is as shown in the Table 5. The water requirement for all the treatments was quantified based on the pan evaporimeter readings, as given below:

Table 5. Pan evaporimeter reading for the entire crop duration of experiment I, mm

Date	Evaporation reading	Date	Evaporation reading
16-Jan	4.3	5-Feb	4.2
17-Jan	4.0	6-Feb	4.7
18-Jan	4.0	7-Feb	4.6
19-Jan	4.0	8-Feb	4.5
20-Jan	4.0	9-Feb	4.7
21-Jan	4.2	10-Feb	4.7
22-Jan	4.4	11-Feb	4.8
23-Jan	4.5	12-Feb	4.7
24-Jan	4.5	13-Feb	4.8
25-Jan	4.6	14-Feb	4.7
26-Jan	4.6	15-Feb	4.8
27-Jan	4.0	16-Feb	4.8
28-Jan	4.0	17-Feb	4.8
29-Jan	4.0	18-Feb	5.3
30-Jan	4.0	19-Feb	4.1
31-Jan	4.6	20-Feb	4.8
1-Feb	4.2	21-Feb	5.0
2-Feb	4.0	22-Feb	5.2
3-Feb	4.0	23-Feb	5.2
4-Feb	4.0	24-Feb	4.9
25-Feb	4.0	11-Apr	5.3
26-Feb	4.0	12-Apr	5.2
27-Feb	3.5	13-Apr	5.3

Table 5. Continued

28-Feb	3.7	14-Apr	5.5
1-Mar	4.0	15-Apr	5.2
2-Mar	4.5	16-Apr	4.7
3-Mar	4.6	17-Apr	5.3
4-Mar	4.5	18-Apr	5.0
5-Mar	4.3	19-Apr	5.0
6-Mar	4.0	20-Apr	4.2
7-Mar	4.0	21-Apr	3.0
8-Mar	4.0	22-Apr	3.5
9-Mar	4.6	23-Apr	4.2
10-Mar	5.3	24-Apr	3.2
11-Mar	5.2	25-Apr	3.5
12-Mar	4.7	26-Apr	3.4
13-Mar	5.5	27-Apr	2.8
14-Mar	4.8	28-Apr	3.0
15-Mar	5.1	29-Apr	3.2
16-Mar	5.3	30-Apr	2.8
17-Mar	4.8	1-May	3.2
18-Mar	5.1	2- May	3.4
19-Mar	4.8	3- May	3.0
20-Mar	4.5	4- May	2.6
21-Mar	5.2	5- May	2.0
22-Mar	4.9	6- May	2.0
23-Mar	5.0	7- May	2.8
24-Mar	4.9	8- May	2.6
25-Mar	4.5	9- May	2.2
26-Mar	5.0	10- May	2.0
27-Mar	4.2	11-May	3.0
28-Mar	3.2	12-May	2.9
29-Mar	4.0	13-May	3.4
30-Mar	3.5	14-May	2.8
31-Mar	3.8	15-May	2.4
1-Apr	3.0	16-May	3.0
2-Apr	4.0	17-May	2.0
3-Apr	4.0	18-May	2.0
4-Apr	0.0	19-May	3.0
5-Apr	3.8	20-May	3.4
6-Apr	3.0	21-May	4.0
7-Apr	4.1	22-May	3.6
8-Apr	3.8	23-May	3.8
9-Apr	0.0		
10-Apr	2.9		

For drip irrigated plots, the following equation was used for quantifying the water requirement:

Water requirement for one plot = spacing x wetted area x No. of plants plot^{-1} x pan evaporation

(Wetted area fraction for closely spaced crops is 0.7)

(Reddy and Reddy, 2005)

For the treatments in which water is given at 75% PE, 75 per cent of the water required from the afore mentioned equation was taken.

For sprinkler irrigated plot, the amount of water to be applied was calculated based on the discharge rates of the sprinkler head and the time for which the system had to be worked for the calculated amount of water to reach the soil.

For hose irrigated plots, water was quantified using traditional bucket method and water lost through evaporation was given thrice in a week, using hose.

The best method of irrigation *i.e.*, sprinkler irrigation at 100% PE and the best performing variety Prathyasa were selected for the experiment II.

Details of irrigation treatments for experiment II

A. I_1 : IW/CPE (0.8)

The ratio between a fixed amount of irrigation water (IW) and cumulative pan evaporation (E_{pan}) from an USWB open pan evaporimeter was used as the basis for scheduling irrigation to the crop.

Experiment is conducted using IW/CPE = 0.8, in which the crop faces a moisture stress.

The depth of water to be applied was fixed by using the formula:

$$D = \frac{(FC-PWP) \times BD \times Z}{100}$$

D = Depth of irrigation

FC = Moisture content at field capacity (%)

PWP = Permanent wilting point (%)

BD = Bulk density (g cc^{-3})

Z = Root zone depth of crop (cm)

(Reddy and Reddy, 2005)

Plate 1. General view of the experimental plot of experiment I

Plate 2 (a). Drip irrigated plots at 60 DAS

Plate 2 (b). Sprinkler irrigated plots at 60DAS

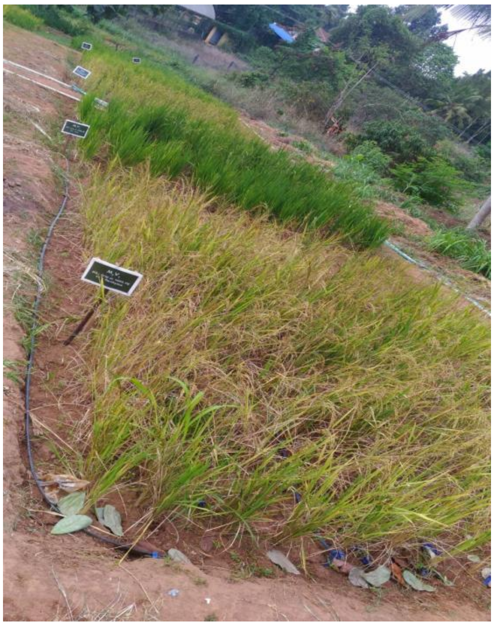

Plate 2 (c). Drip irrigated plots at 90 DAS

Plate 2 (d). Sprinkler irrigated plots at 90 DAS

Plate 3. Hose irrigated plots at 30DAS

Plate 4. Prathyasa and Uma varieties at 90 DAS

B. I_2: Critical growth stage approach

The critical growth stages sensitive to water have been identified and are used for scheduling irrigation. For rice crop, the stages have been identified to be seedling, maximum tillering, panicle initiation and grain filling. During these stages, the crop was irrigated to a depth of 2 cm.

B. I_3 : Irrigation to maintain soil moisture at 100% FC

The field capacity of the soil was estimated by a pressure plate apparatus. To provide water at 100 per cent field capacity, water was provided in two days interval, to a depth of 5 cm to maintain the field capacity throughout the crop period.

C. I_4 : Irrigation to maintain soil moisture at 75 % FC

To provide irrigation at 75 per cent of field capacity, water was provided to the plots in five days interval, to a depth of 5 cm to maintain soil moisture at 75 per cent of the field capacity.

D. S_1 : Field application of hydrogel polymer (2.5 kg ha^{-1})

CUMI jal was broadcasted in the soil at the rate of 2.5 kg ha^{-1} just before sowing.

E. S_2 : Seed treatment with hydrogel polymer (10 g kg^{-1})

For seed treatment of hydrogel polymer, powdered CUMI jal was taken and mixed with water. The rice seeds were soaked in it overnight, as shown in Plate 6 b.

F. Foliar application of Pink Pigmented Facultative Methylotrophs (1%)

One per cent PPFM was sprayed to the leaves at 30 and 45 DAS .

3.2.2.3 Application of Soil Ameliorants

Based on the acidity, lime ($CaCO_3$) @ 350 kg ha^{-1} was applied as basal dose in both the experiments.

3.2.2.4 Application of Fertilizers

For experiment I and II, fertilizers @ 60: 30: 30 kg N P K ha^{-1} recommended for the upland rice varieties (KAU, 2016) were applied uniformly in all the plots. Full dose of P as rajphos was applied as basal dose. N was applied in three splits- 1/3 as basal application, 1/3 at tillering stage and the rest 1/3 at panicle initiation, whereas K was applied in two splits- 1/2 as basal dose and the rest 1/2 at panicle initiation stage of the crop.

3.3 OBSERVATIONS

Two rows of plants were left as border rows on all sides of the plot. Five plants were selected at random from the net plot area of each plot and tagged as observation plants for recording biometric observations.

3.3.1 Growth Characteristics

3.3.1.1 Germination Count at 15 DAS

Germination count of the plants m^{-1} length of the row was taken at 15 days after sowing (DAS).

3.3.1.2 Plant Population at 30 DAS

Plant population m^{-1} length of the row was taken at 30 DAS.

3.3.1.3 Plant Height at 30, 60, 90 DAS and at Harvest

Plant height was measured from 5 randomly selected plants at 30, 60, 90 DAS and at harvest and expressed in cm. The plant height was measured from the base to the tip of the top most leaf at 30, 60 and 90 DAS. At harvest, the height was recorded from the base to the tip of the longest panicle.

Plate 5. General view of the experimental plot of experiment II

Plate 6(a). Pusa CUMI jal hydrogel polymer

Plate 6 (b). Seeds soaked in hydrogel polymer

Plate 7 (a). Field preparation

Plate 7 (b). Irrigation provided using sprinkler

3.3.1.4 Leaf Area Index at Panicle Initiation Stage

Leaf area was computed at 30, 60, 90 DAS and at harvest stage, using the method described by Gomez (1972). The maximum width 'w' and length 'l' of all the leaves of the central tiller of observation hills were recorded, mean values were worked out and LAI was computed using the formula:

$$\text{Leaf area} = l \times w \times k$$

Where k- Adjustment factor (0.75 at up to PI stage and 0.67 at harvest stage)

l- Maximum length of the 3rd leaf blade from the top (cm)

w- Maximum width of leaf blade (cm)

$$\text{LAI} = \frac{\text{Total leaf area tiller}^{-1} \times \text{Number of tillers plant}^{-1}}{\text{Land area occupied by the plant}}$$

3.3.1.5 Number of Tillers m^{-2} at 30, 60, 90 DAS and at Harvest

Tiller number was recorded from observation plants at 30, 60, 90 DAS and at harvest stages, mean was worked out and expressed as number of tillers m^{-1}.

3.3.1.6 Total Dry Matter Production at 30, 60, 90 DAS and at Harvest

The observation plants were uprooted, washed, separated into grain and straw (at harvest stage), initially air dried and later oven dried at 65 ± 5ºC to a constant weight. The mean values were recorded and total dry matter production was computed and expressed in Mg ha^{-1}.

3.3.2 Yield and Yield Attributes

3.3.2.1 Number of Days for 50% Flowering

The number of days taken for 50% flowering in the observation plants were counted and recorded.

3.3.2.2 Number of Panicles m^{-2}

At harvest, the number of panicles in the observation plants were counted and expressed as number of panicles m^{-2}.

3.3.2.3 Length of Panicle

Five panicles were randomly selected from each treatment plot and the length was measured from the point of scar to the tip of the panicle, average length was worked out and expressed in cm.

3.3.2.4 Weight of Panicle

Five panicles were randomly selected form each treatment plot and the weight was recorded on dry weight basis. The mean value was computed and expressed in g.

3.3.2.5 Number of Grains Panicle^{-1}

The grains were separated from each panicle, counted and the average number was worked out.

3.3.2.6 Test Weight of Grain

Thousand grains were counted from the cleaned and dried produce from the observation plants and the weight was recorded in g.

3.3.2.7 Sterility Percentage

Sterility percentage was worked out using the formula:

$$\text{Sterility percentage} = \frac{\text{Number of unfilled grains panicle}^{-1}}{\text{Total number of grains panicle}^{-1}} \times 100$$

3.3.2.8 Grain Yield ha^{-1}

The net plot area was harvested separately, threshed, grains cleaned and dried to 14 per cent moisture level and the weight was recorded. Grain yield was expressed in Mg ha^{-1}.

3.3.2.9 Straw Yield ha^{-1}

Straw harvested from the net plot of each treatment was dried to a constant weight and the weight was expressed as Mg ha^{-1}.

3.3.2.10 Harvest Index

From grain and straw yield values, harvest index was worked out using the following equation as suggested by Donald and Hamblin (1976).

$$\text{Harvest index} = \frac{\text{Economic yield}}{\text{Biological yield}}$$

3.3.3 Physiological Parameters

3.3.3.1 Net Assimilation Rate at 30, 60, 90 DAS and at Harvest

The net assimilation rate (NAR) at 30, 60, 90 DAS and at harvest was calculated using the equation as suggested by Rajput and Jha (2017).

$$\text{NAR} = \frac{(W_2\text{-}W_1) \times (\text{In } L_2\text{-In}L_1)}{(t_2\text{-}t_1) \times L_2\text{-}L_1)}$$

L_1& W_1 = Leaf area and dry weight of the plant respectively at time t_1.

L_2 & W_2=Leaf area and dry weight of the plant respectively at time $t_{2.}$

3.3.3.2 Relative Growth Rate at 30, 60, 90 DAS and at Harvest

The relative growth rate at 30, 60, 90 DAS and at harvest was calculated using the equation as suggested by Rajput and Jha (2017).

$$\text{RGR} = \frac{\text{In } W_2 - \text{In}W_1}{(t_2\text{-}t_1)}$$

W_1 and W_2 are plant dry weight at time t_1 and t_2, respectively

3.3.3.3 Crop Growth Rate at 30, 60, 90 DAS and at Harvest

The crop growth rate at 30, 60, 90 DAS and at harvest was calculated using the equation as suggested by Rajput and Jha (2017).

$$CGR = \frac{W_2 - W_1}{(t_2 - t_1)\ S}$$

W_1 and W_2 are plant dry weight (g) at time t_1 and t_2, respectively
S is land area (m^2) over which dry matter was recorded.

3.3.3.4 Chlorophyll Content at 30, 60, 90 DAS and at Harvest

The chlorophyll content of the crop was estimated using DMSO method as suggested by Arnon (1949). The absorbance at 645 and 663 nm were recorded and the chlorophyll content was calculated using the equations:

$$Chl.a = (12.7 \times A_{663} - 2.69 \times A_{645}) \times V/(1000 \times W)$$

$$Chl.b = (22.9 \times A_{645} - 4.68 \times A_{663}) \times V/(1000 \times W)$$

$$\text{Total chlorophyll} = (20.2 \times A_{645} + 8.02 \times A_{663}) \times V/(1000 \times W)$$

3.3.3.5 Proline Content at 30, 60, 90 DAS and at Harvest

The proline concentration was estimated by using acid ninhydrin method as suggested by Carillo and Gibon (2011). The proline concentration on fresh weight basis was calculated using the formula:

$$\mu\text{moles per g tissues} = \frac{\mu g \text{ proline m } L^{-1} \times \text{m L toluene} \times 5}{115.5 \qquad\qquad \text{g sample}}$$

3.3.3.6 Stomatal Count at 30, 60, 90 DAS and at Harvest

The impression of the flag leaf was taken, 1 cm^{-2} size of it was placed over the microscope slide and viewed under the microscope at 400x magnification.

3.3.3 Soil Analysis

Composite soil samples were collected from 0-30 cm depth from the experimental field prior to the experiment as well as after the experiment. Wet samples were analysed for mechanical composition (of the initial composite sample) and physico-chemical properties adopting the procedures cited in Table 1. Moisture percentage in soil samples was determined and the analytical values were expressed on dry weight basis.

3.3.4 Plant Analysis

At harvest, samples of grain and straw were collected from observation plants. All the collected samples were dried in hot air oven at 65 ± 5° C to a constant weight and powdered for nutrient analysis adopting the procedures as outlined in Table 6.

Uptake of nutrients was computed by multiplying nutrient content of each part with respective dry weight expressed in kg ha^{-1}. The total uptake was also worked out and expressed in kg ha^{-1}.

Table 6. Procedures followed for plant analysis

Plant parameters	Procedure for analysis	Instrument used	Reference
Total N	Single acid (H_2SO_4) digestion followed by distillation	Microkjeldahl digestion and distillation units	Jackson (1973)
Total P	Di-acid (nitric and perchloric acids in 9:4 ratio) digestion followed by vanado-molybdo-phosphoric yellow colour method	Spectro photometer	Jackson (1973)
Total K	Di-acid(nitric and perchloric acids in 9:4 ratio) digestion followed by flame photometry	Flame photometer	Jackson (1973)

3.3.5. Quality Studies

3.3.5.1 Protein Content

The protein content of the seed was analysed using Lawry method (Lawry *et al.*, 1951). The protein content was multiplied with the yield of respective plots to obtain the protein yield (kg ha^{-1}).

3.3.5.2 Carbohydrate Content

The carbohydrate content of the grains was estimated using Anthrones reagent method as suggested by Plummer (1990). The carbohydrate content was multiplied with the yield of respective treatments to obtain the carbohydrate yield per hectare (kg ha^{-1}).

3.3.6 Soil Moisture Studies

3.3.6 .1 Soil Moisture Content

Soil moisture content at 15 cm and 30 cm depth of soil from all the plots were recorded using portable moisture meters at 20, 40, 60 and 80 DAS.

3.3.6.2. Relative leaf water content

The relative leaf water content in leaves was calculated using the equation as suggested by Piecynski *et al*., (2013)

$$\text{RLWC} = \frac{\text{fresh weight} - \text{dry weight}}{\text{Turgid weight} - \text{dry weight}}$$

3.3.6.3Water Use Efficiency

Water use efficiency for various treatments was calculated using equation as suggested by Condon and Hall (2004).The crop WUE was calculated on the basis of crop yield and water used for evapotranspiration using the equation:

$$\text{Crop WUE (kg m}^{-3}\text{)} = \frac{\text{Grain Yield (kg m}^{-2}\text{)}}{\text{Evapotranspiration (mm)}}$$

Field WUE was calculated based on the crop yield and the total amount of water used in the field, using the following equation:

$$\text{Field WUE (kg m}^{-3}\text{)} = \frac{\text{Yield (kg m}^{-2}\text{)}}{\text{Water requirement (mm)}}$$

3.3.6.4 Consumptive Use

Consumptive use of water by the crop was calculated as:

Cu = Water applied to the field- Water drained out from the field

Water drained = water applied through each irrigation- (evaporation reading + soil moisture content) measured before each irrigation.

3.3.7 Pest and Disease Incidence

Incidence of pest and disease was monitored throughout the cropping period.

3.4 ECONOMIC ANALYSIS

Economics of cultivation was calculated considering the cost of inputs and the minimum support price of paddy during the cropping periods. The cost of cultivation for ach treatments in experiment I and experiment II is given in Appendix 3 and Appendix 4 respectively. Net income and B: C ratio were calculated as given below.

Net income (₹ ha^{-1}) = Gross income (₹ ha^{-1}) - Cost of cultivation (₹ ha^{-1})

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

3.5 STATISTICAL ANALYSIS

The data collected from the field experiments were analysed by applying the technique of analysis of variance (ANOVA) for split plot design (Snedecor and Cochran, 1980). Wherever the F values were found significant, critical differences was calculated at five percent probability level.

4. RESULTS

The present experiment entitled "Irrigation scheduling and water stress mitigation strategies in upland rice (*Oryza sativa* L.)" was conducted at the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala during January 2019 to April 2020, to identify a suitable variety and irrigation method for upland rice, to standardize irrigation scheduling and to assess the effect of moisture stress mitigation strategies on the growth, yield and economics of upland rice. The experimental data collected were analysed statistically and the results are presented below:

4.1 EXPERIMENT 1: IDENTIFICATION OF SUITABLE VARIETY AND STANDARDIZATION OF IRRIGATION METHOD

4.1.1 Growth Characters

4.1.1.1 Germination Count at 15 DAS

The germination count m^{-1} row length at 15 DAS was recorded (Table 7) and was found not to vary significantly with respect to the irrigation methods and varieties.

4.1.1.2 Plant Population at 30 DAS

The plant population m^{-1} row length at 30 DAS was recorded and no significant variation was observed among the methods of irrigation and varieties, as shown in the Table 7.

4.1.1.3 Plant Height (cm)

At 30 DAS, the tallest plant (20.96 cm) was observed in m_4 (drip irrigation at 75% PE) which was found to be significant over all other treatments and all other treatments were observed to be on par. At 60 DAS, significantly taller plant height of 59.34 cm was observed in the treatment m_1 (sprinkler irrigation at 100% PE), which was significantly superior to all other treatments. The plant height in treatment m_3 was observed to be significantly taller compared to m_2, which was followed by m_4 and the lowest value was recorded in m_5 (50.50 cm). At 90 DAS,

Table 7. Effect of methods of irrigation and varieties on the germination count (15 DAS) and plant population (30 DAS) of upland rice

Treatments	Germination count (15 DAS)	Plant population (30 DAS)
Irrigation methods(m)		
m_1	9.50	9.00
m_2	8.75	8.75
m_3	9.25	8.75
m_4	8.25	8.00
m_5	8.75	8.25
SE m (±)	0.28	0.33
CD (0.05)	NS	NS
Varieties (v)		
v_1	8.80	8.35
v_2	9.00	8.75
SE m (±)	0.20	0.14
CD (0.05)	NS	NS
Interaction (m xv)		
m_1v_1	9.25	8.75
m_1v_2	9.75	9.25
m_2v_1	8.25	8.50
m_2v_2	9.25	9.00
m_3v_1	9.50	8.75
m_3v_2	9.00	8.75
m_4v_1	8.00	7.50
m_4v_2	8.50	8.50
m_5v_1	9.00	8.25
m_5v_2	8.50	8.25
SE m(±)	0.42	0.46
CD (0.05)	NS	NS

m_1 showed a significantly taller plants of 107.54 cm with respect to irrigation methods and the minimum plant height of 98.50 cm was observed in m_4, as shown in the Table 8.

At harvest, taller plant of 108.34 cm was recorded in m_3 which was on par with m_1 and the shortest plant (99.30 cm) was recorded in m_5 (hose irrigation-farmer's practice-irrigation thrice in a week).

Among varieties, variety v_2 (Uma) showed a significantly higher plant height compared to the variety v_1 (Prathyasa) at 30 and 60, whereas at 90 DAS and at harvest, the variety Prathyasa was observed to have a significantly taller plants.

The interaction between the treatments was significantly higher (24.55 cm) in m_4v_2, followed by m_1v_2, and the lowest plant height of 17.38 cm was observed in m_4v_1 at 30 DAS, whereas, at 60, 90 DAS and at harvest, the interaction effects were found to be non significant.

4.1.1.4 No. of Tillers m^{-2}

The number of tillers m^{-2} was observed at 30, 60, 90 DAS and at harvest. It was observed to be significantly influenced both by the methods of irrigation and varieties, as shown in the Table 9.

At 30 DAS, the treatment m_3 (drip irrigation at 100% PE) observed the highest number of tillers m^{-2} (157.75), followed by m_1 (sprinkler irrigation at 100 % PE) (145.75), which was significantly superior compared to all other treatments, and the lowest value was recorded in the treatment m_5 with 122.75 tillers. At 60 DAS, highest number of tillers m^{-2} (495.13) was observed in the treatment m_1, which was significantly superior to that of all other treatments, followed by treatment m_2 (454.00). The lowest number of tillers m^{-2} was recorded in the treatment m_5 (333.75). A similar trend was noticed at 90 DAS and at harvest also, with the highest number of tillers m^{-2} in m_1 (447.89) and the lowest in treatment m_5 (274.88) at 90 DAS and 442.88 tillers m^{-2} in m_1 and 269.88 tillers m^{-2} in m_5 at harvest.

Table 8. Effect of the methods of irrigation and varieties on the plant height at 30, 60, 90 DAS and at harvest, cm

Treatments	Plant height			
	30 DAS	60 DAS	90 DAS	At harvest
Methods of irrigation (m)				
m_1	19.75	59.34	107.10	108.28
m_2	19.34	55.95	99.88	100.95
m_3	19.49	57.95	107.54	108.34
m_4	20.96	53.78	100.75	101.70
m_5	18.80	50.50	98.50	99.30
SE m(±)	0.38	0.22	0.59	0.59
CD (0.05)	1.187	0.696	1.845	1.861
Varieties (v)				
v_1	18.13	54.53	104.99	104.99
v_2	21.21	56.48	100.52	102.44
SE m(±)	0.26	0.16	0.36	0.35
CD (0.05)	0.788	0.500	1.083	1.059
Interaction (m x v)				
m_1v_1	18.75	57.94	109.95	109.95
m_1v_2	20.75	60.75	104.25	106.60
m_2v_1	18.28	55.13	102.50	102.50
m_2v_2	20.40	56.78	97.25	99.40
m_3v_1	17.88	57.08	109.05	109.05
m_3v_2	21.10	58.83	106.03	107.63
m_4v_1	17.38	52.53	102.93	102.93
m_4v_2	24.55	55.04	98.58	100.48
m_5v_1	18.38	49.97	100.50	100.50
m_5v_2	19.23	51.03	96.50	98.10
SE m(±)	0.56	0.34	0.84	0.85
CD (0.05)	1.721	NS	NS	NS

The variety v_1 (Prathyasa) recorded the highest number of tillers m^{-2} at all the stages of the crop growth except at 30 DAS, with 425.60, 381.00 and 381.00 tillers at 60, 90 DAS and at harvest respectively, which was significantly higher than the variety v_2 (Uma).

The interaction effects between the treatments was found to be non-significant with respect to the irrigation methods as well as varieties at all the stages of the crop growth.

4.1.1.5 Leaf Area Index at Panicle Initiation

The leaf area index (LAI) at panicle initiation was found to be significantly influenced by the irrigation methods and varieties, as shown in the Table 10. The LAI was found to be the highest (5.10) in the treatment m_1 (sprinkler irrigation at 100% PE), which was significantly superior to all other treatments. The treatments m_3 and m_4 were found to be on par and the least LAI was observed in the treatment m_5 (hose irrigation- farmer's practice, thrice a week).

Among the varieties, the variety v_1 (Prathyasa) recorded a significantly higher LAI of 3.72 compared to the variety v_2 (Uma) which recorded LAI of 3.43.

The interaction effect due to the methods of irrigation and varieties was not significant with respect to LAI at panicle initiation of the crop.

4.1.1.6 Dry Matter Production (Mg ha^{-1})

At all the stages of the crop growth, the irrigation methods were found to have significant influence on dry matter production, as indicated in Table 11. At 30 DAS, the highest dry matter production (3.13 Mg ha^{-1}) was observed in the treatment m_1 (sprinkler irrigation at 100% PE) which was on par with treatment m_3 (3.09 Mg ha^{-1}), and all other treatments were found to be on par with each other. At 60, 90 DAS and at harvest, a significantly superior dry matter production was observed in the treatment m_1 compared to all other treatments and the lowest value was observed in the treatment m_5.

Table 9. Effect of the methods of irrigation and varieties on the number of tillers m^{-2} of upland rice at 30, 60, 90 DAS and at harvest

Treatments	No. of tillers m^{-2}			
	30 DAS	60 DAS	90 DAS	At harvest
Methods of irrigation (m)				
m_1	145.75	495.13	447.89	442.88
m_2	126.75	454.00	413.00	408.00
m_3	157.75	414.75	376.25	371.25
m_4	136.00	386.00	348.88	343.50
m_5	122.75	333.75	274.88	269.88
SE m (±)	1.31	3.85	3.13	3.21
CD (0.05)	4.072	11.99	9.765	10.00
Varieties (v)				
v_1	135.40	425.60	381.00	381.00
v_2	140.20	407.85	363.35	353.20
SE m(±)	1.14	2.53	1.79	1.81
CD (0.05)	3.455	7.704	5.449	5.498
Interaction (m x v)				
m_1v_1	142.25	505.50	460.50	460.50
m_1v_2	149.25	484.75	435.25	425.25
m_2v_1	124.50	466.25	424.50	424.50
m_2v_2	129.00	441.75	401.50	391.50
m_3v_1	155.25	418.50	378.50	378.50
m_3v_2	160.25	411.00	374.00	364.00
m_4v_1	132.75	396.75	357.50	357.50
m_4v_2	139.25	375.25	340.25	329.50
m_5v_1	122.25	341.00	284.00	284.00
m_5v_2	123.25	326.50	265.75	255.75
SE m(±)	2.22	5.56	4.43	0.54
CD (0.05)	NS	NS	NS	NS

Table10. Effect of methods of irrigation and varieties on the leaf area index of the crop at panicle initiation stage of the upland rice

Treatments	Leaf area index
Methods of irrigation (m)	
m_1	5.10
m_2	3.79
m_3	3.58
m_4	3.03
m_5	2.37
SE m(±)	0.10
CD (0.05)	0.318
Varieties (v)	
v_1	3.72
v_2	3.43
SE m(±)	0.05
CD (0.05)	0.137
Interaction (m x v)	
m_1v_1	5.27
m_1v_2	4.93
m_2v_1	4.03
m_2v_2	3.56
m_3v_1	3.58
m_3v_2	3.58
m_4v_1	3.17
m_4v_2	2.90
m_5v_1	2.53
m_5v_2	2.20
SE m(±)	0.14
CD (0.05)	NS

Among the varieties, dry matter production of variety v_1 (Prathyasa) was found to be significantly higher compared to v_2 at 60, 90 DAS, and at harvest, with a dry matter production of 4.16 Mg ha^{-1}, 6.88 Mg ha^{-1} and 7.17 Mg ha^{-1} at 60, 90 DAS and at harvest, respectively in the variety Prathyasa and 3.87 Mg ha^{-1}, 5.87 Mg ha^{-1}, 6.15 Mg ha^{-1} at 60, 90 DAS and at harvest, respectively in the variety Uma.

The interaction among the treatments were found to be non-significant at 30 DAS and 60 DAS, whereas, significant differences between the treatment interactions were observed at 90 DAS and at harvest. At 90 DAS, the treatment m_1v_1 was observed to be significantly superior to all other treatment combinations and m_5v_2 recorded the lowest value. A similar trend was observed in the interaction effect of the treatments in the dry matter production at harvest also.

4.1.2 Yield Attributes and Yield

4.1.2.1 No. of Days for 50% Flowering

The irrigation methods as well as varietal differences had a significant influence on the number of days taken for 50 per cent flowering of the crop, as shown in the Table 12.

The treatment m_1 (sprinkler irrigation at 100% PE) was found to take more days (63.25) for 50 per cent of flowering, as compared to other treatments followed by m_3. The number of days taken for 50 per cent flowering by m_2 was on par with m_5, which was significantly higher as compared to m_4.

The variety v_2 (Uma) took significantly more number of days (63.50) for the completion of 50 per cent flowering, as compared to v_1 (Prathaysa) which took 48.65 days for 50 per cent flowering.

Table 11. Effect of the methods of irrigation and varieties on the dry matter production of the crop, Mg ha^{-1}

Treatments	Dry matter production			
	30 DAS	60 DAS	90 DAS	At harvest
Methods of irrigation (m)				
m_1	3.13	5.75	8.35	8.66
m_2	2.57	3.77	6.50	6.82
m_3	3.09	4.59	6.56	6.87
m_4	2.68	3.39	5.69	5.98
m_5	2.40	2.60	4.78	4.97
SE m (±)	0.14	0.10	0.12	0.11
CD (0.05)	0.424	0.308	0.384	0.352
Varieties (v)				
v_1	2.81	4.16	6.88	7.17
v_2	2.74	3.87	5.87	6.15
SE m (±)	0.05	0.08	0.06	0.06
CD (0.05)	NS	0.251	0.184	0.183
Interaction (m x v)				
m_1v_1	3.23	5.84	8.46	8.81
m_1v_2	3.04	5.66	8.25	8.51
m_2v_1	2.66	3.85	6.78	7.13
m_2v_2	2.48	3.68	6.22	6.50
m_3v_1	3.28	4.77	8.06	5.43
m_3v_2	2.89	4.41	5.07	8.31
m_4v_1	2.67	3.50	6.19	6.50
m_4v_2	2.70	3.27	5.18	5.46
m_5v_1	2.23	2.87	4.92	5.10
m_5v_2	2.57	2.34	4.63	4.84
SE m(±)	0.19	0.16	0.17	0.16
CD (0.05)	NS	NS	0.417	0.416

The interaction effect of the treatments were found to be non-significant with respect to 50 per cent flowering of the crop.

4.1.2.2 No. of Panicles m^{-2}

Result on the number of panicles m^{-2} as influenced by the treatments and their interactions are presented in the Table 12.

The methods of irrigation were found to significantly influence the number of panicles m^{-2}. Sprinkler irrigation at 100% PE (m_1) recorded significantly higher number of panicles m^{-2} (211.38) compared to all other treatments. The number of panicles m^{-2} (168.63) in sprinkler irrigation at 75% PE (m_2) was found to be superior compared to drip irrigation at 100% PE (150.38), as well as drip irrigation at 75% PE (138.50), and the lowest value was recorded in the treatment m_5 (114.00).

The varietal differences were also found to have effect on the number of panicles m^{-2}. The variety Prathyasa (v_1) counted significantly higher number of panicles m^{-2} (164.00) as compared to the variety Uma (v_2) (148.75).

The interaction effect of m_1v_1 was found to be significantly higher over all other treatments, followed by m_1v_2, which was superior over m_2v_1. The treatments m_3v_2 and m_4v_1 were on par, which was significantly higher over m_2v_2 and m_3v_1 which were on par with each other. The interaction effect of m_4v_2 and m_5v_2 were found to be on par, which was significantly superior over the treatment m_5v_1.

4.1.2.3 Length of Panicle (cm)

Among the irrigation methods, sprinkler irrigation at 100% PE (m_1) was found to be superior in terms of length of panicle (18.99 cm) over all other treatments, followed by sprinkler irrigation at 75% PE (m_2) with a panicle length of 17.69 cm. Drip irrigation at 100% PE (m_3) recorded a panicle length of 16.53cm, which was significantly higher over m_4, which was on par with m_5 (13.99) as presented in Table 12.

The varieties did not show any significant differences in the length of the panicle, whereas, interaction effects were found to be significant. The interaction effect of m_1v_2 was found to be on par with m_1v_1 and was significantly superior over all other treatments and the treatments m_3v_1 and m_3v_2 were found to be on par with each other. The treatment m_4v_1 was observed to be on par with m_3v_2, which was superior over m_5v_2. The treatments m_5v_2 and m_5v_1 were on par with each other and the lowest value was recorded in m_4v_2.

4.1.2.4 Weight of Panicle (g)

The weight of panicle (2.53 g) was found to be the highest in m_3, which was significantly superior compared to all other treatments and the lowest value was recorded in m_2 as shown in Table 12.

Among the varieties, Prathyasa (v_1) recorded significantly higher panicle weight of 2.04 g compared to the variety Uma (v_2). The interaction effect of m_3v_1 (2.97 g) was significantly higher over all other treatments and the lowest value was observed in m_2v_2.

4.1.2.5 Number of Grains Panicle^{-1}

The number of grains panicle^{-1} was found to be influenced by the irrigation methods and varieties, as indicated in Table 13. It recorded the highest in the treatment m_1 (sprinkler irrigation at 100% PE), which was on par with m_3 (drip irrigation at 100% PE). The treatment m_2 was found to be on par with m_4, which was significantly superior than m_5.

The variety Prathyasa recorded significantly higher number of grains per panicle than the variety Uma. The interaction effect between the treatments were found to be non-significant.

4.1.2.6 Sterility Percentage (%)

The sterility percentage of the grains has been furnished in the Table 13.

Table 12. Effect of the methods of irrigation and varieties on the number of days for 50% flowering, number of panicles m^{-2}, length of panicle and weight of panicle

Treatments	Number of days for 50% flowering	Number of panicle m^{-2}	Length of panicle (cm)	Weight of panicle (g)
Methods of irrigation (m)				
m_1	63.25	211.38	18.99	1.94
m_2	55.00	168.63	17.69	1.53
m_3	58.13	150.38	16.52	2.53
m_4	50.38	138.50	14.48	1.58
m_5	53.63	114.00	13.99	1.86
SE m (±)	0.73	1.49	0.22	0.10
CD (0.05)	2.270	4.637	0.670	0.322
Varieties (v)				
v_1	48.65	164.00	16.34	2.04
v_2	63.50	148.75	16.33	1.70
SE m (±)	0.49	0.70	0.13	0.03
CD (0.05)	1.481	2.130	NS	0.102
Interaction(m x v)				
m_1v_1	55.75	226.00	7.41	2.10
m_1v_2	70.75	196.75	7.77	1.77
m_2v_1	48.00	191.00	5.47	1.61
m_2v_2	62.00	146.25	4.94	1.45
m_3v_1	51.25	144.50	6.04	2.97
m_3v_2	65.00	156.25	6.59	2.09
m_4v_1	42.00	154.25	4.81	1.61
m_4v_2	58.75	122.75	3.98	1.55
m_5v_1	46.25	106.25	5.06	1.88
m_5v_2	61.00	121.75	4.98	1.85
SE m(±)	1.03	2.11	0.32	0.15
CD (0.05)	NS	4.837	0.987	0.233

It was observed to be significantly influenced by the methods of irrigation, but non-significant with respect to the varieties. Among the methods of irrigation, it was observed to be the highest (6.60 %) in m_5 and the lowest value was observed in the plots irrigated using sprinkler at 100% PE (2.88%).

4.1.2.7 Test Weight of Grain (g)

Variation in the test weight of grains was found to be non-significant with respect to methods of irrigation as well as varietal differences, as shown in Table 13.

4.1.2.8 Grain Yield (Mg ha^{-1})

The grain yield was found to be influenced by the methods of irrigation as well as the varietal differences and is depicted in the Table 14.

Among the methods of irrigation, the treatment m_1 recorded the highest grain yield (3.94 Mg ha^{-1}), which was significantly higher compared to all other treatments and the lowest value was recorded in m_5.The grain yield of the variety Prathyasa (v_1) found to be significantly higher (3.13 Mg ha^{-1}) compared to that of variety Uma (2.64 Mg ha^{-1}).

The interaction effects between the treatments were also found to have significant influence on the grain yield of the crop. The interaction m_1v_1 recorded the highest grain yield (4.37 Mg ha^{-1}), which was on a par with m_3v_1 (4.26 Mg ha^{-1}). It was followed by m_3v_1 and the interaction effects of the treatments m_5v_2, m_4v_2 and m_5v_1 were found to be on par with each other.

4.1.2.9 Straw Yield (Mg ha^{-1})

The methods of irrigation and varietal differences had significant influence on the straw yield of the crop as well, as shown in Table 14. The treatment m_1 (sprinkler irrigation at 100% PE) recorded the highest straw yield (7.59 Mg ha^{-1}), which was significantly higher over rest of the treatments. The treatments m_2,

Table 13. Effect of the methods of irrigation and varieties on the number of grains panicle^{-1}, sterility percentage (%) and test weight of grains (g)

Treatments	Number of grains panicle^{-1}	Sterility percentage	Test weight of grain
Methods of irrigation (m)			
m_1	156.25	2.88	26.37
m_2	135.73	4.61	26.30
m_3	152.15	3.58	26.70
m_4	131.43	5.63	26.09
m_5	118.25	6.64	25.93
SE m (±)	1.85	0.29	0.22
CD (0.05)	5.751	0.887	NS
Varieties (v)			
v_1	141.05	4.70	26.37
v_2	136.00	4.65	26.18
SE m (±)	0.90	0.16	0.09
CD (0.05)	2.737	NS	NS
Interaction(m x v)			
m_1v_1	159.75	3.15	26.47
m_1v_2	152.25	2.73	26.27
m_2v_1	138.25	4.74	26.40
m_2v_2	131.75	4.50	26.20
m_3v_1	155.25	3.64	26.77
m_3v_2	149.25	3.73	26.63
m_4v_1	133.50	5.52	26.14
m_4v_2	129.00	5.78	26.03
m_5v_1	118.50	6.73	26.10
m_5v_2	117.75	6.51	25.18
SE m(±)	2.33	0.40	0.31
CD (0.05)	NS	NS	NS

m_5 and m_4 were found be on par with each other, the lowest (4.40) being in m_4 (drip irrigation at 75% PE).

The varietal differences was found to have no influence on the straw yield of the crop. The variety Prathyasa recorded a straw yield of 5.76 Mg ha^{-1}, which was on par with the straw yield of variety Uma (5.65 Mg ha^{-1}).

The interaction m_1v_2 and m_1v_1 were found be on par with each other, which was superior to all other treatments. The treatment m_1v_2 was observed to be superior to m_3v_2, but was on par with m_1v_1. m_3v_2 was significantly higher than m_2v_1, but was on par with m_3v_1. The treatments m_5v_1, m_5v_2 and m_2v_2 were found be on par with each other.

4.1.2.11 Harvest Index

The harvest index was observed to be significantly influenced by the methods of irrigation and varieties, as shown in Table 14. Among the methods of irrigation, m_3 (drip irrigation at 100% PE) was found to record the highest harvest index (0.37), but was on par with treatment m_4 and m_1. The treatments m_4, m_1 and m_2 were found to be on par with each other. Treatment m_5 (conventional irrigation method) recorded the lowest harvest index (0.30).

Among the varieties, v_1 (Prathyasa) recorded a significantly higher harvest index (0.35), compared to that of v_2 (Uma).

The treatment interaction m_3v_1 was found to be on par with the treatment m_1v_1, but was superior than other treatment interactions. All other treatments were on par with each other.

4.1.3 Physiological Parameters

4.1.3.1 Crop Growth Rate (g m^{-2} d^{-1})

The crop growth rate at 0-30 DAS and 30-60 DAS has been found to be significantly influenced by irrigation levels but not influenced by varietal differences. The crop growth rate at 0-30 DAS was observed to be the highest (1.04

Table 14. Effect of methods of irrigation and varieties on the grain yield, straw yield and harvest index of upland rice

Treatments	Grain yield (Mg ha^{-1})	Straw yield (Mg ha^{-1})	Harvest index
Methods of irrigation(m)			
m_1	3.94	7.59	0.34
m_2	2.34	5.21	0.31
m_3	3.76	6.32	0.37
m_4	2.28	4.40	0.35
m_5	2.10	5.02	0.30
SE m (±)	0.05	0.29	0.02
CD (0.05)	0.163	0.894	0.048
Varieties (v)			
v_1	3.13	5.76	0.35
v_2	2.64	5.65	0.32
SE m (±)	0.03	0.09	0.01
CD (0.05)	0.086	NS	0.012
Interaction (m xv)			
m_1v_1	4.37	7.41	0.38
m_1v_2	3.52	7.77	0.31
m_2v_1	2.49	5.47	0.32
m_2v_2	2.18	4.94	0.31
m_3v_1	4.26	6.04	0.41
m_3v_2	3.25	6.59	0.33
m_4v_1	2.51	4.81	0.35
m_4v_2	2.05	3.98	0.34
m_5v_1	2.00	5.06	0.28
m_5v_2	2.20	4.98	0.31
SE m(±)	0.07	0.32	0.02
CD (0.05)	0.203	0.987	0.052

g m^{-2} d^{-1}) in m_1 (sprinkler irrigation at 100% PE), which was on par with m_3 and was significantly superior compared to all other treatments. The treatments m_4 and m_2 were found to be on par with each other, whereas the treatment m_5 (hose irrigation) was found to have the least crop growth rate (0.84 g m^{-2} d^{-1}). At 30-60 DAS, the crop growth rate was observed to be the highest (18.12 g m^{-2} d^{-1}) in m_1 which was significantly superior compared to all other treatments and the lowest value of 7.87 g m^{-2} d^{-1} was recorded in m_5.

At 60-90 DAS, the highest crop growth rate (10.01 g m^{-2} d-^{1}) was observed in m_4 (drip irrigation at 75% PE), but was on par with the treatments m_1 and m_3, but was significantly higher compared to the treatments m_2 and m_5.

The varieties as well as the interaction effect between the treatments were found to be not significantly different in terms of crop growth rate at 0-30 DAS and 30-60 DAS, whereas it was found to be significantly affected by varietal differences at 60-90 DAS. The variety Uma (v_2) was found to have significantly higher crop growth rate (8.65 g m^{-2} d^{-1}) compared to the variety Prathyasa (v_1) (7.64 g m^{-2} d^{-1}).

4.1.3.2 Relative Growth Rate (g g^{-1} d^{-1})

The relative growth rate of the crop was observed to be influenced by the methods of irrigation at 30-60 DAS, but not significant at 0-30 and 60-90 DAS, as presented in Table 16. At 30-60 DAS, the RGR was found to be the highest (0.10 g g^{-1} d^{-1}) for sprinkler irrigation at 100% PE, which was significantly the highest, followed by m_2. The treatment m_2 was on par with m_3 as well as m_4 and it was the lowest in in m_5.

The varieties were not found to have any significant influence on the relative growth rate at 30-60 DAS as well as 60-90 DAS.

The interaction effect between the treatments were observed to be significant at 30-60 DAS. The RGR of the treatment m_1v_2 (0.102 g g^{-1} d^{-1}) was significantly higher over all other treatments followed by m_1v_1 and m_2v_2. The treatments m_2v_1,

Table 15. Effect of the methods of irrigation and varieties on the crop growth rate of upland rice at 0-30, 30-60, and 60-90 DAS, g m^{-2} d^{-1}

Treatments	Crop growth rate		
	0- 30 DAS	30-60 DAS	60-90 DAS
Method of irrigation (m)			
m_1	1.04	18.12	8.67
m_2	0.86	11.69	6.75
m_3	1.03	12.80	8.04
m_4	0.90	12.48	10.01
m_5	0.84	7.87	7.25
SE m (±)	0.03	1.06	0.65
CD (0.05)	0.088	3.300	2.020
Varieties (v)			
v_1	0.95	13.19	7.64
v_2	0.91	11.99	8.65
SE m (±)	0.02	0.65	0.31
CD (0.05)	NS	NS	0.95
Interaction(m x v)			
m_1v_1	1.07	18.38	8.72
m_1v_2	1.02	17.85	8.62
m_2v_1	0.89	11.94	7.89
m_2v_2	0.83	11.45	5.61
m_3v_1	1.09	11.87	3.93
m_3v_2	0.96	13.73	12.16
m_4v_1	0.89	14.95	10.82
m_4v_2	0.90	10.01	9.21
m_5v_1	0.82	8.81	6.84
m_5v_2	0.86	6.93	7.66
SE m(±)	0.40	1.50	0.916
CD (0.05)	NS	NS	2.149

Table 16. Effect of the methods of irrigation and varieties on the relative growth rate of the crop at 0-30, 30-60 and 60-90 DAS, g g^{-1} d^{-1}

Treatments	Relative growth rate		
	0- 30 DAS	30-60 DAS	60-90 DAS
Method of irrigation (m)			
m_1	0.030	0.100	0.012
m_2	0.050	0.090	0.014
m_3	0.031	0.089	0.014
m_4	0.018	0.084	0.012
m_5	0.015	0.079	0.044
SE m (±)	0.01	0.002	0.01
CD (0.05)	NS	0.0070	NS
Varieties (v)			
v_1	0.027	0.089	0.015
v_2	0.029	0.088	0.027
SE m (±)	0.006	0.001	0.007
CD (0.05)	NS	NS	NS
Interaction(m x v)			
m_1v_1	0.030	0.096	0.012
m_1v_2	0.023	0.102	0.013
m_2v_1	0.037	0.089	0.016
m_2v_2	0.063	0.091	0.012
m_3v_1	0.031	0.088	0.008
m_3v_2	0.031	0.09	0.020
m_4v_1	0.022	0.086	0.021
m_4v_2	0.015	0.083	0.020
m_5v_1	0.016	0.086	0.018
m_5v_2	0.013	0.073	0.070
SE m(±)	0.013	0.003	0.015
CD (0.05)	NS	0.005	NS

m_3v_2, m_3v_1 and m_4v_1 were found to be on par with each other and the treatment interaction m_5v_2 recorded the lowest RGR.

4.1.3.3 Net Assimilation Rate (g m^{-2} d^{-1})

The Net Assimilation Rate (NAR) of the crop has also been found to be influenced by the irrigation methods as well as varieties, as shown in Table 17. At 0-30 DAS interval, there was significant differences in the net assimilation rate among the methods of irrigation. The NAR was observed to be the highest (1.56 g m^{-2} d^{-1}) in drip irrigated plot at 100% PE, which was on par with m_4 and was significantly higher over all other treatments. The lowest NAR (0.82 g m^{-2} d^{-1}) was recorded in sprinkler irrigated plots at 75% PE. At 30-60 DAS, the treatment m_1 (sprinkler irrigation at 100% PE) was found to have the highest NAR (5.074 g m^{-2} d^{-1}) which was significantly superior over all other treatments. The treatments m_2, m_3 and m_4 were found to be on par with each other, and the lowest value was recorded in m_5. At 60-90 DAS, the NAR was observed to be the highest in m_4, which was significantly superior compared to all other treatments, followed by m_5, which was on par with m_3. The lowest NAR was observed in m_2.

NAR was not significantly different with respect to varieties at 30-60 DAS, whereas at 60-90 DAS, NAR was observed to be significantly higher in v_2 compared to that of v_1.

