Effect of crop establishment methods and irrigation scheduling on growth, yield and water productivity of wheat in rice-wheat system

काशी हिन्दू विश्वविद्यालय
BANARAS HINDU UNIVERSITY
ESTABLISHED BY PARLIAMENT BY NOTIFICATION NO. 225 OF 1916
BHU
capital of knowledge

THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE OF

Doctor of Philosophy
in
Agronomy

Submitted by

Sanjeev Kumar Kashyap

Supervisor
Prof. U. P. Singh

Co-supervisor
Prof. V. K. Srivastava

DEPARTMENT OF AGRONOMY
INSTITUTE OF AGRICULTURAL SCIENCES
BANARAS HINDU UNIVERSITY
VARANASI- 221 005
UTTAR PRADESH
INDIA

ID. No. PA-15030 **2021** **Enrolment No.** 333365

UNDERTAKING OF THE CANDIDATE

I, **Sanjeev Kumar Kashyap,** research scholar under the supervision of **Dr. U.P. Singh,** Professor and co-supervision, **Dr. V.K. Srivastava,** Professor, Department of Agronomy, Institute of Agricultural Sciences, Banaras Hindu University, give undertaking that the thesis entitled **"Effect of crop establishment methods and irrigation scheduling on growth, yield and water productivity of wheat in rice-wheat system"** submitted by me for the degree of Doctor of Philosophy is a record of first hand research work done by me during the period of study.

I avail myself to responsibility such as an act will be taken on behalf of me, mistakes, errors of fact and misinterpretation are of course entirely my own.

Date: ....
Place: Varanasi **(Sanjeev Kumar Kashyap)**

Annexure – E
[see Clause XIII.2 (b) (iii)]

CANDIDATE'S DECLARATION

I, **Sanjeev Kumar Kashyap,** I.D. No. PA-15030, Enrolment No. 333365, certify that the work embodied in this Ph. D. thesis is my own bonafide work carried out by me under the supervision of **Dr. U. P. Singh**, Professor and co-supervision of **Dr. V. K. Srivastava**, for a period of five years and three month from November, 2015 to March, 2021 at Banaras Hindu University, Varanasi (U.P.). The matter embodied in this Ph.D. thesis has not been submitted for the award of any other degree/diploma.

I declare that I have faithfully acknowledged, given credit to and referred to the research workers wherever their works have been cited in the text and the body of the thesis. I further certify that I have not wilfully lifted up some other's work, para, text, data, results, etc. reported in the journals, books, magazines, reports, dissertations, theses, etc., or available at web-sites and included them in this Ph.D. thesis and cited as my own work.

Date: ....
Place: Varanasi **(Sanjeev Kumar Kashyap)**

CERTIFICATE FROM THE SUPERVISOR

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Co- supervisor
Dr. V. K. Srivastava
(Professor)

Supervisor
Dr. U. P. Singh
(Professor)

(Signature of the Head of the Department with seal)

Annexure – F
[see Clause XIII.1 (c) and XIII.2 (b) (iv)]

COURSE WORK COMPLETION CERTIFICATE

This is to certify that **Sri Sanjeev Kumar Kashyap**, I.D. No. PA-15030, Enrolment No. 333365, a bonafide research scholar of this department, has satisfactorily completed the course work requirement which is a part of his Ph.D. programme.

Date: ....
Place: Varanasi

(Signature of the Head of the Department)

Annexure – F
[see Clause XIII.1 (c) and XIII.2 (b) (iv)]

ORAL AND WRITTEN COMPREHENSIVE EXAMINATION COMPLETION CERTIFICATE

This is to certify that **Sri Sanjeev Kumar Kashyap,** I.D. No. PA-15030, Enrolment No. 333365, a bonafide research scholar of this department, has satisfactorily completed the oral comprehensive and written comprehensive examination which is a part of his Ph. D. programme.

Date: ....
Place: Varanasi

(Signature of the Head of the Department)

Annexure – F
[see Clause XIII.1 (c) and XIII.2 (b) (iv)]

PRE-SUBMISSION SEMINAR COMPLETION CERTIFICATE

This is to certify that **Sri Sanjeev Kumar Kashyap**, I.D. No. PA-15030, Enrolment No. 333365, a bonafide research scholar of this department, has satisfactorily completed the pre-submission seminar on topic **"Effect of crop establishment methods and irrigation scheduling on growth, yield and water productivity of wheat in rice-wheat system"** on **03 December 2020** requirement which is a part of his Ph. D. programme.

Date: ....
Place: Varanasi