The interaction effect between the treatments were not found to be significant at 30-60 DAS, whereas it was significant at 60-90 DAS. At this time period, interaction m_4v_1 recorded the highest NAR which was on par with m_3v_2, m_4v_2 and m_5v_2. The lowest NAR was observed in the treatment combination m_2v_2.

4.1.3.4 Chlorophyll Content (mg g^{-1})

The chlorophyll concentration of the leaves was also influenced by the irrigation methods as well as varietal differences, as shown in Table 18. At 30 DAS, the chlorophyll content was observed to be the highest (1.96 mg g^{-1}) in sprinkler irrigation at 100% PE, which was significantly superior over all other treatments.

Table 17. Effect of method of irrigation and varieties on the net assimilation rate of upland rice at 0-30, 30-60 and 60-90 DAS, g m^{-2} d^{-1}

	Net assimilation rate		
Treatments	0- 30 DAS	30 -60 DAS	60-90 DAS
Method of irrigation (m)			
m_1	1.10	5.07	1.20
m_2	0.82	3.99	1.07
m_3	1.53	4.02	1.54
m_4	1.56	4.04	2.19
m_5	1.20	2.95	1.79
SE m (±)	0.05	0.25	0.10
CD (0.05)	0.140	0.77	0.312
Varieties (v)			
v_1	1.27	3.87	1.41
v_2	1.21	4.16	1.71
SE m (±)	0.03	0.15	0.06
CD (0.05)	NS	NS	0.183
Interaction (m x v)			
m_1v_1	1.14	4.57	1.12
m_1v_2	1.05	5.58	1.28
m_2v_1	1.09	3.92	1.26
m_2v_2	0.56	4.06	0.87
m_3v_1	1.44	3.49	0.77
m_3v_2	1.61	4.55	2.31
m_4v_1	1.68	4.18	2.31
m_4v_2	1.45	3.90	2.08
m_5v_1	1.01	3.19	1.57
m_5v_2	1.38	2.71	1.99
SE m(±)	0.06	0.35	0.14
CD (0.05)	0.207	NS	0.414

The chlorophyll content of the treatment m_2 was significantly higher than m_4. The treatment m_5 was observed to have the lowest (1.14 mg g^{-1}) chlorophyll concentration. At 60 DAS, significantly higher chlorophyll content (2.98 mg g^{-1}) was observed in sprinkler irrigated plots at 100% PE and the lowest (2.25 mg g^{-1}) in conventional method of irrigation. At 90 DAS, the highest chlorophyll (1.71 mg g^{-1}) content was observed in drip irrigated plots at 100% PE which was significantly superior than all other treatments and the lowest chlorophyll content (0.95 mg g^{-1}) was observed in plots irrigated using conventional irrigation. At harvest, a chlorophyll content of 1.05 mg g^{-1} was observed in sprinkler irrigated plots at 100% PE, followed by drip irrigated plots at 100% PE and the lowest (0.51 mg g^{-1}) in hose method of irrigation.

Among the varieties, the variety v_1 recorded significantly higher chlorophyll concentration than the variety v_2 at all the stags of crop growth.

The interaction between the treatments also influenced the chlorophyll concentration of the leaves. At 30 DAS and 60 DAS the treatment combination m_1v_1 recorded the highest chlorophyll concentration of 1.97 mg g^{-1} and 2.99 mg g^{-1} respectively, whereas at 90 DAS and at harvest it was the highest in m_2v_2. At 30 DAS, 60 DAS and at harvest, the lowest value was recorded in m_5v_2, whereas at 90 DAS, it was observed to be the lowest in m_5v_1.

4.1.3.5 Proline Concentration (µ moles g^{-1})

At 30 DAS, proline concentration was found to be significantly the highest in plots irrigated using hose method (23.68 µ moles g^{-1}), followed by the plots irrigated using drip irrigation at 75% PE, which was significantly superior over m_3, m_2 and m_1. The lowest proline concentration was observed in plots irrigated using sprinkler irrigation at 100% PE (9.83 µ moles g^{-1}) as presented in Table 19.

At 60 DAS, a similar trend was observed, with the highest concentration of proline (38.21 µ moles g^{-1}) in plots irrigated using hose and the lowest (25.42 µ moles g^{-1}) in m_1. At 90 DAS, a significantly higher concentration of (24.51 µ moles g^{-1}) was observed in plots irrigated using hose method and the lowest (17.37 µ

Table 18.Effect of methods of irrigation and varieties on the chlorophyll content of leaves at 30, 60, 90 DAS and at harvest, mg g^{-1}

Treatments	Chlorophyll content			
	30 DAS	60 DAS	90 DAS	At harvest
Method of irrigation (m)				
m_1	1.96	2.98	1.63	1.05
m_2	1.40	2.72	1.32	0.75
m_3	1.59	2.92	1.71	1.23
m_4	1.30	2.59	1.22	0.74
m_5	1.14	2.25	0.95	0.51
SE m (±)	0.001	0.006	0.015	0.015
CD (0.05)	0.0040	0.0190	0.0470	0.0470
Varieties (v)				
v_1	1.52	2.71	1.92	0.92
v_2	1.44	2.67	1.81	0.80
SE m (±)	0.001	0.003	0.008	0.008
CD (0.05)	0.0020	0.0100	0.0250	0.0250
Interaction (m x v)				
m_1v_1	1.97	2.99	1.12	1.12
m_1v_2	1.95	2.96	2.14	0.97
m_2v_1	1.44	2.73	0.83	0.83
m_2v_2	1.37	2.72	1.81	0.68
m_3v_1	1.65	2.95	1.21	1.21
m_3v_2	1.52	2.90	2.20	1.24
m_4v_1	1.33	2.62	0.86	0.86
m_4v_2	1.28	2.56	1.58	0.68
m_5v_1	1.19	2.28	0.59	0.59
m_5v_2	1.09	2.22	1.31	0.44
SE m(±)	0.002	0.008	0.021	0.021
CD (0.05)	0.0050	0.0230	0.0570	0.0620

moles g^{-1}) in sprinkler irrigated plot at 100% PE. At harvest, the proline content was found to be non-significant with respect to methods of irrigation.

Among the varieties, the variety Uma was found to have a significantly higher amount of proline, compared to the variety v_1 (Prathyasa) at 30, 60 and 90 DAS.

The interaction effect between the treatments was found to have significant influence on the proline content, with the highest in m_5v_2 at 30 DAS and 60 DAS whereas at 90 DAS a significantly superior value was observed in m_4v_2 the lowest value was recorded in m_1v_1 at 30, 60 and 90 DAS. The interaction effect was observed to be non-significant at harvest.

4.1.3.6 Stomatal Count

The influence of methods of irrigation as well as varieties on the stomatal count has been furnished in the Table 21.

At all the stages of crop growth, it was observed to be significantly higher in the plots irrigated using sprinkler at 100% PE, followed by plots irrigated using drip at 100% PE. The lowest stomatal count was observed in m_5 (hose irrigation-farmer's practice-irrigation given thrice a week)

Among the varieties, a significantly higher stomatal count was observed in the variety v_2 (Uma), compared to the variety v_1 (Prathyasa).

The interaction effect between the treatments was found to significantly influence the stomatal count at 30 DAS, 90 DAS and at harvest, whereas it was not significant at 60 DAS. At 90 DAS and at harvest, it was observed to be the highest in m_3v_2 which was significantly superior to all other treatments and at 30 DAS, it was the highest in m_1v_2.

4.1.4 Quality Aspects of Grains

The various methods of irrigations, as well as varieties were found to have significant influence on the quality aspects of grains, except length-breadth ratio.

Table 19.Effect of methods of irrigation and varieties on the proline content at 30, 60, 90 DAS and at harvest, μ moles g^{-1}

Treatments	30 DAS	60 DAS	90 DAS	At harvest
Method of irrigation (m)				
m_1	9.83	25.42	17.37	4.94
m_2	17.10	32.87	21.01	4.09
m_3	15.27	31.01	19.60	3.93
m_4	20.42	35.90	22.64	3.49
m_5	23.68	38.21	24.51	4.45
SE m (±)	0.16	0.32	0.27	0.38
CD (0.05)	0.504	0.993	0.825	NS
Varieties (v)				
v_1	16.77	31.98	15.41	3.87
v_2	17.75	33.38	26.64	4.49
SE m (±)	0.10	0.16	0.15	0.23
CD (0.05)	0.300	0.993	0.453	NS
Interaction(m x v)				
m_1v_1	9.68	25.32	12.56	5.20
m_iv_2	9.98	25.51	22.19	4.67
m_2v_1	16.20	31.46	15.52	3.53
m_2v_2	18.01	34.28	26.49	4.65
m_3v_1	14.70	29.51	13.84	3.10
m_3v_2	15.83	32.52	25.36	4.75
m_4v_1	19.80	35.46	16.95	3.03
m_4v_2	21.03	36.34	28.33	3.95
m_5v_1	23.45	38.14	18.19	4.50
m_5v_2	23.90	38.27	30.84	4.40
SE m(±)	0.23	0.41	0.37	0.53
CD (0.05)	0.692	1.260	1.027	NS

Table 20. Effect of methods of irrigation as well as varieties on the stomatal count of leaves at 30, 60, 90 DAS and at harvest

Treatments	30 DAS	60 DAS	90 DAS	At harvest
Method of irrigation (m)				
m_1	781.63	6252.00	984.13	657.75
m_2	467.88	3324.50	585.13	514.88
m_3	601.13	5719.75	941.50	655.38
m_4	466.00	3472.25	500.00	492.38
m_5	338.75	3017.88	371.25	340.38
SE m (±)	0.19	1.24	0.35	0.22
CD (0.05)	0.599	3.861	1.078	0.685
Varieties (v)				
v_1	495.05	4137.95	549.26	514.95
v_2	567.10	4576.60	803.55	549.35
SE m (±)	0.11	0.80	0.22	0.12
CD (0.05)	0.331	2.44	0.679	0.355
Interaction(m x v)				
m_1v_1	756.75	694.75	963.21	649.25
m_iv_2	806.50	1273.50	785.41	666.25
m_2v_1	478.75	3251.00	763.52	558.25
m_2v_2	457.00	515.75	884.75	471.50
m_3v_1	434.75	598.00	721.36	567.00
m_3v_2	767.50	1285.00	816.23	743.75
m_4v_1	419.25	441.50	523.41	455.50
m_4v_2	512.75	558.50	631.25	529.25
m_5v_1	385.75	357.50	411.96	344.75
m_5v_2	291.75	385.00	544.26	336.00
SE m(±)	0.27	0.49	0.26	0.31
CD (0.05)	0.750	1.537	0.87	0.804

The impact of the methods of irrigation and varieties on the quality aspects of grains like length-breadth ratio, protein content and carbohydrate content have been furnished below:

4.1.4.1 Length-Breadth Ratio

The length-breadth ratio was not found to be influenced by methods of irrigations as well as varietal differences as presented in Table 21.

4.1.4.2 Protein Content (%)

The protein content in grain was observed to be influenced by the methods of irrigations as well as varieties, as shown in the Table 21. The highest protein content (9.06 %) was observed in the plots irrigated using hose method, which was significantly higher than all other treatments. It was followed by drip irrigation at 75% PE with a protein content of 7.96 %. The lowest protein content was observed in sprinkler irrigated plots at 100% PE.

Among the varieties, the variety Uma was observed to have a significantly higher amount of protein (7.54%) compared to the variety Prathyasa (7.06%). The interaction among the treatments was not found to have any significant influence on the protein content of the grain.

4.1.4.3 Carbohydrate Content (%)

The carbohydrate content in grains was significantly influenced by the different methods of irrigations as well as varieties as shown in the Table 21. It was observed to be the highest (70.81%) in the treatment m_1, which was on par with treatments m_3 and m_5. The treatments m_3 and m_2 were on par with each other. The lowest carbohydrate content (69.87%) was observed in m_4.

The variety Prathyasa, with a carbohydrate content of 70.76% recorded significantly higher carbohydrate content than the variety Uma (69.81%). The interactive effect between the treatments were found to be non-significant in terms of carbohydrate content.

Table 21.Effect of methods of irrigation and varieties on the length-breadth ratio, protein content and carbohydrate content

Treatments	Length-breadth ratio	Protein content (%)	Carbohydrate content (%)
Method of irrigation (m)			
m_1	2.49	5.68	70.81
m_2	2.40	7.80	69.97
m_3	2.44	5.99	70.30
m_4	2.37	7.96	69.87
m_5	2.36	9.06	70.48
SE m (±)	0.04	0.21	0.21
CD (0.05)	NS	0.663	0.642
Varieties (v)			
v_1	2.44	7.06	70.76
v_2	2.38	7.54	69.81
SE m (±)	0.02	0.07	0.15
CD (0.05)	NS	0.218	0.445
Interaction (m x v)			
m_1v_1	2.55	5.34	71.41
m_1v_2	2.43	6.00	70.21
m_2v_1	2.41	7.75	70.41
m_2v_2	2.38	7.86	69.52
m_3v_1	2.51	5.59	70.81
m_3v_2	2.37	6.40	69.80
m_4v_1	2.37	7.67	70.05
m_4v_2	2.36	8.24	69.69
m_5v_1	2.36	8.94	71.13
m_5v_2	2.37	9.18	69.84
SE m(±)	0.06	0.30	0.29
CD (0.05)	NS	NS	NS

4.1.5 Moisture Studies

4.1.5.1 Soil Moisture Content at 15 and 30 cm Depth (%)

The soil moisture content at 15 cm and 30 cm was recorded at 20, 40, 60 and 80 DAS and the results obtained are furnished below and presented in Table 23 and Table 24 respectively.

At 20 DAS, the irrigation methods and varietal differences was not found to have any significant influence on the soil moisture content at 15 cm depth, whereas at 40, 60 and 80 DAS, it was influenced by the treatments. At 40 DAS, soil moisture content was found to be the highest (14.85%) in drip irrigated plots at 100% PE and the lowest (9.73%) in plots irrigated using hose method. The soil moisture at 60 DAS and 80 DAS also showed a similar trend.

At 30 cm depth, irrigation methods had significant influence on the soil moisture at 20, 40, 60 and 80 DAS. At 20 DAS, the highest soil moisture (11.41%) was observed in sprinkler irrigated plots at 100% PE, which was on par with sprinkler irrigated plots at 75% PE. The lowest amount of soil moisture was observed in drip irrigated plots at 75% PE. At 40 DAS, a significantly higher soil moisture (15.07%) was observed in sprinkler irrigated plots at 100% PE, followed by sprinkler irrigated plots at 75% PE (13.02%). The least soil moisture (8.39) was observed in drip irrigated plots at 75% PE, which was significantly inferior compared to drip irrigated plots at 100% PE. A similar trend was observed at 60 DAS, as well as 80 DAS.

Varietal differences did not show any significant influence on the soil moisture content at 15 cm at 20, 40 and 80 DAS. At 60 DAS, it was significantly higher in the variety Prathyasa, compared to that in the variety Uma. At 30 cm depth, soil moisture was influenced by varietal differences. At 20 DAS and 60 DAS, it was significantly higher in the variety Prathyasa, whereas at 40 DAS, it was observed to be the highest in the variety Uma. At 80 DAS, it was observed to be non-significant.

Table 22. Effect of the methods of irrigation and varieties on the soil moisture content at 15 cm at 20, 40, 60 and 80 DAS, %

Treatments	Soil moisture content at 15 cm depth			
	20 DAS	40 DAS	60 DAS	80 DAS
Method of irrigation (m)				
m_1	11.64	13.59	14.77	12.98
m_2	9.38	10.88	12.08	11.69
m_3	10.26	14.85	15.51	13.06
m_4	10.57	11.99	13.72	11.56
m_5	8.82	9.73	10.24	9.28
SE m (±)	0.62	0.08	0.05	0.07
CD (0.05)	NS	0.237	0.156	0.231
Varieties (v)				
v_1	9.90	12.25	13.36	11.79
v_2	10.37	12.16	13.17	11.64
SE m (±)	0.38	0.04	0.04	0.06
CD (0.05)	NS	NS	0.117	NS
Interaction (m x v)				
m_1v_1	11.39	13.48	14.62	13.18
m_1v_2	11.88	13.70	14.92	12.77
m_2v_1	9.52	11.03	12.75	11.52
m_2v_2	9.25	10.72	11.42	11.85
m_3v_1	9.28	14.50	15.28	13.55
m_3v_2	11.25	15.21	15.75	12.56
m_4v_1	10.86	12.32	13.54	11.47
m_4v_2	10.29	11.66	13.90	11.65
m_5v_1	8.47	9.91	10.62	9.22
m_5v_2	9.17	9.55	9.86	9.34
SE m(±)	0.88	0.11	0.07	0.11
CD (0.05)	NS	0.303	0.265	0.351

Table 23. Effect of the methods of irrigation and varieties on the soil moisture content at 30 cm depth at 20, 40, 60 and 80 DAS, %

Treatments	Soil moisture content at 30 cm depth			
	20 DAS	40 DAS	60 DAS	80 DAS
Method of irrigation (m)				
m_1	11.41	15.07	15.88	12.34
m_2	11.38	13.02	13.17	12.61
m_3	6.51	9.28	7.17	7.19
m_4	5.42	8.39	7.35	7.21
m_5	10.11	11.84	11.60	11.50
SE m (±)	0.92	0.22	0.21	0.66
CD (0.05)	2.878	0.670	0.668	2.044
Varieties (v)				
v_1	9.82	11.24	11.19	10.23
v_2	8.11	11.80	10.88	10.23
SE m (±)	0.51	0.10	0.10	0.49
CD (0.05)	1.564	0.301	0.305	NS
Interaction (m x v)				
m_1v_1	12.77	15.03	16.13	13.60
m_1v_2	10.05	15.11	15.63	11.67
m_2v_1	11.48	12.99	13.19	11.49
m_2v_2	11.28	13.05	13.16	13.74
m_3v_1	6.99	9.01	7.14	7.12
m_3v_2	6.04	9.56	7.20	7.26
m_4v_1	5.31	7.77	7.77	7.45
m_4v_2	5.53	9.02	6.92	6.97
m_5v_1	12.55	11.39	11.72	11.48
m_5v_2	7.68	12.30	11.47	11.53
SE m(±)	1.23	0.30	0.30	0.93
CD (0.05)	NS	NS	NS	NS

At 15 cm soil depth, the interaction effect was not significant at 20 DAS, whereas at 40 and 60 DAS, the soil moisture was the maximum in m_3v_2 and the lowest in m_5v_2. At 80 DAS, the highest soil moisture content was observed in m_1v_1 and the lowest in m_5v_1. At 30 cm depth, the interactive effects were found to be non-significant at 20, 40, 60 and 80 DAS.

4.1.5.2 Relative Leaf Water Content (%)

The relative leaf water content of the crop varied significantly with the methods of irrigation. At 30 DAS, the highest RLWC (66.62) was observed in sprinkler irrigated plots at 100% PE, which was significantly superior over all other treatments. It was followed by drip irrigated plots at 100% PE. The sprinkler irrigated plots at 75% PE showed a higher RLWC, compared to drip irrigated plots at 75% PE. The lowest RLWC was observed in plots with conventional methods of irrigation. At 60, 90 DAS and at harvest also, it followed a similar trend as shown in the Table 24.

The varietal differences was observed not to have significant influence on RLWC at 30 and 90 DAS and at harvest. Whereas at 60 DAS, Prathyasa showed a significantly higher RLWC (65.83%) than the variety Uma.

The interaction effects between the treatments were also found to be significant. At 30, 60 and 90 DAS, it was the highest in the treatment m_3v_2, which was significantly superior to all other treatment combinations and the lowest value was recorded in m_5v_2. At harvest, it was found to be non significant.

4.1.5.3 Consumptive Use (mm)

Sprinkler irrigation at 100% PE recorded the highest consumptive use (380.88 mm), which was on par with consumptive use of drip irrigated plots at 100% PE (379.59). The lowest consumptive use of 161.38 mm was observed in the plots irrigated using hose. Among the varieties, the variety Uma recorded a significantly higher consumptive use compared to the variety Prathyasa, as depicted in Table 25.

Table 24. Effect of the methods of irrigation and varieties on the relative leaf water content at 30, 60, 90 DAS and at harvest, %

Treatments	Relative leaf water content (%)			
	30 DAS	60 DAS	90 DAS	At harvest
Method of irrigation (m)				
m_1	66.62	72.42	74.64	53.89
m_2	56.28	66.66	68.95	48.54
m_3	65.39	68.57	70.96	51.52
m_4	54.57	62.34	66.91	46.96
m_5	52.08	57.24	62.04	42.78
SE m (±)	0.24	0.26	0.20	0.19
CD (0.05)	0.740	0.822	0.626	0.597
Varieties (v)				
v_1	58.83	65.84	68.56	48.98
v_2	59.15	65.05	68.84	48.50
SE m (±)	0.15	0.16	0.11	0.18
CD (0.05)	NS	0.822	NS	NS
Interaction (m x v)				
m_1v_1	65.05	71.64	74.12	53.72
m_1v_2	68.19	73.21	75.16	54.07
m_2v_1	55.31	67.81	70.04	49.02
m_2v_2	57.26	65.52	67.86	48.07
m_3v_1	65.15	68.97	70.98	52.01
m_3v_2	65.62	68.17	70.94	51.04
m_4v_1	55.59	62.39	66.05	46.89
m_4v_2	53.55	62.29	67.78	47.02
m_5v_1	53.05	58.39	61.61	43.27
m_5v_2	51.12	56.08	62.48	42.30
SE m(±)	0.34	0.37	0.28	0.27
CD (0.05)	1.036	1.071	0.750	NS

Among the interactions, the treatment combination m_1v_2 recorded significantly the highest consumptive use, followed by m_3v_2 and the lowest consumptive use was recorded in the treatment combination m_4v_1.

4.1.5.4 Water Use Efficiency (kg m^{-3})

The crop water use efficiency and field water use efficiency under different treatments are shown in the Table 25.

The crop water use efficiency was observed to be the highest (1.31 kg m^{-3}) in the plots irrigated using hose, which was on par with the crop water use efficiency of sprinkler irrigated plots at 75% PE (1.23 kg m^{-3}). It was followed by water use efficiency in drip irrigation at 75% PE (1.22 kg m^{-3}) and the lowest crop WUE (1.03 kg m^{-3}) was observed in the drip irrigated plots at 100% PE.

The field water use efficiency recorded a significantly higher value (0.82 kg m^{-3}) in $m_{1,}$ followed by m_3 and the lowest field WUE (0.43 kg m^{-3}) was observed in the treatment m_5.

Among the varieties, the variety Prathyasa recorded a significantly higher crop WUE (1.40 kg m^{-3}) and field WUE (0.75 kg m^{-3}) than the variety Uma.

Among the treatment interactions, m_4v_1 recorded a significantly higher crop WUE (1.53 kg m^{-3}) and field WUE (0.95 kg m^{-3}) and the lowest value was observed in m_1v_1.

4.1.5.5 FC and PWP (%)

The field capacity of the soil of the experimental plot was observed to be 19.23% and permanent wilting point was observed to be 7.62%.

4.1.6 NPK Uptake at Harvest

4.1.6.1 N Uptake (kg ha^{-1})

The N content as well as uptake by grain, straw and total uptake has been presented in Table 26.

Table 25. Effect of the methods of irrigation and varieties on the consumptive use (mm) and water use efficiency (kg mm^{-3}) of upland rice

Treatments	Consumptive use (mm)	Water use efficiency	
		Crop water use Efficiency (kg m^{-3})	Field water use efficiency (kg m^{-3})
Irrigation methods (m)			
m_1	380.88	1.07	0.81
m_2	195.44	1.23	0.64
m_3	379.59	1.03	0.77
m_4	192.81	1.22	0.63
m_5	161.38	1.31	0.43
SE m (±)	0.38	0.03	0.01
CD (0.05)	1.182	0.084	0.040
Varieties (v)			
v_1	227.49	1.40	0.75
v_2	296.55	0.95	0.56
SE m (±)	0.34	0.02	0.01
CD (0.05)	1.026	0.047	0.018
Interaction (i xv)			
m_1v_1	327.51	1.34	0.95
m_1v_2	434.25	0.81	0.68
m_2v_1	167.27	1.49	0.72
m_2v_2	223.61	0.97	0.56
m_3v_1	326.07	1.31	0.93
m_3v_2	433.12	0.75	0.63
m_4v_1	164.56	1.53	0.73
m_4v_2	221.06	0.93	0.53
m_5v_1	152.06	1.32	0.43
m_5v_2	170.71	1.29	0.42
SE m(±)	0.54	0.04	0.02
CD (0.05)	2.312	0.106	0.042

The N uptake by the grain in the treatment m_1 (59.93 kg ha^{-1}) was on par with the N uptake in drip irrigated plots at 100% PE. The N uptake by grain in hose method was significantly higher compared to that in sprinkler irrigated plots at 75% PE. The lowest N uptake by grain was recorded in the plots irrigated by drip at 75% PE.

The N uptake by the straw was found to be the highest in plots irrigated with sprinkler at 100% PE (66.31 kg ha^{-1}) and the lowest in plots irrigated using drip at 75% PE (51.37 kg ha^{-1}).

The total N uptake was observed to be the highest in sprinkler irrigated plots at 100% PE (126.24 kg ha^{-1}), which was on par with drip irrigated plots at 100% PE and the lowest in drip irrigated plots at 75% PE (99.25 kg ha^{-1}).

The N uptake in grain as well as total N uptake was significantly higher in the variety Prathyasa, whereas the N uptake in straw was observed to be non significant with respect to the varieties.

The interaction between the treatments was higher in the combination m_1v_1 (63.61 kg ha^{-1}), which was on par with treatment combination m_3v_1, in terms of the grain N uptake. It was observed to be the lowest (42.57 kg ha^{-1}) in m_4v_2. The straw N uptake was the highest (70.00 kg ha^{-1}) in m_1v_2, which was on a par with the interactions m_1v_1, m_3v_2, m_5v_1 and m_5v_2. The N uptake was the lowest in the interaction m_4v_2. The total N uptake recorded the highest in m_1v_2 (126.25 kg ha^{-1}), which was on par with m_1v_1, m_3v_1 and m_3v_2. The lowest total N uptake was recorded in m_4v_2 (91.93 kg ha^{-1}).

4.1.6.2 P Uptake (kg ha^{-1})

The P uptake in grain was however the highest (3.64 kg ha^{-1}) in sprinkler irrigated plots at 100% PE which was on par with that of grain P uptake in drip irrigated plots at 100% PE as shown in Table 27. It was significantly inferior in plots irrigated using hose irrigation. The P uptake in straw was significantly the highest in sprinkler irrigated plots at 100% PE (4.93 kg ha^{-1}), which was on par

Table 26. Effect of the methods of irrigation and varieties on N uptake by grain, N uptake by straw and total N uptake, kg ha^{-1}

Treatments	N uptake by grain	N uptake by straw	Total N uptake
Irrigation methods (m)			
m_1	59.93	66.31	126.24
m_2	48.49	56.27	104.76
m_3	59.40	61.07	120.47
m_4	46.63	51.37	99.25
m_5	50.70	59.80	110.50
SE m (±)	1.74	3.01	3.36
CD (0.05)	5.410	9.380	10.459
Varieties (v)			
v_1	55.35	59.14	114.50
v_2	50.71	58.79	109.99
SE m (±)	0.55	0.95	1.00
CD (0.05)	1.658	NS	3.051
Interaction (I x v)			
m_1v_1	63.61	62.62	126.23
m_1v_2	56.25	70.00	126.25
m_2v_1	51.44	57.81	109.26
m_2v_2	45.53	54.73	100.26
m_3v_1	63.49	59.35	122.85
m_3v_2	55.32	62.79	118.10
m_4v_1	50.68	55.88	106.57
m_4v_2	42.57	46.85	91.93
m_5v_1	47.54	60.04	107.57
m_5v_2	53.86	59.57	113.43
SE m(±)	1.94	3.37	3.71
CD (0.05)	6.011	10.434	11.517

with drip irrigated plots at 100% PE (4.23 kg ha^{-1}) and the lowest value was recorded in the plots irrigated drip at 75% PE (3.54 kg ha^{-1}). The total uptake was found to be significantly superior in sprinkler irrigated plots at 100% PE (8.57 kg ha^{-1}), followed by drip irrigated plots at 100% PE (7.82 kg ha^{-1}). The lowest total P uptake was observed in plots irrigated using hose.

Among the varieties, the grain P uptake was significantly higher in Prathyasa (3.14 kg ha^{-1}), but was non-significant with respect to straw P uptake. The total P uptake was higher in the variety Prathyasa (7.24 kg ha^{-1}), than that of the variety Uma (6.79 kg ha^{-1}).

The treatment interactions were also observed to significantly influence the grain, straw and total P uptake. The P uptake by grain was found to be the highest in m_3v_1, which was significantly higher compared to all other treatment combinations. The lowest P uptake was recorded in m_5v_1. The P content in straw was the highest in m_4v_2 and the lowest in m_1v_1.The straw P uptake was significantly higher in the treatment combination m_1v_2 and the lowest in m_4v_2. The treatment combination m_1v_2 recorded significantly higher total P uptake compared to all other treatments and the lowest was observed in m_4v_2.

4.1.6.3 K Uptake (kg ha^{-1})

The K uptake in grain recorded the highest in drip irrigated plots at 75% PE, which was significantly higher compared to all other treatments as indicated in Table 28. It was followed by drip irrigated plots at 100 % PE and significantly lowest K uptake was recorded in plots irrigated using hose irrigation. The K uptake by straw was however not significantly influenced by the methods of irrigation. The total uptake was significantly superior in drip irrigated plots at 75% PE, which was on par with drip irrigated plots at 100% PE. It recorded the lowest in sprinkler irrigated plots at 75% PE.

Among the varieties, grain K uptake and total K uptake was the highest in the variety Prathyasa, compared to the variety Uma, whereas K uptake by straw was not significantly influenced by the varieties.

Table 27. Effect of the methods of irrigation and varieties on the P uptake by grain, P uptake by straw and total P uptake, kg ha^{-1}

Treatments	P uptake by grain	P uptake by straw	Total P uptake
Irrigation methods (m)			
m_1	3.64	4.93	8.57
m_2	2.62	4.10	6.73
m_3	3.60	4.23	7.82
m_4	2.63	3.54	6.17
m_5	2.17	3.64	5.82
SE m (±)	0.06	0.21	0.20
CD (0.05)	0.196	0.666	0.622
Varieties (v)			
v_1	3.14	4.10	7.24
v_2	2.72	4.07	6.79
SE m (±)	0.04	0.07	0.08
CD (0.05)	0.106	NS	0.231
Interaction (i xv)			
m_1v_1	3.89	4.64	8.53
m_1v_2	3.38	5.23	8.61
m_2v_1	2.79	4.29	7.07
m_2v_2	2.46	3.92	6.38
m_3v_1	4.06	4.04	8.10
m_3v_2	3.12	4.42	7.54
m_4v_1	2.85	3.81	6.65
m_4v_2	2.41	3.28	5.68
m_5v_1	2.12	3.75	5.87
m_5v_2	2.23	3.53	5.77
SE m(±)	0.09	0.30	0.23
CD (0.05)	0.258	0.452	0.720

Among the treatment interactions, the highest K uptake in grain (39.80) was observed in m_3v_1 and the lowest (22.86) in m_2v_2. The K uptake by straw was found to be the highest in m_1v_2 and the lowest in m_4v_2. The total uptake of K was the highest (63.51 kg ha^{-1}) in m_4v_1 and the lowest (46.30 kg ha^{-1}) in m_2v_2.

4.1.7 Soil analysis

4.1.7.1 N Content in Soil Before and After Harvest (kg ha^{-1})

The data on available nitrogen after the experiment revealed that it was significantly influenced by the treatments, as indicated in Table 29. It was the highest (214.80 kg ha^{-1}) in drip irrigated plots at 75% PE, followed by drip irrigated plots at 100 % PE (199.93 kg ha^{-1}) and the lowest (123.98 kg ha^{-1}) in plots irrigated using hose method.

The N content in soil was after harvest was observed to be significantly higher (177.54 kg ha^{-1}) in the variety Prathyasa, than the variety Uma (175.61 kg ha^{-1}).

The interaction among the treatments was observed to be the highest in the treatment combination m_4v_2, which was on par with m_4v_1 and the lowest was observed in m_5v_2.

4.1.7.2 P Content in Soil Before and After Harvest (kg ha^{-1})

The P content of the soil, before the experiment is furnished in the Table 29. The P content of the soil after harvest was found to be significantly influenced by the methods of irrigation. It was observed to be the highest (23.23 kg ha^{-1}) in drip irrigated plots at 75% PE and the lowest (13.01 kg ha^{-1}) in sprinkler irrigated plots at 100% PE.

The varietal differences as well as the interaction between the treatments were not found to have any significant influence on the P content of the soil after harvest.

Table 28. Effect of the methods of irrigation and varieties on K uptake by grain, K uptake by straw and total K uptake, kg ha^{-1}

Treatments	K uptake grain	K uptake straw	Total K uptake
Irrigation methods (m)			
m_1	28.09	25.77	53.87
m_2	25.01	24.07	49.08
m_3	33.79	23.93	57.72
m_4	35.78	22.64	58.41
m_5	26.65	24.14	50.89
SE m (±)	0.62	1.18	0.90
CD (0.05)	1.927	NS	2.812
Varieties (v)			
v_1	32.47	24.22	56.47
v_2	27.26	23.99	49.08
SE m (±)	0.33	0.44	0.46
CD ((0.05)	1.006	NS	1.393
Interaction (i xv)			
m_1v_1	31.91	24.53	56.44
m_1v_2	24.28	27.02	51.30
m_2v_1	27.16	24.70	51.86
m_2v_2	22.86	23.44	46.30
m_3v_1	39.80	22.47	62.27
m_3v_2	27.78	25.39	53.17
m_4v_1	38.03	25.48	63.51
m_4v_2	33.83	19.80	53.32
m_5v_1	25.48	23.93	49.41
m_5v_2	27.83	24.35	52.17
SE m(±)	0.81	1.66	1.28
CD (0.05)	2.498	3.075	3.161

Table 29. Available N and P in soil before and after the experiment, kg ha^{-1}

Treatments	Available soil N after the experiment	Available soil P after the experiment
Method of irrigation (m)		
m_1	163.75	13.01
m_2	180.40	13.02
m_3	199.93	22.64
m_4	214.80	23.23
m_5	123.98	11.85
SE m (±)	0.92	0.51
CD (0.05)	2.871	1.600
Varieties (v)		
v_1	177.54	17.06
v_2	175.61	16.44
SE m (±)	0.28	0.36
CD (0.05)	0.849	NS
Interaction (m x v)		
m_1v_1	163.11	13.08
m_1v_2	164.39	12.93
m_2v_1	185.03	14.29
m_2v_2	176.78	11.74
m_3v_1	197.96	22.40
m_3v_2	201.91	22.89
m_4v_1	213.93	23.52
m_4v_2	215.67	22.95
m_5v_1	128.66	12.03
m_5v_2	119.30	11.68
SE m(±)	1.02	0.73
CD (0.05)	3.169	NS
Available soil N before the experiment was 226.54 kg ha^{-1} and available P in the soil before the experiment was 17.38 kg ha^{-1}		

4.1.7.3 K Content of the Soil Before and After Harvest (kg ha^{-1})

The K content of the soil before harvest is shown in the Table 30. The K content of the soil after harvest was found to be significantly different with respect to the methods of irrigation. It was observed to be significantly higher in drip irrigated plots at 75% PE, followed by drip irrigated plots at 100% PE and was the lowest in sprinkler irrigated plots at 100% PE.

The K content in soil after harvest was also found to be significantly influenced by the varietal differences, with a significantly higher value in the variety Uma. The interactive effects were also found to significantly influence the K content in soil after harvest, the highest being in m_4v_1 which was on par with m_4v_2. The lowest K content was observed in the treatment combination m_1v_1.

4.1.7.4 Organic Carbon Content of Soil After Harvest (%)

The organic carbon content of the soil before the experiment is given in the Table 30. The organic carbon content of the soil was found to be the highest (1.13%) in drip irrigation at 75% PE and conventional method of irrigation and the lowest value of 1.08% was recorded in sprinkler irrigated plots at 100% PE.

The varieties as well as the interaction effects between the treatments did not have any significant influence on the organic carbon content of the soil.

4.1.8 Incidence of Pests and Diseases

Stem borer was the major pest of the crop and the number of attacked plants m^{-2} has been presented in the Table 31.

It was observed to be significantly higher in sprinkler irrigated plots at 100 % PE, followed by plots irrigated using hose method and the lowest attack was observed in plots irrigated using drip at 75% PE.

It was found to be non significant with respect to varietal differences.

Table 30. Available K and organic carbon before and after the experiment, kg ha^{-1}

Treatments	Available K after the experiment (kg ha^{-1})	Available organic carbon before the experiment (%)
Method of irrigation (m)		
m_1	215.96	1.08
m_2	223.28	1.10
m_3	233.95	1.11
m_4	240.91	1.13
m_5	224.98	1.13
SE m (±)	0.52	0.01
CD (0.05)	1.604	0.024
Varieties (v)		
v_1	227.052	1.10
v_2	228.58	1.16
SE m (±)	0.16	0.01
CD (0.05)	0.483	NS
Interaction (m x v)		
m_1v_1	214.85	1.06
m_1v_2	217.07	1.11
m_2v_1	222.87	1.10
m_2v_2	223.69	1.11
m_3v_1	233.19	1.11
m_3v_2	234.72	1.11
m_4v_1	240.99	1.12
m_4v_2	240.85	1.14
m_5v_1	223.38	1.12
m_5v_2	226.58	1.13
SE m(±)	0.73	0.01
CD (0.05)	1.101	NS
Available K before the experiment was 265.16 kg ha^{-1} and available organic carbon before the experiment was 1.18 %		

Table 31. Effect of methods of irrigation and varieties on stem borer attack

Treatments	No. of attacked plants m^{-2}
Methods of irrigation (m)	
m_1	8.13
m_2	7.63
m_3	4.00
m_4	2.75
m_5	5.13
SE m(±)	0.25
CD(0.05)	0.762
Varieties (v)	
v_1	5.40
v_2	5.65
SE m(±)	0.14
CD (0.05)	NS
Interaction (i x v)	
m_1v_1	8.00
m_1v_2	8.25
m_2v_1	7.50
m_2v_2	7.75
m_3v_1	4.25
m_3v_2	3.75
m_4v_1	2.50
m_4v_2	3.00
m_5v_1	4.75
m_5v_2	5.50
SE m(±)	0.35
CD (0.05)	NS

4.1.7 Economics of Cultivation

4.1.7.1 Net Returns (₹ ha^{-1})

Significantly higher net returns (₹1,16,199.60 ha^{-1}) was observed in sprinkler irrigated plots at 100% PE, and from sprinkler irrigated plots at 75% PE, a net returns of ₹ 39,886.25 ha^{-1} was recorded. From drip irrigated plots at 100% PE, net returns obtained was ₹ 89,870.63 ha^{-1} was obtained. The net returns obtained from the plots irrigated using hose method was observed to be the lowest (₹2, 250.56 ha^{-1})

Among the varieties, higher net returns was obtained from the variety Prathyasa (₹63,928 ha^{-1}) compared to the variety Uma (₹ 43,837.00 ha^{-1}).

The net returns from the interactive effects between the treatments was observed to be the highest (₹1,32,465.50 ha^{-1}) in m_1v_1, followed by m_3v_1 (₹ 1,08,478.80 ha^{-1}). The lowest net returns was obtained from m_5v_1, with a net loss of ₹1,608.75 ha^{-1}.

4.1.7.2 B: C Ratio

The benefit-cost ratio recorded the highest (2.46) in sprinkler irrigated plots at 100% PE, followed by drip irrigation at 100 @ PE (1.98) and the lowest B: C ratio (1.02) was recorded in hose irrigated plots.

Among the varieties, a significantly higher B: C ratio (1.76) was obtained from the variety Prathyasa, compared to the variety Uma (1.52).

A significantly higher B: C ratio was observed in treatment combination m_1v_1 (2.67), followed by m_1v_2 and the lowest was recorded in the treatment combination m_5v_1 (0.98).

Table 32. Net returns and B: C ratio obtained in different methods of irrigations and varieties

Treatments	Net returns (₹ ha^{-1})	B: C ratio
Irrigation methods (m)		
m_1	116199.60	2.46
m_2	39886.25	1.50
m_3	89870.63	1.98
m_4	21207.50	1.23
m_5	2250.63	1.02
SE m (±)	1934.10	0.02
CD (0.05)	6025.560	0.065
Varieties (v)		
v_1	63928.85	1.76
v_2	43837.00	1.52
SE m (±)	1152.04	0.01
CD (0.05)	3504.290	0.036
Interaction (i xv)		
m_1v_1	132465.50	2.67
m_1v_2	99933.75	2.26
m_2v_1	47547.50	1.60
m_2v_2	32225.00	1.41
m_3v_1	108748.80	2.18
m_3v_2	70992.50	1.77
m_4v_1	32491.25	1.35
m_4v_2	9923.75	1.11
m_5v_1	-1608.75	0.98
m_5v_2	6110.00	1.06
SE m(±)	2735.23	0.03
CD (0.05)	7936.330	0.082

4.2 EXPERIMENT II: STANDARDIZATION OF IRRIGATION SCHEDULING AND MOISTURE STRESS MITIGATION STRATEGIES FOR UPLAND RICE

4.2.1 Growth Parameters

The impact of different approaches of scheduling irrigation and the moisture stress mitigation strategies on upland rice has been studied and is furnished below:

4.2.1.1 Germination Count (15 DAS)

Germination count was taken m^{-1} of row length and the various approaches of scheduling irrigation was not found to have any significant influence on the germination count of the crop, whereas various moisture stress mitigation strategies showed significant impact on the germination count, as shown in Table 33 a and 33 b. It was found to be the highest (9.85) in s_3 *i.e.,* plots treated with hydrogel (field application @ 2.5 kg ha^{-1} + seed treatment @ 10 g kg^{-1}), followed by the germination count in the plots in which seed treatment of hydrogel polymer (10g kg^{-1}) was done. The lowest germination was observed in absolute control. The interaction effect between the treatments was found to be non-significant.

4.2.1.2 Plant Population (30 DAS)

The plant population of the crop was taken m^{-1} of row length and at 30 DAS was not found to be influenced by the approaches of scheduling irrigation, whereas it was found to be significantly influenced by the various moisture stress mitigation strategies and is presented in Table 33 a and 33 b. It was the highest (9.85) in plots treated with hydrogel (field application @ 2.5 kg ha^{-1} + seed treatment @ 10 g kg^{-1}), which was significantly superior over all other treatments. It was followed by the plots in which seed treatment of hydrogel @ 10 g kg^{-1} was done. The lowest plant population was observed in absolute control plots. The interactive effects between the treatments was found to be non-significant.

Table 33 a. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies on germination count (15 DAS) and plant population (30 DAS) per meter row length

Treatments	Germination count	Plant population
Approaches of scheduling irrigation (i)		
i_1	8.96	8.72
i_2	9.00	8.84
i_3	9.00	8.84
i_4	8.68	8.60
SE m(±)	0.10	0.11
CD (0.05)	NS	NS
Moisture stress mitigation strategies (s)		
s_1	8.85	8.80
s_2	9.30	9.30
s_3	9.85	9.85
s_4	8.40	8.10
s_5	8.15	7.70
SE m(±)	0.094	0.10
CD	0.265	0.286

Table 33 b. Interaction effect of approaches of scheduling irrigation and moisture stress mitigation strategies on the germination count (15 DAS) and plant population (30 DAS) per meter row length

Interaction (i x s)	Germination count	Plant population
i_1s_1	9.00	8.80
i_1s_2	9.40	9.20
i_1s_3	10.00	10.00
i_1s_4	8.20	7.80
i_1s_5	8.20	7.80
i_2s_1	9.00	9.00
i_2s_2	9.40	9.40
i_2s_3	10.00	10.00
i_2s_4	8.40	8.00
i_2s_5	8.20	7.80
i_3s_1	8.80	8.80
i_3s_2	9.40	9.40
i_3s_3	10.00	10.00
i_3s_4	8.60	8.40
i_3s_5	8.20	7.60
i_4s_1	8.60	8.60
i_4s_2	9.00	9.20
i_4s_3	9.40	9.40
i_4s_4	8.40	8.20
i_4s_5	8.00	7.60
SE m(±)	0.20	0.24
CD (0.05)	NS	NS

4.2.1.3 Plant Height (cm)

The height of the plant was significantly influenced by the different approaches of scheduling irrigation at 30, 60, 90 DAS and at harvest, as presented in Table 34 a and 34 b. At all stages of the crop, it was observed to be the tallest in i_3 (irrigation to maintain soil moisture at 100% FC), which was observed to be significantly higher over all other approaches of scheduling irrigations. It was followed by i_2 (critical growth stage approach) which was significantly superior over irrigating the crop at irrigation to maintain soil moisture at 75% FC as well as irrigating the crop at an IW/CPE of 0.8. The shortest plants were observed in irrigating the crop at 0.8 IW/CPE ratio.

Among the moisture stress mitigation strategies, s_3 (field application @ 2.5 kg ha^{-1} + seed treatment of hydrogel polymer @10 g kg^{-1}) performed best in terms of the height of plant. The plants in plots in which seed treatment with hydrogel polymer @ 10 g kg^{-1} was given was significantly taller than the plants in plots with field application of hydrogel polymer @ 2.5 kg ha^{-1}. The shortest plants were observed in plants in plots of absolute control.

The interaction effect between the treatments was also found to be significant with respect to the height of the plants at all the stages of crop. The treatment combination i_3s_3 recorded significantly taller plants at all the stages of the crop, followed by the treatment i_2s_3. The shortest plants was recorded in the treatment interaction i_1s_5 at 20 DAS, whereas at all other stages of crop growth, the treatment i_4s_5 recorded the shortest plants.

4.2.1.4 No. of tillers m^{-2}

The influence of various approaches of scheduling irrigation as well as the moisture stress mitigation strategies on the number of tillers m^{-2} has been furnished in the Table 35 a and 35 b.

The number of tillers was found to be significantly influenced by the different approaches of scheduling irrigation at 30, 60, 90 DAS and at harvest. At all the stages of the crop, it was found to be significantly the highest in plots

Table 34 a. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies on the height of the plant at 30, 60 and 90 DAS, cm

Treatments	Plant height		
	30 DAS	60 DAS	90DAS
Approaches of scheduling irrigation (i)			
i_1	21.61	62.58	94.79
i_2	24.13	64.50	102.10
i_3	25.62	68.41	106.96
i_4	22.37	63.30	94.55
SE m(±)	0.12	0.27	0.23
CD (0.05)	0.384	0.847	0.714
Moisture stress mitigation strategies (s)			
s_1	24.19	64.35	101.91
s_2	25.28	66.42	105.00
s_3	27.48	72.04	111.88
s_4	20.74	59.90	95.04
s_5	19.49	57.10	84.18
SE m(±)	0.17	0.29	0.51
CD	0.482	0.814	1.417

Table 34 b. Interaction effect of approaches of scheduling irrigation and moisture stress mitigation strategies on the plant height at 30,60 and 90 DAS, cm

Interaction (i x v)	Plant height		
	30 DAS	60 DAS	90 DAS
i_1s_1	23.56	62.90	95.14
i_1s_2	22.76	63.52	99.04
i_1s_3	24.84	68.88	107.18
i_1s_4	18.80	59.28	90.26
i_1s_5	18.10	58.30	82.32
i_2s_1	25.16	63.76	105.20
i_2s_2	26.74	65.70	107.88
i_2s_3	28.90	71.52	114.22
i_2s_4	20.62	61.58	97.74
i_2s_5	19.24	59.92	85.48
i_3s_1	26.96	67.68	109.30
i_3s_2	27.70	70.70	111.96
i_3s_3	30.32	77.08	116.94
i_3s_4	22.64	64.86	101.82
i_3s_5	20.48	61.72	94.78
i_4s_1	21.08	63.06	98.00
i_4s_2	23.92	65.76	101.10
i_4s_3	25.84	70.68	109.18
i_4s_4	20.88	59.90	90.34
i_4s_5	20.12	57.10	74.12
SE m(±)	0.28	0.61	0.51
CD (0.05)	0.978	1.66	1.417

Table 35 a. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies on the number of tillers m^{-2} at 30, 60 and 90 DAS

Treatments	No. of tillers m^{-2}		
	30 DAS	60 DAS	90DAS
Approaches of scheduling irrigation (i)			
i_1	157.64	435.80	296.36
i_2	168.72	474.40	326.64
i_3	184.72	487.84	345.08
i_4	163.96	453.16	326.72
SE m(±)	0.99	1.82	7.59
CD (0.05)	3.094	5.682	23.65
Moisture stress mitigation strategies (s)			
s_1	175.15	501.05	369.80
s_2	169.00	493.50	343.00
s_3	181.70	506.45	374.45
s_4	162.45	440.95	295.40
s_5	155.50	371.60	235.85
SE m(±)	0.64	1.52	8.98
CD	1.822	4.273	25.43

Table 35 b. Interaction effect of approaches of scheduling irrigation and moisture stress mitigation strategies on the number of tillers m^{-2} at 30, 60 and 90 DAS

Treatment interactions	Number of tillers m^{-2}		
	30 DAS	60 DAS	90 DAS
i_1s_1	162.40	487.20	357.40
i_1s_2	158.20	479.60	332.80
i_1s_3	167.60	492.20	357.00
i_1s_4	153.00	414.00	247.00
i_1s_5	147.00	306.00	187.60
i_2s_1	176.80	505.40	370.60
i_2s_2	168.60	496.60	353.00
i_2s_3	185.40	512.00	375.80
i_2s_4	159.20	449.80	282.40
i_2s_5	153.60	406.40	251.40
i_3s_1	191.20	516.80	380.00
i_3s_2	185.20	512.80	368.20
i_3s_3	196.40	521.00	386.20
i_3s_4	179.00	475.00	309.00
i_3s_5	171.80	413.60	282.00
i_4s_1	170.20	494.80	371.20
i_4s_2	164.00	485.00	318.00
i_4s_3	177.40	500.60	378.80
i_4s_4	158.60	425.00	343.20
i_4s_5	149.60	360.40	222.40
SE m(±)	2.22	4.08	16.98
CD (0.05)	3.799	8.814	NS

irrigated to maintain 100% FC, followed by irrigation at critical growth stages of the crop. The number of tillers m^{-2} in the plots irrigated to maintain soil moisture at 75% FC was significantly higher compared to the plots irrigated with IW/CPE of 0.8. Among the moisture stress mitigation strategies, the highest number of tillers m^{-2} was observed in the treatment s_3 *i.e.*, the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @ 10g kg^{-1}). The plots in which soil incorporation of hydrogel polymer @ 2.5 kg ha^{-1} was given recorded a higher number of tillers m^{-2} compared to seed treatment with hydrogel polymer @ 10 g kg^{-1}. It was followed by plots in which foliar application of Pink Pigmented Facultative Methylotrophs (1%) was given. The lowest number of tillers m^{-2} was observed in the absolute control plots.

The interaction between the treatments was observed to be significant at 30 and 60 DAS, whereas it was not found to be significant at 90 DAS. Among the treatment interactions, treatment combination i_3s_3 recorded significantly superior number of tillers at 30 and 60 DAS and the lowest was recorded in treatment interaction i_1s_5.

4.1.2.5 Leaf Area Index at Panicle Initiation

Leaf area index at panicle initiation was observed to be significantly influenced by the approaches of scheduling irrigation and moisture stress mitigation strategies and is furnished in Table 36 a and 36 b. It was significantly higher in the plots irrigated to maintain 100 % FC (5.21) and the lowest value of 4.29 was recorded in the plots irrigated at IW/CPE of 0.8.

Among the moisture stress mitigation strategies, the highest leaf area index of 5.90 was observed in s_3, closely followed by s_1 and the lowest value was observed in the absolute control plots.

The interaction effect was also found to be significant and the treatment i_3s_3 recorded the highest value of 6.25, which was significantly higher than all other treatment combinations.

Table 36 a. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies on the leaf area index of upland rice at panicle initiation stage

Treatments	Leaf area index
Approaches of scheduling irrigation (i)	
i_1	4.29
i_2	4.87
i_3	5.21
i_4	4.47
SE (m±)	0.02
CD (0.05)	0.054
Moisture stress mitigation strategies (s)	
s_1	5.78
s_2	5.11
s_3	5.90
s_4	3.72
s_5	3.04
SE (m±)	0.02
CD (0.05)	0.058

Table 36 b. Interaction effect of approaches of scheduling irrigation and moisture stress mitigation strategies on the leaf area index of upland rice at panicle initiation stage

Treatment interaction (i x s)	Leaf area index
i_1s_1	5.55
i_1s_2	4.78
i_1s_3	5.67
i_1s_4	3.09
i_1s_5	2.38
i_2s_1	5.83
i_2s_2	5.29
i_2s_3	6.02
i_2s_4	3.80
i_2s_5	3.40
i_3s_1	6.16
i_3s_2	5.56
i_3s_3	6.25
i_3s_4	4.40
i_3s_5	3.68
i_4s_1	5.58
i_4s_2	4.82
i_4s_3	5.66
i_4s_4	3.58
i_4s_5	2.70
SE m(±)	0.04
CD (0.05)	0.116

4.1.2.6 Dry Matter Production (Mg ha^{-1})

The dry matter production was found to be significantly influenced by the different approaches of scheduling as well as moisture stress mitigation strategies as depicted in Table 37 a and 37 b. At all the stages of crop growth, it was observed to be the highest in plots irrigated to maintain 100% FC which was significantly superior compared to all other treatments. The dry matter production in plots irrigated at critical growth stages recorded significantly higher dry matter production compared to plots irrigated at 75% FC. It was observed to be the lowest (2.07 Mg ha^{-1}) in plots irrigated at an IW/CPE of 0.8 at 60 and 90 DAS, whereas at 30 DAS, it was significantly the lowest in i_4.

Among the moisture stress mitigation strategies, a significantly higher dry matter production was observed in s_3, followed by field application of hydrogel polymer (2.5 kg ha^{-1}). A significantly higher dry matter production was observed in the plots in which seed treatment of hydrogel polymer (10 g kg^{-1}) was done, compared to plots treated with PPFM (1%) and the lowest dry matter was recorded in the absolute control plots at all the stages of the crop.

The interaction effects between the treatment also significantly influenced the dry matter production. At all the stages, it was observed to be the highest in the treatment combination i_3s_3, followed by i_2s_3 and the lowest was observed in i_4s_5 at 30 DAS. At 60 and 90 DAS, it recorded the highest in i_3s_3 and the lowest in i_1s_5.

4.2.2 Yield Attributes

4.2.2.1 Number of Days for 50% Flowering

The number of days for 50 percent flowering was found to be influenced by the approaches of scheduling irrigation as well as the moisture stress mitigation strategies as depicted in Table 38 a and 38 b. The number of days taken was found to be the lowest (52.32) in the plots irrigated at an IW/CPE of 0.8 and it was found to be the highest (54.60) in the plots irrigated to maintain 100% FC.

Table 37 a. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies on the dry matter production at 30, 60 and 90 DAS, Mg ha^{-1}

Treatments	Dry matter production (Mg ha^{-1})		
	30 DAS	60 DAS	90DAS
Approaches of scheduling irrigation (i)			
i_1	2.21	4.79	6.86
i_2	2.41	5.26	7.40
i_3	2.71	5.54	8.06
i_4	2.07	4.99	7.06
SE m(±)	0.03	0.20	0.02
CD (0.05)	0.083	0.060	0.048
Moisture stress mitigation strategies (s)			
s_1	2.60	5.25	7.72
s_2	2.31	5.53	7.38
s_3	2.98	5.86	8.04
s_4	2.09	5.00	7.11
s_5	1.77	4.08	6.47
SE m(±)	0.03	0.02	0.02
CD	0.077	0.063	0.059

Table 37 b. Interaction effect of approaches of scheduling irrigation and moisture stress mitigation strategies on the dry matter production at 30, 60 and 90 DAS, Mg ha^{-1}

Interaction (i x s)	Dry matter production		
	30 DAS	60 DAS	90 DAS
i_1s_1	2.45	5.00	7.28
i_1s_2	2.25	5.16	6.91
i_1s_3	2.73	5.60	7.49
i_1s_4	1.94	4.63	6.58
i_1s_5	1.69	3.55	6.05
i_2s_1	2.67	5.31	7.84
i_2s_2	2.42	5.78	7.45
i_2s_3	2.89	5.91	8.10
i_2s_4	2.19	5.09	7.18
i_2s_5	1.86	4.20	6.41
i_3s_1	2.83	5.61	8.35
i_3s_2	2.54	5.90	8.07
i_3s_3	3.70	6.13	8.70
i_3s_4	2.41	5.35	7.87
i_3s_5	2.08	4.71	7.31
i_4s_1	2.46	5.08	7.41
i_4s_2	2.05	5.28	7.09
i_4s_3	2.59	5.79	7.88
i_4s_4	1.82	4.93	6.82
i_4s_5	1.42	3.84	6.11
SE m(±)	0.060	0.043	0.035
CD (0.05)	0.156	0.129	0.120

Among the various moisture stress mitigation strategies, the maximum number of days (61.20) for 50 per cent flowering was observed in the treatment s_3 (field application of hydrogel @ 2.5 kg ha^{-1} + seed treatment of hydrogel @ 10 g kg^{-1}), which was observed to be significantly higher compared to all other treatments and the least number of days for 50 per cent flowering was observed in absolute control plots.

The interaction effects were also found to be significant with respect to the number of days for 50 per cent flowering. It was observed to be significantly highest in i_3s_3 and the lowest in i_4s_5.

4.2.2.2 Number of panicles m^{-2}

The number of panicles per metre square recorded the highest (205.80) in plots irrigated to maintain moisture at 100 percentage field capacity, followed by plots irrigated to maintain 2 cm of water at critical stages of growth and the lowest (163.36) number of panicles m^{-2} was observed in plots irrigated at an IW/CPE of 0.8, as presented in Table 38and 38 b.

Among the moisture stress mitigation strategies, significantly higher number of panicles m^{-2} (212.35) was observed in the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @ 10g kg^{-1}), followed by seed treatment with hydrogel polymer @ 10 g kg^{-1}.The lowest number of panicles was recorded in absolute control plots. Among the interaction effects, the highest number of panicles (233.20) was observed in the treatment combination i_3s_3, followed by i_3s_1 and the lowest number of panicles was observed in the treatment combination i_1s_5.

4.2.2.3 Length of Panicle (cm)

The length of the panicle was also found to be significantly influenced by the various approaches of scheduling irrigation and various moisture stress mitigation strategies, as presented in Table 38 a and 38b. The panicle was observed to be the longest (19.41 cm) in the plots irrigated with 2 cm depth at critical stages of growth, followed by irrigation to maintain 100 percentage field capacity. The shortest panicle (18.74 cm) was observed in plots irrigated at 75 % field capacity.

Among the moisture stress mitigation strategies, the significantly longest panicle (19.49 cm) was observed in plots treated with hydrogel (field application @ 2.5 kg ha^{-1} + seed treatment @ 10 g kg^{-1}). It was followed by plots treated with PPFM (1%) and the lowest value of 18.83 cm was observed in s_2.

The interactive effects between the treatments were also found to be significantly different with respect to the panicle length. It was significantly highest in the treatment combination i_3s_3, followed by i_2s_3, and the lowest was observed in the combination i_4s_2.

4.2.2.3 Weight of panicle (g)

The panicle weight as influenced by the treatments has been furnished in the Table 38 a and 38 b.

The weight of the panicle was found to be the highest in plots irrigated to maintain 100 % FC (2.46 g), followed by the plots irrigated to maintain moisture 2 cm at critical growth stages of the crop (2.41 g) and the lowest panicle weight of 2.16 g was observed in the plots irrigated at IW/CPE of 0.8.

The moisture stress mitigation strategies also significantly influenced the panicle weight of the crop. It was the highest in the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @ 10g kg^{-1}). It was found to be significantly higher over all other treatments and was followed by field application of hydrogel polymer @ 2.5 kg ha^{-1}. The lowest panicle weight of 1.49 g was observed in the absolute control plots.

The interactive effect between the treatments was significantly higher in the combination i_3s_3, followed by i_4s_3 and the lowest was observed in the treatment combination i_1s_5.

Table 38 a. Effect of the approaches of scheduling irrigation and varieties on the number of days for 50% flowering, number of panicles m^{-2}, length of panicle, weight of panicle

Treatments	Number of days for 50% flowering	Number of panicles m^{-2}	Length of panicle (cm)	Weight of panicle (g)
Approaches of scheduling irrigation (i)				
i_1	52.32	163.36	18.81	2.16
i_2	53.64	195.36	19.41	2.41
i_3	54.60	205.80	19.36	2.46
i_4	52.32	173.28	18.74	2.33
SE m(±)	0.219	0.754	0.111	0.013
CD (0.05)	0.682	2.348	0.346	0.040
Moisture stress mitigation strategies (s)				
s_1	55.50	204.90	18.96	2.78
s_2	53.00	190.25	18.83	2.59
s_3	61.20	212.35	19.49	2.94
s_4	49.75	172.45	19.10	1.91
s_5	46.65	142.30	19.02	1.49
SE m(±)	0.166	0.942	0.095	0.018
CD(0.05)	0.471	2.668	0.268	0.051

Table 38 b. Interaction effect of the approaches of scheduling irrigation and varieties on the number of days for 50% flowering, number of panicles m^{-2}, length of panicle, weight of panicle

Treatment interaction (i x s)	Number of days for 50% flowering	Number of panicles m^{-2}	Length of panicle (cm)	Weight of panicle (g)
i_1s_1	53.60	183.40	18.90	2.70
i_1s_2	51.40	171.80	18.34	2.51
i_1s_3	59.60	192.20	18.90	2.82
i_1s_4	49.60	154.60	18.82	1.58
i_1s_5	47.40	114.80	19.08	1.17
i_2s_1	56.00	215.60	19.58	2.80
i_2s_2	53.40	206.60	19.46	2.61
i_2s_3	61.40	220.60	19.70	2.96
i_2s_4	51.20	182.20	19.22	1.99
i_2s_5	46.20	151.80	19.08	1.67
i_3s_1	56.40	226.00	18.82	2.83
i_3s_2	53.80	211.60	19.24	2.72
i_3s_3	64.20	233.20	20.36	3.07
i_3s_4	50.20	192.40	19.36	2.17
i_3s_5	48.40	165.80	19.02	1.54
i_4s_1	56.00	194.60	18.54	2.79
i_4s_2	53.40	171.00	18.28	2.53
i_4s_3	59.60	203.40	18.98	2.90
i_4s_4	48.00	160.60	19.00	1.87
i_4s_5	44.60	136.80	18.90	1.58
SE m(±)	0.490	1.685	0.248	0.029
CD (0.05)	0.974	5.425	0.551	0.104

4.2.2.5. Number of Grains Panicle^{-1}

The number of grains panicle^{-1} was influenced by the different approaches of scheduling irrigation and different moisture stress mitigation strategies as well as interaction, as presented in Table 39 a and 39 b. A significantly higher number of grains panicle^{-1} (154.20) was observed in treatment i_3 (irrigation to maintain 100 % FC), followed by the plots irrigated to maintain 2 cm depth of water at critical growth stages of the crop. The lowest number of grains (135.56) was observed in the plots in which irrigation was provided at an IW/CPE of 0.8.

Among the moisture stress mitigation strategies, a significantly higher number of grains panicle^{-1} was observed in the treatment s_3 (hydrogel polymer field application @ 2.5 kg ha^{-1} + seed treatment @ 10 g kg^{-1}), which was followed by plots in which field application of 2.5 kg ha^{-1} hydrogel was given. The lowest number of grains per panicle was observed in the absolute control plots.

The interactive effect among the treatments were also found to be significant with respect to the number of grains panicle^{-1} with the highest in i_3s_3 and the lowest in i_1s_5.

4.2.2.6 Sterility Percentage (%)

The sterility percentage of grains was observed to be significantly the highest (3.38%) in the plots irrigated to maintain moisture at 75 % FC, followed by the plots irrigated at an IW/CPE of 0.8 (3.30 %) and is depicted in Table 39 a and 39 b. The lowest sterility percentage (2.36 %) was observed in the plots irrigated to maintain moisture at 100 % FC.

Among the moisture stress mitigation strategies, the lowest sterility percentage of grains (2.31%) was observed in the treatment s_3 (hydrogel treatment of field application @ 2.5kg ha^{-1} + seed treatment @ 10g kg^{-1}) and the highest sterility percentage (4.05 %) was observed in absolute control plots.

Among the interactive effects, the highest sterility percentage was observed in the treatment combination i_1s_5, followed by i_4s_5 and the lowest was observed in the treatment combination i_3s_3.

4.2.2.7 Test Weight of Grain (g)

The test weight of the grain was observed to be significantly influenced by the approaches of scheduling irrigation as well as the various moisture stress mitigation strategies, as shown in Table 39 a and 39 b. It recorded the highest (26.38 g) in plots irrigated to maintain soil moisture at 100 % FC, followed by the plots in which irrigation was given to maintain 2 cm depth of water at critical stages of crop growth (26.26 g). It was found to be the lowest in the plots in which irrigation was given to maintain 75 % FC.

Among the moisture stress mitigation strategies, a significantly higher test weight (26.79 g) was observed in the plots treated with hydrogel (field application @ 2.5 kg ha^{-1} + seed treatment @ 10g kg^{-1}), followed by s_1 and s_2, which recorded the same value (26.28 g) and the lowest value was recorded in absolute control plots.

Among the interaction effects, the highest test weight was observed in the treatment combination i_3s_3, followed by the combination i_2s_3 and the lowest test weight was observed in the treatment combination i_1s_5.

4.2.2.8 Grain Yield (Mg ha^{-1})

The grain yield was observed to be significantly influenced by the methods of irrigation as well as various moisture stress mitigation strategies as presented in Table 40 a and 40 b. Among the different approaches of scheduling irrigation, it was significantly higher (3.61Mg ha^{-1}) in the plots irrigated to maintain 100 % FC, followed by the plots irrigated to maintain 2 cm water at critical growth stages of the crop (3.51Mg ha^{-1}). It was observed to be the lowest in the plots irrigated at an IW/CPE of 0.8 (2.59 Mg ha^{-1}).

Table 39 a. Effect of the approaches of scheduling irrigation and varieties on the number of grains panicle^{-1}, sterility percentage, test weight of grain

Treatments	Number of grains panicle^{-1}	Sterility percentage (%)	Test weight of grain (g)
Approaches of scheduling irrigation (i)			
i_1	135.56	3.30	26.19
i_2	148.96	2.57	26.25
i_3	154.20	2.36	26.38
i_4	142.76	3.38	26.17
SE m(±)	0.92	0.13	0.03
CD (0.05)	2.855	0.392	0.089
Moisture stress mitigation strategies (s)			
s_1	151.80	2.54	26.28
s_2	138.60	2.87	26.28
s_3	159.20	2.31	26.79
s_4	142.95	2.74	26.04
s_5	131.20	4.05	25.85
SE m(±)	1.09	0.23	0.03
CD (0.05)	3.094	0.657	0.092

Table 39 b. Interaction effect of the approaches of scheduling irrigation and varieties on the number of grains panicle^{-1}, sterility percentage, test weight of grain

Interaction (i x s)	Number of grains panicle^{-1}	Sterility percentage (%)	Test weight of grain (g)
i_1s_1	145.20	2.62	26.19
i_1s_2	131.40	2.74	26.39
i_1s_3	152.40	2.49	26.61
i_1s_4	129.60	2.78	26.00
i_1s_5	119.20	5.89	25.78
i_2s_1	154.00	2.47	26.33
i_2s_2	140.60	3.27	26.10
i_2s_3	161.20	1.99	26.91
i_2s_4	146.80	2.59	26.04
i_2s_5	142.20	2.53	25.90
i_3s_1	158.80	2.02	26.37
i_3s_2	146.00	2.75	26.31
i_3s_3	169.20	1.77	27.16
i_3s_4	152.40	2.22	26.11
i_3s_5	144.60	3.04	25.95
i_4s_1	149.20	3.07	26.23
i_4s_2	136.40	2.73	26.33
i_4s_3	154.00	2.99	26.47
i_4s_4	143.00	3.37	26.01
i_4s_5	131.20	4.74	25.79
SE m(±)	2.049	0.281	0.064
CD (0.05)	6.300	1.325	0.188

Among the moisture stress mitigation strategies, the treatment s_3 (field application of hydrogel polymer @ 2.5 kg ha^{-1} + seed treatment with hydrogel polymer @ 10g kg^{-1}) recorded a significantly higher grain yield (4.37 Mg ha^{-1}) compared to all other treatments. It was followed by the grain yield of plots in which field application of hydrogel polymer @ 2. 5kg ha^{-1} was given. The lowest grain yield (1.51 Mg ha^{-1}) was recorded in the absolute control plots.

Interactive effects was however found to be non significant with respect to the grain yield.

4.2.2.9 Straw Yield (Mg ha^{-1})

The data on the straw yield of the crop as influenced by the various approaches of scheduling irrigation as well as the moisture stress mitigation strategies have been furnished in the Table 40 a and 40 b.

Among the various approaches of scheduling irrigation, a significantly higher straw yield (6.78 Mg ha^{-1}) was observed in the plots irrigated to maintain soil moisture at 100 percentage field capacity, followed by irrigation to maintain 2 cm depth of water at critical stages of crop growth. A significantly lower straw yield was observed in the plots irrigated at an IW/CPE of 0.8, which recorded 5.45 Mg ha^{-1}.

A significantly higher straw yield (7.72 Mg ha^{-1}) as observed in the treatment s_3 (field application of hydrogel polymer @ 2.5 ha^{-1} + seed treatment @ 10g kg^{-1}), followed by plots in which field application of hydrogel polymer @ 2.5 kg ha^{-1} was done. The lowest straw yield was recorded in the absolute control plots.

Among the interactions, significantly higher straw yield was observed in the treatment combination i_3s_3, followed by i_3s_1 and the lowest straw yield was observed in i_1s_5.

4.2.2.10 Harvest Index

The harvest index of the crop was also observed to be significantly influenced by the various approaches of scheduling irrigation as well as the moisture stress mitigation strategies as shown in Table 40 a and 40 b. Among the various approaches of scheduling irrigation, a harvest index of 0.34 was observed to be in the plots irrigated to maintain 2 cm depth of water at critical stages of crop growth and the plots irrigated to maintain 100 % FC. The lowest harvest index was observed in the plots in i_1 and i_4.

Among the moisture stress mitigation strategies, a significantly higher harvest index was observed in plots in which field application of hydrogel polymer @ 2.5 kg ha^{-1} was done, which was on par with s_3.The lowest harvest index was observed in absolute control plots.

The interactive effects among the treatments was also found to significantly influence the harvest index of the crop with the highest in the treatment combination $i_2s_1$and the lowest in i_3s_5.

4.2.3 Physiological Parameters

The impact of various approaches of scheduling irrigation and the moisture stress mitigation strategies on the various physiological parameters of the crop have been furnished below:

4.2.3.1 Crop Growth Rate (g m^{-2} d^{-1})

The crop growth rate (CGR) at 0-30, 30-60 and 60-90 DAS were found to be influenced by the various approaches of scheduling irrigation, as well as the moisture stress mitigation strategies, as presented in Table 41 a and 41 b.

At 0-30 DAS, the CGR was found to be significantly the highest (4.51g m^{-2} d^{-1}) in the plots irrigated to maintain 100% FC, followed by the plots irrigated to maintain 2 cm depth of water at critical stages of crop growth. It was the lowest (3.45) in the plots irrigated to maintain 75 % FC.

Table 40 a. Effect of the approaches of scheduling irrigation and moisture stress mitigation strategies on grain yield, straw yield , harvest index

Treatments	Grain yield (Mg ha^{-1})	Straw yield (Mg ha^{-1})	Harvest index
Approaches of scheduling irrigation (i)			
i_1	2.59	5.45	0.31
i_2	3.51	6.45	0.34
i_3	3.61	6.78	0.34
i_4	2.91	6.19	0.31
SE m(±)	0.061	0.018	0.003
CD (0.05)	0.190	0.057	0.009
Moisture stress mitigation strategies (s)			
s_1	4.15	6.76	0.38
s_2	3.46	6.38	0.35
s_3	4.37	7.72	0.36
s_4	2.27	5.79	0.28
s_5	1.51	4.42	0.26
SE m(±)	0.072	0.03	0.007
CD (0.05)	0.203	0.086	0.024

Table 40 b. Interaction effect of the grain yield, straw yield , harvest index on the approaches of scheduling irrigation and moisture stress mitigation strategies.

Interaction (i x s)	Grain yield (Mg ha^{-1})	Straw yield (Mg ha^{-1})	Harvest index
i_1s_1	3.47	6.27	0.35
i_1s_2	3.02	6.07	0.33
i_1s_3	3.79	7.43	0.34
i_1s_4	1.71	5.17	0.25
i_1s_5	0.94	2.03	0.29
i_2s_1	4.86	6.92	0.41
i_2s_2	3.78	6.45	0.37
i_2s_3	4.57	7.78	0.37
i_2s_4	2.55	6.02	0.30
i_2s_5	1.77	5.09	0.26
i_3s_1	4.47	7.19	0.38
i_3s_2	4.03	6.84	0.37
i_3s_3	5.00	8.07	0.38
i_3s_4	2.75	6.20	0.31
i_3s_5	1.80	5.57	0.23
i_4s_1	3.80	6.66	0.36
i_4s_2	3.03	6.18	0.33
i_4s_3	4.13	7.61	0.35
i_4s_4	2.05	5.77	0.26
i_4s_5	1.51	4.70	0.24
SE m(±)	0.136	0.041	0.007
CD (0.05)	NS	0.174	0.024

At 30-60 DAS, the CGR as significantly higher in plots irrigated to maintain 75 percentage field capacity. The plots irrigated to maintain 100 percentage field capacity and the plots maintained at 2 cm depth at critical stages of crop growth were found to be on par with each other. The lowest CGR was recorded in the plots irrigated at an IW/CPE of 0.8. At 60-90 DAS, the highest CGR was observed in plots in which 100 % FC was maintained, followed by plots irrigated to maintain 2 cm depth of water at critical stages of crop growth which was on par with plots irrigated at an IW/CPE of 0.8 and the lowest value was observed in plots in which 75% FC was maintained.

Among the moisture stress mitigation strategies, the highest crop growth rate (4.96 g m^{-2} d^{-1}) at 0-30 DAS was observed in the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @ 10 g kg^{-1}), followed by plots in which hydrogel polymer @ 2.5 kg ha^{-1} was incorporated. The lowest CGR was observed in absolute control plots.

At 30-60 DAS, the highest CGR was observed in s_2 (5.37 g m^{-2} d-^{1}), s_3 and s_4, and the lowest was observed in absolute control plots. Whereas, at 60-90 DAS, the highest CGR was observed in plots incorporated with hydrogel polymer @ 2.5kg ha^{-1}, followed by s_3 (field application of hydrogel polymer @ 2.5 kg ha-1 + seed treatment of hydrogel polymer @10g kg^{-1}). The lowest was observed in the plots in which seed treatment of hydrogel polymer @10g kg^{-1} was done.

The interaction among the treatments were also found to be significant at all the stages of crop growth. At 0-30 DAS, it was the highest in the treatment combination i_3s_3 (6.16 g m-^{2} d^{-1}), followed by i_2s_3. The lowest CGR was observed in the treatment combination i_4s_5 (2.37g m^{-2} d^{-1}). At 30-60 DAS, the highest CGR was recorded in the treatment combination i_3s_2, which was on par with i_2s_2 and the lowest value was recorded in the treatment combination i_1s_5. At 60-90 DAS, it recorded the highest in $i_3s_1$and the lowest in i_2s_2.

Table 41 a. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies on the crop growth rate at 0-30, 30-60 and 60-90 DAS, g m^{-2} d^{-1}

Treatments	Crop growth rate (g m^{-2} d^{-1})		
	0-30 DAS	30-60 DAS	60-90 DAS
Approaches of scheduling irrigation (i)			
i_1	3.69	4.25	3.55
i_2	4.01	4.75	3.56
i_3	4.51	4.72	4.20
i_4	3.45	4.86	3.46
SE m(±)	0.042	0.061	0.041
CD (0.05)	0.132	0.19	0.127
Moisture stress mitigation strategies (s)			
s_1	4.34	4.41	4.12
s_2	3.86	5.37	3.19
s_3	4.96	4.80	3.64
s_4	3.49	4.80	3.52
s_5	2.93	3.86	3.78
SE m(±)	0.046	0.058	0.058
CD (0.05)	0.130	0.165	0.165

Table 41 b. Interaction effect of approaches of scheduling irrigation and moisture stress mitigation strategies on the crop growth rate at 30, 60 and 90 DAS, g m^{-2} d^{-1}

Treatment interaction (i x s)	Crop growth rate		
	0-30 DAS	30-60 DAS	60-90 DAS
i_1s_1	4.08	4.25	3.79
i_1s_2	3.74	4.86	3.37
i_1s_3	4.56	4.77	3.15
i_1s_4	3.23	4.25	3.25
i_1s_5	2.81	3.10	4.17
i_2s_1	4.45	4.39	4.23
i_2s_2	4.03	5.60	2.78
i_2s_3	4.82	5.03	3.65
i_2s_4	3.65	4.84	3.47
i_2s_5	3.11	3.90	3.68
i_3s_1	4.71	4.64	4.56
i_3s_2	4.23	5.61	3.62
i_3s_3	6.16	4.05	4.29
i_3s_4	4.02	4.91	4.19
i_3s_5	3.44	4.38	4.33
i_4s_1	4.10	4.36	3.88
i_4s_2	3.41	5.40	3.00
i_4s_3	4.31	5.34	3.48
i_4s_4	3.04	5.18	3.15
i_4s_5	2.37	4.03	3.78
SE m(±)	0.094	0.136	0.091
CD (0.05)	0.265	0.338	0.334

4.2.3.2 Relative Growth Rate (g g^{-1} d^{-1})

The relative growth rate of the crop was found to be significantly influenced by the various approaches of scheduling irrigation as well as the moisture stress mitigation strategies as indicated in Table 42 a and 42 b and explained below:

Among the various approaches of scheduling irrigation, at 0-30 DAS, the RGR was observed to be significantly higher in the plots irrigated to maintain 100 % FC, followed by irrigation at an IW/CPE ratio of 0.8. The lowest RGR was observed in plots irrigated to maintain 75 % field capacity. At 30-60 DAS it was observed to be non significant. Whereas, the RGR at 60-90 DAS in i_1, i_3 and i_4 were found to be on par with each other and significantly lower RGR was observed in i_2.

Among the moisture stress mitigation strategies, at 0-30 DAS, RGR recorded significantly higher value in s_1 (field application with hydrogel polymer @ 2.5kg ha^{-1}), which was on par with s_3. It was the lowest in absolute control plots. At 30-60 DAS, it was found to be non significant. At 60-90 DAS, a significantly higher RGR was observed in absolute control plots, followed by field application of hydrogel polymer @ 2.5 kg ha^{-1}.

The interactive effects among the treatments were also found to be significant with respect to RGR, at 0-30 DAS and 60-90 DAS. At 0-30 DAS, it recorded the highest in i_1s_1 and the lowest RGR was recorded in i_4s_5. At 30-60 DAS, it was observed to be non-significant. Whereas at 60-90 DAS, the highest RGR was recorded in i_1s_5 and the lowest in the treatment combination i_2s_2.

4.2.3.3 Net Assimilation Rate (g m^{-2} d^{-1})

The net assimilation rate of the crop was also found to be significantly influenced by the various approaches of scheduling irrigation as well as the moisture stress mitigation strategies as shown in Table 43 a and 43 b and furnished

Table 42 a. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies on the RGR of the crop at 0-30, 30-60 and 60-90 DAS, g g^{-1} d^{-1}

Treatments	Relative growth rate		
	0-30 DAS	30-60 DAS	60-90 DAS
Approaches of scheduling irrigation (i)			
i_1	0.030	0.026	0.012
i_2	0.029	0.026	0.011
i_3	0.033	0.033	0.012
i_4	0.023	0.029	0.012
SE m(±)	0.001	0.004	0.000
CD (0.05)	0.004	NS	0.001
Moisture stress mitigation strategies (s)			
s_1	0.037	0.023	0.013
s_2	0.028	0.029	0.009
s_3	0.036	0.022	0.010
s_4	0.024	0.029	0.012
s_5	0.019	0.039	0.015
SE m(±)	0.002	0.005	0.000
CD (0.05)	0.004	NS	0.001

Table 42 b. Interaction effect of approaches of scheduling irrigation and moisture stress mitigation strategies on the RGR of the crop at 0-30, 30-60 and 60-90 DAS, g g^{-1} d^{-1}

Treatment interaction (i x s)	Relative growth rate		
	0-30 DAS	30-60 DAS	60-90 DAS
i_1s_1	0.051	0.023	0.013
i_1s_2	0.027	0.028	0.009
i_1s_3	0.034	0.024	0.010
i_1s_4	0.022	0.029	0.012
i_1s_5	0.018	0.025	0.018
i_2s_1	0.033	0.023	0.013
i_2s_2	0.030	0.029	0.008
i_2s_3	0.035	0.024	0.010
i_2s_4	0.026	0.0258	0.011
i_2s_5	0.020	0.027	0.014
i_3s_1	0.035	0.023	0.013
i_3s_2	0.031	0.027	0.010
i_3s_3	0.043	0.017	0.012
i_3s_4	0.029	0.027	0.013
i_3s_5	0.024	0.072	0.014
i_4s_1	0.030	0.024	0.012
i_4s_2	0.024	0.032	0.009
i_4s_3	0.032	0.025	0.010
i_4s_4	0.020	0.033	0.011
i_4s_5	0.012	0.033	0.015
SE m(±)	0.002	0.005	0.000
CD (0.05)	0.004	NS	0.001

below:

At 0-30 DAS, the NAR was found to be the same (0.003 g m^{-2} d^{-1}) for all the treatments. At 30-60 DAS, it was the highest in the plots irrigated to maintain moisture at 75 % FC, followed by plots irrigated at an IW/CPE of 0.8. The lowest NAR was recorded in the plots irrigated to maintain 2 cm depth of water at critical stages of crop growth. The NAR at 60-90 DAS was observed to be the highest in the plots irrigated at an IW/CPE of 0.8, which was on par with irrigation to maintain 75 % FC and the lowest value was observed in the plots irrigated to maintain 100 % FC.

Among the moisture stress mitigation strategies, at 30 DAS, the net assimilation rate was observed to be the same (0.003 g m^{-2} d^{-1}) all the treatments. At 30-60 DAS, it was observed to be the highest in the absolute control plots, followed by the plots in which PPFM (1%) spray at panicle initiation stage was given. The NAR was the lowest in plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1}+ seed treatment @ 10g kg^{-1}) and at 60-90 DAS, it was observed to be the lowest in s_2, which was on par with s_3.

Among the interactions, at 30-60 DAS, the NAR was observed to be the highest in treatment combination i_4s_5, followed by i_4s_4 and the lowest NAR was recorded in i_3s_3. Whereas at 60-90 DAS, the highest NAR was observed in i_1s_5, followed by i_1s_4 and the lowest value was recorded by i_2s_2.

4.2.3.4 Chlorophyll Content (mg g^{-1})

The chlorophyll content of leaves was also found to be significantly influenced by the various approaches of scheduling irrigation as well as moisture stress mitigation strategies, as shown in Table 44 a and 44 b.

Among the approaches of scheduling irrigation, at all stages of crop growth, the chlorophyll content in leaves was observed to be the highest in the plots irrigated to maintain 100 % FC, followed by the plots irrigated to maintain 2 cm depth of water at critical stages of crop growth. The lowest chlorophyll content was recorded in the plots irrigated at an IW/CPE of 0.8.

Table 43 a. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies on the net assimilation rate of the crop at 30, 60 and 90 DAS, g m^{-2} d^{-1}

Treatments	Net assimilation rate	
	NAR 30-60 DAS	NAR 60-90 DAS
Approaches of scheduling (i)		
i_1	1.36	0.70
i_2	1.21	0.59
i_3	1.27	0.62
i_4	1.46	0.67
SE m(±)	0.025	0.019
CD (0.05)	0.078	0.059
Moisture stress mitigation strategies (s)		
s_1	1.18	0.58
s_2	1.28	0.45
s_3	1.11	0.48
s_4	1.46	0.75
s_5	1.59	0.96
SE m(±)	0.03	0.02
CD (0.05)	0.085	0.06

Table 43 b. Interaction effect of the effect of approaches of scheduling irrigation and moisture stress mitigation strategies on the net assimilation rate of the crop at 30-60 and 60-90 DAS, g m^{-2} d^{-1}

Interaction (i x s)	NAR (30-60 DAS)	NAR (60-90 DAS)
i_1s_1	1.29	0.53
i_1s_2	1.09	0.44
i_1s_3	1.42	0.42
i_1s_4	1.58	1.01
i_1s_5	1.42	1.09
i_2s_1	0.99	0.55
i_2s_2	1.37	0.40
i_2s_3	0.99	0.46
i_2s_4	1.10	0.68
i_2s_5	1.58	0.84
i_3s_1	1.41	0.55
i_3s_2	1.20	0.49
i_3s_3	0.81	0.52
i_3s_4	1.40	0.63
i_3s_5	1.55	0.93
i_4s_1	1.02	0.71
i_4s_2	1.44	0.47
i_4s_3	1.24	0.51
i_4s_4	1.77	0.67
i_4s_5	1.81	0.98
SE m(±)	0.056	0.042
CD (0.05)	0.173	0.118

At 30, 60 and 90 DAS, among the moisture stress mitigation strategies, the chlorophyll content was observed to be the highest in the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @ 10g kg^{-1}), followed by the chlorophyll content in plots in which seed treatment of hydrogel polymer @ 10 g kg^{-1} was done.

Among the interactive effect between the treatments, a significantly higher chlorophyll content was observed in i_3s_3, followed by i_4s_3 and the lowest value was recorded in i_1s_5, at all the stages of crop growth.

4.2.3.5 Proline Content (µ moles g^{-1})

The proline concentration was observed to be the highest in the plots irrigated at an IW/CPE of 0.8, at all stages of crop growth, followed by the plots irrigated to maintain 75% FC, as shown in Table 45 a and 45 b. The lowest proline concentration was observed in the plots irrigated to maintain 100 % FC.

At all the stages of the crop, among the moisture stress mitigation strategies, the highest proline concentration was observed in the absolute control plots, followed by the plots sprayed with PPFM (1%) at panicle initiation stage. The lowest proline concentration was recorded by the plots treated with hydrogel polymer (soil incorporation @ 2.5 kg ha^{-1} + seed treatment @ 10 g kg^{-1}).

Among the interactive effects, the highest proline content was recorded in the treatment combination i_1s_5, followed by i_4s_5 and significantly lowest proline content was found in i_3s_3

4.2.3.6 Stomatal Count

The stomatal count of the leaves was also found to be significantly influenced by the various approaches of scheduling irrigation as well as the moisture stress mitigation strategies as indicated in Table 46 a and 46 b.

Table 44 a. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies on the chlorophyll content of leaves at 30, 60 and 90 DAS, mg g^{-1}

Treatments	Chlorophyll content		
	30 DAS	60 DAS	90 DAS
Approaches of scheduling irrigation (i)			
i_1	1.14	1.88	1.42
i_2	1.28	2.18	1.52
i_3	1.40	2.43	1.59
i_4	1.21	2.00	1.45
SE m(±)	0.01	0.02	0.01
CD (0.05)	0.039	0.046	0.027
Moisture stress mitigation strategies (s)			
s_1	1.23	2.24	1.52
s_2	1.49	2.54	1.87
s_3	1.77	2.73	2.03
s_4	0.93	1.77	1.10
s_5	0.87	1.34	0.98
SE m(±)	0.01	0.02	0.01
CD (0.05)	0.033	0.056	0.033

Table 44 b. Interaction effects of the approaches of scheduling irrigation and moisture stress mitigation strategies on the chlorophyll content of leaves at 30, 60 and 90 DAS, mg g^{-1}

Treatment interaction (ixs)	Chlorophyll content		
	30 DAS	60 DAS	90 DAS
i_1s_1	1.06	2.07	1.43
i_1s_2	1.31	2.30	1.79
i_1s_3	1.57	2.65	1.97
i_1s_4	0.92	1.32	1.02
i_1s_5	0.84	1.07	0.90
i_2s_1	1.27	2.16	1.61
i_2s_2	1.57	2.61	1.90
i_2s_3	1.79	2.77	2.09
i_2s_4	0.94	1.90	1.09
i_2s_5	0.85	1.47	0.93
i_3s_1	1.41	2.52	1.52
i_3s_2	1.72	2.84	1.95
i_3s_3	1.96	2.96	2.16
i_3s_4	0.97	2.20	1.20
i_3s_5	0.94	1.65	1.12
i_4s_1	1.16	2.21	1.51
i_4s_2	1.35	2.42	1.84
i_4s_3	1.77	2.53	1.89
i_4s_4	0.89	1.67	1.07
i_4s_5	0.85	1.16	0.95
SE m(±)	0.028	0.033	0.019
CD (0.05)	0.068	0.114	0.067

.

Table 45 a. Effect of the approaches of scheduling irrigation and moisture stress mitigation strategies on the proline content of the crop at 30, 60 and 90 DAS, μ moles g^{-1}

Treatments	Proline content		
	30 DAS	60 DAS	90 DAS
Approaches of scheduling irrigation (i)			
i_1	16.06	23.48	19.08
i_2	8.74	13.06	10.52
i_3	6.29	5.27	8.34
i_4	12.08	16.72	13.44
SE m(±)	0.613	0.163	0.514
CD (0.05)	1.911	0.507	0.507
Moisture stress mitigation strategies (s)			
s_1	8.53	13.70	10.11
s_2	11.99	12.50	9.23
s_3	5.95	8.97	7.89
s_4	10.43	16.41	13.52
s_5	17.07	21.59	21.59
SE m(±)	0.672	0.152	0.452
CD (0.05)	1.903	0.432	1.414

Table 45 b. Interaction effect of the approaches of scheduling irrigation and moisture stress mitigation strategies on the proline content of upland rice at 30, 60 and 90 DAS

Interaction (i x s)	Proline content		
	30 DAS	60 DAS	90 DAS
i_1s_1	11.30	23.48	15.23
i_1s_2	17.04	19.80	14.31
i_1s_3	9.43	15.90	12.52
i_1s_4	16.08	25.70	16.45
i_1s_5	26.45	32.54	23.41
i_2s_1	7.39	11.52	9.51
i_2s_2	11.27	14.29	14.30
i_2s_3	4.17	5.49	4.13
i_2s_4	7.62	14.32	10.34
i_2s_5	13.25	19.70	15.22
i_3s_1	6.26	5.73	6.11
i_3s_2	5.73	5.25	4.98
i_3s_3	3.41	4.14	3.92
i_3s_4	7.19	5.08	6.14
i_3s_5	8.87	6.15	9.47
i_4s_1	9.17	14.08	12.33
i_4s_2	13.92	10.64	9.62
i_4s_3	6.78	10.34	9.44
i_4s_4	10.83	20.55	16.23
i_4s_5	19.71	27.96	22.14
SE m(±)	1.372	0.364	1.241
CD (0.05)	3.885	0.886	4.127

At all the stages of the crop, the stomatal count was observed to be the highest in the plots irrigated to maintain 100% FC, followed by the plots in which irrigation was given to maintain 2 cm depth at critical stages of crop growth. The lowest stomatal count was recorded in the plots irrigated at an IW/CPE of 0.8 at 30 and 60 DAS, whereas at 90 DAS, it was the lowest in i_4.

Among the moisture stress mitigation strategies, the highest stomatal count was observed in the plots treated with hydrogel polymer (soil incorporation @ 2.5 kg ha^{-1} + seed treatment @ 10 g kg^{-1}), followed by the plots in which soil incorporation of hydrogel polymer @ 2.5 kg ha^{-1} was done. The lowest value was recorded in the absolute control plots, at all the stages.

Among the interactive effects, at all the stages of the crop growth, the highest stomatal count was observed in the treatment combination i_3s_3, followed by i_3s_1 and the lowest stomatal count was recorded in i_1s_5.

4.2.4 Quality Aspects of Grain

The impact of various approaches of scheduling irrigation and the moisture stress mitigation strategies on the quality aspects of grain is given below:

4.2.4.1 Length-Breadth Ratio

The length-breadth ratio of the grains was observed to be non-significantly different with respect to the approaches of scheduling irrigation as well as moisture stress mitigation strategies (Table 47 a and 47 b).

4.2.4.2 Protein Content (%)

The protein content of the grain was observed to be significantly different with respect to the approaches of scheduling irrigation and moisture stress mitigation strategies as shown in Table 47 a and 47 b and as explained below:

A significantly higher protein content was recorded in the plots irrigated at 0.8 IW/CPE (6.75), followed by the plots irrigated to maintain 75% FC and the

Table 46 a. Effect of the approaches of scheduling irrigation and moisture stress mitigation strategies on the stomatal count in leaves at 30, 60 and 90 DAS

Treatments	Stomatal count		
	30 DAS	60 DAS	90 DAS
Approaches of scheduling irrigation (i)			
i_1	590.00	5064.76	1000.28
i_2	668.48	5840.60	1113.64
i_3	719.36	6888.48	1247.20
i_4	614.20	5421.20	989.08
SE m(±)	0.106	0.393	0.170
CD (0.05)	0.298	1.225	0.529
Moisture stress mitigation strategies (s)			
s_1	822.75	7183.35	1265.40
s_2	640.05	6176.00	965.95
s_3	841.50	7418.05	1719.90
s_4	511.20	4772.20	803.70
s_5	424.00	3469.20	682.80
SE m(±)	0.118	0.286	0.227
CD (0.05)	0.334	0.809	0.643

Table 46 b. Interaction effect of the approaches of scheduling irrigation and moisture stress mitigation strategies on the stomatal count in at 30, 60 and 90 DAS

Interaction (i x s)	Stomatal count		
	30 DAS	60 DAS	90 DAS
i_1s_1	789.80	6531.80	1228.80
i_1s_2	597.80	6119.40	854.60
i_1s_3	812.80	6875.40	1553.00
i_1s_4	427.20	3412.60	755.00
i_1s_5	322.40	2384.60	610.00
i_2s_1	848.40	7268.00	1267.80
i_2s_2	669.20	5666.40	1005.40
i_2s_3	874.60	7463.60	1764.80
i_2s_4	539.40	4908.00	844.80
i_2s_5	410.80	3879.00	685.40
i_3s_1	882.60	7974.20	1384.40
i_3s_2	733.40	7778.20	1093.60
i_3s_3	899.60	8120.40	2010.00
i_3s_4	565.80	6118.60	951.00
i_3s_5	515.40	4451.00	797.00
i_4s_1	770.20	6959.40	1180.60
i_4s_2	559.80	5140.00	910.20
i_4s_3	779.00	7418.05	1551.80
i_4s_4	512.40	4772.20	664.00
i_4s_5	449.60	3469.20	638.80
SE m(±)	0.236	0.879	0.380
CD (0.05)	0.667	1.678	1.305

lowest value was observed in the plots irrigated to maintain 100% FC (4.21 %).

Among the moisture stress mitigation strategies, the highest protein content (7.23%) was observed in the absolute control plots, followed by s_4 and the lowest value was recorded in s_3 (3.31 %). The interaction between the treatments were also observed to be significantly different, with the highest value recorded in the treatment combination i_1s_5, followed by i_1s_4 and the lowest value was recorded in i_3s_3.

4.2.4.3 Carbohydrate Content (%)

The carbohydrate content of the grain was observed to be non significant with respect to the approaches of scheduling irrigation and moisture stress mitigation strategies (Table 47a and 47 b).

4.2.5 Moisture studies

4.2.5.1 Soil Moisture Content at 15 cm and 30 cm Depth (%)

The soil moisture content at 15 cm depth at 20, 40, 60 and 80 DAS is shown in the Table 48 a and 48 b.

At 20, 40, 60 and 80 DAS, the soil moisture content at 15 cm depth has been observed to be the highest in the plots irrigated to maintain 100 percentage field capacity, followed by the plots irrigated to maintain 2 cm depth at the critical stages of crop growth. The lowest soil moisture percentage was recorded in the plots irrigated at an IW/CPE of 0.8. A similar trend was observed at 20, 40, 60 and 80 DAS at 30 cm depth also, and is presented in Table 49 a and 49 b.

Among the moisture stress mitigation strategies, a significantly higher soil moisture at 20,40,60 and 80 DAS was observed in the plots treated with hydrogel polymer (field application @ 2.5kg ha^{-1} + seed treatment @10 g kg^{-1}), followed by the plots treated with hydrogel polymer @ 2.5 kg ha^{-1}. The lowest soil moisture content was observed in s_4. Soil moisture content showed a similar trend at 30 cm depth of soil (Table 49 a and 49 b).

Table 47 a. Effect of the approaches of scheduling irrigation and moisture stress mitigation strategies on the quality aspects of grains

Treatments	Length-breadth ratio	Protein content (%)	Carbohydrate content (%)
Approaches of scheduling irrigation (i)			
i_1	2.59	6.75	62.96
i_2	2.63	4.64	63.37
i_3	2.65	4.21	63.19
i_4	2.59	6.17	64.02
SE m(±)	0.033	0.09	0.256
CD (0.05)	NS	0.307	NS
Moisture stress mitigation strategies (s)			
s_1	2.59	4.57	62.49
s_2	2.57	5.29	63.26
s_3	2.63	3.31	63.01
s_4	2.64	6.82	63.54
s_5	2.66	7.23	62.94
SE m(±)	0.035	0.11	0.285
CD (0.05)	NS	0.302	NS

Table 47 b. Interaction effect of the approaches of scheduling irrigation and moisture stress mitigation strategies on the quality aspects of grains

Interaction (i x s)	Length-breadth ratio	Protein content (%)	Carbohydrate content (%)
i_1s_1	2.59	6.07	61.87
i_1s_2	2.45	6.83	64.15
i_1s_3	2.58	4.37	62.65
i_1s_4	2.66	7.83	63.98
i_1s_5	2.65	8.65	62.16
i_2s_1	2.62	3.39	62.35
i_2s_2	2.62	4.33	63.25
i_2s_3	2.70	2.66	63.98
i_2s_4	2.65	6.32	62.85
i_2s_5	2.58	6.50	64.42
i_3s_1	2.59	3.44	62.89
i_3s_2	2.62	3.34	62.49
i_3s_3	2.70	1.75	63.37
i_3s_4	2.58	6.06	63.81
i_3s_5	2.75	6.46	63.44
i_4s_1	2.55	5.38	62.84
i_4s_2	2.57	6.65	63.16
i_4s_3	2.57	4.46	62.04
i_4s_4	2.67	7.05	63.52
i_4s_5	2.57	7.03	63.44
SE m(±)	0.074	0.22	0.573
CD (0.05)	NS	0.617	NS

The interactive effects among the treatments were also found to be significantly different with respect to the soil moisture content at 15 cm and 30 cm depth of soil. It was observed to be the highest in the treatment combination i_3s_3, followed by i_3s_1 and the lowest value was recorded in i_1s_5, at all the stages of crop growth.

4.2.5.2 Relative Leaf Water Content (%)

The relative leaf water content of the leaves was found to be significantly influenced by the approaches of scheduling irrigation, as well as the moisture stress mitigation strategies as indicated in Table 50 a and 50 b.

At 20, 40, 60 and 80 DAS, the relative leaf water content was observed to be the highest in the plots irrigated to maintain 100 % FC, followed by the plots in which 2 cm depth of water was maintained at critical stages of crop growth. The lowest RLWC was observed in the plots irrigated at an IW/CPE of 0.8.

Among the moisture stress mitigation strategies, the highest RLWC was recorded in the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @ 10 g kg^{-1} at all the stages except 60 DAS, followed by the plots treated with hydrogel polymer @ 2.5 kg ha^{-1}. At 60 DAS, it was the highest in s_1. The lowest RLWC was observed in absolute control plots.

The interaction effect between the treatments was also found to significantly influence the RLWC, with the highest value in the treatment combination i_3s_3, followed by i_3s_1 and the lowest value was recorded in i_1s_5.

4.2.5.3 Consumptive Use (mm)

The consumptive use of the crop is shown in the Table 51 a and 51 b.

The highest consumptive use (1132.36 mm) was observed in the plots in which irrigation was given to maintain 100 % FC, which was significantly superior to all other treatments followed by the plots in which 2 cm depth of water was maintained at critical stages of crop growth. The lowest consumptive use was recorded in the plots irrigated at an IW/CPE of 0.8 (518.62 mm).

Table 48 a. Soil moisture content at 15 cm depth as influenced by various approaches of scheduling irrigation and moisture stress mitigation strategies, %

Treatments	Soil moisture content at 15 cm depth			
	20 DAS	40 DAS	60 DAS	80 DAS
Approaches of scheduling irrigation (i)				
i_1	11.15	11.02	11.15	12.00
i_2	15.38	15.22	15.38	15.55
i_3	16.92	16.68	16.92	17.04
i_4	13.75	13.57	13.75	14.18
SE m(±)	0.070	0.059	0.07	0.061
CD (0.05)	0.217	0.183	0.217	0.189
Moisture stress mitigation strategies (s)				
s_1	15.22	15.01	15.22	15.67
s_2	14.02	13.84	14.02	14.62
s_3	15.65	15.45	15.65	15.87
s_4	13.49	13.35	13.49	13.90
s_5	13.11	12.97	13.11	13.40
SE m(±)	0.063	0.059	0.063	0.089
CD (0.05)	0.178	0.167	0.178	0.253

Table 48 b. Interaction effect of soil moisture content at 15 cm depth as influenced by various approaches of scheduling irrigation and moisture stress mitigation strategies, %

Interaction (i x s)	20 DAS	40 DAS	60 DAS	80 DAS
i_1s_1	12.85	12.82	12.85	14.23
i_1s_2	10.77	10.62	10.77	12.31
i_1s_3	13.35	13.06	13.35	13.58
i_1s_4	9.63	9.54	9.63	10.28
i_1s_5	9.16	9.06	9.16	9.58
i_2s_1	16.02	15.91	16.02	16.15
i_2s_2	15.46	15.18	15.46	15.64
i_2s_3	16.28	16.14	16.28	16.52
i_2s_4	14.88	14.76	14.88	14.89
i_2s_5	14.23	14.08	14.23	14.54
i_3s_1	17.81	17.28	17.81	17.72
i_3s_2	16.13	16.03	16.13	16.25
i_3s_3	18.46	18.24	18.46	18.34
i_3s_4	16.10	15.95	16.10	16.66
i_3s_5	16.11	15.93	16.11	16.23
i_4s_1	14.19	14.05	14.19	14.59
i_4s_2	13.74	13.54	13.74	14.28
i_4s_3	14.52	14.352	14.52	15.02
i_4s_4	13.34	13.14	13.34	13.77
i_4s_5	12.94	12.79	12.94	13.26
SE m(±)	0.156	0.131	0.156	0.136
CD (0.05)	0.365	0.342	0.365	0.513

Table 49 a. Effect of the approaches of scheduling irrigation and moisture stress mitigation strategies on the soil moisture content at 30 cm depth at 20, 40, 60 and 80 DAS, %

Treatments	Soil moisture content at 30 cm depth			
	20 DAS	40 DAS	60 DAS	80 DAS
Approaches of scheduling irrigation (i)				
i_1	12.77	12.63	12.52	13.20
i_2	17.18	17.41	16.86	16.59
i_3	18.42	18.26	18.02	18.56
i_4	15.67	15.32	15.08	15.69
SE m(±)	0.092	0.147	0.109	0.167
CD (0.05)	0.286	0.459	0.339	0.521
Moisture stress mitigation strategies (s)				
s_1	16.96	15.85	16.04	17.38
s_2	15.57	15.89	15.51	16.14
s_3	17.42	17.38	17.02	17.08
s_4	15.22	15.83	15.25	14.71
s_5	14.89	14.31	14.13	14.73
SE m(±)	0.11	0.124	0.124	0.143
CD (0.05)	0.312	0.352	0.350	0.405

Table 49 b. Interaction effect of the approaches of scheduling irrigation and moisture stress mitigation on the soil moisture content at 30 cm depth at 20, 40, 60 and 80 DAS, %

Interaction (i x s)	20 DAS	40 DAS	60 DAS	80 DAS
i_1s_1	14.39	12.21	13.23	15.29
i_1s_2	12.52	13.99	12.35	13.73
i_1s_3	14.76	15.20	15.09	14.57
i_1s_4	11.31	11.11	11.02	11.29
i_1s_5	10.88	10.62	10.89	11.13
i_2s_1	18.28	17.02	16.86	17.73
i_2s_2	16.93	16.85	16.85	17.20
i_2s_3	18.14	17.94	16.90	16.95
i_2s_4	16.48	19.05	18.37	15.07
i_2s_5	16.07	16.18	15.31	15.99
i_3s_1	19.08	18.44	18.72	19.29
i_3s_2	17.46	17.30	17.29	18.08
i_3s_3	20.52	20.43	20.26	20.46
i_3s_4	17.42	17.94	17.05	17.47
i_3s_5	17.61	17.22	16.79	17.49
i_4s_1	16.07	15.71	15.35	17.21
i_4s_2	15.36	15.43	15.53	15.56
i_4s_3	16.25	15.93	15.83	16.34
i_4s_4	15.68	15.21	14.56	15.01
i_4s_5	15.00	14.31	14.13	14.32
SE m(±)	0.205	0.330	0.243	0.374
CD (0.05)	0.636	0.726	0.714	0.833

Table 50 a. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies at 20, 40, 60 and 80 DAS on the relative leaf water content, %

Treatments	Relative leaf water content			
	20 DAS	40 DAS	60 DAS	80 DAS
Approaches of scheduling irrigation (i)				
i_1	45.95	58.21	41.83	39.08
i_2	63.85	70.33	59.63	56.79
i_3	67.36	73.05	65.89	62.82
i_4	53.14	63.59	51.46	48.22
SE m(±)	0.193	0.204	0.235	0.251
CD (0.05)	0.601	0.636	0.733	0.783
Moisture stress mitigation strategies (s)				
s_1	57.77	67.57	55.62	52.14
s_2	58.13	65.50	50.99	51.80
s_3	61.03	70.68	53.25	54.22
s_4	57.61	65.47	51.50	51.75
s_5	53.33	58.98	48.70	48.73
SE m(±)	0.233	0.169	0.222	0.200
CD (0.05)	0.659	0.477	0.627	0.565

Table 50 b. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies at 20, 40, 60 and 80 DAS on the relative leaf water content, %

Interaction (i x s)	Relative leaf water content			
	20 DAS	40 DAS	60 DAS	80 DAS
i_1s_1	46.71	61.03	41.42 .	37.12
i_1s_2	48.92	59.29	42.40	40.58
i_1s_3	51.44	62.75	44.85	42.96
i_1s_4	43.97	56.45	41.92	38.85
i_1s_5	38.71	51.54	38.55	35.89
i_2s_1	64.40	71.01	61.97	59.21
i_2s_2	63.97	68.05	58.52	56.49
i_2s_3	65.50	75.16	62.42	59.83
i_2s_4	64.63	69.48	59.62	56.23
i_2s_5	60.75	67.93	55.61	52.19
i_3s_1	67.75	72.95	66.23	63.22
i_3s_2	67.12	72.24	65.11	61.92
i_3s_3	70.66	77.73	67.93	64.76
i_3s_4	66.21	71.72	66.08	62.99
i_3s_5	65.06	70.63	64.07	61.23
i_4s_1	52.21	65.27	52.86	49.01
i_4s_2	52.51	62.42	50.99	48.21
i_4s_3	56.50	67.06	53.25	49.33
i_4s_4	55.64	64.23	51.50	48.91
i_4s_5	48.81	58.98	48.70	45.61
SE m(±)	0.233	0.456	0.526	0.562
CD (0.05)	0.659	0.985	1.288	1.168

Among the moisture stress mitigation strategies, the highest consumptive use (885.90 mm) was observed in s_3, followed by s_1 and the lowest value was recorded in s_5.

The treatment interaction was observed to be significant, with the highest value in i_3s_3, which was significantly superior to all other treatment combinations and the lowest in i_1s_5.

4.2.5.4 Water Use Efficiency (kg m^{-3})

The water use efficiency of the crop with respect to different treatments has been furnished in the Table 51 a and 51 b.

The highest crop water use efficiency of 0.49 kg m^{-3} has been recorded in the plots irrigated at an IW/CPE of 0.8, followed by the plots in which 2 cm depth of water was maintained at critical stages of crop growth. The lowest crop water use efficiency of 0.31 kg m^{-3} was recorded in the plots irrigated to maintain 100 percentage field capacity.

Among the moisture stress mitigation strategies, the highest crop water use efficiency of 0.53 kg m^{-3} was observed in the plots treated with hydrogel (field application @ 2.5 kg ha^{-1} + seed treatment @ 10g kg^{-1}), followed by the plots in which field application of hydrogel polymer was done @ 2.5 kg ha^{-1}. The lowest crop WUE was recorded in the absolute control plots.

The interaction effect between the treatments was also found to be significantly different with respect to the crop water use efficiency. The highest WUE was observed in i_1s_3, followed by i_1s_1 and the lowest water use efficiency was recorded in i_3s_5.

The field water use efficiency was observed to be significantly higher (0.40 kg m^{-3}) in i_1, followed by i_2 and the lowest field WUE was observed in the treatment i_3.

Among the moisture stress mitigation strategies, the highest field WUE (0.43 kg m^{-3}) was observed in s_3, followed by s_1 and the lowest field WUE was observed in s_5 (0.14 kg m^{-3}).

The interaction effect was observed to be significantly influenced by the approaches of scheduling irrigation and moisture stress mitigation strategies, with the highest value in i_1s_3 which was significantly higher compared to all other treatment combinations and the lowest value was observed in i_3s_5.

4.2.5.5 FC and PWP (%)

The FC of the soil of experimental plot was observed to be 19.23 and PWP was observed to be 7.62.

4.2.6 Plant Analysis

4.2.6.1 N Uptake at Harvest (kg ha^{-1})

The N uptake by grain and straw, as well as total N uptake was found to be significantly influenced by the approaches of scheduling irrigation, as well as moisture stress mitigation strategies and is furnished in Table 52 a and 52 b. The N uptake by grain recorded the highest value (6.15 kg ha^{-1}) in the plots irrigated at 100% FC, followed by the plots irrigated to maintain 2 cm depth of water at critical stages of crop growth. The lowest value was observed in the plot irrigated at an IW/CPE of 0.8 (3.21 kg ha^{-1}).

The highest N uptake by straw was recorded in the plots irrigated at 75 % FC, followed by plots irrigated to maintain 2 cm depth of water at critical stages of crop growth and the lowest value was recorded in plots irrigated at 100% FC. The highest total uptake of N was recorded in the plots irrigated at 100% FC, which was on par with the plots irrigated to maintain 2 cm depth of water at critical stages of crop growth and the lowest total N uptake was observed in the plots irrigated at an IW/CPE of 0.8.

Table 51 a. Effect of the approaches of scheduling irrigation and moisture stress mitigation strategies on the consumptive use (mm), crop WUE (kg m^{-3}) and field WUE (kg m^{-3})

Treatments	Consumptive use (mm)	Crop WUE (kg m^{-3})	Field WUE (kg m^{-3})
Approaches of scheduling irrigation (i)			
i_1	518.62	0.49	0.40
i_2	935.28	0.36	0.34
i_3	1132.36	0.31	0.24
i_4	717.44	0.40	0.26
SE (m±)	2.94	0.003	0.004
CD (0.05)	9.172	0.0090	0.0116
Moisture stress mitigation strategies (s)			
s_1	845.78	0.50	0.40
s_2	823.35	0.44	0.34
s_3	885.90	0.53	0.43
s_4	800.80	0.29	0.23
s_5	773.80	0.20	0.14
SE (m±)	3.49	0.004	0.005
CD (0.05)	9.880	0.013	0.0135

Table 51 b. Interaction effect of the approaches of scheduling irrigation and moisture stress mitigation strategies on the consumptive use (mm), crop WUE (kg m^{-3}) and field WUE (kg m^{-3})

Interaction (i x s)	Consumptive use (mm)	Crop WUE (kg m^{-3})	Field WUE (kg m^{-3})
i_1s_1	530.30	0.65	0.53
i_1s_2	516.80	0.58	0.47
i_1s_3	550.00	0.69	0.58
i_1s_4	507.60	0.34	0.26
i_1s_5	488.40	0.19	0.15
i_2s_1	952.40	0.45	0.42
i_2s_2	934.00	0.40	0.37
i_2s_3	961.40	0.48	0.45
i_2s_4	915.40	0.28	0.28
i_2s_5	913.20	0.19	0.17
i_3s_1	1152.40	0.39	0.30
i_3s_2	1119.40	0.36	0.27
i_3s_3	1265.60	0.39	0.33
i_3s_4	1088.60	0.25	0.18
i_3s_5	1034.80	0.17	0.12
i_4s_1	747.00	0.51	0.34
i_4s_2	723.20	0.42	0.27
i_4s_3	766.60	0.54	0.37
i_4s_4	691.60	0.30	0.18
i_4s_5	658.80	0.23	0.14
SE m(±)	6.58	0.007	0.01
CD (0.05)	20.120	0.026	0.0 27

. Among the moisture stress mitigation strategies, the highest grain and straw N uptake was found in the plots treated with hydrogel polymer (seed treatment @ 10g kg^{-1}) and the lowest value was recorded in absolute control plots. The total N uptake also followed a similar trend.

The interaction effects were also found to be significant with respect to N uptake in grain, straw and total uptake. The grain N uptake recorded the highest in i_3s_1, followed by i_3s_2 and the lowest value was observed in i_1s_3. The N uptake in straw recorded a significantly higher value in i_2s_2, followed by i_2s_4 and the lowest value was found in i_3s_3. The total N uptake was observed to be the highest in i_2s_2, followed by i_3s_2 and the lowest in i_1s_5.

4.2.6.2 P Uptake at Harvest (kg ha^{-1})

P uptake in grain was the highest in the plots irrigated to maintain 100% FC and a significantly higher straw P uptake was observed in the plots irrigated to maintain 75% FC. The total P uptake was the highest in the plots irrigated to maintain 2 cm depth of water, followed by the plots irrigated to maintain 75 % FC and is presented in the Table 53 and the lowest value was observed in i_1.

Among the moisture stress mitigation strategies, the highest grain P uptake was recorded in the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1}), which was on par with s_3 and the lowest value was recorded in the treatment s_5. A significantly higher straw P uptake was recorded in the treatment s_3, followed by s_1 and the lowest straw P uptake was recorded in the treatment s_5. The highest P uptake was recorded in the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @ 10 g kg^{-1}), followed by the treatment s_1, and the lowest value was observed in s_5.

The interaction effects were also found to be significant with respect to P uptake at harvest. The grain P uptake was the highest in i_2s_1, followed by i_3s_3 and the lowest in i_1s_5. The highest value of straw P uptake was observed in i_1s_3, followed by i_4s_3 and the lowest value was recorded in i_1s_5. The highest uptake of P

Table 52 a. Effect of the approaches of scheduling irrigation and moisture stress mitigation strategies on the N uptake in grain, N uptake in straw and total biomass N uptake, kg ha^{-1}

Treatments	N uptake in grain	N uptake straw	Total biomass N uptake
Approaches of scheduling irrigation (i)			
i_1	2.24	5.10	7.33
i_2	5.35	5.68	11.03
i_3	6.15	4.99	11.14
i_4	3.21	5.86	9.09
SE m(±)	0.080	0.046	0.101
CD (0.05)	0.248	0.143	0.316
Moisture stress mitigation strategies (s)			
s_1	4.84	5.20	10.04
s_2	5.05	6.19	11.26
s_3	3.99	4.77	8.75
s_4	4.22	6.04	10.26
s_5	3.09	4.84	7.93
SE m(±)	0.115	0.072	0.143
CD (0.05)	0.327	0.203	0.405

Table 52 b. Interaction effect of the approaches of scheduling irrigation and moisture stress mitigation strategies on the N uptake in grain, N uptake in straw and total biomass N uptake, kg ha^{-1}

Interaction (i x s)	N uptake in grain	N uptake in straw	Total N uptake
i_1s_1	2.33	5.43	7.76
i_1s_2	2.67	6.33	9.00
i_1s_3	1.77	5.30	7.07
i_1s_4	2.81	5.66	8.47
i_1s_5	1.61	2.76	4.37
i_2s_1	6.10	5.53	11.63
i_2s_2	6.72	6.56	13.29
i_2s_3	5.42	4.25	9.67
i_2s_4	4.96	6.41	11.37
i_2s_5	3.53	5.65	9.18
i_3s_1	7.45	4.43	11.89
i_3s_2	7.29	5.55	12.84
i_3s_3	5.83	3.46	9.28
i_3s_4	5.66	5.80	11.46
i_3s_5	4.51	5.69	10.20
i_4s_1	3.45	5.42	8.87
i_4s_2	3.51	6.34	9.91
i_4s_3	2.93	6.05	8.98
i_4s_4	3.46	6.26	9.71
i_4s_5	2.72	5.25	7.97
SE m(±)	0.178	0.103	0.227
CD (0.05)	0.662	0.391	0.820

was observed in the treatment combination i_1s_3 and the lowest value was observed in i_1s_5.

4.6.3 K Uptake at Harvest (kg ha^{-1})

The K uptake in grain, straw and total K uptake was found to be significantly influenced by approaches of scheduling irrigation as well as moisture stress mitigation strategies, as shown in the Table 54 a and 54 b. Among the various approaches of scheduling irrigation, the grain K uptake recorded the highest value in the plots irrigated at an IW/CPE of 0.8, followed by the plots irrigated to maintain 100% FC. The straw K uptake recorded the highest value in the plots irrigated to maintain 75% FC, followed by plots irrigated to maintain 2 cm depth of water at critical growth stags of the crop. The plots irrigated at an IW/CPE of 0.8 recorded the highest total K uptake and the lowest value in the plots irrigated to maintain 100% FC.

Among the moisture stress mitigation strategies, the highest grain uptake of K was observed in treatment s_3, which was significantly higher over all other treatments, followed by treatment s_1. A significantly higher straw K uptake was observed in the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @ 10g kg^{-1}), followed by the plots in which seed treatment of hydrogel polymer @ 10g kg^{-1} was done and the lowest value was recorded in s_5. The total K uptake was observed to be the highest in the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @ 10g kg^{-1}), followed by the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1}) and the lowest value was recorded in the absolute control plots.

Among the interaction effects, a significantly higher grain K uptake was observed in i_1s_3, followed by i_1s_2 and the lowest value was recorded in i_1s_5. The treatment combination i_1s_3 recorded the highest straw K uptake, followed by i_4s_2 and the lowest value was observed in i_1s_5. The highest total biomass uptake of K was found in the treatment combination i_1s_3 and the lowest in i_1s_1.

Table 53 a. Effect of the approaches of scheduling irrigation and moisture stress mitigation strategies on the P uptake in grain, P uptake in straw and total biomass P uptake, kg ha^{-1}.

Treatments	P uptake in grain	P uptake in straw	Total P uptake
Approaches of scheduling irrigation (i)			
i_1	2.38	3.90	6.27
i_2	3.00	3.79	6.77
i_3	3.03	3.54	6.69
i_4	2.46	4.27	6.73
SE m(±)	0.054	0.025	0.085
CD (0.05)	0.169	0.079	0.265
Moisture stress mitigation strategies (s)			
s_1	3.52	4.14	7.66
s_2	3.05	3.99	7.04
s_3	3.51	4.62	8.11
s_4	2.07	3.70	5.77
s_5	1.44	2.92	4.52
SE m(±)	0.062	0.023	0.085
CD (0.05)	0.175	0.065	0.242

Table 53 b. Interaction effect of the approaches of scheduling irrigation and moisture stress mitigation strategies on the P uptake in grain, P uptake in straw and total biomass P uptake, kg ha^{-1}.

Interaction (i x s)	P uptake in grain	P uptake in straw	Total P uptake
i_1s_1	3.18	4.39	7.56
i_1s_2	2.80	4.35	7.16
i_1s_3	3.40	5.22	8.62
i_1s_4	1.62	3.76	5.38
i_1s_5	0.92	1.75	2.67
i_2s_1	4.04	3.99	8.03
i_2s_2	3.32	3.80	7.11
i_2s_3	3.57	4.25	7.73
i_2s_4	3.54	3.65	6.00
i_2s_5	1.73	3.25	4.98
i_3s_1	3.69	3.65	7.34
i_3s_2	3.49	3.55	7.04
i_3s_3	3.71	3.95	7.66
i_3s_4	2.51	3.30	5.81
i_3s_5	1.73	3.26	5.61
i_4s_1	3.16	4.54	7.70
i_4s_2	2.60	4.24	6.84
i_4s_3	3.37	5.06	8.44
i_4s_4	1.80	4.09	5.89
i_4s_5	1.38	3.42	4.80
SE m(±)	0.121	0.057	0.190
CD (0.05)	0.358	0.134	0.495

Table 54 a. Effect of the approaches of scheduling irrigation and moisture stress mitigation strategies on the K uptake in grain, K uptake in straw and total K uptake, kg ha^{-1}

Treatments	K uptake in grain	K uptake straw	Total K uptake
Approaches of scheduling irrigation (i)			
i_1	19.06	13.38	32.43
i_2	16.27	13.50	29.77
i_3	17.13	10.75	27.88
i_4	16.88	14.85	31.24
SE m(±)	0.144	0.143	0.303
CD (0.05)	0.450	0.446	0.943
Moisture stress mitigation strategies (s)			
s_1	21.91	13.66	35.57
s_2	19.66	13.93	33.60
s_3	22.27	14.19	36.46
s_4	13.46	13.43	26.88
s_5	9.36	10.39	19.15
SE m(±)	0.253	0.148	0.436
CD (0.05)	0.717	0.418	1.236

Table 54 b. Interaction effect of the approaches of scheduling irrigation and moisture stress mitigation strategies on the K uptake in grain, K uptake in straw and total K uptake, kg ha^{-1}

Interaction (i x s)	K uptake in grain	K uptake in straw	Total K uptake
i_1s_1	25.53	14.78	40.31
i_1s_2	22.67	15.13	37.80
i_1s_3	26.40	15.92	42.30
i_1s_4	13.24	14.27	27.51
i_1s_5	7.45	6.80	14.24
i_2s_1	19.56	14.14	33.70
i_2s_2	18.48	13.86	32.34
i_2s_3	20.75	15.07	35.80
i_2s_4	13.04	13.22	26.26
i_2s_5	9.50	11.22	20.72
i_3s_1	21.04	10.92	31.96
i_3s_2	19.47	10.85	30.32
i_3s_3	21.37	11.09	32.46
i_3s_4	14.11	10.57	24.68
i_3s_5	9.67	10.30	19.97
i_4s_1	21.52	14.78	36.30
i_4s_2	18.04	15.89	33.93
i_4s_3	20.55	14.68	35.24
i_4s_4	13.43	15.66	29.08
i_4s_5	10.84	13.23	21.67
SE m(±)	0.323	0.320	0.677
CD (0.05)	1.448	0.855	2.504

4.2. 7 Soil Analysis

4.2.7.1 Available N Before and After the Experiment (kg ha^{-1})

Available N in the soil before and after the experiment has been furnished in Table 55 a and 55 b. The available N in soil after the experiment was found to significantly different with respect to the treatments.

It was observed to be the highest in the plots irrigated at an IW/CPE of 0.8, followed by the plots irrigated at 75% FC and the lowest available soil N was recorded in the plots irrigated at 100% FC. Among the moisture stress mitigation strategies, the highest N content was recorded in the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1}), followed by plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @ 10g kg^{-1}). Among the interactions, the highest value was recorded in treatment combination i_1s_1, followed by i_1s_5 and the lowest value was recorded in the treatment combination i_3s_5.

4.2.7.2 Available P Before and After the Experiment (kg ha^{-1})

The available P before experiment is shown in the Table 55 a and 55 b. The available P in soil after the experiment was found to be significantly different with respect to the approaches of scheduling irrigation as well as the moisture stress mitigation strategies. It was observed to be the highest in the plots irrigated at an IW/CPE of 0.8 and the lowest value was recorded in the plots irrigated at 100% FC. Among the moisture stress mitigation strategies, a significantly higher available soil P was observed in the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1}+ seed treatment @ 10 g kg^{-1}), followed by treatment s_1 and the lowest soil P was observed in the treatment s_4. The interaction was also observed to be significant with respect to the treatments, with the highest value observed in i_4s_1, followed by i_2s_3 and the lowest value was recorded in the treatment combination i_4s_5.

Table 55 a. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies on the available soil N and P in the soil, kg ha^{-1}

Treatments	Available soil N after the experiment	Available soil P after the experiment
Approaches of scheduling irrigation (i)		
i_1	156.00	18.41
i_2	122.46	17.37
i_3	115.73	16.28
i_4	153.76	17.35
SE m(±)	1.003	0.225
CD (0.05)	3.123	0.701
Moisture stress mitigation strategies (s)		
s_1	151.21	19.02
s_2	138.07	17.96
s_3	147.56	19.90
s_4	129.51	16.05
s_5	118.59	13.84
SE m(±)	0.959	0.276
CD (0.05)	2.716	0.780
The available soil N before the experiment was 210.37 kg ha^{-1} and available soil P before the experiment was 18.64 kg ha^{-1}		

Table 55 b. Interaction effect of approaches of scheduling irrigation and moisture stress mitigation strategies on the available soil N and P in the soil, kg ha^{-1}

Interaction (i x s)	Available soil N after the experiment	Available soil P after the experiment
i_1s_1	175.98	20.43
i_1s_2	159.83	19.92
i_1s_3	170.36	19.71
i_1s_4	148.75	16.78
i_1s_5	125.09	15.22
i_2s_1	131.94	15.48
i_2s_2	124.32	16.15
i_2s_3	132.84	20.78
i_2s_4	114.81	18.54
i_2s_5	108.36	15.87
i_3s_1	131.69	19.22
i_3s_2	112.46	17.49
i_3s_3	121.53	19.61
i_3s_4	109.65	12.53
i_3s_5	103.63	12.57
i_4s_1	165.22	20.94
i_4s_2	155.98	18.27
i_4s_3	165.48	19.48
i_4s_4	144.81	16.34
i_4s_5	137.28	11.70
SE m(±)	2.242	0.503
CD (0.05)	5.570	1.588

4.2.7.3 Available K Before and After the Experiment (kg ha^{-1})

The available K in the soil before and after the experiment is shown in the Table 56 a and 56 b. It was observed that after the experiment, there was no significant differences in the available K among the various approaches of scheduling irrigation, whereas among the various moisture stress mitigation strategies, a significantly higher value was recorded in the absolute control plots. The interaction effects were found to be non-significant.

4.2.7.4 Available Organic Carbon (%)

The available organic carbon was observed to be non-significant with respect to the approaches of scheduling irrigation and moisture stress mitigation strategies, as indicated in the Table 56 a and 56 b.

4.5.8 Incidence of Pests and Diseases

The major pest observed was stem borer and the number of stem borer attacked plants m^{-2} in different treatments are presented in Table 57 a and 57 b. It was not significantly influenced by the approaches of scheduling irrigation and moisture stress mitigation strategies.

4.5.9 Economics of Cultivation

The economics of cultivation in terms of net returns ha^{-1} and B : C ratio has been presented in Table 58 and explained below:

4.5.9.1 Net Returns (₹ ha^{-1})

Significantly higher net returns of ₹ 97,407.00 was obtained in the treatment i_3 (irrigation to maintain 100% FC)), followed by i_2 and the lowest net returns was observed in the treatment i_1.

Among the moisture stress mitigation strategies, the highest net returns of ₹ 1,31,735.00 ha^{-1} was recorded in treatment s_3 (field application of hydrogel

Table 56 a. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies on the available soil K and organic carbon in the soil

Treatments	Available soil K after the experiment (kg ha^{-1})	Soil organic carbon after the experiment (%)
Approaches of scheduling irrigation (i)		
i_1	226.21	0.997
i_2	222.64	0.956
i_3	220.75	0.970
i_4	228.89	0.962
SE m(±)	4.173	0.029
CD (0.05)	NS	NS
Moisture stress mitigation strategies (s)		
s_1	213.43	1.017
s_2	227.31	0.963
s_3	220.35	0.941
s_4	229.99	0.967
s_5	232.00	0.969
SE m(±)	4.658	0.065
CD (0.05)	13.19	NS
Available K before the experiment was 267.69 kg ha^{-1} and available organic carbon before the experiment was 1.23%		

Table 56 b. Interaction effect of approaches of scheduling irrigation and moisture stress mitigation strategies on the available soil K and organic carbon in the soil

Interaction (i x s)	Available soil K after experiment	Available soil OC after experiment
i_1s_1	190.25	1.098
i_1s_2	235.34	0.990
i_1s_3	228.35	0.970
i_1s_4	236.49	1.004
i_1s_5	240.62	0.924
i_2s_1	218.81	1.032
i_2s_2	222.72	0.950
i_2s_3	216.21	0.840
i_2s_4	226.71	0.972
i_2s_5	228.76	0.984
i_3s_1	217.48	0.998
i_3s_2	222.15	0.952
i_3s_3	211.15	0.976
i_3s_4	226.10	0.948
i_3s_5	226.88	0.978
i_4s_1	227.19	0.940
i_4s_2	229.01	0.958
i_4s_3	225.68	0.976
i_4s_4	230.65	0.946
i_4s_5	231.77	0.988
SE m(±)	9.330	0.065
CD (0.05)	NS	NS

Table 57 a. Effect of the approaches of scheduling irrigation and moisture stress mitigation strategies on the number of stem borer attacked plants m^{-2}

Treatments	Number of attacked plants m^{-2}
Approaches of scheduling irrigation (i)	
i_1	6.64
i_2	7.32
i_3	6.96
i_4	6.56
SE (m±)	0.193
CD (0.05)	NS
Moisture stress mitigation strategies (s)	
s_1	6.80
s_2	6.70
s_3	7.10
s_4	7.00
s_5	6.75
SE (m±)	0.219
CD (0.05)	NS

Table 57 b. Interaction effect of the approaches of scheduling irrigation and moisture stress mitigation strategies on the number of stem borer attacked plants m^{-2}

Interaction (i x s)	Number of attacked plants m^{-2}
i_1s_1	6.20
i_1s_2	6.20
i_1s_3	7.00
i_1s_4	6.60
i_1s_5	7.20
i_2s_1	7.20
i_2s_2	7.40
i_2s_3	7.40
i_2s_4	7.40
i_2s_5	7.20
i_3s_1	7.20
i_3s_2	7.00
i_3s_3	7.20
i_3s_4	7.20
i_3s_5	6.20
i_4s_1	6.60
i_4s_2	6.20
i_4s_3	6.80
i_4s_4	6.80
i_4s_5	6.40
SE m(±)	0.431
CD (0.05)	NS

polymer @ 2.5 kg ha^{-1} + seed treatment @ 10g kg^{-1}), followed by treatment s_1 and the lowest value of ₹ 33,275.25 ha^{-1} was observed in the absolute control plots.

Among the interactive effects, a significantly higher net return of ₹ 1,58,000. 00 ha^{-1} was obtained from the treatment combination i_3s_3, followed by a return of ₹ 1,32,990.00 ha^{-1} in i_3s_1, whereas a net loss of ₹ 29,410.00 ha^{-1} was recorded in i_1s_5.

4.5.9.1 B : C ratio

The benefit – cost ratio of the various treatments has been shown in the Table 58 a and 58 b. Among various approaches of scheduling irrigation, the highest benefit-cost ratio of 2.20 has been recorded in the plots in which irrigation was given to maintain 100 % FC, followed by the plots in which irrigation to maintain 2 cm depth of water at critical stages of irrigation was provided, in which a B:C ratio of 2.07 was obtained. The lowest B: C ratio of 1.63 has been recorded in the plots in which irrigation was given at an IW/CPE of 0.8.

A significantly higher B: C ratio of 2.61 was observed in the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @ 10g kg^{-1}), followed by treatment s_1 (field application of hydrogel polymer @ 2.5 kg ha^{-1}), whereas the lowest B: C ratio of 1.04 was recorded in the absolute control plots.

Among the treatment interactions, the highest B: C ratio of 2.92 was observed in i_3s_3, followed by i_3s_1 and the lowest value was observed in i_1s_5.

Table 58 a. Effect of the approaches of scheduling irrigation and moisture stress mitigation strategies on the net returns and B: C ratio

Treatments	B: C ratio	Net returns (₹ ha^{-1})
Approaches of scheduling irrigation (i)		
i_1	1.63	50869.00
i_2	2.07	86892.60
i_3	2.20	97407.00
i_4	1.82	66225.20
SE (m±)	0.01	806.95
CD (0.05)	0.031	2513.99
Moisture stress mitigation strategies (s)		
s_1	2.38	112497.50
s_2	2.12	89527.50
s_3	2.61	131735.00
s_4	1.50	39655.00
s_5	1.04	33275.25
SE (m±)	0.02	1645.89
CD (0.05)	0.058	4660.90

Table 58 b.Interaction effect of the approaches of scheduling irrigation and moisture stress mitigation strategies on the B: C ratio and net returns

Interaction (i x s)	B: C ratio	Net returns (₹ ha^{-1})
i_1s_1	2.11	89390.00
i_1s_2	1.91	72110.00
i_1s_3	2.32	107390.00
i_1s_4	1.19	14865.00
i_1s_5	0.63	-29410.00
i_2s_1	2.51	123070.00
i_2s_2	2.29	103400.00
i_2s_3	2.70	139430.00
i_2s_4	1.64	51615.00
i_2s_5	1.21	16948.00
i_3s_1	2.63	132990.00
i_3s_2	2.44	115190.00
i_3s_3	2.92	158000.00
i_3s_4	1.75	60595.00
i_3s_5	1.26	20260.00
i_4s_1	2.29	104540.00
i_4s_2	1.85	67410.00
i_4s_3	2.50	122120.00
i_4s_4	1.40	31545.00
i_4s_5	1.07	5511.00
SE m(±)	0.02	1804.39
CD (0.05)	0.117	9387.026

5. DISCUSSION

The results of the field experiments conducted with the objectives of identifying a suitable variety and irrigation method for upland rice, to standardize irrigation scheduling and to assess the effect of moisture stress mitigation strategies on the growth, yield and economics of upland rice are discussed in this chapter:

5.1. EXPERIMENT I- IDENTIFICATION OF SUITABLE VARIETY AND STANDARDIZATION OF IRRIGATION METHOD

5.1.1 Growth Characters

Observations on the growth characters of rice *viz.* germination count, plant population, height of plant, number of tillers m^{-2}, dry matter production at 30, 60, 90 DAS and at harvest and leaf area index at panicle initiation were recorded.

Plant height showed an increasing trend up to harvest stage, irrespective of treatments. The different methods of irrigation were found to significantly influence the growth attributes of the crop. At all the stages, microirrigation was found to be significantly superior compared to that of the hose method (hose irrigation) of irrigation. The height of the plant was observed to be the highest for sprinkler irrigation at 100% PE, compared to all other treatments at 60 DAS, whereas at 90 DAS and at harvest, it was significantly the highest in plots irrigated using drip at 100% PE, which was on par with the plots irrigated using sprinkler at 100% PE. It was followed by drip irrigation at 100% PE. The hose method of irrigation was found to be inferior in plant height compared to irrigation using microirrigation, at all the stages of the crop growth. Among the varieties, the variety Uma showed an increased plant height compared to the variety Prathyasa at 30 and 60 DAS, whereas at 90 DAS and at harvest, it was significantly higher in the variety Parthyasa (Fig. 5). The interaction effects were observed to be non significant at 60, 90 DAS and at harvest, whereas at 30 DAS, it was significantly higher in m_4v_2. The number of tillers m^{-2} at 60, 90 DAS and at harvest was significantly the highest in sprinkler irrigated plots at 100% PE, whereas at 30 DAS, it was observed to be the highest in drip irrigated plots at 100% PE. Among the varieties, it was significantly higher in the variety Uma at 30 DAS, whereas at 60 and 90 DAS and at harvest, it was significantly superior in the variety Prathyasa. The treatment interaction was however observed not to have any significant influence on the number of tillers m^{-2} at any stages of the crop growth (Fig.6). The leaf area index at panicle initiation and the dry matter production at 30, 60, 90 DAS and at harvest were observed to be significantly higher in the sprinkler irrigated plots at 100% PE. Among the varieties, the variety Prathyasa recorded significantly higher value for leaf area index at panicle initiation stage (Fig.7) and dry matter production at all the stags of crop growth, as indicated in Figure 8. Among the treatment interactions, dry matter production was observed to be the highest in variety Prathyasa irrigated with sprinkler at 100% PE.

These findings are consistent with the results reported by Yang *et.al*. (2007) indicating that intermittent irrigation using sprinkler irrigation and maintaining moist, mostly aerobic soils not only enhances tillering but also the root system's development and functioning. In drip irrigation, only the root zone of the crop, rather than the entire land surface on which crop is grown is irrigated and the root spread is limited. So, compared to sprinkler irrigation, the vegetative growth is reduced in case of drip irrigation. Whereas, plots irrigated using drip irrigation performed well compared to hose method. It is because drip irrigation supplies water at a rate sufficient to satisfy crop evaporative demand by maintaining high matric and osmotic potentials of the soil water, which minimizes water and osmotic stresses. The maintenance of soil moisture at nearly constant and optimum levels by renewing the water supply to the root zone nearly at the same rate as it is used by the plant results in low soil suction and facilitates water and nutrient uptake by the plant and high soil hydraulic conductivity. The soil on the other hand, is never saturated in a properly managed drip irrigated system, and adequate irrigation is maintained throughout the growing period of the crop, thus ensuring adequate growth of the crop.

At all the stages of the crop, irrigation at 100% PE was found to perform better in sprinkler irrigation as well as drip irrigation compared to 75% PE. Increase in plant height in higher irrigation levels might be due to optimum soil moisture availability favouring the nutrient uptake, resulting in better growth as against

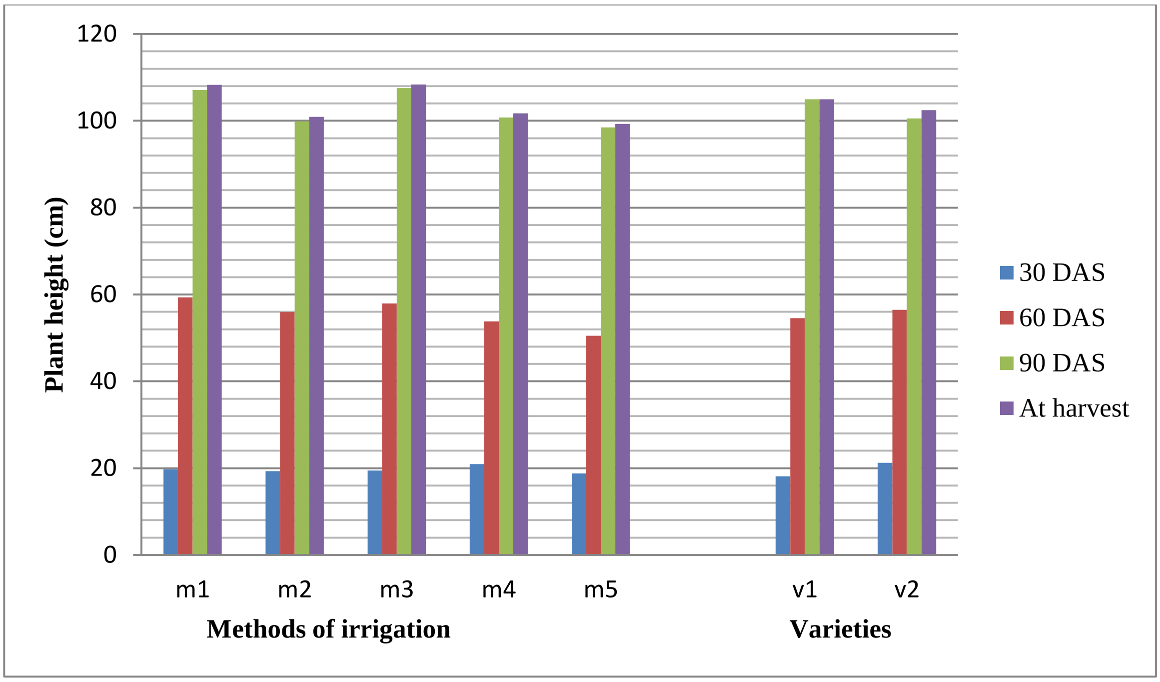

Fig. 5. Effect of methods of irrigation and varieties on the plant height at 30, 60 and 90 DAS and at harvest, cm

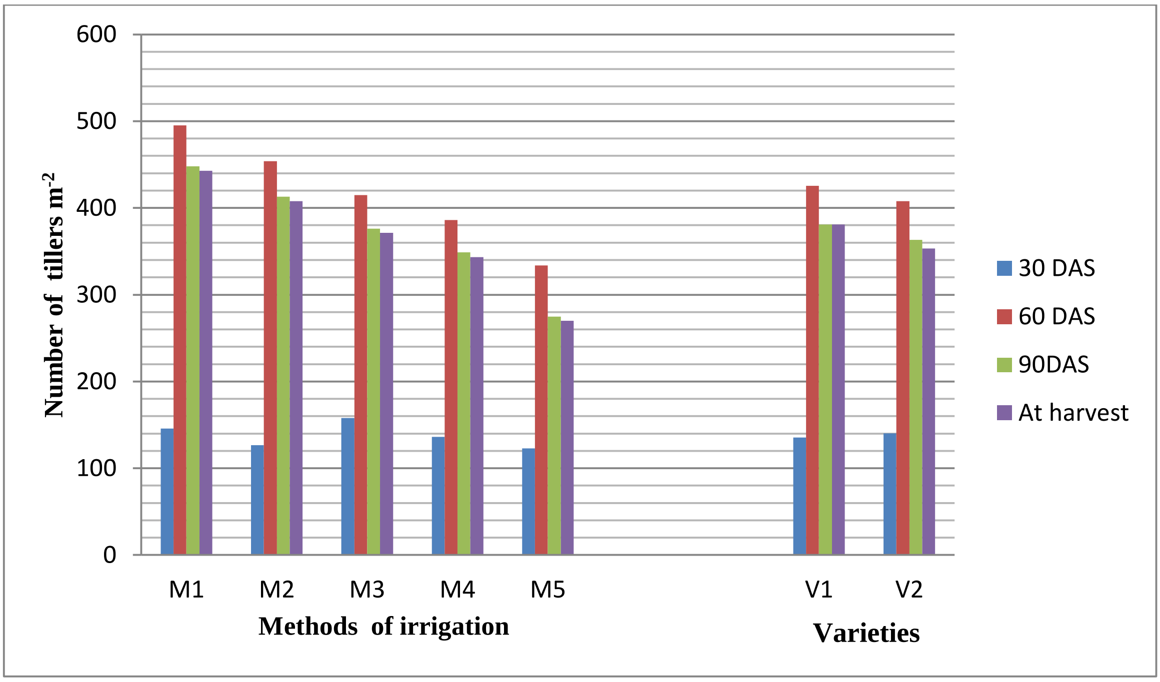

Fig. 6. Effect of methods of irrigation and varieties on the number of tillers m^{-2} at 30, 60, 90 DAS and at harvest

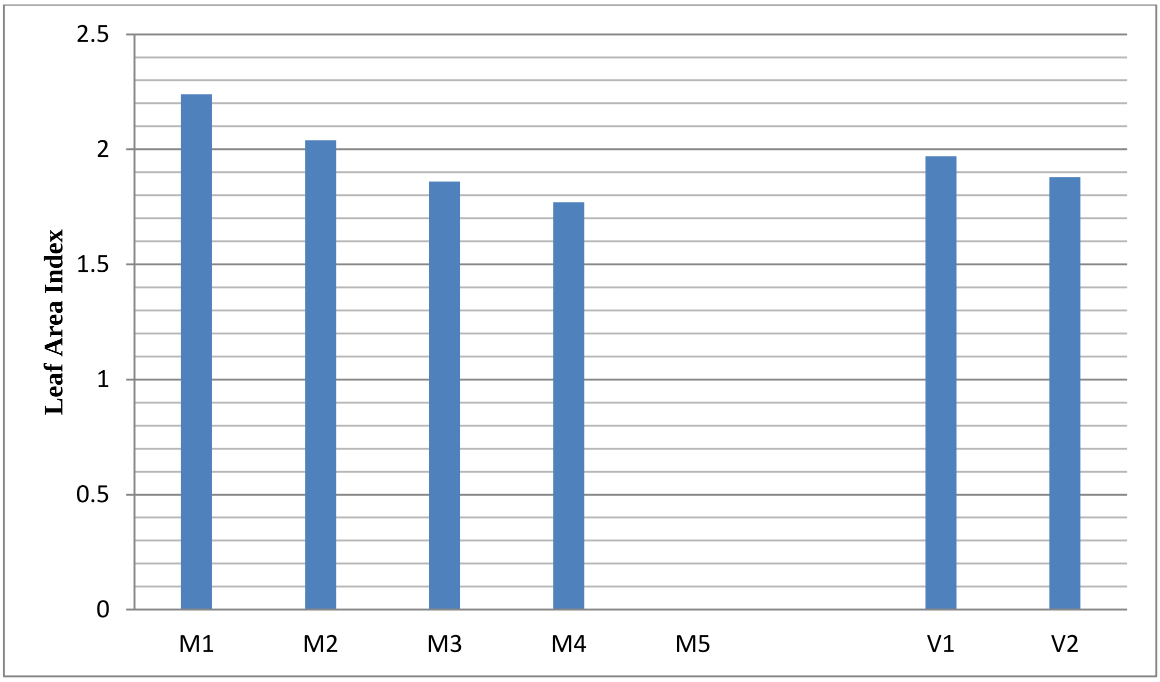

Fig. 7. Effect of methods of irrigation and varieties on the leaf area index at panicle initiation

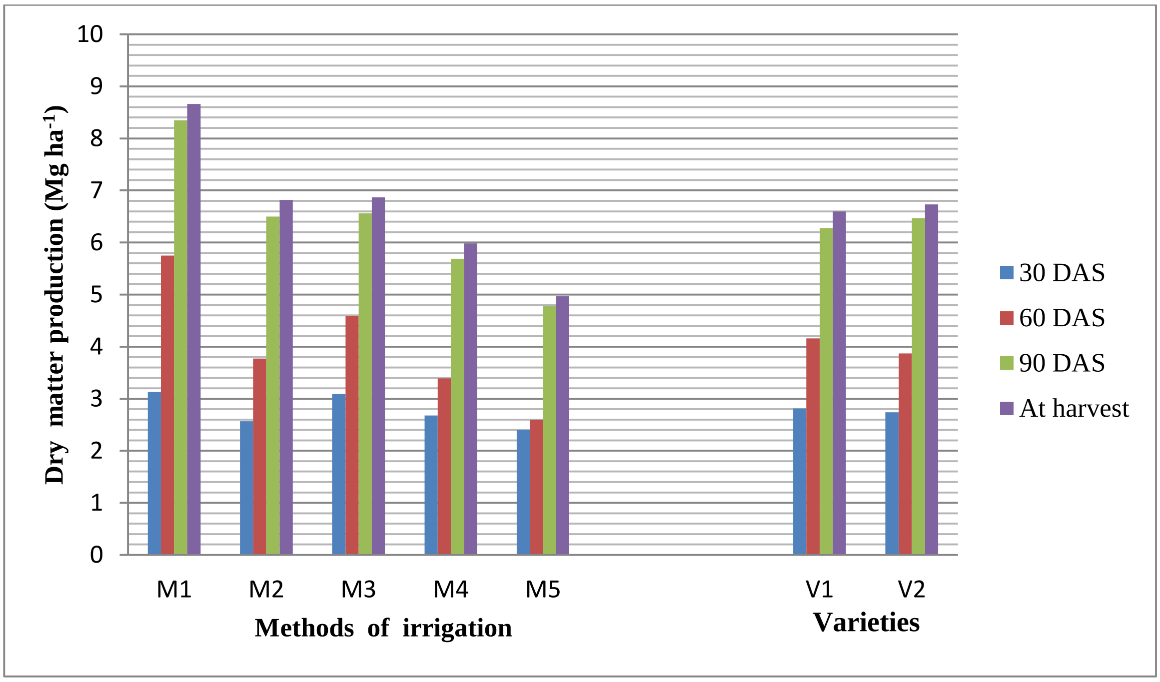

Fig. 8. Effect of methods of irrigation and varieties on the dry matter production at 30, 60, 90 DAS and at harvest, Mg ha^{-1}

scheduling irrigation at 75% PE. The irrigation scheduled at 100% PE provides higher soil moisture availability due to which plant absorbed more water and resulted in higher plant height, number of tillers and dry matter production as compared to other levels.

Under all the irrigation methods, the variety Prathyasa performed better than the variety Uma in terms of all other growth attributes.

5.1.2 Yield Attributes and Yield

Observations on the yield attributes and yield, like number of days for 50% flowering, number of panicles m^{-2}, length of panicle, weight of panicle, number of grains $panicle^{-1}$, sterility percentage, test weight of grain, grain yield and straw yield were recorded and the discussion regarding it have been furnished below:

The number of panicles per m^2 was found to be significantly higher in sprinkler irrigation at 100% PE compared to all other treatments as shown in the Table 12. Drip irrigation was found to perform better than hose irrigation with respect to number of panicles $m\text{-}^2$. Length of panicle also showed a similar trend, whereas the weight of panicle was found to be the highest in drip irrigation at 100% which was significantly superior compared to all other treatments. Sprinkler irrigation at 100% PE was superior in terms of number of grains per panicles, but was on par with drip irrigation at 100% PE as shown in the Table 13 and Figure 9. Test weight of grain was found to be non-significant with respect to methods of irrigation as well as varieties. The grain yield was observed to be the highest in sprinkler irrigation at 100% PE, followed by drip irrigation at 100% PE (Table 14 and Fig.13). Similar trend was observed in case of straw yield also .The harvest index was observed to be the highest in drip irrigated plots at 100% PE (Fig.16).

The highest yield attributes and yield in sprinkler irrigation at 100% PE might be due to the increased number of tillers, which resulted in increased number of panicles thereby producing maximum grain yield. Though same amount of water was applied through irrigation in both sprinkler and drip at 100% PE, as water application in drip was limited to the root one, resulting in reduced root spread also limited production of tillers, whereas, water application at 100% PE through sprinkler has resulted in an uniform application across the field, producing extensive root system and other growth attributes. The increased number of tillers has also resulted in highest straw yield. The highest grain yield and straw yield has resulted in the maximum biomass yield also. The significantly higher panicle weight in drip irrigation at 100% PE may be because of maintenance of optimum soil moisture in the crop with the better control of irrigation water application in the drip system. The maintenance of optimum soil moisture in the crop root zone throughout the growing season, results in an uniform growth.

In addition, in drip irrigation, damage and loss due to water contact with foliage are eliminated, resulting in better quality of produce. Conventional method of irrigation, in which water was applied through hose has recorded the lowest yield attributes and yield compared to micro irrigation methods, because the soil in case of plots irrigated using microirrigation methods is never saturated and adequate irrigation could be maintained throughout the growing period of the crop.

The significantly higher yield attributes and yield in the variety Prathyasa is probably due to the higher number of tillers which produced more number of panicles and thereby higher grain yield.

The treatment combination m_1v_1 recorded the highest grain yield, reflecting the suitability of the variety Prathyasa and sprinkler irrigation at 100% PE under upland conditions.

5.1.3 Physiological Parameters

The crop growth rate at the active stage of the crop was observed to be the highest in sprinkler irrigation at 100% PE and the lowest in hose irrigated plots (Table 15). Variation in trends of crop growth rate in different irrigation treatments reveals that the crop growth rate declined by water stress. The largest value (18.12 $g\ g^{-1}\ d^{-1}$) belonged to sprinkler irrigation at 100 % PE. Irrigation methods as well as different levels of irrigation influences crop growth rate via affecting leaves development

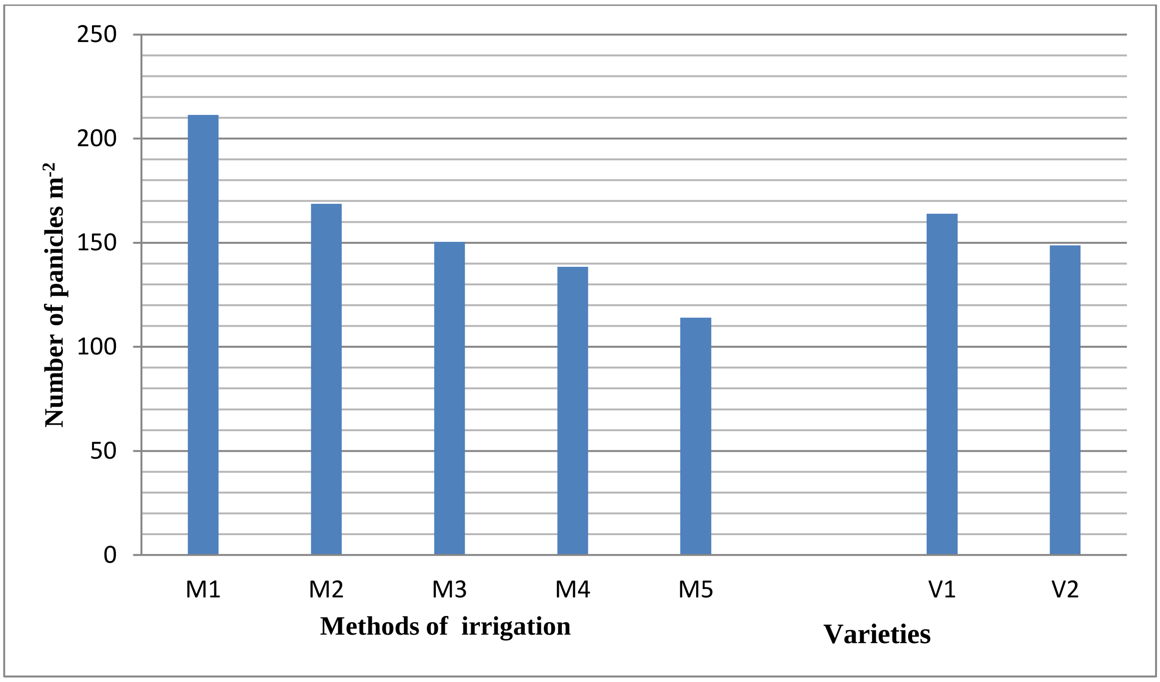

Fig. 9. Effect of methods of irrigation and varieties on the number of panicles m^{-2}

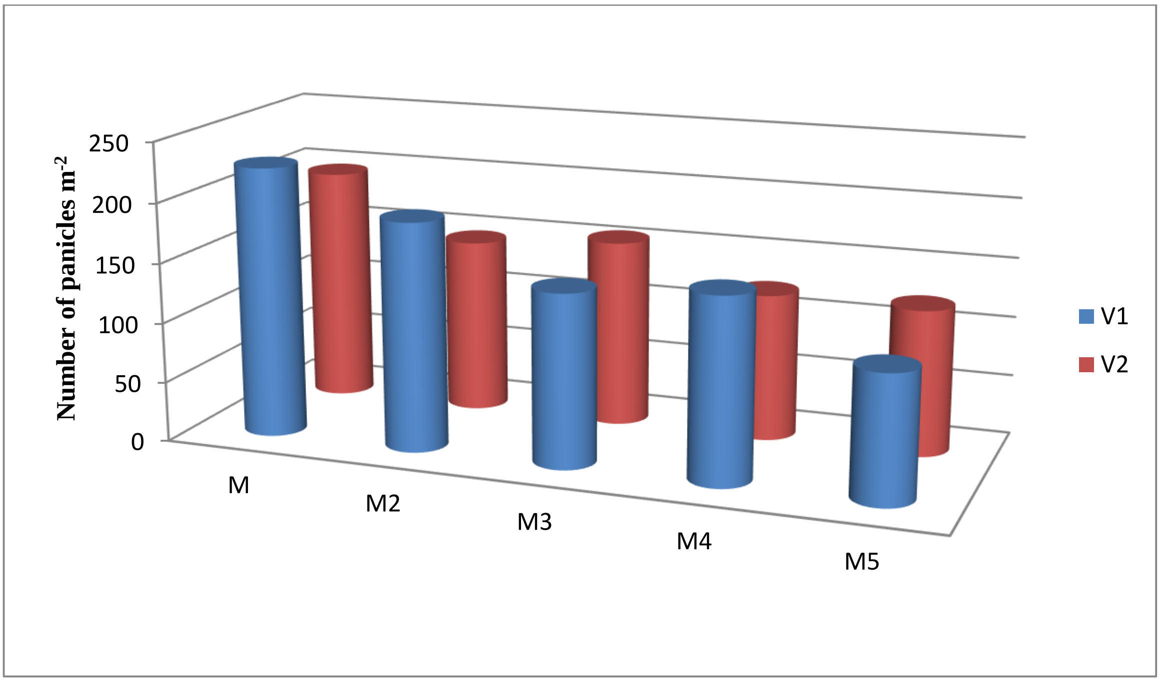

Fig. 10. Interaction effect of methods of irrigation and varieties on the number of panicles m^{-2}

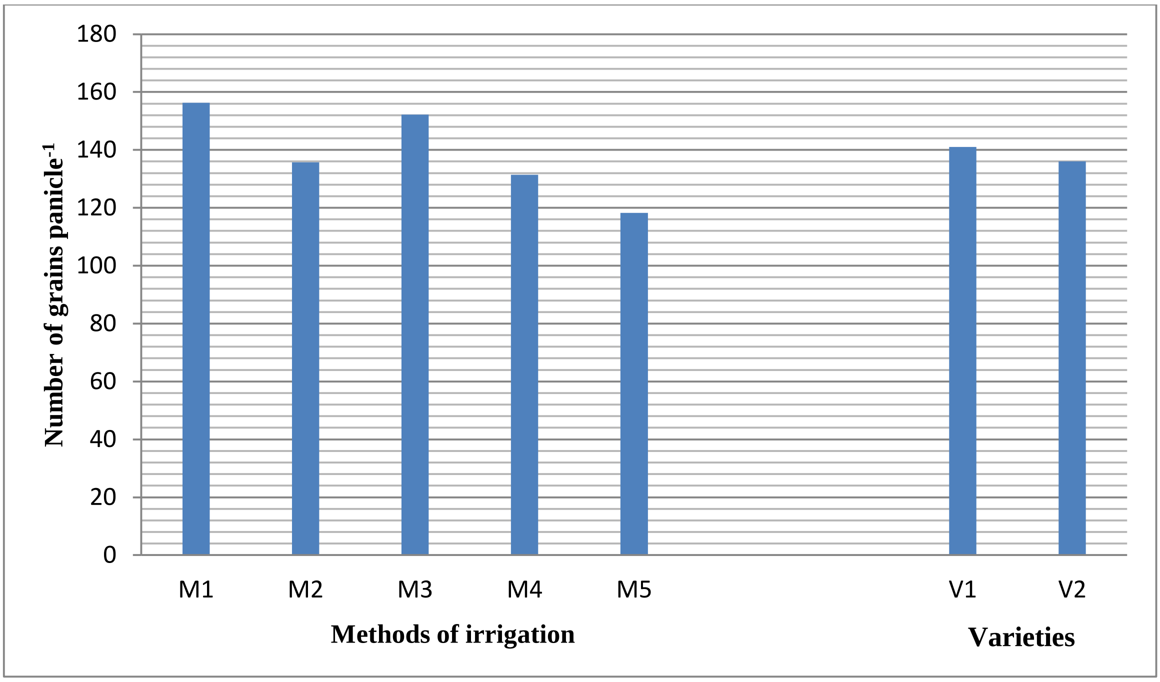

Fig. 11. Effect of methods of irrigation and varieties on the number of grains per panicle

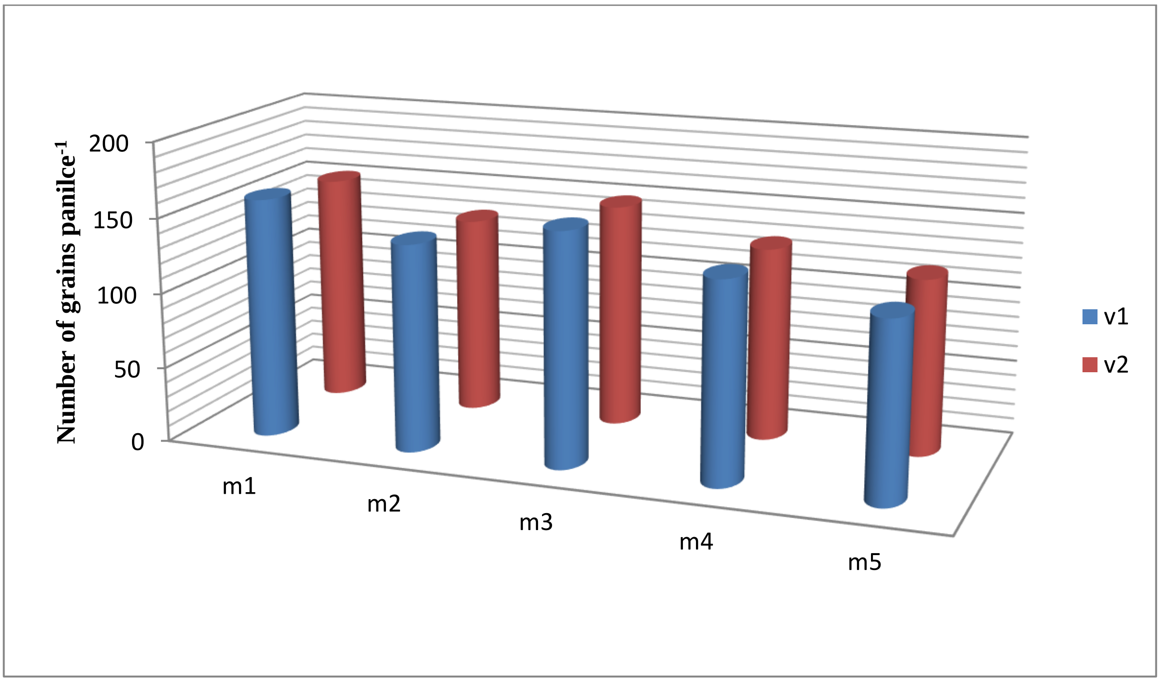

Fig.12. Interaction effect of methods of irrigation and varieties on the number of grains panicle^{-1}

and dry matter production. Findings of research in rice by Rushdi and Rzadvst (1991) also matched the results discussed above. Decreasing value of crop growth rate (CGR) can be attributed to more dissipation and faster ageing of leaves in the stressed conditions obtained at the treatments of lower crop growth rate.

The relative growth rate was observed to be the highest in sprinkler irrigation at 30-60 DAS, but in all other stages, it was found to be non-significant with respect to the methods and levels of irrigation as shown in the Table 16. The significant differences in the RGR at 30-60 DAS can be supported by similar findings by Hajihasaniasl (2007) who reported closure of stomas, reduction in photosynthesis rate and decreasing dry matter production in the treatments with lower RGR.

The net assimilation rate was also influenced by the irrigation methods as well as the various levels of irrigation as shown in the Table 17. At 30-60 DAS, at the active growth stage of the crop, the NAR was observed to be the highest in sprinkler irrigation at 100% PE. But at 0-30 DAS, it was the highest in drip irrigated plots at 100% PE and at 60-90 DAS, it was the highest in drip irrigated plots at 75% PE. Since moisture stress in all other treatments causes closure of stomas, photosynthesis rate with respect to leaf area is lowered and net assimilation rate decreases as well. This finding is in agreement with results obtained by Bakht *et al.* (2010) who observed that when there occurs moisture stress in crop, there is decrease in the rate of photosynthesis. Lu *et al*. (2000) observed that decrease in the rate of photosynthesis in leaves cause parallel decrease in NAR and eventually low grain yield.

The chlorophyll content at 30 DAS, as well as 60 DAS was the highest in sprinkler irrigated plots at 100% PE and at 90 DAS and at harvest, it was the highest in drip irrigated plots at 100% PE. The variety Prathyasa recorded significantly superior chlorophyll content compared to the variety Uma at all the stages. The treatment combination m_1v_1 recorded the highest chlorophyll concentration at 30 and 60 DAS, and at 90 DAS and at harvest, it was significantly higher in m_3v_2 and the lowest in m_5v_2 and m_5v_1 respectively at 30, 60 DAS and 90 DAS and harvest (Table18). These results are in close confirmation with the findings of Santos *et al*.

(2009), who observed that increase in water stress can reduce significantly the total chlorophyll content. Also, Timung *et al.* (2017) have reported that the varieties having the lowest per cent reduction in chlorophyll contents might be tolerant under drought condition. An increasing trend of osmotic adjustment with decreasing solute is a mechanism developed for the plant to survive in dry conditions. The higher amount of chlorophyll-a and chlorophyll-b attributes to the accumulation of solutes in the cell sap through passive accumulation from reduced cell size (Morgan, 1984).

The highest proline concentration at all the stages of the crop was observed in the plots irrigated using hose method of irrigation and the lowest amount was recorded in sprinkler irrigated plots at 100% PE (Table 19). Among the varieties, Uma had a significantly higher proline concentration compared to variety Prathyasa. A positive correlation between magnitude of free proline accumulation and drought tolerance has been suggested as an index for determining drought tolerance potential of cultivars. The major reason for increase in the proline concentration during water stress was due to lesser incorporation of continuously synthesized proline amino acid during proline synthesis.

The stomatal count at all stages of the crop was the highest in sprinkler irrigated plots at 100% PE, followed by that of drip irrigated plots at 100% PE and the lowest in plots with hose method of irrigation (Table 20). Yang *et al*. (2007) reported that the increase in stomatal density is positively correlated with WUE, which is confirmed by the results obtained. An increase in WUE with high stomatal density might also indicate a high acclimation capacity to a gradually increasing water deficit, and suggest an evolutionary adaptation to environmental stresses.

5.1.4 Quality Aspects of Grain

The length-breadth ratio was not found to be significantly influenced by the methods of irrigation as well as varietal differences as depicted in Table 21. However, the protein content was observed to be the highest (17.50%) in the plots

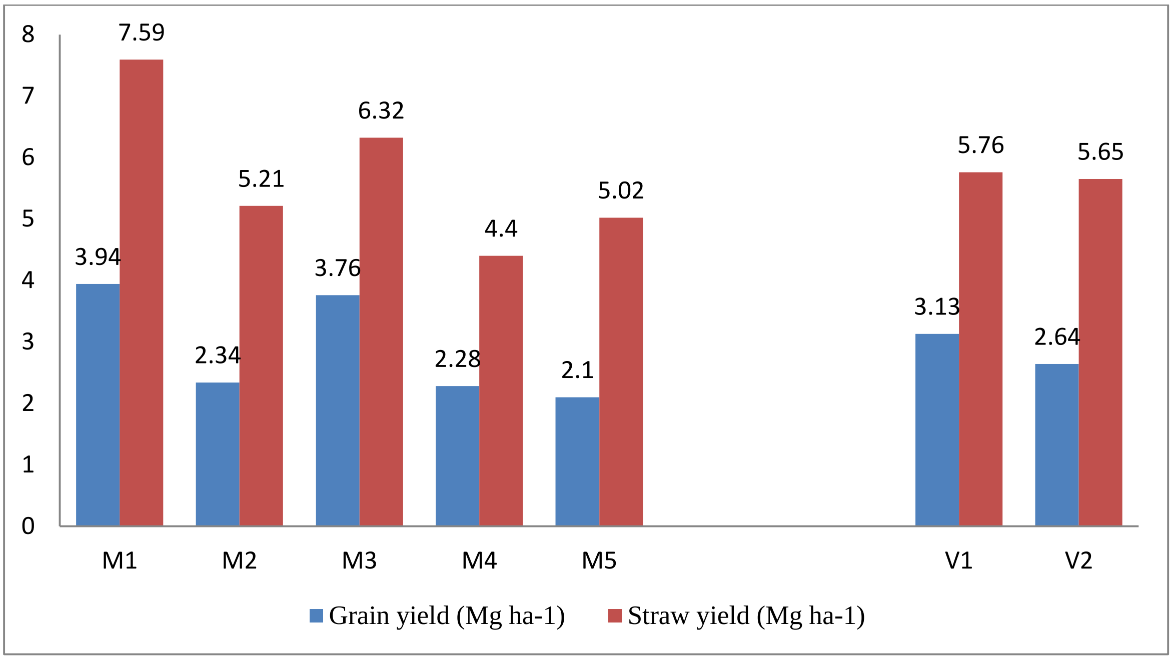

Fig. 13. Effect of methods of irrigation and varieties on the grain yield and straw yield, Mg ha^{-1}

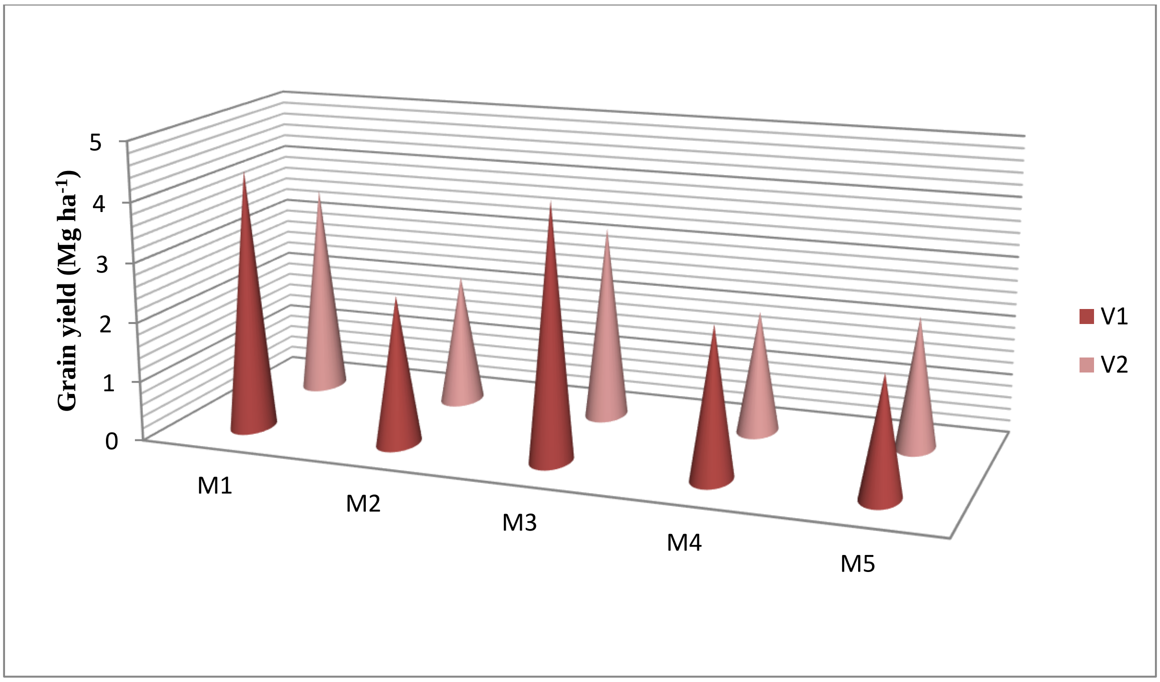

Fig.14. Interaction effect of methods of irrigation and varieties on the grain yield, Mg ha^{-1}

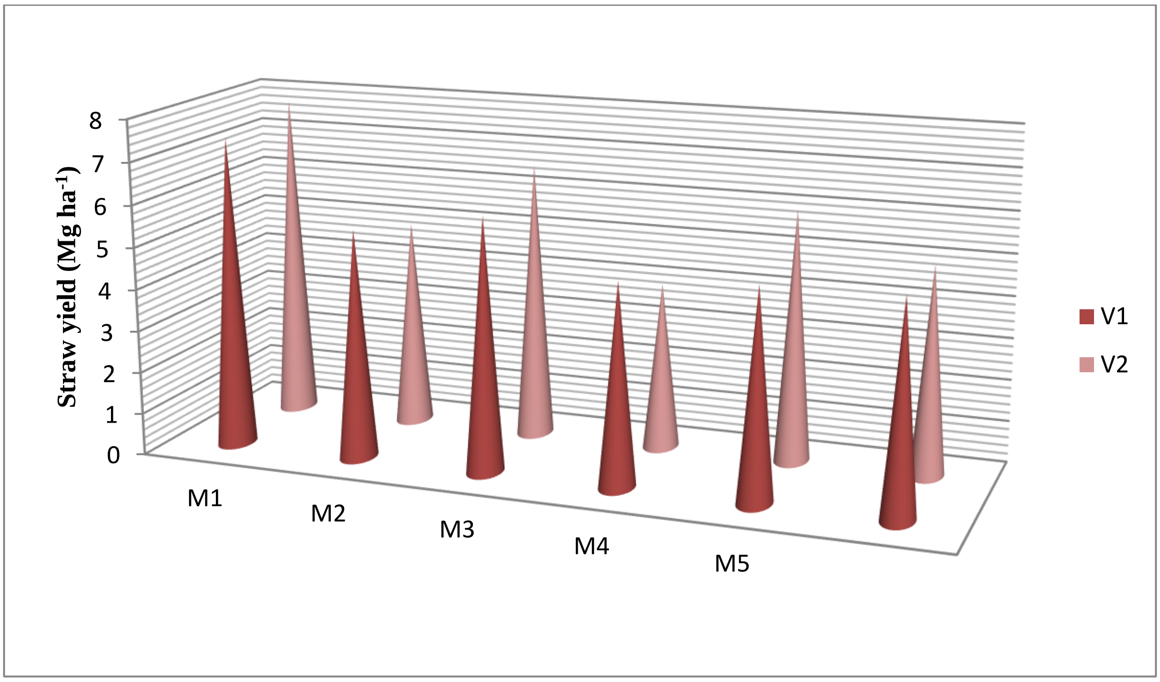

Fig. 15. Interaction effect of methods of irrigation and varieties on the straw yield, Mg ha^{-1}

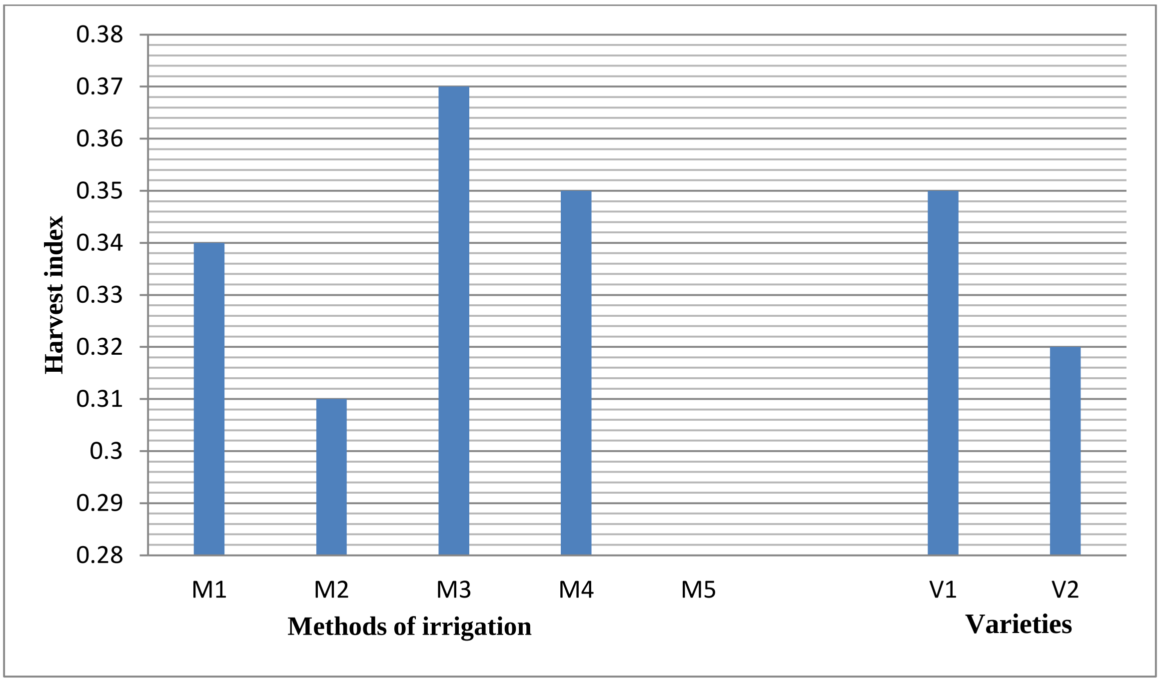

Fig.16. Effect of methods of irrigation and varieties on the harvest index of the crop

irrigated using hose and the lowest protein content of 13.77 % was recorded in the sprinkler irrigated plots at 100% PE. The variety Uma recorded higher protein content than the variety Prathyasa. The high protein content under water stress can be ascribed to the increase in the activities of glutamate synthase and glutamine synthetase, which are involved in nitrogen metabolism by promoting nitrogen accumulation and increasing the protein content in the grain (Cai *et al*., 2007).

The carbohydrate content in sprinkler and drip irrigated plots at 100% PE, as well as plots irrigated using hose method was on par with each other. The variety Prathyasa had a significantly higher carbohydrate content than the variety Uma. Chalky grains are primarily caused by the insufficient development of starch grains in the endosperm cells (Tashiro & Ebata, 1975).

5.1.5 Moisture Studies

The soil moisture content at 40, 60 and 80 DAS at 15 cm depth was observed to be the highest in drip irrigated plots at 100% PE and the lowest in plots irrigated using hose (Table 22). The soil moisture content at 20, 40, 60 and 80 DAS at 30 cm depth was however observed to be the highest in sprinkler irrigated plots at 100% PE and the lowest in drip irrigated plots at 75% PE (Table 23). The higher moisture content at 15 cm depth in drip irrigated plots at 100% PE was because, here irrigation is only given to a part of the land surface minimizing evaporation losses and reduces weed growth, so that transpirational losses are reduced to a great extent. The very low moisture content in plots with hose method of irrigation was due to the increased percolation losses as well as higher evaporation losses. Whereas, at 30 cm depth, moisture content was observed to be higher in sprinkler irrigated plots at 100% PE and lower in drip irrigated plots at 75% PE. It is because, more of water gets infiltrated in sprinkler irrigation, whereas the moisture in drip irrigation is restricted to the root zone of the crop. At 20, 40 and 80 DAS, the varieties did not have any influence on the soil moisture content, whereas at 60 DAS, it was the highest in the variety Prathyasa. It can be due to the higher uptake of water by the variety, because of the higher crop biomass.

The relative leaf water content of the crop was also influenced by the methods of irrigation and levels as well (Table 24). The highest RLWC was observed in sprinkler irrigated plots at 100% PE, followed by drip irrigated plots at 100% PE. The lowest RLWC was observed in plots irrigated using hose method. This happens because under water deficit, the cell membrane is subjected to changes such as increase in penetrability and decrease in sustainability (Blokhina *et al*., 2003). It was in confirmation with the studies of Blackman *et al.,* 1995) who revealed damages of dehydrated cells, including cleavage in the membrane and sedimentation of cytoplasm content.

A significantly higher consumptive use was observed in plots irrigated using sprinkler at 100% PE (Table 25). The consumptive use of the sprinkler and drip irrigated plots at 100% PE were on par with each other and the lowest was observed in the hose irrigated plots (161.38 mm). It was because, in hose irrigation as well as sprinkler and drip irrigated plots at 100% PE, irrigation was provided on the basis of daily evaporation loss and the amount of moisture lost daily was provided by irrigation. In drip and sprinkler irrigated plots at 75% PE, only 75% of the water lost by evaporation was applied through irrigation, accounting to lower consumptive use by them. In hose irrigated plots, most of the water applied was lost in percolation, accounting to lower consumptive use by the crop. The significantly higher consumptive use in Uma, compared to that of Prathyasa was due to longer crop duration of Uma.

The highest crop water use efficiency among the methods of irrigation was observed in plots irrigated using hose and the lowest value was recorded in the plots irrigated using drip at 100% PE (Fig. 17). The significantly higher value recorded in the hose irrigated plots was because of the higher grain yield per water used for evapotranspiration in the treatment. The field water use efficiency was however significantly the highest in sprinkler irrigated plots at 100% PE and the lowest value was recorded in the plots irrigated using hose (Fig. 19). It was

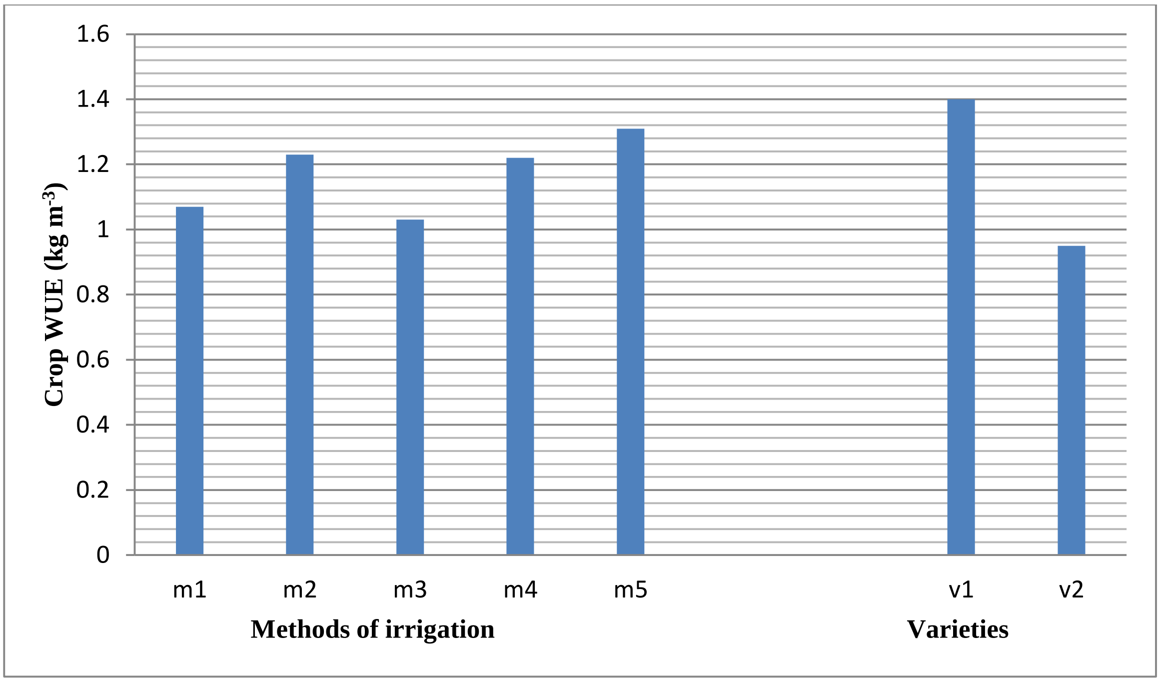

Fig. 17. Effect of methods of irrigation and varieties on the crop WUE, kg m^{-3}

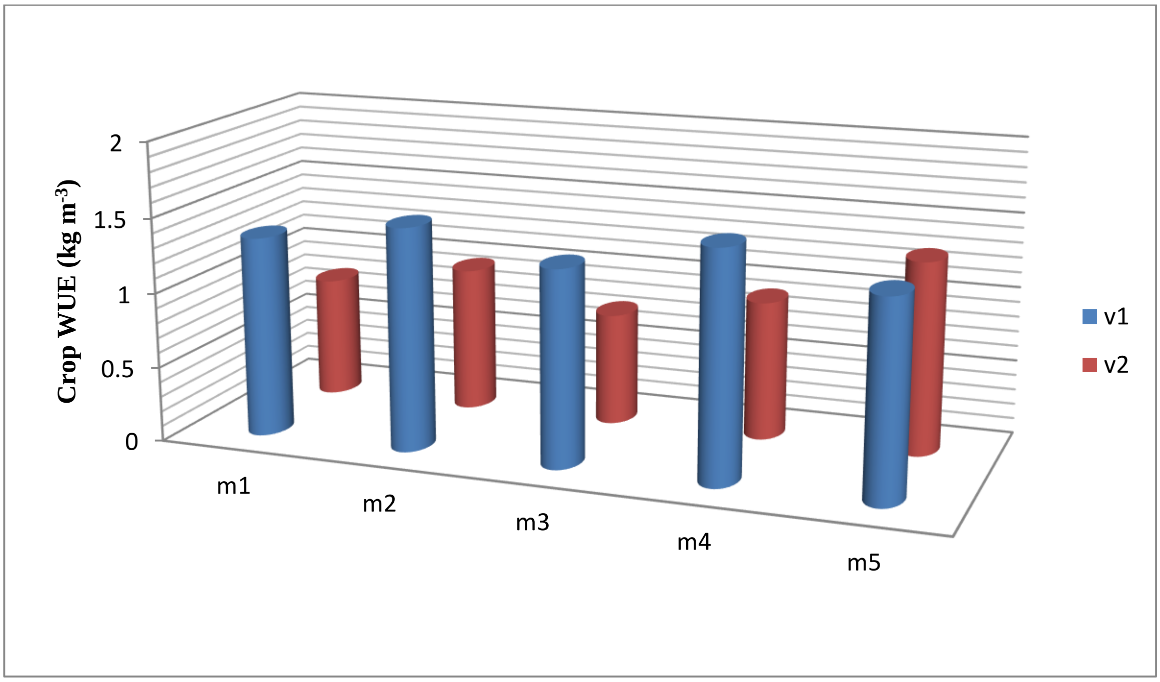

Fig. 18. Interaction effect of methods of irrigation and varieties on the crop WUE, kg m^{-3}

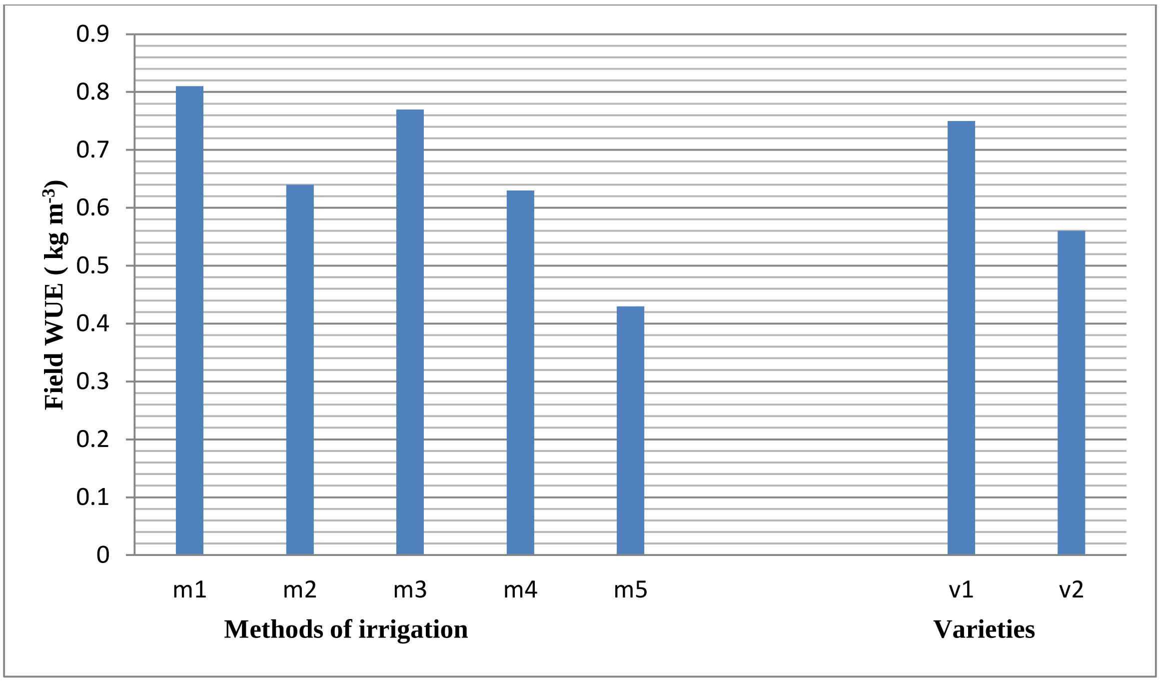

Fig.19. Effect of methods of irrigation and varieties on the field WUE, kg m^{-3}

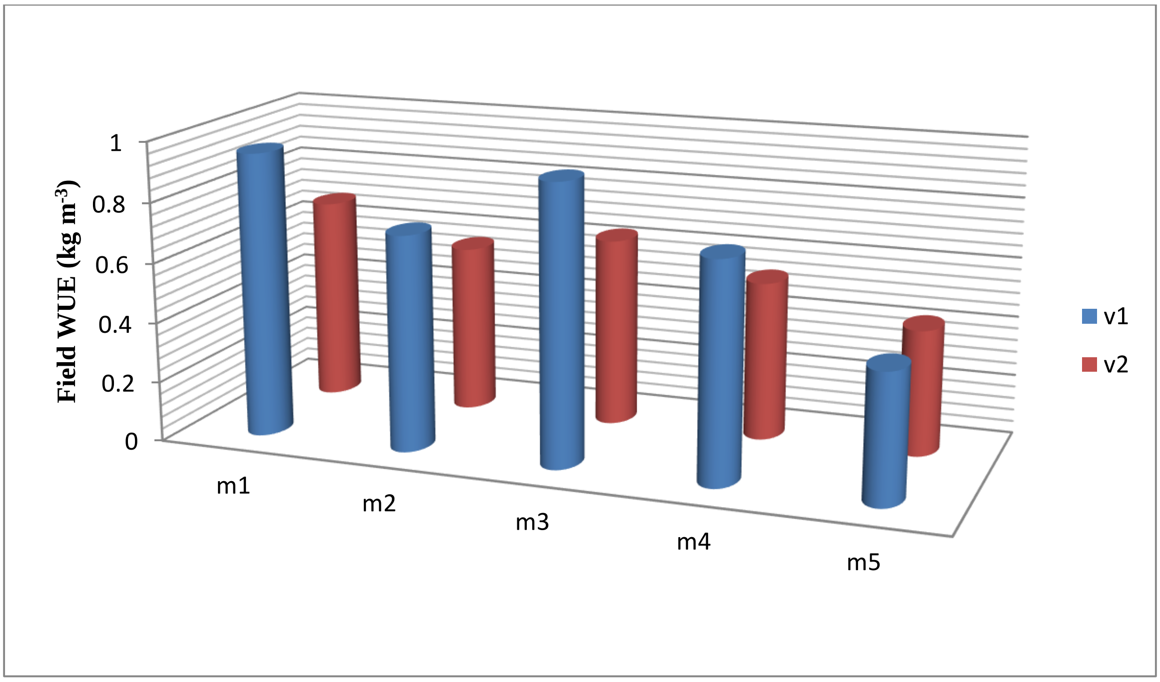

Fig.20. Interaction effect of methods of irrigation and varieties on the field WUE, kg m^{-3}

because most of the water applied to the field in case of hose irrigated plots gets drained off and percolated. Whereas, most of the water applied to the sprinkler irrigated plots gets utilized for consumptive use by the crop. The significantly higher grain water use efficiency in the variety Prathyasa is because of the higher grain yield with respect to the water used for evapotranspiration, compared to that in the variety Uma.

5.1.6 Plant Analysis

Intermittent irrigation creates favourable soil physical, chemical and biological properties that support plant growth under mostly aerobic soil conditions, encouraging deeper rooting depth and creating favourable micro-climates in the soil, which support abundance of micro-organisms and more availability of micro-nutrients. Better root systems provide good anchorage for the plants and sustain effective use of applied fertilizers by checking losses from leaching (Stoop *et al*., 2002). The present study revealed that the treatments differed significantly in the grain nitrogen uptake, straw nitrogen uptake as well as the total biomass nitrogen uptake. The nitrogen uptake in grain was observed to be the highest in sprinkler irrigation at 100% PE and was on par with drip irrigation at 100% PE, but significantly superior over hose method of irrigation as well as drip irrigation and sprinkler irrigation at 75% PE. The nitrogen uptake in straw was also observed to be the highest in sprinkler irrigation at 100% PE, but was on par with drip irrigation at 100% PE as well as hose method of irrigation. The total uptake showed a similar trend as in grain nitrogen uptake, with the highest in sprinkler irrigation at 100% PE (126.24 kg ha^{-1}) and the lowest (99.25 kg ha^{-1}) in hose method of irrigation. The results have revealed that the optimum availability of soil moisture plays a key role in the processes of mineralization and solubilisation, affecting the availability and uptake of nutrients, and contributing to plant growth and yield. The low nitrogen uptake in conventionally irrigated rice is due to the increased percolation and poor synchronisation between crop demand and availability of nitrogen, which can lead to leaching of the nitrate below the rooting zone (Anderson *et al*., 1998). Also, the root system if vigorous have early and fast growth and profuse proliferation to intercept and capture the NO^{3-} before it moves below the rooting depth (Liao *et al*., 2004). The well developed root system root in sprinkler irrigated plots might have resulted in better interception and capture of the NO^{3-}.

According to Lemaire and Millard (1999), plant N uptake is feedback regulated by shoot N and C signalling irrespective of the source of soil N. A positive regulation comes from a C signal corresponding to photosynthetic assimilate transported by phloem from leaves to roots, and a negative signal comes from organic N re-circulated from shoots to roots (Lejay *et al*., 1999). The LAI at 100% PE sprinkler irrigation in the variety Prathyasa was found to be the highest (2.35), with the highest growth rate (Table 11). Thus, an increase in plant growth rate increases the leaf area and then the plant photosynthetic rate, leading to a positive C signal to the root transport system for nitrate absorption. The results were in confirmation with the study by Sivapalan (2001) whose observations showed that unlike in conventional methods of irrigation the relatively small increments of water added by micro irrigation practices like drip and sprinkler irrigation systems and careful irrigation scheduling, the soil profile is often not becoming saturated at 20 cm depth. These irrigation practices apparently allow a larger proportion of all available N sources to remain in the root zone. Residual nitrate and ammonium, a larger part of the fertilizer N, and a larger part of any other N source are less apt to be leached. According to Feibert *et al*, (1998), by using microirrigation techniques, the substantial amounts of N are mineralized from soil organic matter and become available for plant growth.

A similar trend was observed in the P (Table 27) as well as K (Table 28) uptake, with the highest P and K uptake from the plots irrigated using sprinkler irrigation at 100% PE and the lowest in plots irrigated using irrigation at 75% PE and hose method of irrigation.

5.1.7 N, P, K and OC Content of Soil Before and After Experiment

The N content of the soil after experiment was found to be significantly different among the treatments. It was the highest in drip irrigated plots at 75 % PE and the lowest in plots irrigated using hose method. It was due to the higher loss of nitrogen through leaching from the plots irrigated using hose method and lesser N is being lost from the plots with drip irrigation at 75% PE because in this only root zone area is wet and the N in remaining part of the area remains without being removed. The crop uptake of N is also found to be minimal here.

In case of P, the highest content in soil was observed in drip irrigated plots at 75% PE and the lowest in plots irrigated using hose method. It can be because of P removal from the soil through runoff and erosion, and leaching. Surface runoff is the major pathway for phosphorus loss from soils. Runoff water carries away both soluble (dissolved) P and particulate (eroded soil particles) P from soil surface.

5.1.8 Pest Incidence

Stem borer attack was observed to be the major pest incidences of the crop and it was significantly influenced by the methods of irrigation. It was recorded to be the highest in the plots irrigated using sprinkler at 100% PE, followed by the plots irrigated using sprinkler at 75% PE. The attack was the lowest in the plots irrigated using drip at 75%. Spread of infestations takes place in sprinkler irrigation as a result of sprinkling and splashing of water on foliage. Drip irrigation restricts such spread of pathogens as in drip, irrigation water is carried in closed conduits and is delivered right near the plants at small discharges.

5.1.9 Economics of Cultivation

The net returns was calculated and was observed to be the highest in sprinkler irrigated plots at 100% PE. It was followed by the net returns obtained from drip irrigation at 100% PE, and the lowest net returns was obtained from the from the plots irrigated using hose. Among the varieties, the variety Prathyasa earned higher net returns compared to the variety Uma. A benefit cost ratio of 2.46 was obtained from the plots irrigated using sprinkler irrigation at 100% PE and the lowest B: C ratio of was obtained from hose irrigated plots. The higher monetary returns from the plots irrigated using sprinkler irrigated plots was because of the lower installation costs compared to the drip irrigation as well as higher yield obtained among all the treatments. Among the interactive effects, the treatment combination of sprinkler irrigation at 100% PE, compounded with the performance of the variety Prathyasa generated a net return of as high as ₹1,32,465.50 ha^{-1} and a B:C ratio of 1.92, suggesting that it is highly recommended for enhanced and highly profitable yield under upland condition.

5.2 EXPERIMENT 2- STANDARDIZATION OF IRRIGATION SCHEDULING AND MOISTURE STRESS MITIGATION STRATEGIES FOR UPLAND RICE

5.2.1 Growth Characters

Observations on the growth characters of rice *viz.* germination count, plant population, height of plant, number of tillers m^{-2}, dry matter production at 30, 60, 90 DAS and at harvest and leaf area index at panicle initiation were recorded. The growth attributes were observed to be significantly influenced by the various approaches of scheduling irrigation as well as moisture stress mitigation strategies at all the stages of crop growth as explained below:

The plant height, number of tillers m^{-2}, leaf area index and dry matter production were observed to be significantly higher in the plots irrigated at 100% FC at all the stages of crop growth which was followed by the plots irrigated to maintain 2 cm depth of water at critical stages of crop growth (Fig.21, Fig.22, Fig. 23 and Fig. 24). A significantly higher value in the growth characters were observed in the plots irrigated at 75% FC compared to the plots irrigated at an IW/CPE of 0.8. Increase in plant height in higher irrigation levels might be due to optimum soil moisture availability favouring the nutrient uptake, resulting in better growth at 100% FC as against scheduling irrigation at 75% FC and 0.8 IW/CPE. The irrigation scheduled at 100% FC provides higher soil moisture availability due to which plants absorbed more water and resulted in better growth attributes as compared to other levels. This might be due to more and frequent irrigations resulted in better growth, synthesising activity and assimilation rate leading to increase in growth attributes. The above results are in conformity with the findings

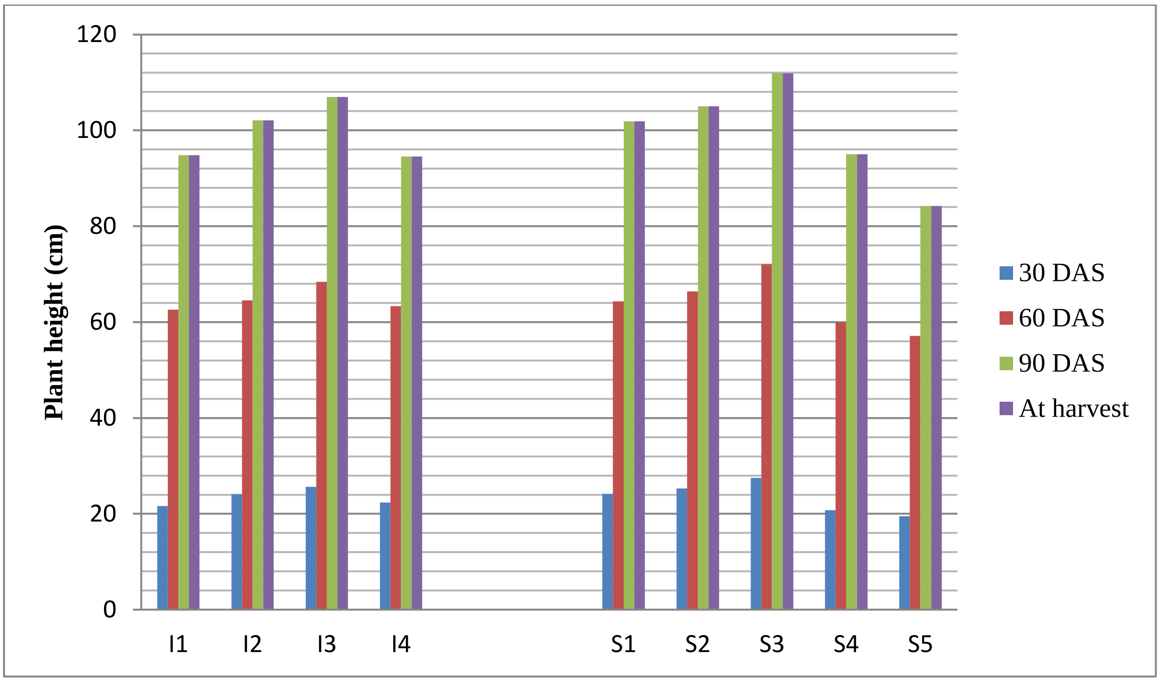

Fig. 21. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies on plant height, at 30, 60 and 90 DAS, cm

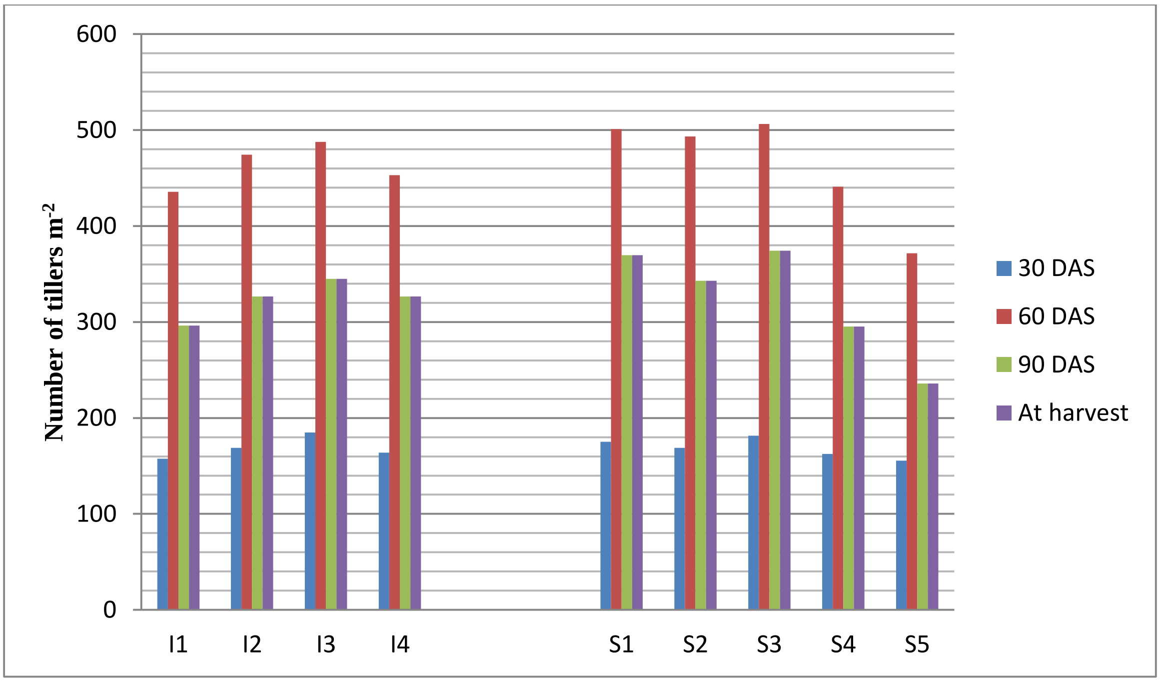

Fig.22. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies on number of tillers at 30, 60 and 90 DAS

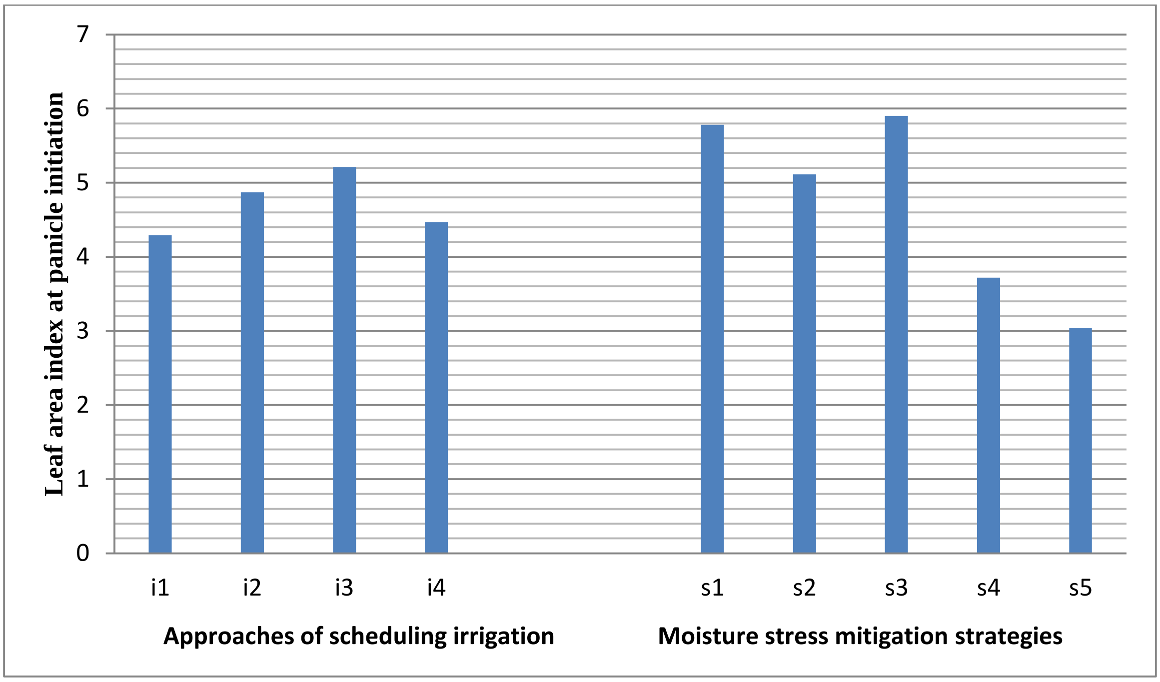

Fig.23. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies on leaf area index at panicle initiation

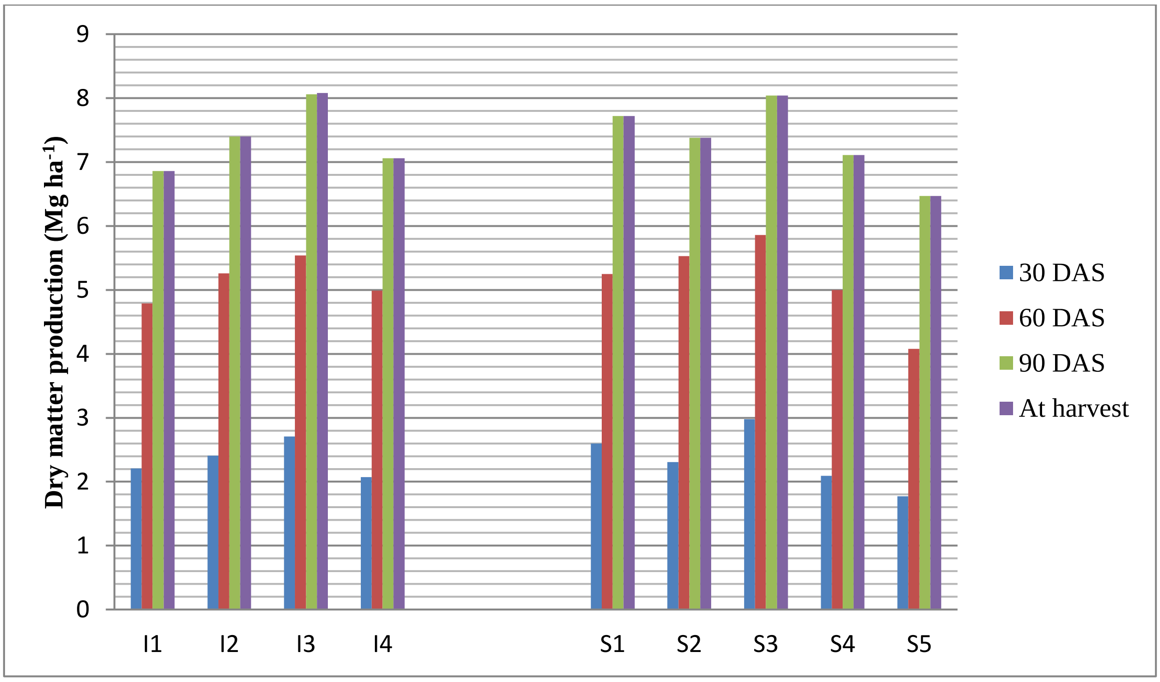

Fig.24. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies on dry matter production at 30, 60 and 90 DAS, Mg ha^{-1}

reported by Biswas and Bhatacharya (1987). The results are in line with the findings of Aliaga *et al.* (1986), who is of the view that high water table increased the number of tillers, due to easy availability of water to the plants.

Among the moisture stress mitigation strategies the highest value in the growth characters was recorded in the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @10 g kg^{-1}), followed by the plots in which seed treatment of hydrogel polymer @ 10 g kg^{-1} only was done. The plots in which field application of hydrogel polymer @ 2.5kg ha^{-1} recorded a significantly higher value in the growth attributes compared to the plots sprayed with 1% PPFM spray at panicle initiation stage. The lowest value was recorded in the absolute control plots. The results were in confirmity with the studies of Roy *et al.* (2019) who recorded a higher plant height, leaf area as well as number of tillers in the hydrogel polymer treated plots compared to the non-hydrogel polymer treated plots.

Hydrogel is hydrophilic in nature with the capacity to absorb huge quantity of water almost 200–400 times its weight. Thus, its application in rhizosphere helps to retain moisture for a longer time period and helps overcome dry spells. Increased moisture availability in the surface soil layer enhanced germination of the crop and resulted in increased plant population. There was an increment of plant population in hydrogel treated plots compared to other plots. Increased plant population in turn indicates higher tillering and a higher number of effective tillers per unit area. Enhancement in the number of tillers is solely attributed to hydrogel application since all other management practices were uniformly practised for all the treatments. The crop also showed robust tillering due to more moisture retention with hydrogel. Hydrophilic polymer increases the turgor pressure inside the cells by maintaining sufficient amount of water as per crop requirement and thus causing increase in leaf area and other related growth parameters.

The results are however contradictory with some researchers who found no effect of soil amendment with hydrogel on emergence and early seedling growth in different species (Ingram and Yeager 1987, Akhter *et al.*, 2004).

5.2.2 Yield Attributes

The number of days for 50% flowering was the longest in the plots irrigated at 100% FC, followed by the plots irrigated to maintain 2 cm depth of water at critical stages of crop growth as indicated in Table 38. The lowest value was recorded in the plots irrigated at an IW/CPE of 0.8. The number of panicles m^{-2}, length of panicle, weight of panicle, number of grains $panicle^{-1}$, grain yield, straw yield and harvest index followed a similar trend (Fig. 25, Fig. 26, Fig. 27 and Fig. 30). The sterility percentage in grain was observed to be the highest in the plots irrigated at 75% FC, followed by the plots irrigated at an IW/CPE of 0.8 (Table 39). The lowest sterility percentage was recorded in the plots irrigated at 100% FC. The result was in accordance with the studies of Rahman and Yoshida (1985), who observed that panicle exertion showed an inhibitory effect in lower irrigation levels, due to water stress under moisture stress conditions. Sudhakar *et al.* (1989) reported that soil moisture stress during tillering stage resulted in significant reduction in panicle number.

The increase in the weight of the panicle in higher irrigation levels is due to the higher number of filled spikelets $panicle^{-1}$ and higher test weight of the grains in case of treatments with higher irrigation levels. The increase in test weight under the treatment 100% FC might be due to additional moisture supply due to application of frequent irrigations. Shortage of assimilate supply due to inhibition of photosynthetic processes is one of the major factors determining grain filling (Matsushima and Wada, 1958; Yoshida, 1981; Evans, 1996; Egli, 1998). The increased number of filled spikelets in treatments receiving higher number of irrigations, as compared to the treatments receiving lower number of irrigations is due to increased supply of assimilates under increased moisture supply.

Inhibition of photosynthesis during the grain filling period due to environmental stresses such as water deficit can result in a major reduction in grain dry matter in rice (Kobata and Takami, 1986; Kobata and Moriwaki, 1990; Takami *et al.*, 1990). The grain sterility under reduced water application may be directly related to the stress experienced during flowering to panicle ripening. The

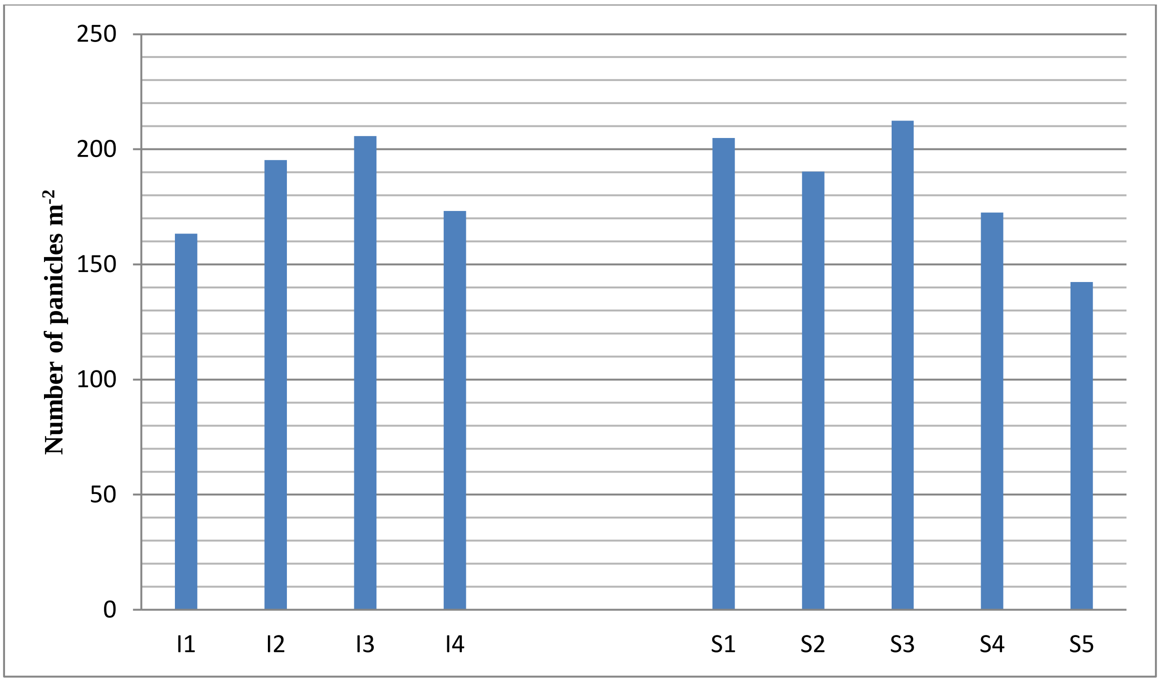

Fig.25. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies on number of panicles m^{-2}

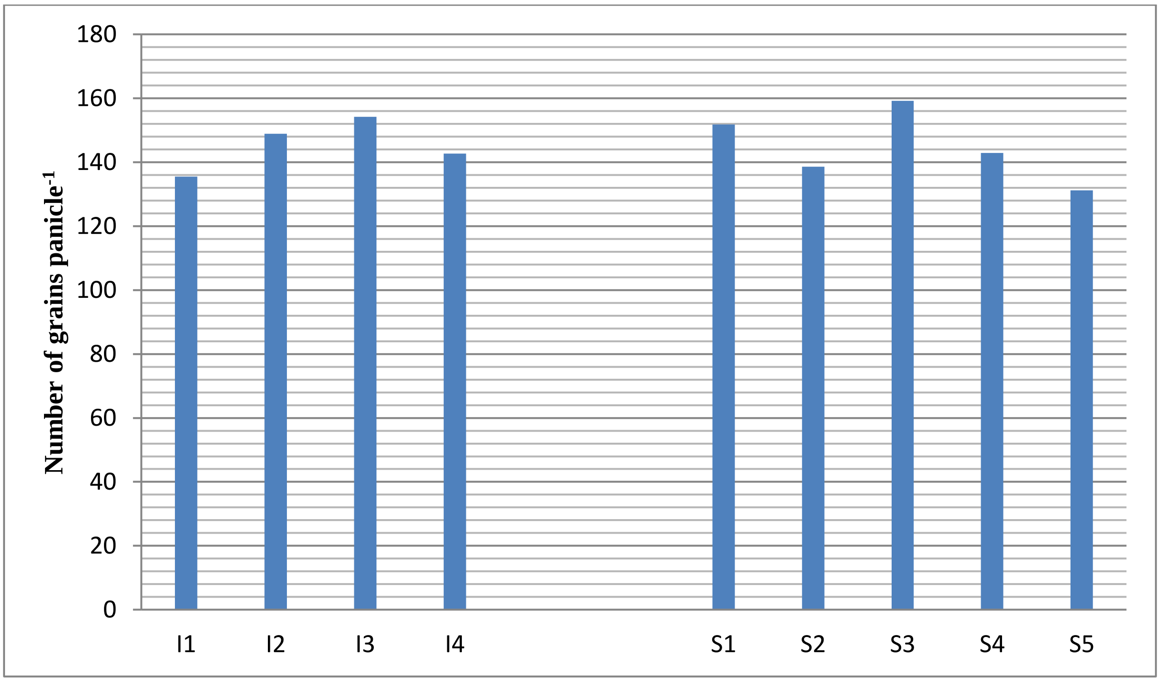

Fig.26. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies on number of grains panicle^{-1}

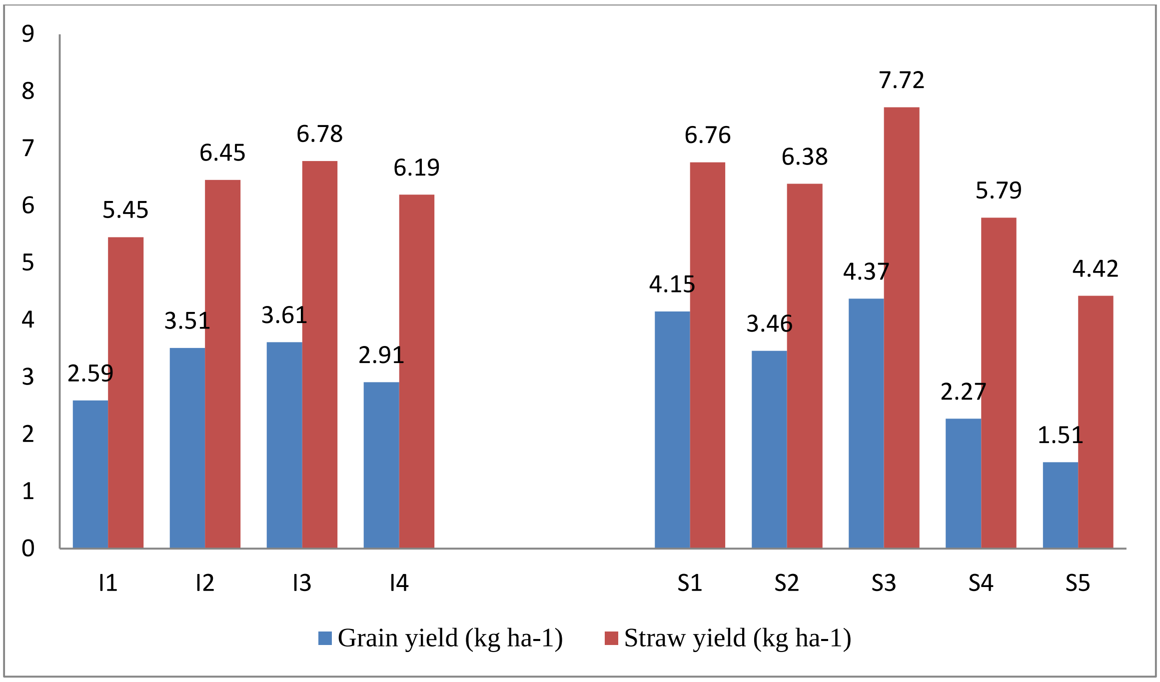

Fig.27. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies on grain yield and straw yield, Mg ha^{-1}

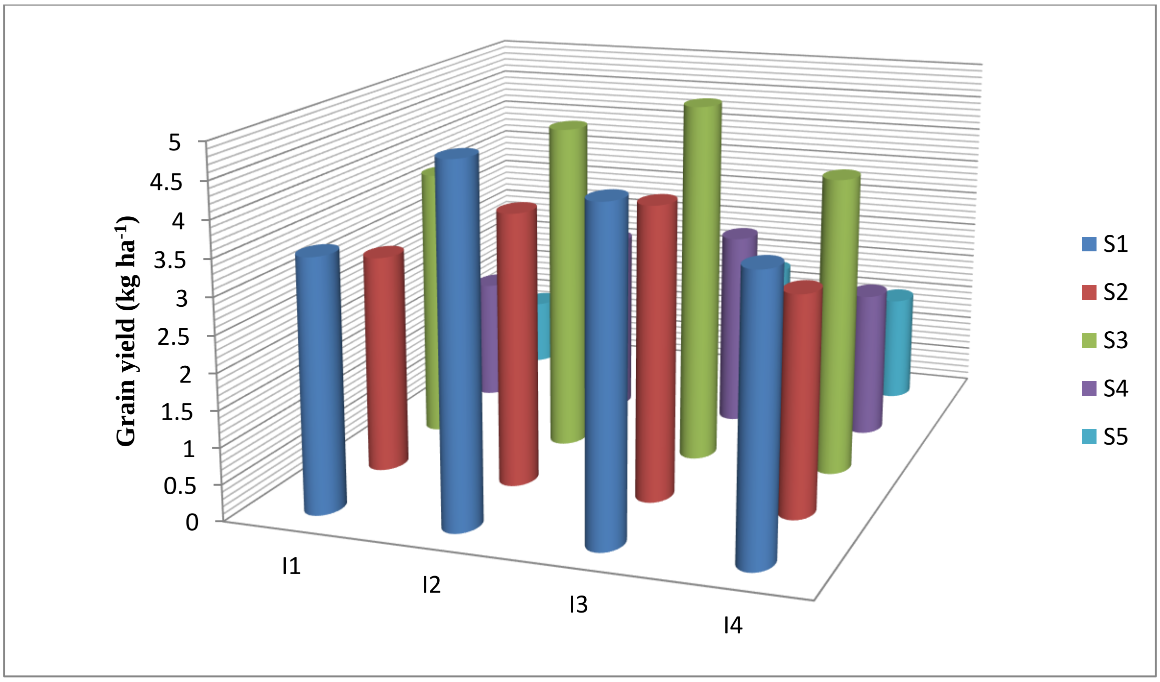

Fig.28. Interaction effect of approaches of scheduling irrigation and moisture stress mitigation strategies on grain yield, Mg ha^{-1}

deleterious effect of water deficit on spikelet opening might have resulted in high chaff percentage. It was in accordance with the studies of Lenka and Garnayak (1991) and Ekanayake *et al.*, (1989). Sudhakar *et al.* (1989) reported that stress during development and ripening reduced the percentage of filled grains of rice.

The reduction in crop yield at lesser irrigated treatments might be due to the severe and mild moisture stress experienced by the crop. Under the moisture stress situation increased soil mechanical resistance and poor root growth may occur. Philips (1996) reported that under unsaturated soil moisture environment a vapour gap would be formed around the roots by their turgour pressure under water stress. Such a gap if ever present would reduce the availability of nutrients to the roots probably due to lesser contact between roots and soil particles causing drastic reduction in uptake of nutrients and dry matter production. This might be the major reason for lower yield of crop with high moisture stress. The increase in grain yield in irrigated plots is due to the concomitant increase of the yield attributes at higher levels of irrigation Lee *et al.* (1985) indicated that soil moisture stress reduced the number of spikelets panicle^{-1} and filled grain percentage resulting in yield reduction up to 50 per cent in rice. It is reported that yield reduction under moisture stress is mainly due to the increased number of unfilled grains panicle^{-1} rather than reduction in panicle number per unit area. Similar trend was also observed by Sheela (1993). The increased straw yield with increasing levels of irrigation is attributed to the combined effect of plant height, tiller production and dry matter production, which were favourably influenced by irrigation levels. The stunted growth, poor tiller production coupled with extremely low leaf area might have resulted lower straw yield in the treatment, which was provided with lowest irrigation. This finding is in agreement with the studies of Singh and Singh (1993) and Pant *et al.* (1987).

Among the moisture stress mitigation strategies, the number of days for 50% flowering was observed to be the longest in the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} +seed treatment @10g kg^{-1}), followed by the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1}). The plots in which seed treatment of hydrogel polymer @ 10g kg^{-1}was done, showed a significantly higher value than the plots in which the crop was sprayed with PPFM (1%) at panicle initiation stage. The lowest value was observed in the absolute control plots. A similar trend was shown in case of the number of panicles m^{-2}, length of panicle, weight of panicle, number of grains $panicle^{-1}$, grain yield, straw yield and harvest index (Table 40).

Encouraging impact of hydrogel application on yield attributes of different crops has been reported by various researchers. An increase in water holding capacity due to hydrogel amendment significantly reduced the irrigation requirement of many plants (Taylor and Halfacre, 1986). In a study by Anupama *et al.*,2005, *Chrysanthemum* grown in a soil-less medium with hydrogel application (0.5% wt/wt) showed increased number of flowers $plant^{-1}$ as well as flower size compared to no hydrogel application. Increased yield in soybean, cucumber, rice, *etc.* due to hydrogel application has been reported by several workers (Borivoj *et al.*, 2006, Yezdani *et al.*, 2007). Increased spike length and the number of grains per ear for wheat have also been reported by them. The number of panicles formed is governed by the number of effective tillers, which was increased due to hydrogel application. The leaves are the main photosynthetic organs in the plant which ultimately relocates photosynthates from vegetative to reproductive parts. The number of leaves thus, can have direct implication on the crop yield. The study revealed that the application of hydrogel had significant impact in increasing the number of leaves $plant^{-1}$. The plant growth is governed by various factors of which water and nutrient are the two most important components. The optimum supply of both components ensures increased cell division and hence better plant growth and higher ear length for the hydrogel amended plots. Increase in the number of grains per ear indicates better absorption of plant nutrients and higher photosynthetic activity resulting in more carbohydrate assimilation. Since hydrogel application is likely to improve the water availability, this concurrently improves the nutrient uptake and photosynthetic activity resulting in increased number of grains per ear. The grain yield is essentially a function of the number of effective tillers, number of panicles, number of grains per panicle *etc.* As a result of hydrogel amendment, all these parameters were remarkably improved which was reflected in the grain yield.

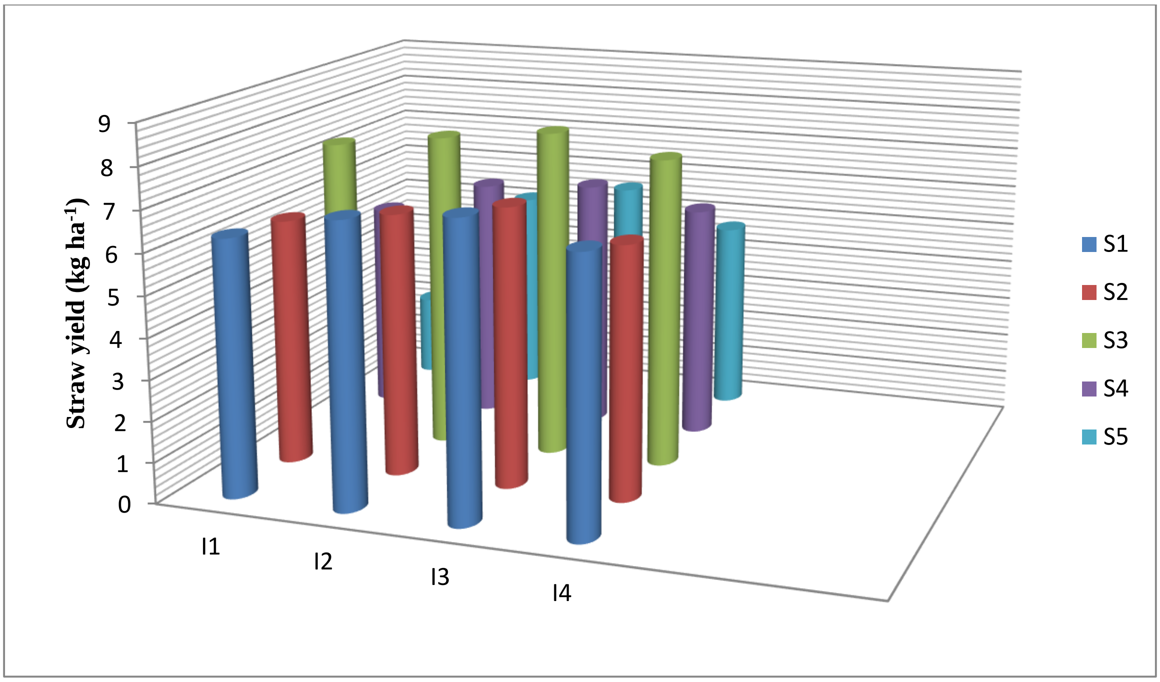

Fig.29. Interaction effect of approaches of scheduling irrigation and moisture stress mitigation strategies on straw yield, Mg ha^{-1}

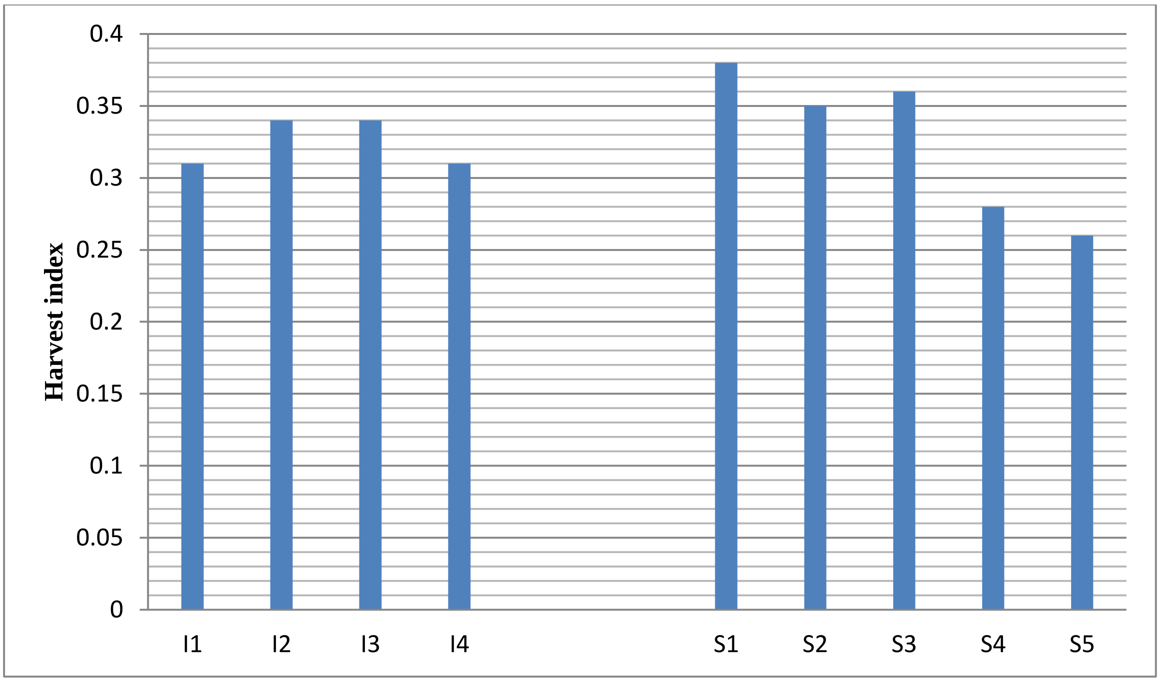

Fig.30. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies on harvest index

The plots which were treated with PPFM (1%) spray performed better in terms of yield attributes compared to that of the absolute control plots. PPFM bacteria have the ability to release plant-growth regulation molecules (Dourado *et al.,* 2015) and thereby increasing the tolerant capacity under stress conditions. Similar result was observed by Madhaiyan *et al.,* (2004) who reported that PPFM inoculation has resulted in increased seedling vigour, dry matter production and yield.

5.2.3 Physiological Parameters

The crop physiological parameters like the crop growth rate, relative growth rate, net assimilation rate, chlorophyll content, proline content and the stomatal count of the leaves at 30, 60 and 90 DAS have been found to be significantly influenced by the various approaches of scheduling irrigation as well as the moisture stress mitigation strategies and the discussion regarding it has been furnished below:

The CGR and RGR have been found to be the highest in the plots irrigated at 100% FC, followed by the plots irrigated to maintain 2 cm depth of water at critical stages of crop growth as shown in Table 41 and Table 42. The plots irrigated at 100 % FC recorded a significantly higher CGR compared to all other treatments at 0-30 and 60-90 DAS. The RGR also recorded the highest in plots irrigated to maintain 100% FC. The NAR was the same in all the treatments at 0-30 DAS, whereas at 30-60, it was the highest in plots irrigated at 75% FC, followed by the plots irrigated at IW/CPE of 0.8 and the lowest value was recorded in the plots irrigated at 100% FC and at 60-90 DAS, it was the highest in the plots irrigated at IW/CPE of 0.8, followed by the plots irrigated at 75% FC and the lowest value was observed in the plots irrigated at 100% FC.

The chlorophyll content at 30, 60 and 90 DAS recorded the highest value in the plots irrigated at 100% FC, followed by the plots irrigated to maintain 2 cm depth of water at critical stages of crop growth and the lowest value was observed in the plots irrigated at an IW/CPE of 0.8 (Table 44). A similar trend was observed in case of stomatal count in leaves also (Table 46). Whereas in case of proline concentration, the highest value was recorded in the plots irrigated at 0.8 IW/CPE, followed by the plots irrigated at 75% FC and the lowest value was recorded in the plots irrigated at 100% FC (Table 45).

Among the moisture stress mitigation strategies, the highest CGR, RGR, chlorophyll content and stomatal count were observed to be the highest in the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @ 10 g kg^{-1}), followed by the plots treated with hydrogel (field application @ 2.5kg ha^{-1}). The plots treated with hydrogel polymer (seed treatment@ 10 g kg^{-1}) recorded a significantly higher values than the plots treated with PPFM (1%) and the lowest values were recorded in the absolute control plots.

Crop growth rate (CGR) and Relative Growth Rate (RGR) is low at early growth stages because the plant cover is incomplete and the plants intercept and absorb only part of the solar radiation. Growth rate is quickly increased during development because of the expansion of leaf area and less radiation penetrating through plant cover to the soil surface. Maximum CGR and RGR occurred when plants were sufficiently high or dense to probe all the environmental factors. This phenomenon can be justified by closure of stomas, reduction in photosynthesis rate and decreasing dry matter production in case of reduced irrigation levels. This coincides with the report of Lorens *et al.* (1987) as well where LAI increased with crop growth, reaching a maximum value in which the maximal capability of intercepting solar energy was reached, when CGR is also maximum.

The chlorophyll content was observed to be lower in reduced water conditions. This is because, water stress reduces chlorophyll content in leaves and controls crop productivity through CO_2 assimilation (Sheela and Alexander, 1996; Awal and Ikeda, 2002). The results suggest that water stress might affect Chl-related plant growth and development (Jahan *et al.*, 2014).

The proline concentration was the highest in the treatments with reduced water conditions. The major reason for increase in the proline concentration during water stress was due to lesser incorporation of continuously synthesized proline amino acid during proline synthesis. Proline accumulation is also responsible for the hydration of biopolymers, surviving as a readily utilizable energy source and serving as a nitrogen source during periods of inhibited growth. Clifford *et al.*

(1998) studied proline accumulation in ber and found that there was 35 fold increase in proline concentration in leaves during drought conditions. Proline accumulation during drought is also supported by Chaitanya *et al.* (2009) and Ramanjulu and Sudhakar (2000) in mulberry, Lakmini *et al.* (2006) in coconut and Rao *et al.* (2008) in important tree species of Tarai region.

The reduced number of stomata under reduced water conditions can be an adaptation to water stressed conditions. When plant roots are subjected to water stress, ABA (abscisic acid) accumulation is initiated by a drought-sensing mechanism located in the roots, where it can be exported to leaves (Pei and Kuchitsu, 2005), thus reducing water loss by stomatal regulation (Cominelli *et al.*, 2005; Gudesblat *et al.*, 2007).

5.2.4 Quality Aspects of Grain

The length - breadth ratio and the carbohydrate content of the grains was found to be not significantly influenced by the approaches of scheduling irrigation as well as the moisture stress mitigation strategies. In case of protein content, the highest protein content was recorded in the plots irrigated at IW/CPE of 0.8, followed by the plots irrigated to maintain a 75% FC. The least protein content was observed in the plots irrigated at an IW/CPE of 0.8.

Among the moisture stress mitigation strategies, the highest protein content was observed in the absolute control plots, followed by the plots treated PPFM (1%) spray at panicle initiation stage. The plots treated with hydrogel polymer (seed treatment @ 10 g kg^{-1}) had a higher protein content compared to the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1}), which was on a par with the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1}+ seed treatment @10 g kg^{-1}). The high protein content under water stress can be ascribed to the increase in the activities of glutamate synthase and glutamine synthetase, which are involved in nitrogen metabolism by promoting nitrogen accumulation and increasing the protein content in the grain (Cai *et al.*, 2007).

5.2.5. Moisture Studies

At 20, 40, 60 and 80 DAS, the moisture content in the soil was observed to be the highest in the plots irrigated at 100% FC, followed by the plots irrigated to maintain 2 cm depth of irrigation at critical stages of crop growth (Table 48 and Table 49). The lowest moisture content was observed in the plots irrigated at an IW/CPE of 0.8. It was because of the more frequent irrigations provided in the pots with higher moisture content. Among the moisture stress mitigation strategies, a significantly higher moisture content was observed in the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @ 10g kg^{-1}), followed by the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1}). The plots treated with hydrogel polymer (seed treatment @ 10g kg^{-1}) recorded higher moisture content than the plots treated with PPFM (1%) spray and the lowest moisture was observed in the absolute control plots. It is because of the capacity of the hydrogel to absorb and retain water as much as 80–180 times its original volume while on weight basis it can absorb as high as 400 times its original weight (Roy *et al.*, 2019). The hydrogels can also modify various physical properties of soil like infiltration rates, density, soil structure and compaction and improves the water holding capacity of the soil. A similar trend was observed in the relative leaf water content, as in the soil moisture content.

The consumptive use was the highest in the plots irrigated at 100% FC, followed by the plots irrigated to maintain 2 cm depth of water at critical stages of crop growth and the lowest consumptive use was recorded in the plots irrigated at an IW/CPE of 0.8 (Table 51). The lower consumptive use in the plots irrigated at IW/CPE was due to the longer irrigation interval in this treatment, which resulted in lesser water consumption by the crop. Among the moisture stress mitigation strategies, the consumptive use was significantly higher s_3 and the lowest in absolute control plots.

The crop water use efficiency recorded the highest value in the plots irrigated at IW/CPE of 0.8, followed by the plots irrigated to maintain 75% FC (Table 51 and Fig. 31). The lowest water use efficiency was observed in the plots irrigated at 100% FC. The lowest water use efficiency in the plots irrigated at 100% FC is because of the higher consumptive use of the crop in these plots. Though the yield is highest in this treatment, the very high consumptive use in this leads to lower water use efficiency. Among the moisture stress mitigation strategies, the

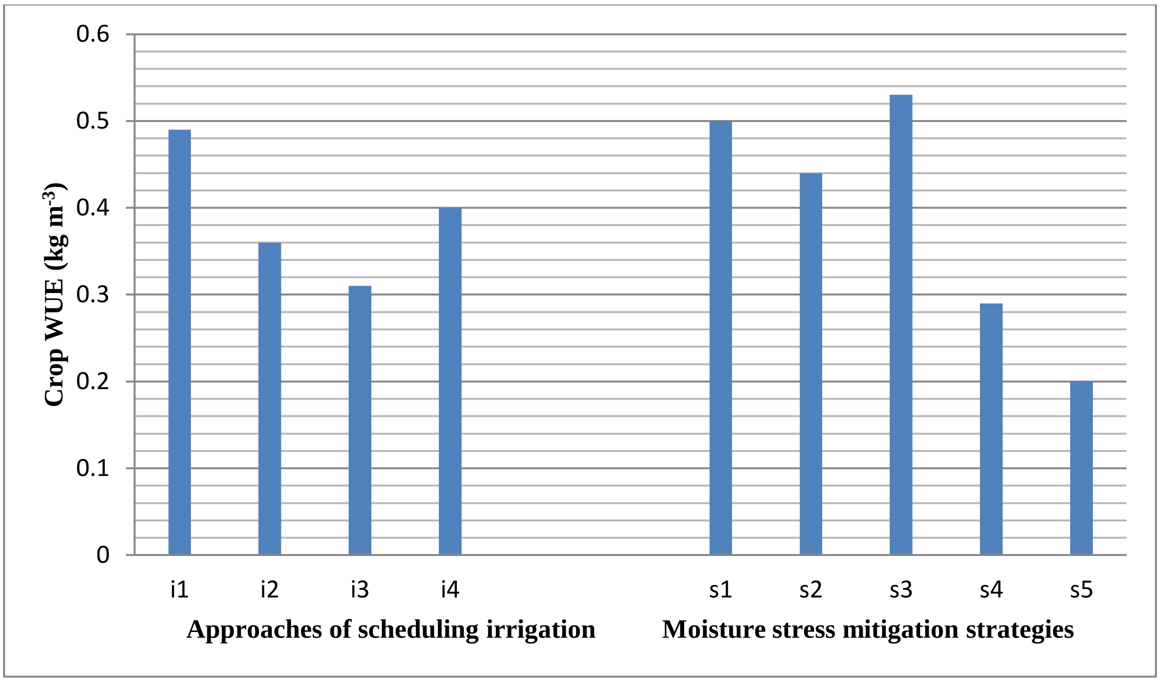

Fig.31. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies on crop WUE, kg m^{-3}

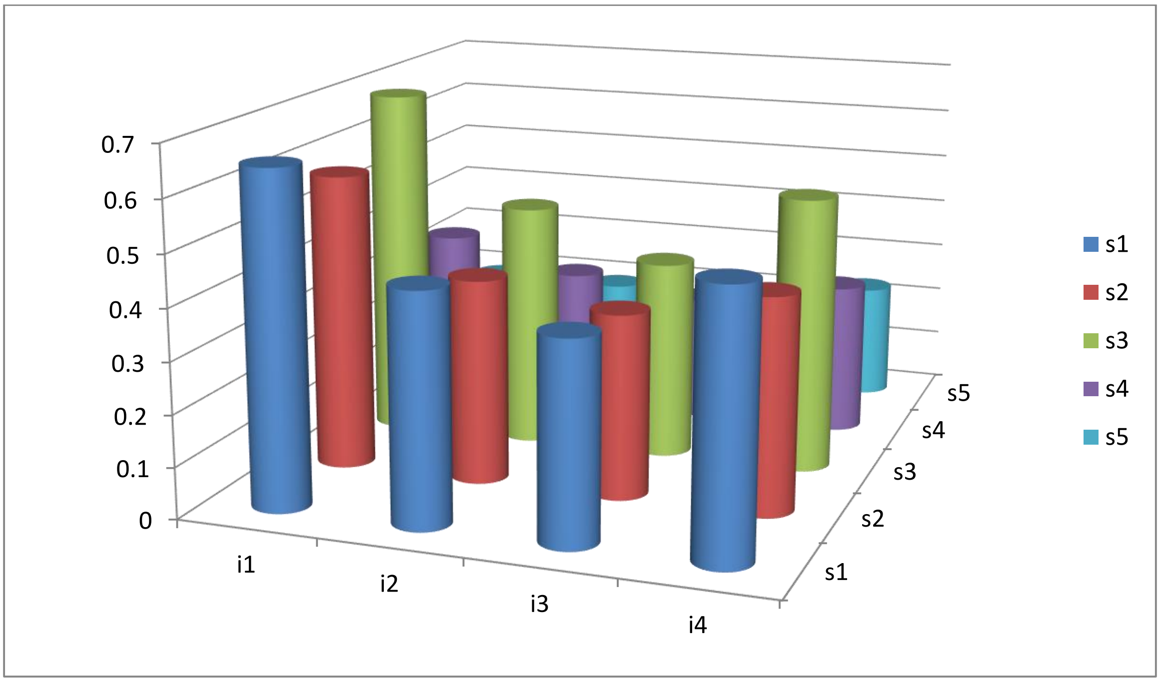

Fig.32. Interaction effect of approaches of scheduling irrigation and moisture stress mitigation strategies on crop WUE, kg m^{-3}

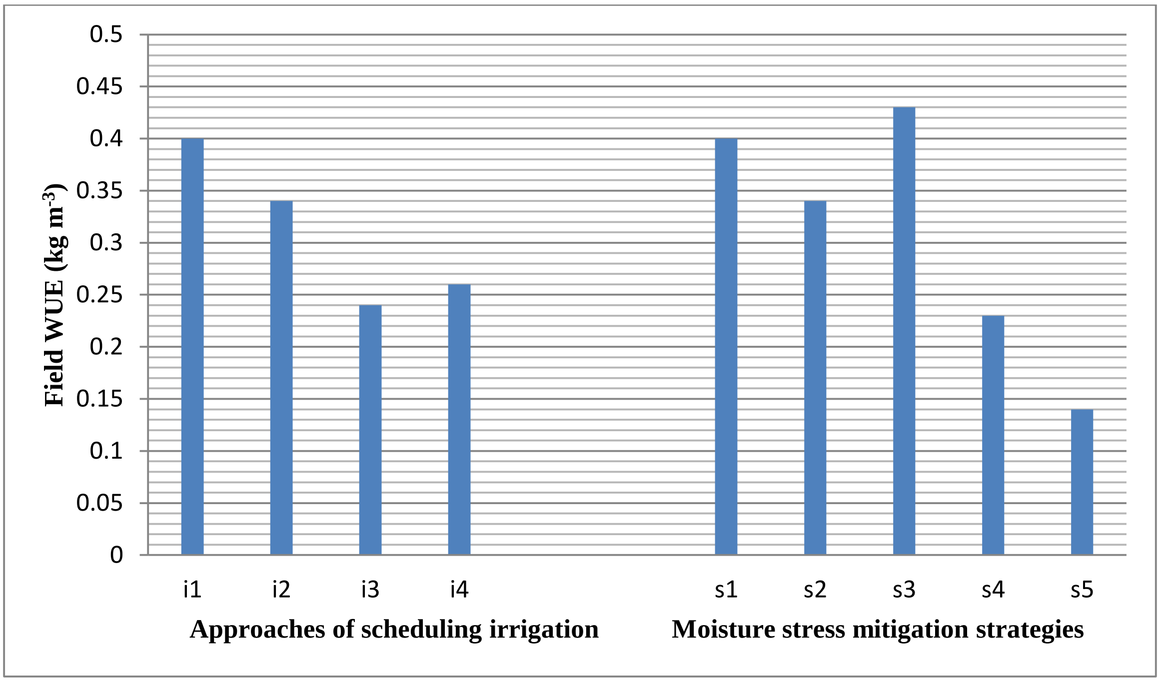

Fig.33. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies on field WUE, kg m^{-3}

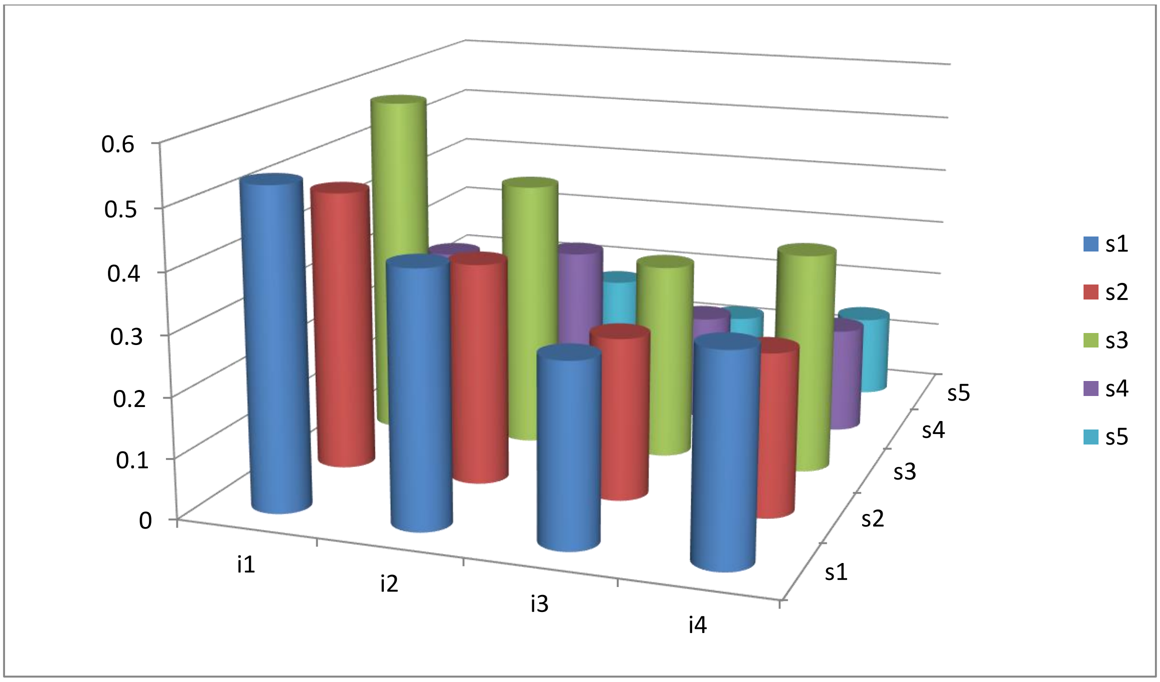

Fig.34. Effect of approaches of scheduling irrigation and moisture stress mitigation strategies on field WUE, kg m^{-3}

highest water use efficiency was observed in the plots treated with hydrogel polymer (field application @ 2.5kg ha^{-1} + seed treatment @ 10 g kg^{-1}), followed by the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1}). The plots treated with PPFM (1%) spray recorded higher water use efficiency than the absolute control plots. The field WUE also followed a similar trend (Fig. 33). It is because of the higher yield in the plots treated with hydrogel polymer, compared to the non-hydrogel treated plots at the same evapotranspiration, which can be considered as the consumptive use by the crop. The hydrophilic polymers improve soil water retention properties, thus enhancing crop productivity. Hydrogel absorbs water after applied irrigation from soil and water which it releases back to the soil as and when the plant demands it and so it feeds the necessary water into the root system of the plant, when water is in short in the soil.

5.2.6 NPK Uptake at Harvest

The straw N uptake and total N uptake was the highest in the plots irrigated at 75% FC and the lowest in the plots irrigated at 100% FC (Table 52) and N uptake by grain was the highest in the plots irrigated at 100% FC and the lowest in the plots irrigated at IW/CPE of 0.8. The higher N uptake by the crop in the plots irrigated to maintain 100% FC maybe because of the higher N content as well as higher grain N content and biomass yield from these plots. The lowest N uptake by straw is recorded from the plots irrigated to maintain 100% FC, because of the lower N content in the straw. The lower N content in straw at higher irrigation levels can be attributed to the fact that the crop N demand at any time of the crop cycle is the result of maximum crop mass and the critical plant N concentration, which is the minimum plant N concentration corresponding to maximum crop mass (Greenwood *et al.*, 1990).

The P uptake by grain was the highest in the plots irrigated at 100% FC and the lowest in plots irrigated at IW/CPE of 0.8. The P uptake by straw reported the highest in plots irrigated at 75% FC and the lowest in plots irrigated at 100% FC. The total P uptake was the highest in plots irrigated to maintain 2 cm depth of water at critical stages of crop growth. The K uptake by grain was significantly highest in the plots irrigated at an IW/CPE and the lowest in plots irrigated to maintain 100% FC.

Among the moisture stress mitigation strategies, the highest N uptake by grain, straw and total uptake was recorded in the treated with hydrogel polymer (seed treatment @ 10 g kg^{-1}), whereas, the highest P uptake by straw and total uptake was recorded the plots treated with hydrogel (field application @ 2.5 kg ha^{-1} + seed treatment @10 g kg^{-1}).The straw and total K uptake also followed a similar trend as P uptake by straw and total uptake.

5.2.7 Soil Analysis

The soil available N and P after the experiment were found to be significantly influenced by the treatments, after the experiment, whereas K and OC content were observed to be non-significant (Table 55 and Table 56).

The available N and P content after the experiment was observed to be significantly higher in the plots irrigated at an IW/CPE of 0.8, followed by the plots irrigated at 75% FC. The lowest N and P content were recorded in the plots irrigated at 100% FC. It is because, water content is an important property of soils, influencing soil solution chemistry and nutrient uptake by plants. Optimum soil moisture facilitates in the plots irrigated at 100% FC facilitates nutrient accumulation in crop which resulted in lower available nutrients in the soil after the experiment. The results are in confirmation with the study by Chaithanya *et al.*, 2017, who reported that the variations in soil moisture significantly governed variations in accumulations of N, P and K in wheat, to the tune of 46.8% in N, 79.9% in P and 78.6% variations in K accumulation.

Among the moisture stress mitigation strategies, a significantly higher N, P and K was observed in the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @ 10 g kg^{-1}), followed by the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1}) and the lowest value was recorded in the absolute control plots. The hydrogel polymer, as they can encapsulate nutrients and adsorb a large amount of water, when applied in the soil hold the nutrients in them, reducing the release of the nutrients to crops and soil.

5.2.8 Pest Incidence

The major pest of the crop was stem borer and was not found to be significantly influenced either by approaches of scheduling irrigation, or the moisture stress mitigation strategies (Table 57).

5.2.9 Economics of Cultivation

The economics of cultivation was worked out in terms of net income and benefit-cost ratio (Table 58). Among the approaches of scheduling irrigation, the highest B:C ratio of 2.20 was observed in the plots irrigated at 100% FC, followed by the plots irrigated to maintain 2 cm depth of water at critical stages of crop growth. The plots irrigated at an IW/CPE ratio of 0.8 recorded the lowest BC ratio of 1.63. In terms of net returns, the highest net returns was generated in the plots irrigated at 100% FC, which recorded a net returns of ₹ 97,407.00 ha^{-1}. Higher grain and straw yield from the plots irrigated at 100% FC has reflected in the monetary returns and hence it can be recommended as an effective approach of scheduling irrigation for a profitable rice cultivation of upland rice. The lower monetary returns obtained from the plots irrigated at IW/CPE of 0.8 and the plots irrigated at 75% FC is due to the reduced yield because of the moisture stress experienced by the crop.

Among the various moisture stress mitigation strategies, the highest B:C ratio of 2.61 was generated from the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @10g kg^{-1}), followed by the plots treated with hydrogel polymer polymer (seed treatment @ 10g kg^{-1}) with a B: C ratio of 2.38. The plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1}) recorded a significantly higher B: C ratio than the plots treated with PPFM (1%) spray. The lowest BC ratio of 1.04 was obtained from the absolute control plots.

The highest net returns of ₹ 1,31,735.00 ha^{-1} was obtained from the plots treated with hydrogel polymer (field application @ 2.5kg ha^{-1} + seed treatment @ 10 g kg^{-1}) which indicates that it serves as an efficient and profitable technology for moisture stress mitigation in rice cultivation under upland conditions. Though the price of hydrogel adds to the expenditure, the higher returns obtained results in a net profit. In the absolute control plots, where there was no adoption of any stress mitigation strategies, the lowest net returns of ₹ 39,655 ha^{-1} was observed.

In the interaction effects, B: C ratio as high as 2.92 and net returns of ₹ 1,58,000.00 ha^{-1} was generated from the treatment combination i_3s_3, in which the plots were irrigated at 100% FC and hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @10g kg^{-1}) was applied, which increased the profit and so is highly recommendable.

7. SUMMARY

The investigation entitled "Irrigation scheduling and water stress mitigation strategies in upland rice (*Oryza sativa* L.)" was carried out as two field experiments in the Instructional Farm, College of Agriculture, Vellayani from 2019 to 2020 to identify a suitable variety and irrigation method for upland rice, to standardize irrigation scheduling and to assess the effect of moisture stress mitigation strategies on the growth, yield and economics of upland rice.

Field experiment I entitled "Identification of suitable variety and standardization of irrigation method**"** was conducted during January 2019 to May 2019. The experiment was laid out in split plot design with five main plot treatment and two sub plot treatments in four replications. The treatments included, $\mathbf{m_1}$: sprinkler irrigation at 100% PE; $\mathbf{m_2}$: sprinkler irrigation at 75% PE; $\mathbf{m_3}$: drip irrigation at 100% PE; $\mathbf{m_4}$: drip irrigation at 75% PE; $\mathbf{m_5}$: hose irrigation (farmer's practice-irrigation given thrice in a week) as main plot treatments and subplot treatments were rice varieties, $\mathbf{v_1}$: Prathyasa; $\mathbf{v_2}$: Uma.

Plant height showed an increasing trend up to harvest stage, irrespective of treatments. The different methods of irrigation were found to significantly influence the growth attributes of the crop. At all the stages, microirrigation was found to be significantly superior compared to that of the conventional method (hose irrigation) of irrigation. The height of the plant was observed to be the highest for sprinkler irrigation at 100% PE, compared to all other treatments at 60 DAS, whereas at 90 DAS and at harvest, it was significantly the highest in plots irrigated using drip at 100% PE, which was on par with the plots irrigated using sprinkler at 100% PE. It was followed by drip irrigation at 100% PE. The hose method of irrigation was found to be inferior in plant height compared to irrigation using microirrigation, at all the stages of the crop growth. Among the varieties, the variety Uma showed an increased plant height compared to the variety Prathyasa at 30 and 60 DAS, whereas at 90 DAS and at harvest, it was significantly higher in the variety Parthyasa. The interaction effects were observed to be non significant at 60, 90 DAS and at harvest, whereas at 30 DAS, it was significantly higher in m_4v_2. The number of tillers at 60, 90 DAS and at harvest was significantly the highest in sprinkler irrigated plots at 100% PE, whereas at 30 DAS, it was observed to be the highest in drip irrigated plots at 100% PE. Among the varieties, it was significantly higher in the variety Uma at 30 DAS, whereas at 60 and 90 DAS and at harvest, it was significantly superior in the variety Prathyasa. The treatment interaction was however observed not to have any significant influence on the number of tillers m^{-2} at any stages of the crop growth. The leaf area index at panicle initiation and the dry matter production at 30, 60, 90 DAS and at harvest were observed to be significantly higher in the sprinkler irrigated plots at 100% PE. Among the varieties, the variety Prathyasa recorded significantly higher value for leaf area index at panicle initiation stage and the dry matter production at 60 DAS, whereas the dry matter production at 90 DAS was significantly superior in the variety Uma.

At all the stages of the crop, irrigation at 100% PE was found to perform better in sprinkler irrigation as well as drip irrigation compared to 75% PE. Under all the irrigation methods, the variety Prathyasa performed better than the variety Uma in terms of all other growth attributes.

The number of panicles m^{-2} was found to be significantly higher in sprinkler irrigation at 100% PE compared to all other treatments. Drip irrigation was found to perform better than hose irrigation with respect to number of panicles m^{-2}. Length of panicle also showed a similar trend, whereas the weight of panicle was found to be the highest in drip irrigation at 100% which was significantly superior compared to all other treatments. Sprinkler irrigation at 100% PE was superior in terms of number of grains $panicle^{-1}$, but was on par with drip irrigation at 100% PE. Test weight of grain was found to be non-significant with respect to methods of irrigation as well as varieties. The grain yield was observed to be the highest in sprinkler irrigation at 100% PE, followed by drip irrigation at 100% PE. Similar trend was observed in case of straw yield as well as biomass yield. The harvest index was observed to be the highest in drip irrigated plots at 100% PE. The treatment combination m_1v_1 recorded the highest grain yield as well as biomass yield, reflecting the suitability of the variety and sprinkler irrigation at 100% PE under upland conditions.

The crop growth rate at the active stage of the crop was observed to be the highest in sprinkler irrigation at 100% PE and the lowest in hose irrigated plots. The relative growth rate was observed to be the highest in sprinkler irrigation at 30-60 DAS, but in all other stages, it was found not to be significant with respect to the methods and levels of irrigation. The net assimilation rate was also influenced by the irrigation methods as well as the levels of irrigation. At 30-60 DAS, at the active growth stage of the crop, the NAR was observed to be the highest in sprinkler irrigation at 100% PE. But at 0-30 DAS, it was the highest in drip irrigated plots at 100% PE and at 60-90 DAS, it was the highest in drip irrigated plots at 75% PE.

The chlorophyll content at 30 DAS, as well as 60 DAS was the highest in sprinkler irrigated plots at 100% PE and at 90 DAS and at harvest, it was the highest in drip irrigated plots at 100% PE. The variety Prathyasa recorded significantly superior chlorophyll content compared to the variety Uma at all the stages. The treatment combination m_1v_1 recorded the highest chlorophyll concentration at 30 and 60 DAS, and at 90 DAS and at harvest, it was significantly higher in m_3v_2 and the lowest in m_5v_2 and m_5v_1 respectively at 30, 60 DAS and 90 DAS and harvest. The highest proline concentration at all the stages of the crop was observed in the plots irrigated using hose method of irrigation and the lowest amount was recorded in sprinkler irrigated plots at 100% PE. Among the varieties, Uma had a significantly higher proline concentration compared to variety Prathyasa. The stomatal count at all stages of the crop was the highest in sprinkler irrigated plots at 100% PE, followed by that of drip irrigated plots at 100% PE and the lowest in plots with hose method of irrigation.

The length-breadth ratio was not found to be significantly influenced by the methods of irrigation as well as varietal differences. However, the protein content was observed to be the highest in the plots irrigated using hose and the lowest protein content was recorded in the sprinkler irrigated plots at 100% PE. The variety Uma recorded higher protein content than the variety Prathyasa. The carbohydrate content in sprinkler and drip irrigated plots at 100% PE, as well as plots irrigated using hose method was on par with each other. The variety Prathyasa had a significantly higher carbohydrate content than the variety Uma.

The soil moisture content at 40, 60 and 80 DAS at 15 cm depth was observed to be the highest in drip irrigated plots at 100% PE and the lowest in plots irrigated using hose. The soil moisture content at 20, 40, 60 and 80 DAS at 30 cm depth was however observed to be the highest in sprinkler irrigated plots at 100% PE and the lowest in drip irrigated plots at 75% PE. The highest RLWC was observed in sprinkler irrigated plots at 100% PE, followed by drip irrigated plots at 100% PE.

A significantly higher consumptive use was observed in plots irrigated using sprinkler at 100% PE. The consumptive use of the sprinkler and drip irrigated plots at 100% PE were on par with each other and the lowest value was observed in the hose irrigated plots. The highest crop water use efficiency among the methods of irrigation was observed in plots irrigated using hose and the lowest value was recorded in the plots irrigated using drip at 100% PE. The field water use efficiency was however significantly the highest in sprinkler irrigated plots at 100% PE and the lowest value was recorded in the plots irrigated using hose. A significantly higher grain water use efficiency was observed in the variety Prathyasa.

The treatments differed significantly in the grain nitrogen uptake, straw nitrogen uptake as well as the total biomass nitrogen uptake. The nitrogen uptake in grain was observed to be the highest in sprinkler irrigation at 100% PE and was on par with drip irrigation at 100% PE, but significantly superior over hose method of irrigation as well as drip irrigation and sprinkler irrigation at 75% PE. The nitrogen uptake in straw was also observed to be significantly the highest in sprinkler irrigation at 100% PE, but was on par with drip irrigation at 100% PE as well as hose method of irrigation. Total biomass uptake showed a similar trend as in grain nitrogen uptake, with the highest value in sprinkler irrigation at 100% and the lowest in hose method of irrigation. A similar trend was observed in the P as well as K uptake, with the highest P and K uptake from the plots irrigated using sprinkler irrigation at 100% PE and the lowest in the plots irrigated using irrigation at 75% PE and hose method of irrigation.

The N content of the soil after experiment was found to be significantly different among the treatments. It was the highest in drip irrigated plots at 75 % PE and the lowest in plots irrigated using hose method. In case of phosphorous, the highest content in soil was observed in drip irrigated plots at 75% PE and the lowest in plots irrigated using hose.

The stem borer attack was observed to be the major pest incidences of the crop and it was significantly influenced by the methods of irrigation as well. It was recorded to be the highest in the plots irrigated using sprinkler at 100% PE, followed by the plots irrigated using sprinkler at 75% PE. The attack was the lowest in the plots irrigated using drip at 75%.

The net returns was observed to be the highest in sprinkler irrigated plots at 100% PE. It was followed by the net returns obtained from drip irrigation at 100% PE, and the lowest net returns was obtained from the plots irrigated using hose. Among the varieties, the variety Prathyasa earned higher net returns compared to the variety Uma. A benefit cost ratio of 2.46 was obtained from the plots irrigated using sprinkler irrigation at 100% PE and the lowest B: C ratio of 1.02 was obtained from hose irrigated plots. The treatment interaction m_1v_1 recorded the highest B: C ratio of 2.67, which was significantly higher over all other treatments.

Field experiment II entitled “Standardization of irrigation scheduling and moisture stress mitigation strategies for upland rice” was conducted during January 2020 to April 2020. The experiment was laid out in split plot design with four main plot treatments and five sub plot treatments in five replications. The main plot treatments included approaches of scheduling irrigation and the treatments were, **i_1**: irrigating the crop at IW/CPE of 0.8; **i_2**: critical growth stage approach (irrigation at seedling, maximum tillering, panicle initiation, flowering and grain filling stages to a depth of 2 cm); **i_3**: irrigation to maintain soil moisture at 100% FC; **i_4**: irrigation to maintain soil moisture at 75% FC. The sub-plot treatments included, **s_1**: field application of hydrogel polymer (2.5 kg ha^{-1}); **s_2**: seed treatment with hydrogel polymer (10 g kg^{-1}); **s_3**: field application of hydrogel polymer + seed treatment of hydrogel polymer; **s_4**: foliar application of PPFM (1%); **s_5**: absolute control plots.

The plant height, number of tillers m^{-2}, leaf area index and dry matter production were observed to be significantly higher in the plots irrigated to maintain 100% FC at all the stages of crop growth which was followed by the plots irrigated to maintain 2 cm depth of water at critical stages of crop growth. A significantly higher value in the growth characters were observed in the plots irrigated to maintain 75% FC compared to the plots irrigated at an IW/CPE of 0.8.

Among the moisture stress mitigation strategies the highest value in the growth characters was recorded in the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @10 g kg^{-1}), followed by the plots in which seed treatment of hydrogel polymer @ 10 g kg^{-1} only was done. The plots in which field application of hydrogel polymer @ 2.5kg ha^{-1} recorded a significantly higher value in the growth attributes compared to the plots sprayed with 1% PPFM spray at panicle initiation stage. The lowest value was recorded in the absolute control plots.

The number of days for 50% flowering was the longest in the plots irrigated to maintain 100% FC, followed by the plots irrigated to maintain 2 cm depth of water at critical stages of crop growth. The lowest value was recorded in the plots irrigated at an IW/CPE of 0.8. The number of panicles m^{-2}, length of panicle, weight of panicle, number of grains $panicle^{-1}$, grain yield, straw yield and harvest index followed a similar trend. The sterility percentage in grain was observed to be the highest in the plots irrigated to maintain 75% FC, followed by the plots irrigated at an IW/CPE of 0.8. The lowest sterility percentage was recorded in the plots irrigated to maintain 100% FC.

Among the moisture stress mitigation strategies, the number of days for 50% flowering was observed to be the longest in the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} +seed treatment @10g kg^{-1}), followed by the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1}). The plots in which seed treatment of hydrogel polymer @ 10g kg^{-1} was done, showed a significantly higher value than the plots in which the crop was sprayed with PPFM (1%) at panicle initiation stage. The lowest value was observed in the absolute control plots. A similar trend was observed in case of the number of panicles m^{-2}, length of panicle, weight of panicle, number of grains per panicle, grain yield, straw yield and harvest index.

The CGR and RGR have been found to be the highest in the plots irrigated to maintain 100% FC, followed by the plots irrigated to maintain 2 cm depth of water at critical stages of crop growth. The plots irrigated to maintain 100 % FC recorded a significantly higher CGR compared to all other treatments at 0-30 and 60-90 DAS. The RGR also recorded the highest in plots irrigated to maintain 100% FC. The NAR was the same in all the treatments at 0-30 DAS, whereas at 30-60, it was the highest in plots irrigated to maintain 75% FC, followed by the plots irrigated at IW/CPE of 0.8 and the lowest value was recorded in the plots irrigated to maintain 100% FC and at 60-90 DAS, it was the highest in the plots irrigated at IW/CPE of 0.8, followed by the plots irrigated to maintain 75% FC and the lowest value was observed in the plots irrigated to maintain 100% FC.

The chlorophyll content at 30, 60 and 90 DAS recorded the highest value in the plots irrigated to maintain 100% FC, followed by the plots irrigated to maintain 2 cm depth of water at critical stages of crop growth and the lowest value was observed in the plots irrigated at an IW/CPE of 0.8. A similar trend was observed in case of stomatal count in leaves also. Whereas in case of proline concentration, the highest value was recorded in the plots irrigated at 0.8 IW/CPE, followed by the plots irrigated to maintain 75% FC and the lowest value was recorded in the plots irrigated to maintain 100% FC.

Among the moisture stress mitigation strategies, the highest CGR, RGR, chlorophyll content and stomatal count were observed to be the highest in the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @ 10 g kg^{-1}), followed by the plots treated with hydrogel (field application @ 2.5kg ha^{-1}). The plots treated with hydrogel polymer (seed treatment @ 10 g kg^{-1}) recorded a significantly higher values than the plots treated with PPFM (1%) and the lowest values were recorded in the absolute control plots.

The length -breadth ratio and the carbohydrate content of the grains was found to be not significantly influenced by the approaches of scheduling irrigation as well as the moisture stress mitigation strategies. In case of protein content, the highest protein content was recorded in the plots irrigated at IW/CPE of 0.8, followed by the plots irrigated to maintain a 75% FC. The least protein content was observed in the plots irrigated to maintain 100% FC.

Among the moisture stress mitigation strategies, the highest protein content was observed in the absolute control plots, followed by the plots treated PPFM (1%) spray at panicle initiation stage. The plots treated with hydrogel polymer (seed treatment @ 10g kg^{-1}) had a higher protein content compared to the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1}),which was on par with the plots treated with hydrogel polymer (field application @ 2.5kg ha^{-1}+ seed treatment @10g kg^{-1}).

At 20, 40, 60 and 80 DAS, the moisture content in the soil was observed to be the highest in the plots irrigated to maintain 100% FC, followed by the plots irrigated to maintain 2 cm depth of irrigation at critical stages of crop growth. The lowest moisture content was observed in the plots irrigated at an IW/CPE of 0.8. Among the moisture stress mitigation strategies, a significantly higher moisture content was observed in the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @ 10g kg^{-1}) and the lowest moisture was observed in the absolute control plots. The consumptive use was the highest in the plots irrigated to maintain 100% FC, followed by the plots irrigated to maintain 2 cm depth of water at critical stages of crop growth and the lowest consumptive use was recorded in the plots irrigated at an IW/CPE of 0.8.

The crop water use efficiency recorded the highest value in the plots irrigated at IW/CPE of 0.8, followed by the plots irrigated to maintain 75% FC. The lowest water use efficiency was observed in the plots irrigated to maintain 100% FC. Among the moisture stress mitigation strategies, the highest water use efficiency was observed in the plots treated with hydrogel polymer (field application @ 2.5kg ha^{-1} + seed treatment @ 10 g kg^{-1}), followed by the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1}). The plots treated with PPFM (1%) spray recorded higher water use efficiency than the absolute control plots. The field WUE also followed a similar trend.

The straw N uptake and total biomass N uptake was the highest in the plots irrigated to maintain 75% FC and the lowest in the plots irrigated to maintain 100% FC and the N uptake by grain was the highest in the plots irrigated to maintain 100% FC and the lowest in the plots irrigated at IW/CPE of 0.8. The P uptake by grain was the highest in the plots irrigated to maintain 100% FC and the lowest in plots irrigated at IW/CPE of 0.8. The P uptake by straw reported the highest in plots irrigated to maintain 75% FC and the lowest in plots irrigated to maintain 100% FC. The biomass P uptake was the highest in plots irrigated to maintain 2 cm depth of water at critical stages of crop growth. The K uptake by grain and biomass was significantly highest in the plots irrigated at an IW/CPE and the lowest in plots irrigated to maintain 100% FC.

Among the moisture stress mitigation strategies, the highest N uptake by grain, straw and total biomass was recorded in the treated with hydrogel polymer (seed treatment @ 10 g kg^{-1}), whereas, the highest P uptake by straw and total biomass was recorded the plots treated with hydrogel (field application @ 2.5 kg ha^{-1} + seed treatment @10 g kg^{-1}).The straw and total biomass K uptake also followed a similar trend as P uptake by straw and total biomass.

The soil available N and P after the experiment were found to be significantly influenced by the treatments, after the experiment, whereas K and OC content were observed to be non-significant. The available N and P content after the experiment was observed to be significantly higher in the plots irrigated at an IW/CPE of 0.8, followed by the plots irrigated to maintain 75% FC. The lowest N and P content were recorded in the plots irrigated to maintain 100% FC.

Among the moisture stress mitigation strategies, a significantly higher N, P and K was observed in the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @ 10 g kg^{-1}), followed by the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1}) and the lowest value was recorded in the absolute control plots.

Among the approaches of scheduling irrigation, the highest B: C ratio of 2.20 was observed in the plots irrigated to maintain 100% FC, followed by the plots irrigated to maintain 2 cm depth of water at critical stages of crop growth. The plots irrigated at an IW/CPE ratio of 0.8 recorded the lowest B: C ratio of 1.63. In terms of net returns, the highest net returns was generated in the plots irrigated to maintain 100% FC, which recorded a net returns of ₹ 97,407.00 ha^{-1}. Among the various moisture stress mitigation strategies, the highest B: C ratio of 2.61 was generated from the plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @10g kg^{-1}), followed by the plots treated with hydrogel polymer (seed treatment @ 10g kg^{-1}) with a B: C ratio of 2.38. The plots treated with hydrogel polymer (field application @ 2.5 kg ha^{-1}) recorded a significantly higher B: C ratio than the plots treated with PPFM (1%) spray. The lowest BC ratio of 1.04 was obtained from the absolute control plots.

The highest net returns of ₹ 1,31,735.00 ha^{-1} was obtained from the plots treated with hydrogel polymer (field application @ 2.5kg ha^{-1} + seed treatment @ 10 g kg^{-1}) which indicates that it serves as an efficient and profitable technology for moisture stress mitigation in rice cultivation under upland conditions. In the interaction effects, B: C ratio as high as 2.92 and net returns of ₹ 1,58,000.00 ha^{-1} was generated from the treatment combination i_3s_3, in which the plots were irrigated to maintain 100% FC and hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @10g kg^{-1}) was applied, which increased the profit and so is highly recommendable.

The results of the study revealed the suitability of the variety Prathyasa, irrigated using sprinkler irrigation at 100% PE for higher yield and monetary returns under upland conditions. The higher grain yield and monetary benefits also reflected the effectiveness of irrigating upland rice to maintain 100 % FC as an effective approach of scheduling irrigation, with the application of hydrogel polymer (soil incorporation @ 2.5kg ha^{-1} + seed treatment @10 g kg^{-1}) as the most suitable moisture stress mitigation strategy for enhanced yield and economic benefits in upland rice cultivation.

Future line of work

- The results of the study conducted during summer season can be verified in *kharif* season.
- Increased dose of application of hydrogel polymer gel can be experimented.
- Effect of PPFM application can be studied at more number of stages of the crop.

6. REFERENCES

Abobatta, W. 2018. Impact of hydrogel polymer in agricultural sector. *Adv. Agr. Environ. Sci*. 1(2): 59-64.

Abrol, I.P. and Sharma, R.R. 1990. Efficient water management is crucial for achieving self sufficiency in food. *Indian farming.* 40 (7): 25-27.

Acharyna, M.S., Singh, J., Gupta, A.P., and Singh, A.K. 1993. Sprinkler and drip irrigation systems. In: Lisa, A. (ed.), *Central Board of Irrigation and Power*, (2^{nd} Ed.).New Delhi, pp. 74-76.

Agaba, H., Orikiriza, L.J.B., Obua, J., and Kabasa, J.D. 2011. Hydrogel amendment to sandy soil reduces irrigation frequency and improves the biomass *of Agrostis stolonifera*. *Agri. Sci.* 2(4): 544-550.

Agrawal, M.C. and Agrawal, R.P. 1977. Evaluation of sprinkler irrigation performance in farmers field. A paper presented at the XV Annual Convention of the ISAE held at College of Agriculture, Pune.

Ahmed, A.T., Khalil, K.W. Ghany, F.A., and Awadalla, S.Y. 1996. Ameliorating the properties of virgin sandy soils and its impact on wheat production. *Desert Inst. Bull*. 46: 39-339.

Ahmed, S.S. and Fahmy, A.H. 2019. Applications of natural polysaccharide polymers to overcome water scarcity on the yield and quality of tomato fruits. *J. Soil Sci. Agric. Eng*. 10 (4): 199-208.

Akca, Y. and Samsunlu, E. 2015. The effect of salt stress on growth, chlorophyll content, proline and nutrient accumulation, and K/NA ratio in walnut. *Pak. J. Bot*. 24(5): 034-039.

Akhter, J., Mahmood, K., Malik, K.A., Mardan, A., Ahmad, M., and Iqbal, M.M. 2004. Effects of hydrogel amendment on water storage of sandy loam and loam soils and seedling growth of barley, wheat and chickpea. *Plant Soil Environ*. *50*: 463–469.

Akinbile, O.C. 2010. Behavioural pattern of upland rice agronomic parameters to variable water supply in Nigeria. *J. Plant Breed. Crop Sci.* 2(4): 073-080.

Alekhya, G. 2020. Cropping geometry and *in situ* soil moisture conservation practices in upland rice. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur,137 p.

Aliaga, M.J.R., Galarza, S.L., and Maroto, B.J.V. 1986. Rice cultivation with intermittent irrigation. *Agric. Spain 55:36-38.*

Anderson, G.C., Fillery, I.R.P., Dolling, P.J., and Asseng, S. 1998. Nitrogen and water flows for pasture-ley and lupin-wheat rotations in deep sands. Nitrogen mineralisation and utilisation. *Aust. J. Agric. Res.* 49:329-343.

Anning, D.K., Ofori, J., and Narh, S. 2019. Effect of irrigation management methods on growth, grain yield and water productivity of three lowland rice (*Oryza sativa* L.) varieties. *West Afr. J. Appl .Ecol.* 26(2): 93-104.

Anupama, S., Singh, M. C., Kumar, B. S., and Kumar, P.A. 2005. Performance of new super absorbent polymer on seedling and post planting growth and water use pattern of Chrysanthemum under controlled environment. *Acta Horticulturae*. 618: 215–224.

Arnon, D. 1949. Copper enzymes isolated chloroplasts, polyphenoloxidase in *Beta vulgaris. Plant Physiol.* 24:1-15.

Arsa, I.G.B., Ariffin, G., Aini, N., and Lalel, H.J.D. 2016. Evaluation of grain yield and aroma of upland rice (pare wangi var.) as response to soil moisture and salinity. *Curr. Agric. Res. J.* 4 (1): 03-08.

Awal, M.A., and Ikeda, T. 2002. Recovery strategy following the imposition of episodic soil moisture deficit in stands of peanut (*Arachis hypogaea* L.). *J. Agro. Crop Sci.* 188: 185 –192.

Aydinsakir, K., Erdal, S., Buyuktas, D., Bastug, R., and Toker, R. 2013. The influence of regular deficit irrigation applications on water use, yield, and quality components of two corn (*Zea mays* L.) genotypes. *Agric. Water Manag*. 128:65-71.

Badel, M., Sarobol, E., and Degevione, A. 2013. Impact of soil moisture depletion levels at different growth stages on growth, evapotranspiration and biomass yield of bread wheat grown under semi-arid conditions. *Sci. Eng. Technol. Res*. 1(3):122-125.

Bakht, J.M., Shafi, M., Yousef., and Aman khan, M. 2010. Effect of irrigation on physiology and yield of sunflower hybrids. *Pak. J. Bot*. 42(2): 1317-1326.

Bansal, R., Sharma, N., Soman, P., Singh, S., Bhardwaj, A.K Pandiaraj, T., and Bhardwaj, R.K. 2018. On-Farm drip irrigation in rice for higher productivity and profitability in Haryana, India. *Int. J. Curr. Microbiol. App. Sci. 7*(2): 506-512.

Biswas, C.R. and Bhattacharya, B. 1987. Water management for coastal saline soils. *Int. Rice. Res. News Let. 12:38.*

Blackman, S.A., Obendorf, R.L., and Leopold, A.C. 1995. Maturation proteins and sugars in desiccation tolerance of developing soybean seeds. *Plant Physiol.* 100: 225-230.

Blake, G.R. 1965. Bulk density core method. Methods of soil analysis. Part 1. *Am. Soc. Agron*. Madison, USA, pp.375-376.

Blokhina, O. E., Virolainen, K.V., and Fagersted, T. 2003. Anti-oxidative damage and oxygen deprivation stress. *Ann. Bot.* 9:179-194.

Borivoj, S., Rak, L., and Bubenikova, I. 2006. The effect of hydroabsorbent on selected soil biological and biochemical characteristics and its possible use in revitalization. *Ecologia*. 25:422–429.

Borrell, A., Garside, A., and Shu, F.K. 1997. Improving efficiency of water for irrigated rice in a semi- arid tropical environment. *Field Crops Res*. 52:231–248.

Bouman, B.A.M., Peng, S., Castaneda, A.R., and Visperas, R.M. 2005. Yield and water use of irrigated tropical aerobic systems. *Agric. Water Manage*. 74: 87–105.

Bouman, B.A.M., Yang, X., Wang, H.Q., Wang, Z., Zhao, J., and Chen, B. 2006. Performance of aerobic rice varieties under irrigated conditions in North China. *Field Crops Res*. 97: 53–65.

Bouyoucos, C.J. 1962. Hydrometer method improved for making particle size analysis of soil. *J. Agron*. 54(3): 464-465.

Bredenkamp, G. 2000. Improved retention of macronutrients/reduced leaching [e-book]. University of Pretoria. Available: http://www.silvix.co.za/aquasoil. htm.

Cabangon, R. J., Tuong, T.P., Castillo, E.G., and Bao, L.X. 2004. Effect of irrigation method and N-fertilizer management on rice yield, water productivity and nutrient-use efficiencies in typical lowland rice conditions in China. *Paddy Water Environ*. 2: 195-206.

Cai, Y.X., Wang, W., and Zhu, Q.S. 2007. Effects of water stress on nutrient quality and accumulation of protein in rice grains. *Chin. J. Plant Ecol.* 31: 536.

Carillo, P. and Gibbon, A. 2011. Nitrogen metabolism in durum wheat under salinity: accumulation of proline and glycine betaine. *Funct. Plant Biol.* 35: 412–426.

Cetin, O. and Bilgel, L. 2002. Effects of different irrigation methods on shedding and yield of cotton. *Agric. Water Manage*. 54: 1-15.

Cetin, O., Yildirim, O., Uygan, D., and Boyaci, H. 2002. Irrigation Scheduling of drip-irrigated tomatoes using class A pan evaporation. *Turk. J. Agric. Forest*. 26: 171-178.

Chaitanya, K.V., Rasineni, G.K., and Reddy, A.R. 2009. Biochemical responses to drought stress in mulberry (*Morus alba* L.): Evaluation of proline, glycine betain and abscisic acid accumulation in five cultivar. *Acta Physiol. Plant.* 31(3): 437-443.

Chaithanya, K.A., Patra, S.K., Bhattacharya, K., and Patra, P.K. 2017. Changes in Plant Availability and Uptake of NPK along with Soil Moisture. *Int. J. Pure App. Biosci*. 5 (4): 1671-1676.

Chen, S., Shao, J., Wang, R., Zhang, X., and Jiang, J., 2007. Enhancement of hydrogel on salt resistance of *Populus popularis* and its mechanism. *J. Beijing For. Univ*. 29: 79-84.

Choudhury, B.U., Bouman, B.A.M., and Singh, A.K. 2007. Yield and water productivity of rice–wheat on raised beds at New Delhi, India. *Field Crops Res*. 100: 229–239.

Clifford, S.C., Arndt, S.K., Corlett, J.E., Joshi, S., Sankhla, N., Popp, M., and Jones, H.G. 1998. The role of solute accumulation, osmotic adjustment and changes in cell wall elasticity in drought tolerance in *Ziziphus mauritiana* (Lamk.). *J. Exp. Botany*. 49(323): 967-977.

Cominelli, E., Galbiati, M., Vavasseur, A., Conti, L., Sala, T., Vuysteke, M., Leonhardt, N., Dellaporta, S., and Tonelli, C. 2005. A guard-cell-specific myb transcription factor regulates stomatal movements and plant drought tolerance. *Curr. Biol*. 15: 1196–1200.

Condon, A.G. and Hall, A. 2004. Breeding for higher water use efficiency. *J. Exp. Bot.* 55(407): 2447-2460.

Datta, D.K. 1973. Field studies on sprinkler irrigation. M. Tech thesis, Agricultural Engineering Department, I.I.T., Kharagpur, West Bengal, p 223.

Donald, C.M. and Hamblin, J. 1976. Biological yield and harvest index of cereals as agronomic and plant breeding criteria. *Adv. Agron*. 28: 361-405.

Dong, B., Molden, D., Loeve, R., Li, Y.H., Chen, C.D., and Wang, J. Z. 2004. Farm level practices and water productivity in Zanghe irrigation system. *Paddy Water Environ.* 2: 217– 226.

Dourado, M.N., Neves, A.A., Santos, D.S., and Araujo, W.L. 2015. Biotechnological and agronomic potential of endophytic pink - pigmented methylotrophic *Methylobacterium* spp. *Biomed. Res. Int.* 114: 909 - 916.

Egli, D.B. 1998. *Seed biology and the yield of grain crops*. Cambridg Univ. Press, Wallingford, UK, p 178.

Eissa, M.A. and Negim, O.E. 2018. Nutrients uptake and water use efficiency of drip irrigated maize under deficit irrigation. *J. Plant. Nutr.* 42(1): 79-88.

Ekanayake, I.J., De Datta, S.K., and Steponkus, P.L. 1989. Spikelet sterility and flowering response of rice to water stress at anthesis. *Ann. Botany,* 63(2): 257-264.

Ertek A., and Kara, B. 2013.Yield and quality of sweet corn under deficit irrigation. *Agric. Water Manage*. 129:138-144.

Esmailian, Y., Ghanbari, A., Babaeian, M., and Tavassoli, A. 2011. Influence of organic and inorganic fertilizers and waste water irrigation on yield and quality traits of corn. *Am. Eurasian J. Agric. Environ. Sci.* 10(4): 658- 666.

Evans, L. T. 1996. *Crop evolution, adaptation and yield.* Cambridge Univ. Press, UK, 500 p.

Farhad, W., Cheema, M.A., Saleem, M.F, Radovich, T., Abbas, F., Hammad, H.M., and Wahid, M.A. 2013. Yield and quality response of maize hybrids to composted poultry manure at three irrigation levels. *Int. J. Agric. Biol*. 15: 181-190.

Feibert, E.B.G., Shock, C.C., and Saunders, L.D. 1998. Nitrogen fertilizer requirements of potatoes using carefully scheduled sprinkler irrigation. *Hort. Sci*. 32: 262-265.

Ferguson, J.A. and Gilmore, J.T. 1977. Centre pivot sprinkler irrigation of rice. *Arkansas Farm Res.*12: 20-24.

Frantz, J.M., Locke, J.C., Pitchay, D.S., and Krause, C.R. 2005. Actual performance versus theoretical advantages of polyacrylamide hydrogel throughout bedding plant production. *Hort. Sci.* 27: 973-74.

Gagandeep, P. and Gandhi, N. 2015. Effect of Different Varieties of Basmati Rice on their Phenological and Yield Contributing Characters. *J. Acad. Ind. Res*. 3(9): 450–452.

Garba, A.A., Mahmoud, B.A., Adamu, Y., and Ibrahim, U. 2013. Effect of variety, seed rate and row spacing on the growth and yield of rice in Bauchi, Nigeria. *Afr. J. Food Agric. Nutr. Dev*. 13(4): 8155-8166.

Getachew, M. and Birhan, T. 2015. Growth and Yield of Rice (*Oryza sativa* L.*)* as affected by Time and Ratio of Nitrogen Application at Jimma, South-West Ethiopia. *Int. J. Agric. Innovations. Res.* 4(1): 2319-1473.

Gleick, P. H. 2002. Soft water paths. *Nature*. 418: 373

Gomez, K.A. 1972. *Techniques of field experiments with rice.* International Rice Research Institute, Los Banos, Philippines, 633 p.

Greenwood, D.J., Lemaire, G., Goose, G., Cruz, P., Draycott, A., and Neetson, J.J. 1990. Decline in percentage of N of C_3 and C_4 crops with increasing plant mass. *Ann. Bot*. 66: 425-436.

Gudesblat, G.E., Iusem, N.D., and Morris, P.C. 2007. Guard cell-specific inhibition of Arabidopsis MPK3 expression causes abnormal stomatal responses to abscisic acid and hydrogen peroxide. *New Phytol.* 173: 713–721.

Gurfel, M., Baccouri, O., Boujnah, D., and Chaibi,W. 2009. Impacts of water stress on gas exchange, water relations, chlorophyll content and leaf structure in the two main Tunisian olive (*Olea europaea* L.) cultivars. *Sci. Hortic*. 119(3): 257-263.

Hajihosniasl, N., Rushdie, M., Ghaffari, M., and Alizadeh, A. 2007. The effect of drought stress and leaf cutting on growth index of sunflower. *J. Res. Agron*.1: 27-31.

Hamoud, Y.A., Wang, Z., Guo, X., Shaghalh, H., Sheteiwy, M., Chen, S., Qiu, R., and Elbashier, M.A. 2019. Effect of Irrigation Regimes and Soil Texture on the Potassium Utilization Efficiency of Rice. *Agronomy.* [e-journal] 9(2). Available:100 https://doi.org/10.3390/agronomy9020100/vol9/issue2/index /html/.EISSN 2073-4395 [20 February 2019].

Hardy, O. A.A., and Shafi, A.M. 2009. Physio-bio-chemical properties of the sandy soil conditioned with acrylamide hydrogels after cucumber plantation. *Aust. J.Basic Appl. Sci.* 3: 3145-51

Harish, M.N., Choudhary, A.K., Singh, Y.V., and Pooniya, V. 2017. Effect of promising rice (Oryza sativa L.) varieties and nutrient management practices on growth, development and crop productivity in Eastern Himalayas. *Ann. Agric. Res.* 38(4): 375-384.

Hassan, S.F., Hameed, K.A., Karim H.A., Ethafa., Kadim, A.N., and Hassan, Y.H. 2015. response of three rice cultivars to the intermittent irrigation in Southern Iraq. *Int. J. Appl. Agric. Sci.* 1(2): 36-41.

Hla A K. and Scherer T.F. 2003. *Introduction to micro-irrigation.* North Dakota State University Extension Service, Fargo, N.D., USA, 1243p. Available: *h*ttps://library.ndsu.edu/ir/bitstream/handle/10365/5108/ae1243.pdf *[14March 2003]*.

Huang, D.F., Xil, L., Wang, Z.Q., Liu, L.J., and Yang, J.C . 2008. Effects of irrigation regimes during grain filling on grain quality and concentration and distribution of cadmium in different organs of rice. *Acta Agro. Sin*. 34: 456-464.

Hüttermann, A., Zommorodi, M., and Reise, K. 1999. Addition of hydrogels to soil for prolonging the survival of *Pinus halepensis* seedlings subjected to drought. *Soil Tillage Res*. 50 (3): 295-304.

INCID. 1998. Annual Report 1997-1998. Indian National Committee on Irrigation and Drainage, New Delhi, 94p.

Ingram, D.L. and Yeager, T.H. 1987. Effects of irrigation frequency and a water-absorbing polymer amended on *Ligustrum* growth and moisture retention by a container medium. *J. Environ. Hort*. *5*: 19–21.

Islam, M.R., Hu, Y., Mao, S., Jia, P., Eneji, A.E., and Xue, X. 2011. Effects of water saving superabsorbent polymer on antioxidant enzyme activities and lipid peroxidation in corn (*Zea mays* L.) under drought stress. *J. Sci. Food Agric*. 91: 813–819.

Jabasingh, C. and Saravana, B.S. 2013. Proline Content of *Oryza sativa* L. under water stress. *J. Acad. Ind. Res.* 2(7): 442-445.

Jackson, M.L. 1973. *Soil Chemical Analysis* (2nd Ed.). Prentice Hall of India (Pvt) Ltd, New Delhi, 498p.

Jadhav, A.S., Dahiphale, V.V., Gunjkar, M.U., and Dahiphale, A.V. 2000. Response of upland Basmati rice to irrigation application on vertisols. *J. Maharashtra Agric. Univ.* 24: 339-340.

Jadhav, A.S., Dhoble, M.V., and Chavan, D.A. 2003. Effect of irrigation and nitrogen on yield and quality of Basmati rice. *J. Maharashtra Agric. Univ.* 28: 187-188.

Jahan, M.S., Nozulaidi, M.B.N., Moneruzzaman, M.K., Ainun, A., and Husna, N. 2014. Control of plant growth and water loss by a lack of light-harvesting complexes in photosystem-II in *Arabidopsis thaliana ch1-1* mutant. *Acta Physiol . Plant*. 36: 1627-1635.

Jasbir, K. and Kumar, V.K. 2015. Influence of nitrogen levels, irrigation regimes and planting methods on growth attributes and yield of spring maize. *Agri. Res. J.* 52(1): 13-18.

Jury , W.A, and Vaux, H.J. 2007. The emerging global water crisis: managing scarcity and conflict between water users. *Adv. Agron*. 95: 1-76.

Kachhadiya, S.P., Chovatia, P.K., Jadav, K.V., and Sanandia, S.T. 2010. Effect of irrigation, mulches and antitranspirants on yield, quality and economics of summer pearl millet. *Int. J. Agric. Sci. 6(1): 278-282.*

Kanber, R., Tekinel, O., Onder, S., and Koksal, H. 1993. Comparison of irrigation length of cotton under Cukurova climatic conditions. *Turk. J. Agric. Forest.* 18: 81-86.

Karasu, A., Kuscu, H. and Mehmet, O. 2015. Yield and economic return response of silage maize to different levels of irrigation water in a sub-humid zone. *Zemdirbiste Agric.* 102(3): 313-318.

Kate, Y., Kamoshita, A., Yamagishi, J., and Abe, J. 2015. Growth of Three Rice (*Oryza sativa* L.) Cultivars under Upland Conditions with Different Levels of Water Supply. *Plant Prod . Sci.* 9 (4): 422-434.

KAU (Kerala Agricultural University). 2016. *Package of Practices Recommendations: Crops* (15th Ed.) Kerala Agricultural University, Thrissur, 380p.

Khadem, S.A., Galavi, M., Ramrodi, M., Mousavi, S.R., Rousta, M.J., and Moghadam, R.P. 2010. Effect of animal manure and super absorbent polymer on corn leaf relative water content, cell membrane stability and leaf chlorophyll content under dry condition. *Aust. J. Crop Sci.* 4: 642-647.

Khairi, M., Noulaidi, M., Afifah, A., and Jahan, M.S. 2015. Effect of various water regimes on rice production in lowland irrigation. *Aust . J. Crop. Sci*. 9(2): 153-159.

Kirda, C. and Kanber, R. 1999. Water, no longer a plentiful resource, should be used sparingly in irrigated agriculture. In: Kirda, C., Moutonnet, P., Hera, C., and Nielsen, D.R. (eds), *Crop yield response to deficit irrigation*. Kluwer Academic Publishers, Dordrecht, The Netherlands, 111 p.

Kobata, T. and Moriwaki, N. 1990. Grain Growth Rate as a Function of drymatter production rate: An experiment with two rice cultivars under different radiation environments. *Jap. J. Crop Sci.* 59(1):1-7.

Kobata, T. and Takami, S. 1986. The effects of water stress on the grain filling in rice. *Jap. J. Crop Sci*.48: 75–81.

Kooij, A., Zwarteveen, M., Boesveld, H., and Kuper, M. 2013. The efficiency of drip irrigation unpacked. *Agric. Water Manage.* 123: 103-110.

Koupaei, A.J and Jafar, A.K. 2006. Effects of a hydrophilic polymer on the field performance of an ornamental plant (*Cupressus arionica*) under reduced irrigation regimes. *Iran. Polym. J.* 15(9):715-725.

Koupei, A.J., Mesforoush, M., and Sohrab, F. 2004. Effect of super absorbent polymers on soil hydraulic properties. In: *Proceedings of 8th national conference on hydraulic engineering*. n.d. Cold Coast, Australia. pp.1-12.

Kramer, P.J. 1988. Measurement of plant water status: Historical perspectives and current concerns. *Irrig. Sci.* 9: 275–287.

Kumar, J., Katre, P., and Kumar, B. 2017. Effect of different irrigation methods on yield attributes and economics of chickpea and coriander intercropping in *Vertisol* of Chhattisgarh plains. *Int. J. Chem. Stud.* 5(4): 695-698.

Kumar, J.L.G. and Sensba, T. 2008. Yield, irrigation production efficiency and economic return of broccoli (*Brassica oleracea* var. italica) under different irrigation methods and schedules. *J. Environ. Res. Dev*. 2 (4): 513-522.

Kumar, R., Trivedi, H., Yadav, R., Das, B.. and Bist, A.S. 2016. Effect of drip irrigation on yield and water use efficiency on Brinjal (*Solanum melongena*) cv. Pant samrat. *Int. J. Eng. Sci. Res. Technol.* 5(10): 7-17.

Kundu, D.K., Neue, H.U.. and Singh, R. 1998. Comparative effects of flooding and sprinkler irrigation on growth and mineral composition of rice in an alfisol. In: Anup, D. (ed.), *Proceedings of the National Seminar on Micro- Irrigation Research in India: Status and Perspective for the 21st Century*, 27-28 July 1998, Bhubaneswar, pp 123-124.

Lakmini, W.G.D., Nainanayake, N.P.A.D., and De Costa, W.A.J.M. 2006. Biochemical changes of four different coconut (*cocos nucifera* L.) forms under moisture stress condition. *J. Agri. Sci.* 2(3): 1-7.

Lawry, O.H, Rosbrough, N.J., Farr, A.L., and Randall, R.J. 1951. Protein measurement with the folin phenol reagent. *J. Biol. Chem. 193:* 265.

Lee, S.P., Lee, W.H., Choi, K.B., Choi, S.K., Youn, Y.S., Kim, R.H., Lee, K.S., and Choi, D.U. 1985. Studies on the drought status of paddy rice and feasible dry seeded rice cultural practices for the area in Gyeonbug, Korea. Research Reports on the Rural Development Admininstration. *Crops.* 27(2): 77-85.

Lejay, L., Tillard, P., Lepetit, M., Olive, F.D., Filleur, S., Daniel, F., and Gojon, A. 1999. Molecular and functional regulation of two nitrate uptake systems by N- and C-status of Arabidopsis plants. *Plant J*. 18: 509-519.

Lemaire, G. and Millard, P. 1999. An ecophysiological approach to modelling resources fluxes in competing plants*. J. Exp. Bot.* 50: 15-28.

Lemaire, G. and Salette, J. 1984. Relation entre dynamique de croissanceet dynamique de prelenement d'azote par un pueplement de graminees fourageres. 1-Etude de I'effet dumilieu. *Agronomie.* 4:423-430.

Lenka, D. and Garnayak, L.M. 1991. Effect of weather situation and moisture stress on growth and development of upland rice in oxisols of Bhubaneshwar. Indian *J. Agric. Sci*. 61(12): 865-871.

Li, Y. and Barker, R. 2001. Increasing water productivity for paddy irrigation in China. *Paddy Water Environ*. 2, 187–193.

Liao, M.T., Fillery, I.R.P., and Palta, J.A. 2004. Early vigorous growth is a major factor influencing nitrogen uptake in wheat. *Funct. Plant Biol*.31:121-129.

Lorens, G.F., Bennett, J.M., and Loggale, L.B.1987. Differences in drought resistance between two corn hybrids and Component analysis and growth rates. *Agron. J*. 79: 808-813.

Lu, J., Ookawa, T. and Hirasawa, T.2000 The effects of irrigation regimes on the water use, dry matter production and physiological responses of paddy rice. *Plant Soil.* 223(1): 209–218.

Madhaiyan, M., Poonguzhali, S., Senthilkumar, M., Seshadri, S., Chung, H., Yang, J., and Sundaram, S. 2004. Growth promotion and induction of systemic resistance in rice cultivar Co-47 (*Oryza sativa* L.) by *Methylobacterium* spp. *Bot. Bull. Aca. Sin*. 45: 315 -324.

Madramootoo, C.A. and Rigby, M. 1991. Effects of trickle irrigation on the growth sunscald of bell peppers (*Capsicum annuum* L.) in southern Quebec. *Agric. Water Manage*. 19(2):181-189.

Magalhaes, G.E.W., Rodrigues, F.C., Silva, F., and Rocha, A.N.F. 1987. Plant growth and nutrient uptake in hydrophilic gel treated soil. *Commun. Soil Sci. Plant Anal.* 18: 1469-1478.

Maheswari, L.S.J., Maragatham, N., and G. James Martin. 2008. Relatively simple irrigation scheduling and nitrogen application enhances the productivity of aerobic rice. *Am. J. plant physiol. 2: 261-268.*

Mahmood, N. and Ahmad, R.N. 2005. Determination of water requirements and response of wheat to irrigation at different soil moisture depletion levels. *Int. J. Agric. Biol.* 7(5): 812-815.

Mandal, K.G., Kundu, D.K., Thakur, A.K., Kannan, K., Brahmanand, P.S., and Kumar, A. 2013. Aerobic rice response to irrigation regimes and fertilizer nitrogen rates. *J. Food Agric. Environ.* 11(3): 1148–1153.

Mandal, K.G., Thakur, A.K., and Ambast, S.K. 2019. Current rice farming, water resources and micro-irrigation. *Curr. Sci*. 116: 568-576.

Mangold, J.M. and Sheley, R.L. 2007. Effects of soil texture, watering frequency, and a hydrogel on the emergence and survival of coated and uncoated crested wheatgrass seeds. *Ecol. Rest* 25: 6-11.

Matsushima, S. and Wada, G. 1958. Analysis of developmental factors determining yield and its application to yield prediction and culture improvement of lowland rice: 48. *Proc. Crop Sci. Soc. Jpn., 27:201-203.*

McCauley, G.N. 1990. Sprinkler vs. flood irrigation in traditional rice production regions of southeast Texas. *Agron. J.* 82: 677–683.

Medley, J. and Wilson, L.T. 2005. The use of sub-surface drip irrigation for rice. In In: Wendt, J.B.(ed.), *Proceeding of the 10th National Convention System on Cotton and Rice Conference,* n.d 2005,Texas, USA, pp.33–34.

Meena, R.K., Parihar, S.S., Singh, M. and Khanna, M. 2015. Influence of date of sowing and irrigation regimes on crop growth and yield of wheat (Triticum aestivum) and its relationship with temperature in semi-arid region. *Indian J. Agron.* 60(1): 92-98.

Mehta, K.G. 1993. *Feasibility of sprinkler irrigation in fenugreek.* Central Board of Irrigation and Power Series No.8, New Delhi, 80 p.

Moghadam, T., Shirani-Rad, H.R., Mohammadi, A.H.N., Habibi, G., Modarres, S., Mashhadi, S.A.M., and Dolatabadian, M.A. 2013. Response of six oilseed rape genotypes to water stress and hydrogel application. *Pesquisa Agro. Trop.* 39 : 243-50.

Moghadam, T.H.R., Ashkiani, A., and Ghooshchii, F. 2013. Effect of super absorbent polymer on growth, yield components and seed yield of wheat grown under irrigation withholding at different stages. *Res. Crops.*14: 48-53.

Mohammad, T., Deva, W., and Ahmad, Z. 2002. Genetic variability of different plant and yield characters in rice. *Sarhad J. Agric.*18: 207-210.

Mojaddam, M., Mandegar, S., Hovayzeh, M.S., and Shokuhfar, A. 2012. Effect of Irrigation Ending Date on Physiological Growth Parameters, and Yields of Sunflower Hybrids. *Adv. Environ. Biol*. 6(1): 33-41.

Molden, D. 2007. *Water for food, water for life: a comprehensive assessment of water management in agriculture*. International Water Management Institute Earthscan,London,396p.Available:https://cgspace.cgiar.org/handle/10568/36463.pdf[14 February 2007].

Morgan, J.M. 1984. Osmoregulation and Water Stress in Higher Plants. *Annu. Rev. Plant Physiol.* 35: 299–319.

Murthy, K.V. and Reddy, D.S. 2013. Effect of irrigation and weed management practices on Nutrient uptake and Economics of production of Aerobic rice. *J. Agric. Vet. Sci.* 3(1): 15-21.

NABARD. 1989. Sprinkler irrigation in Semi-arid areas of Rajasthan: An Ex-Post Evaluation study. Evaluation study series, No. 36, National bank for Agriculture and Rural Development, Bombay.

NABARD. 1997. An ex-post evaluation of sprinkler irrigation schemes in Barmer District of Rajasthan. Evaluation study series, Jaipur No. 7, National bank for Agriculture and Rural Development Regional office, Jaipur.

Nalayani, P., Anandham, R., Raj, S.P. and Chidambaram, P. 2014. Pink pigmented facultative methylotrophic bacteria (PPFMB)- a potential bioinoculant for cotton nutrition. *Cotton Res. J.* 6: 50–53.

Nazarli, H., Faraji, F., and Zardashti, M.R. 2011. Effect of drought stress and polymer on osmotic adjustment and photosynthetic pigments of sunflower. *Cerctari Agron. Maldova*. 1(145): 278-283.

Nicknejad, R., Zarghami, M., Nasiri, H., Pirdashti, D.B., Tari., and H. Fallah. 2009. Investigation of physiological indices of different rice (*oryza sativa* l.) varieties in relation to source and sink limitation. *Asian J. Plant Sci. 8: 385-389.*

Nikolaeva, M.K., Maevskaya, S.N., Shugaev, A.G., and Bukhov, N.G. 2010. Effect of drought on chlorophyll content and antioxidant enzyme activities in leaves of three wheat cultivars varying in productivity. *Russ. J. Plant Physiol.* 57(1): 87-95.

Nilsen, E.T and Orcutt, D.M. 2007. *The Physiology of Plants under Stress*. (2nd Ed.). Wiley publishers, New York, 704 p.

NMMI (National Mission on Micro Irrigation). 2014. *Annual Report* 2013-2014. National Mission on Micro Irrigation, 127p.

Padhye, A.H. 1990. *Micro and sprinkler irrigation in India.* Congress on the use of plastics in agriculture, New Delhi, 362 p.

Panda, R.K., Behera, S.K., and Kashyap, P.S. 2003. Effective management of irrigation water for wheat crop under stress conditions using simulation modelling [abstract]. In*: Abstracts*, *Seventh International Water Technology Conference*, 1-3 April, 2003, Egypt. p. 62. Abstract No. 7.4.3.

Pant, H.P., Sherrard, J.H., and Pearson, C.J. 1987. Establishment of rice determined by interaction between cultivar, sowing depth and time between irrigation and sowing in North West Australia. *Field Crop Res*. 16: 273-282.

Parihar, S.S. and R.B. Tiwari, 2003. Effect of irrigation and nitrogen level on yield,nutrient uptake and water use of late sown wheat (*Triticum aestivum*). *Indian J. Agron. 48(2):103-107.*

Parthasarathy, T., Vanitha, K., Mohandas, S., and Vered, E. 2018. Evaluation of drip irrigation system for water productivity and yield of rice. *Agron. J.* 110(6): 1-12.

Pascual, V. and Wang, Y. 2016. Impact of Water Management on Rice Varieties, Yield, and Water Productivity under the System of Rice Intensification in Southern Taiwan. *Water*. 9(1):3.

Paul, J.C., Mishra, J.N., Pradhan, P.L., and Panigrahi, B. 2013. Effect of drip and surface irrigation on yield, water-use-efficiency and economics of capsicum (c*apsicum annum* l.) grown under mulch and non-mulch conditions in eastern coastal India. *Eur. J. Sustainable Dev.* 2(1): 99-108.

Pei, Z.M. and Kuchitsu, K. 2005. Early ABA signaling events in guard cells. *J. Plant Growth Regul*. 24: 296–307.

Perry, C., Steduto, P., Allen, R.G., and Burt, C.M. 2009. Increasing productivity in irrigatedagriculture: Agronomic constraints and hydrological realities. *Agric. Water Manage.* 96 (11): 1517-1524.

Philips, J.R. 1966. Plant water relations – some physical aspects. *Ann. Rev. Plant Physio*. 17: 245-268.

Piecynski, M., Marcewski, W., and Henning, J. 2013. Down-regulation of CBP80 gene expression as a strategy to engineer a drought-tolerant potato. *Plant Biotechnol. J.*11:459-469.

Plummer, D.T.1990. *An Introduction to Practical Biochemistry* (3rd Ed.). Mc Grow Hill publishers, NewYork, 179 p.

Postel, S.L. 2002. Entering an era of water scarcity: the challenges ahead. *Ecol. Appl.* 10(4): 941-948.

Rahim, H.A.A, Hegazy, E.A., and El-Mohdy, H.L.A. 2007. Radiation synthesis of hydrogels to enhance sandy soils water retention and increase plant performance. *J Appl. Polym. Sci.* 93: 1360-71.

Rahman, M.S. and Yoshida, S. 1985. Effect of water stress on grain filling in rice. *Soil Sci. Plant Nut*. 31(4):497-511.

Rajput, A. and Jha, G. 2017. Physiological Parameters Leaf Area Index, Crop Growth Rate, Relative Growth Rate and Net Assimilation Rate of Different Varieties of Rice Grown Under Different Planting Geometries and Depths in SRI. *Int. J. Pure App. Biosci*. 5(1): 362-367.

Ramamoorthy, K., Arokiaraj, A., and Balasubramanian, A. 1998. Response of upland direct-seeded rice (*Oryza sativa*) to soil-moisture regime and weed control. *Indian J. Agron.* 43: 82-86.

Ramanjaneyulu, A.V., Neelima, T.L., and Reddy, D.K. 2013. *Role of farm ponds in rainfed Agriculture and research progress.* Technical Bulletin1/DLA/RARS ANGRAU, Palem, 215p.

Ramanjulu, S. and Sudhakar, C. 2000. Proline metabolism during dehydration in two mulberry genotypes with contrasting drought tolerance. *J. Plant Physiol*. 157(1): 81-85.

Rao, K.V.R., Gangwar, S., Keshri, R., Chourasia, L., Bajpai, A., and Soni, K. 2016. The effects of drip irrigation system for enhancing rice (*Oryza sativa* L.) yield under system of rice intensification management. *Appl. Ecol. Environ. Res*. 15(4): 487-495.

Rao, P.B., Kaur, A., and Tewari, A. 2008. Drought resistance in seedlings of five important tree species in Tarai region of Uttarakhand. *Trop. Ecol.* 49(1): 43-52.

Reddi, G.H. and Reddy, T.Y.2005. Efficient use of irrigation water (2nd Ed.) Kalyani publishers, New Delhi, 492p.

Rehman, A., Ahmad, R. and Safdar, M. 2011. Effect of hydrogel on the performance of aerobic rice sown under different techniques. *Plant Soil Environ.* 57: 321–325.

Richards, L.A. and Weaver, L.R., 1943. Fifteen-atmosphere percentage as related to the permanent wilting percentage. *Soil Sci*. 56(5): 331-340.

Roy, T., Kumar, S., Chand, L., Kadam, D.M., Bihari, B., Shrimali, S.S., Bishnoi, R., Maurya, U.K., Singh, M., Muruganandam, M., Singh, L., Sharma, S.K., and Mallik, A. 2019. Impact of Pusa hydrogel application on yield and productivity of rainfed wheat in North West Himalayan region. *Current Sci.* 116(7): 1246-1251.

Rushdie, M. and Rzadvst, S. 1991. Effects of different irrigation levels on qualitative and quantitative characteristics of Sunflower. *Iran. J. Agric. Sci.* 36(5): 1249-1256.

Safarnejad, A. 2008. Morphological and biochemical responses to osmotic stress in alfalfa (*Medicago sativa* L.). *Pak. J. Bot.*40: 735-746.

Santos, M.G., Ribeiro, R.V., Machado, E.C., and Pimentel, C. 2009. Photosynthetic parameters and leaf water potential of five common bean genotypes under mild water deficit. *Biol. Plant*. 53(2): 229-236.

Saren, B.K. and Jana, P.K. 2001. Effect of depth of irrigation level and time of nitrogen application on growth, yield and nutrient uptake wheat (*Triticum aestivum*). *Indian J. Agric. Sci*. 46: 227-232.

Sarkar, N., Ghosh, U., and Biswas, R.K. 2018. Effect of drip irrigation on yield and water use efficiency of summer rice cultivation in pots. *J. pharmacogn. Phytochem*. 7(1): 37-40.

Sarvestani, Z.M., Pirdashti, H., Sanavay, S.A.M.M., and Balouchi, H. 2008 .Study of water stress effects in different growth stages on yield and yield components of different rice (*Oryza sativa* L.) cultivars. *Pak. J. Biol. Sci. 11(10):1303-1309.*

Sathyan, T., Aswathy, K.M., Dhanya, M.K., Aswathy, T.S., Preethy, T.T., and Murugan, M. 2017. Impact of pink pigmented facultative methylotrophic bacteria and synthetic materials on small cardamom (*Elettaria cardamomum* Maton.) under drought. *Pharma. Innovation J.* 7(1): 01-04.

Sendurkumaran, S. 2001. Effect of hydrophilic polymers on yield and quality of tomato. *Int. J. Pure. Appl. Sci*. 2 (4): 56-61.

Senthil Kumar, G., Ramesh, T., Subrahmaniyan, K., and Ravi, V. 2018. Effect of Sprinkler Irrigation Levels on the Performance of Rice Genotypes under Aerobic Condition. *Int. J. Curr. Microbiol. App. Sci 7*(3): 1848-1852.

Shahanila, P.P., Prameela, P., Visalakshi, K.P., and John, P.S. 2015. Aerobic rice in uplands with micro sprinkler irrigation. *J. Trop. Agric*. 54(1): 79-83.

Shahid, B.D. and Ram, H. 2016. Grain yield, nutrient uptake and water-use efficiency of wheat (*Triticum aestivum*) under different moisture regimes, nutrient and hydrogel levels. *Indian J. Agron.* 61:58-61.

Sharda, R., Mahajan, G., Siag, M., Singh, A., and Chauhan, B.S. 2016. Performance of drip irrigated dry seeded rice (*Oryza sativa* L.) in South Asia. *Paddy Water Environ.* 15: 93–100.

Sharma, S.K. 1984. *Principles and practices of Irrigation Engineering.* Oxford and International Book House Publications, New York, 257p.

Sharma, P., Kaushal, A., Singh, A., and Garg, S. 2016. Growth and yield attributes of okra under influence of drip irrigation. *Int. J. Eng. Res. Appl.* 6(2): 85-91.

Sheela, K.R. 1993. Agronomic evaluation of rice cultivars for rainfed conditions of Kerala. Ph. D thesis, Kerala Agricultural University, Thrissur.

Sheela, K.R., and Alexander, V.T. 1996. Physiological response of rice varieties as influenced by soil moisture and seed hardening. *Indian J. Plant Physiol.* 38: 269-271.

Shekara, B.G., Sharnappa, N., and Krishnamurthy, N. 2010. Effect of irrigation schedules on growth and yield of aerobic rice (*Oryza sativa* L.) under varied levels of farmyard manure in Cauvery command area. *Indian. J. Agron.* 55(1): 35-39.

Shirazi, S.M., Yusop, Z., Zardari, N.H., and Ismail, Z. 2014. Effect of Irrigation Regimes and Nitrogen Levels on the Growth and Yield of Wheat. *Adv. Agric.* [e-journal]. Available: http://dx.doi.org/10.1155/2014/250874.

Silberbush, M.E., Adar, M., and Malach, Y.D. 1993. Use of an hydrophilic polymer to improve water storage and availability to crops grown in sand dune cabbage irrigated by sprinkling with different water salinities. *Agric. Water Manage*. 23(4): 315–327.

Silva, H., Arriagada, C., Campos, S., Beginsky, C., and Galdames, G.C. 2018. Effect of sowing date and water availability on growth of plants of chia (*Salvia hispanica* L) established in Chile. *Plos one.* [e-journal]13(9). Available: https://doi.org/10. 1371/journal.pone.0203116/vol13/issue9/full/3.[12 September 2018].

Singh, K.P. and Singh, K. 1993. Seed germination and seedling growth responses of some rice cultivars to water potential treatments. *Indian J. Plant Physiol*. 26:182-188.

Sivakumar, R., Chandrasekaran, P., Srividhya, S., and Vijayakumar, M. 2018. Impact of pink-pigmented facultative methylotroph on physiological, growth analytical traits and yield of tomato (*Solanum lycopersicum*) under drought condition. *Int. J. Microbiol. Res*. 10(5): 1205-1208.

Sivakumar, R., Nandhitha, G.K., Chandrasekaran, P., Boominathan, P., and Senthilkumar, M. 2017. Impact of pink pigmented facultative methylotroph and PGRs on water status, photosynthesis, proline and NR activity in tomato under drought. *Int. J. Curr. Microbiol. App. Sci. 6*(6): 1640-1651.

Sivanappan, R.K. 1987. *Sprinkler irrigation*. Oxford and IBH publishing Co. Pvt. Ltd., University of California, Berkely, 670p.

Sivapalan, S. 2001. Effect of a polymer on growth and yield of soybeans (*Glycine max*) grown in a coarse textured soil. In: *Proceedings Irrigation 2001 Regional Conference,* n.d, Toowoomba, Queensland, Australia, pp.93-99.

Snedecor, G. W. and Cochran, W. G. 1980. *Statistical Methods* (7th Ed.) Iowa State University Press, Ames Iowa, 225p.

Sokoto, M.B. and Muhammad, A. 2013. Response of rice varieties to water stress in Sokoto, Sudan, Savannah and Nigeria. *J. Biosci. Med.* 2:68-74

Soman, P., Prasad, M.S., Balasubramaniam, V.R., Singh, S., Dhavarajan, C., Patil, V.B., and Jha, S. 2018. Effect of drip irrigation and fertigation on the performance of several rice cultivars in different rice ecosystems in India. *Int. J. Agric. Sci.* 10(14): 6672-6675.

Spanu, A., Murtas, A. and Ballone, F. 2009. Water use and crop coefficients in sprinkler irrigated rice. *Ital. J. Agron*. 2: 47–58.

Stoop, W., Uphoff, N., and Kassam, A. 2002. A review of agricultural research issues raised by the system of rice intensification (SRI) from Madagascar: opportunities for improving farming systems for resource-poor farmers. *Agric. Syst*. 71: 249–274.

Subbaiah, B.V. and Asija, G.L.A.1956. A rapid procedure for the estimation of available nitrogen in soil. *Curr. Sci*. 25:259-360.

Sudhakar, N., Pande, H. K., and Tripathi, R.S. 1989. Influence of moisture stress at three stages on growth and yield and the contents of chlorophyll and proline in three rice varieties. *Thai. J. Agric. Sci.,* 22(2):137-144.

Suman, B.M., Sheeja, K.R., Prathapan, K., Syriac, E.K., and Radhakrishnan, N.V. 2018. Effect of nutrient levels and nutrient schedules on physiological parameters and grain yield of upland rice intercropped in coconut garden. *J. Appl. Nat. Sci.* 10(3): 964 – 970.

Tabbal, D.F., Bouman, B.A. M., Bhuiyan, S.I., Sibayan, E.B., and Sattar, M.A. 2002. On-farm strategies for reducing water input in irrigated rice; case studies in the Philippines. *Agric. Water Manage.* 56(2): 93–112.

Takami, S., Kobata, T., and Bavel, C.H.M. 1990. Quantitative method for analysis of grain yield in rice. *Agron. J.* 82:1149-1153.

Tashiro, T. and Ebata, M. 1975. Studies on white-belly rice kernel IV Opaque rice endosperm viewed with a scanning electron microscope. *Proc. Crop Sci. Soc. Jpn*. 44: 205-214.

Taylor, K.C. and Halfacre R.G. 1986. Hydrophilic polymer effect on nutrient and water availability to *Ligustrum ludicum* 'compactum' grown in pinebark medium. *Hort. Sci. 18*: 603.

Thakur, A., Mohanty, R.K., Patil, D., and Kumar, A. 2014. Impact of water management on yield and water productivity with system of rice intensification and conventional transplanting system in rice. *Paddy Water Environ*. 12(4): 413-424.

Timung, B., Bharali, B., and Kouwar, J. 2017. Physiological parameters of some upland rice (*Oryza sativa* L.) genotypes under moisture stress condition. *J. Pharmacogn. Phytochem*. 6(6): 1636-1640.University Extension Service, Fargo, N.D., USA, 1243p. Available: *h*ttps://library.ndsu.edu/ir/bitstream /handle/10365/5108/ae1243.pdf [14March 2003].

Thomas, U.C., Vargheese, K., and Thomas, A. 2014. Response of upland rice varieties to different levels of irrigation, nutrients and seed priming. *J. Aquat. Biol. Fish.* 2: 775-779.

Viero, P.W.M., Little, K.M., and Oscroft, D.G.2000. The effect of a soil-amended hydrogel on the establishment of Eucalyptus grandis x E. camaldulensis clone grown on the sandy soils of Zululand. *South Afr. For. J.* 188: 21-28.

Vories, E.D., Counce, P.A., and Keisling, T.C. 2002. Comparison of flooded and furrow irrigated rice on clay. *Irrigation sci*. 21(3):139-144.

Vories, E.D., Tacker, P.L., and Hogan, R. 2005. Multiple inlet approach to reduce water requirements for rice production. *Appl. Eng. Agric*. 21(4): 611–616.

Walkley, A.J. and Black, C.A. 1934. Estimation of soil organic carbon by the chromic acid titration method. *Soil Sci.* 37: 29-38.

Waly, A., Karamany, E.M.F., Shaaban, A.M., Bakry, A.B., and Elwa, T. 2004. Utilization of hydrogel for reducing water irrigation under sandy soil condition. *Res. J. Pharm. Biol. Chem.* Sci. 6(2): 1018-1023.

Westcott, M.P. and Vines, K.W. 1986. A comparison of sprinkler and flood irrigation for rice. *Agron. J*. 78: 637–640.

Weston, E. J., Dalal, R. C, Strong, W. M, Lehane, K. J, Cooper, J. E., and King , A. J. 1996. In: *Proceeding of the 8th Australian Agronomy Conference,* n.d. Toowoomba, Queensland, Australia: pp. 578-589.

Xiang, Y., Zou, H., Zhang, F., Qiang, S., Wu, Y., Fan, J., and Wang, X. 2019. Effect of irrigation level and irrigation frequency on the growth of mini Chinese cabbage and residual soil nitrate nitrogen. *Sustainability*. 11(1): 111-116.

Yang, L., Han, M., Zhou, G., and Li, J. 2007. The changes of water-use efficiency and stoma density of Leymus chinensis along Northeast China Transect. *Acta Ecol. Sin.* 27: 16–24.

Yangyuoru. M., Boateng, E., Adiku, S.G.K., Acquah, D., Adjadeh, T.A., and Mawunya, F. 2006. Effects of natural and synthetic soil conditioners on soil moisture retention and maize yield. *J. Appl. Ecol.* 9: 1-8.

Yazdani, F., Alahdadi, A., and Behbahani, M.R. 2008. Effect of super absorbent polymer (terawatt a200) and different levels of drought stress on soybean yield and yield components. *Res. Agric. Horti. Constr.* 75: 34-41.

Yazdani, F., Allahdadi, I., and Akbari, G.A. 2007. Impact of superabsorbent polymer on yield and growth analysis of soybean (*Glycine max* l.) under drought stress condition. *Pak. J. Biol. Sci*. 10: 4190-4196.

Yoshida, S. 1981. *Fundamentals of rice crop science*. International Rice Research Institute Los Banos, Philippines, 269p. Available: http://books.irri.org/ 9711040522_ content.pdf.

Zhang, H., Xue, Y., Wang, Z., Yang, J., and Zhang, J. 2009. An alternate wetting and moderate soil drying regime improves root and shoot growth in rice. *Crop Sci.* 49: 2246–2260.

Zhang, J., Li, Y., Zahng, H., Dong, P., and Wei, C. 2019. Effects of different water conditions on rice growth at the seedling stage. *Rev. Caat.* 32(2): 100-116.

Zimmermann, M.B. and Hurrell, R.F. 2002. Improving iron, zinc and vitamin A nutrition through plant biotechnology. *Curr. Opin. Biotechnol.* 13:142–145.

IRRIGATION SCHEDULING AND WATER STRESS MITIGATION STRATEGIES IN UPLAND RICE

(*Oryza sativa* L.)

GRITTA ELIZABETH JOLLY

(2017-21-031)

Abstract of the thesis
Submitted in partial fulfillment of the
requirements for the degree of

DOCTOR OF PHILOSOPHY IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF AGRONOMY
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM - 695 522
KERALA, INDIA
2021

ABSTRACT

The study entitled "Irrigation scheduling and water stress mitigation strategies in upland rice (*Oryza sativa* L.)" was carried out as two field experiments at the Instructional Farm, College of Agriculture, Vellayani from 2017 to 2020 to identify a suitable variety and irrigation method for upland rice, to standardize irrigation scheduling and to assess the effect of moisture stress mitigation strategies on the growth, yield and economics of upland rice.

Experiment I entitled "Identification of suitable variety and standardization of irrigation method**"** was conducted from January 2019 to May 2019. The experiment was laid out in split plot design with five main plot treatments and two sub plot treatments, in four replications. The treatments included sprinkler irrigation at 100% PE, sprinkler irrigation at 75% PE, drip irrigation at 100% PE, drip irrigation at 75% PE and hose irrigation (farmer's practice-irrigation given thrice in a week) as main plot treatments and rice varieties Uma and Prathyasa as sub-plot treatments.

The height of the plant, number of tillers m^{-2}, leaf area index and dry matter production were observed to be significantly the highest for the variety Prathyasa irrigated using sprinkler irrigation at 100% PE and hose irrigation was significantly inferior to all other methods of irrigation. The variety Prathyasa irrigated using sprinkler irrigation at 100% PE also recorded the highest number of panicles m^{-2} (226.00), number of grains per panicle (159.75) and grain yield (4.37 Mg ha^{-1}).

The highest RLWC and consumptive use (434.25 mm) by the crop was observed in the variety Uma irrigated using sprinkler at 100% PE, followed by drip irrigated plots at 100% PE. The highest crop water use efficiency (1.53 kg m^{-3}) was observed in the variety Prathyasa irrigated using hose method and the highest field water use efficiency (0.95 kg m^{-3}) was observed in the variety Prathyasa irrigated using sprinkler at 100% PE.

The economics of cultivation in terms of net returns (₹1,32,465.50 ha^{-1}) and B:C ratio (2.67) were observed to be the highest in the variety Prathyasa irrigated using sprinkler irrigation plots at 100% PE, followed by the variety Prathyasa irrigated using drip irrigation at 100% PE.

Field experiment II entitled "Standardization of irrigation scheduling and moisture stress mitigation strategies for upland rice" was conducted during January 2020 to April 2020. The experiment was laid out in split plot design with four main plot treatments and five sub plot treatments in five replications (the best treatment from the experiment I - sprinkler method of irrigation at 100% PE and the variety Prathyasa were used for the experiment II). The main plot treatments included approaches of scheduling irrigation: IW/CPE of 0.8, critical growth stage approach, irrigation to maintain soil moisture at 100% FC and irrigation to maintain soil moisture at 75% FC. The sub-plot treatments included field application of hydrogel polymer (20 kg ha^{-1}), seed treatment with hydrogel polymer (10 g kg^{-1}), hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @10g kg^{-1}), foliar application of PPFM (1%) and absolute control.

The plant height, number of tillers m^{-2}, leaf area index and dry matter production were observed to be significantly higher in the plots irrigated at 100% FC, treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @10 g kg^{-1}), which was followed by the plots irrigated to maintain 2 cm depth of water at critical stages of crop growth.

The number of days for 50% flowering, the number of panicles m^{-2} (233.20), length of panicle (20.36 cm), weight of panicle (3.07 g), number of grains $panicle^{-1}$ (169.20), grain yield (5.00 Mg ha^{-1}) and straw yield (8.07 Mg ha^{-1}) were the highest in the plots irrigated at 100% FC and treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @10g kg^{-1}.

. The consumptive use by the crop was significantly the highest in the plots irrigated at 100% FC (1265.60 mm) and treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @ 10g kg^{-1}).The crop water use efficiency recorded the highest value (0.69 kg m^{-3}) in the plots irrigated at IW/CPE of 0.8 and treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @ 10g kg^{-1}) and a significantly higher field water use efficiency (0.58) was recorded in the plots irrigated at IW/CPE of 0.8 and treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @ 10g kg^{-1})

The highest B: C ratio (2.92) and net returns (₹ 1,58,000.00 ha^{-1}) were obtained from the plots irrigated at 100% FC and treated with hydrogel polymer (field application @ 2.5 kg ha^{-1} + seed treatment @ 10g kg^{-1}.

The results of the study revealed suitability of the variety Prathyasa, irrigated using sprinkler irrigation at 100% PE for higher yield and monetary returns under upland conditions. It also reflected the suitability of irrigating upland rice at 100 % FC as an effective approach of scheduling irrigation, along with the application of hydrogel polymer (field application @ 2.5kg ha^{-1} + seed treatment @ 10 g kg^{-1}) as the most suitable moisture stress mitigation strategy for upland rice cultivation for enhanced yield and economic returns under water stress conditions.

സംഗ്രഹം

'കരനെൽകൃഷിയിലെ ജലസേചനക്രമവും ജലസമ്മർദത്തിന്റെ അതിജീവന തന്ത്രവും' എന്ന വിഷയത്തിൽ വെള്ളായണി കാർഷിക കോളേജിലെ ഇൻസ്ട്രക്ഷണൽ ഫാമിൽ 2019 - 2020 കാലയളവിൽ രണ്ട് കൃഷിയിട പരീക്ഷണങ്ങൾ നടത്തുകയുണ്ടായി. ഒന്നാമത്തെ പരീക്ഷണമായ 'ജലസേചനരീതികളുടെ നിലവാരവൽക്കരണവും അനുയോജ്യമായ ഇനം തിരിച്ചറിയലും' 2019 ജനുവരി മുതൽ 2019 മേയ് വരെയുള്ള കാലയളവിൽ നടത്തി. 100% പാൻ ബാഷ്പീകരണത്തിൽ സ്പ്രിംഗ്ളർ ജലസേചനം 75% പാൻ ബാഷ്പീകരണത്തിൽ സ്പ്രിംഗ്ളർ ജലസേചനം, 100% പാൻ ബാഷ്പീകരണത്തിൽ ഡ്രിപ്പ് ജലസേചനം 75% പാൻ ബാഷ്പീകരണത്തിൽ ഡ്രിപ്പ് ജലസേചനം, ബാഷ്പീകരണത്തിന്റെ അടിസ്ഥാനത്തിൽ ആഴ്ചയിൽ മൂന്ന് തവണ എന്ന ക്രമത്തിൽ ഹോസിലൂടെയുള്ള ജലസേചനം എന്നീ ട്രീറ്റ്മെന്റുകൾ അഞ്ച് പ്രധാന പ്ലോട്ടുകളിലായും പ്രത്യാശ, ഉമ എന്നീ നെല്ലിനങ്ങൾ ഉപപ്ലോട്ടുകളിലെ ട്രീറ്റ്മെന്റുകളായും നാല് റെപ്ലിക്കേഷനുകളിലായി സ്പ്ളിറ്റ് പ്ലോട്ട് ഡിസൈൻ എന്ന പരീക്ഷണരീതി അവലംബിച്ച് പരീക്ഷിച്ചു. ഇവയിൽ 'പ്രത്യാശ' ഇനത്തിൽ 100% പാൻ ബാഷ്പീകരണത്തിൽ സ്പ്രിംഗ്ളർ ഉപയോഗിച്ച് ജലസേചനം നടത്തിയപ്പോൾ ഏറ്റവും മികച്ച വിളവും ആദായവും ലഭിച്ചു.

'ജലസേചനക്രമീകരണത്തിന്റെ മാനദണ്ഡവൽക്കരണവും ജലസമ്മർദ്ദ ലഘൂകരണതന്ത്രവും' എന്ന രണ്ടാമത്തെ കൃഷിയുടെ പരീക്ഷണം 2020 ജനുവരി മുതൽ 2020 ഏപ്രിൽ വരെ നടത്തി. ഈ പരീഷണത്തിൽ, ഒന്നാമത്തെ പരീഷണത്തിൽ മികവുകാട്ടിയ സ്പ്രിംഗ്ളർ ജലസേചനരീതിയും മികവുകാട്ടിയ ഇനമായ പ്രത്യാശയുമാണ് ഉപയോഗിച്ചത്. 0.8 ഐ.ഡബ്ളിയൂ / സി.പി.ഇ. ജലസേചനം, നിർണ്ണായക വളർച്ചഘട്ടങ്ങളിൽ 2 സെ.മി. ആഴം നിലനിർത്തിക്കൊണ്ടുള്ള ജലസേചനം, 100% ഫീൽഡ്ശേഷി നിലനിർത്തിക്കൊണ്ടുള്ള ജലസേചനം, 75% ഫീൽഡ്ശേഷി നിലനിർത്തിക്കൊണ്ടുള്ള ജലസേചനം എന്നീ ട്രീറ്റ്മെന്റുകൾ നാലു പ്രധാന പ്ലോട്ടുകളിലായും ഹൈഡ്രോജെൽ പോളിമർ (ഹെക്ടർ ഒന്നിന് 2.5 കിലോഗ്രാം മണ്ണിൽ ചേർക്കൽ), ഹൈഡ്രോജെൽ പോളിമർ (ഒരു കിലോ വിത്തിൽ 10 ഗ്രാം എന്ന നിരക്കിൽ), ഹൈഡ്രോജെൽ പോളിമർ (ഹെക്ടർ ഒന്നിന് 2.5 കിലോഗ്രാം മണ്ണിൽ ചേർക്കൽ + ഒരു കിലോഗ്രാം വിത്തിൽ 10 ഗ്രാം എന്ന നിരക്കിൽ), 1% പി പി എഫ് എം തളിക്കൽ, ജലസമ്മർദ്ദ ലഘൂകരണ തന്ത്ര

ങ്ങളൊന്നും ഇല്ലാത്ത ഒരു ട്രീറ്റ്മെന്റ് എന്നിവ അഞ്ച് ഉപപ്ലോട്ടുകളിലായും അഞ്ച് റെപ്ലി ക്കേഷനുകളിലായി സ്പ്ളിറ്റ് പ്ലോട്ട് ഡിസൈനിൽ പരീക്ഷിച്ചു. ഇവയിൽ 100% ഫീൽഡ്ശേഷി നിലനിർത്തികൊണ്ടുള്ള ജലസേചനത്തിനൊപ്പം ഹൈഡ്രോജെൽ പോളി മർ (ഹെക്ടർ ഒന്നിന് 2.5 കിലോഗ്രാം മണ്ണിൽ ചേർക്കൽ + ഒരു കിലോഗ്രാം വിത്തന് 10 ഗ്രാം എന്ന നിരക്കിൽ) പ്രയോഗിച്ചപ്പോൾ മികച്ച വിളവും വർദ്ധിച്ച അറ്റാദായവും വരവ് ചെലവ് അനുപാതവും ലഭിക്കുകയുണ്ടായി.

കരനെൽകൃഷിയിൽ സ്പ്രിംഗ്ളർ ഉപയോഗിച്ചുകൊണ്ടുള്ള ജലസേചനം, ജലോപ യോഗത്തിന്റെ കാര്യക്ഷമത വർദ്ധിപ്പിക്കുന്നതിനോടോപ്പം മികച്ച വിളവ് ഉൽപ്പാദിപ്പിക്കു ന്നു. അതിനോടോപ്പം സ്പ്രിംഗ്ളർ ഉപയോഗിച്ച് 100% ഫീൽഡ്ശേഷി നില നിർത്തികൊണ്ട് ജലസേചനം നടത്തുകയും ഹൈഡ്രോജെൽ പേളിമർ (ഹെക്ടർ ഒന്നിന് 2.5 കിലോഗ്രാം മണ്ണിൽ ചേർക്കൽ + ഒരു കിലോഗ്രാം വിത്തിന് 10 ഗ്രാം എന്ന നിര ക്കിൽ) ജലസമ്മർദ്ദ ലഘൂകരണത്തിനായി ഉപയോഗിക്കുകയും ചെയ്താൽ മികച്ച വിളവും ആദായവും ലഭിക്കുമെന്നതിനാൽ ഇത് ശുപാർശ ചെയ്യാവുന്നതാണ്.

APPENDIX I

Weather parameters during January to May, 2019

Standard week	Rainfall	Max T(°C)	Min T(°C)	Max RH (%)	Min RH (%)	Evaporation (mm)
8	9.1	32.8	22.4	96	75	3.9
9	0	33.4	24	93	73	4.4
10	8.9	32.6	24.2	94.8	74.5	4.1
11	3	33.4	24.8	93	74	4.1
12	5.3	33.6	25	90.1	74.9	4.45
13	0	34	25.6	88	74	4.8
14	1.1	34.2	25.6	86	72	4.8
15	13.2	32.6	25.2	89	72	5.2
16	1.5	33.2	25.8	89	77	4.6
17	4.3	34.2	26.8	83	75	5.1
18	2	34.4	26	79	73	4.9
19	6.8	33.2	25.6	95	74	4.2
20	27.3	32.4	24.2	90	74	4.8
21	10.7	32.4	24	91	81.6	3.4
22	13.6	31.6	24	94	80.9	3.1
23	18.1	30.2	24.6	96.7	85.7	2.4
24	9.1	31.2	24.8	92	76	2.6
25	14.3	31.8	24	94	85	3.2
26	6.3	31.6	24.4	89	88	3.6
27	1.3	31.6	24.6	84	73	2.8
28	9.9	29.1	22	93.2	86.8	0.8
29	21.28	30.4	23.6	92	74	2.1

APPENDIX II

Weather parameters during January to April, 2020

Standard week	Rainfall	Max T(°C)	Min T(°C)	Max RH (%)	Min RH (%)	Evaporation (mm)
8	4.5	30.2	23.1	93	78	2.3
9	0	31.8	24.2	92.8	76	3.1
10	2.1	32.1	25.1	94	73	4.3
11	0	30.6	22.6	91	77	3.9
12	0	33.1	24.6	89	74	3.6
13	3.2	32.6	25.8	89.5	75	4.2
14	5.3	33.1	24.7	90.6	77	2.9
15	0	33.4	25.7	91.3	75	3.6
16	0.8	32.8	24.9	86.3	77	3.5
17	9.1	31.9	20.6	89.2	78	3.8
18	6.8	30.6	22.4	90.3	74	4.4
19	0	31.7	23.5	91.6	79	2.8
20	2.3	32.3	24.7	93.8	76	3.3
21	4.7	30.8	23.6	90.3	75	3.9

APPENDIX III

Cost of cultivation of experiment I

Treatments	Cost of cultivation (₹ ha^{-1})
m_1v_1	79,530
m_1v_2	79,530
m_2v_1	79,530
m_2v_2	79,530
m_3v_1	92,030
m_3v_2	92,030
m_4v_1	92,030
m_4v_2	92,030
m_5v_1	1,06,900
m_5v_2	1, 06,900

Details of the cost incurred in experiment I

For sprinkler irrigated plots, estimated cost of cultivation for single crop (₹ ha^{-1})

Number of labourers for sowing – 10

Number of labourers for weeding (3) – 30

Number of labourers for harvest -5

Total number of labourers – 50

Total labourer charge = 50 x 800 = ₹ 40,000

Miscellaneous charge (seed, fertilizer, pesticides, etc...) – ₹ 27,000

Cost of sprinkler installation – ₹ 1, 25, 300

For drip irrigated plots, estimated cost of cultivation for single crop (₹ ha^{-1})

Number of labourers for sowing – 10

Number of labourers for weeding (3) – 30

Number of labourers for harvest -5

Total number of labourers – 50

Total labourer charge = 50 x 800 = ₹ 40,000

Miscellaneous charge (seed, fertilizer, pesticides, etc...) – ₹ 27,000

Cost of drip installation – ₹ 2, 50, 300

For hose irrigated plots, estimated cost of cultivation for single crop (₹ ha^{-1})

Number of labourers for sowing – 10

Number of labourers for weeding (4) – 45

Number of labourers for harvest -5

Number of labourers for irrigation – 40

Total labourer charge = ₹ 80,000

Miscellaneous charge (seed, fertilizer, pesticides, etc...) – ₹ 27,000

APPENDIX IV

Cost of cultivation of experiment II

Treatments	Cost of cultivation (₹ ha^{-1})
i_1s_1	69530
i_1s_2	67780
i_1s_3	70030
i_1s_4	68155
i_1s_5	67280
i_2s_1	70530
i_2s_2	68780
i_2s_3	71030
i_2s_4	69155
i_2s_5	68280
i_3s_1	70530
i_3s_2	68780
i_3s_3	71030
i_3s_4	69155
i_3s_5	68280
i_4s_1	69530
i_4s_2	67780
i_4s_3	70030
i_4s_4	68155
i_4s_5	67280

Details of the cost incurred in experiment II (₹ ha^{-1})

Number of labourers for sowing – 10

Number of labourers for weeding (3) – 30

Number of labourers for harvest -5

Total number of labourers – 50

Total labourer charge = 50 x 800 = ₹ 40,000

Miscellaneous charge (seed, fertilizer, pesticides, etc...) – ₹ 27,000

Cost of sprinkler installation – ₹ 1, 25, 300

Cost of PUSA cumijal hydrogel polymer – ₹ 900 kg^{-1}

Cost of PPFM – ₹ 650 L^{-1}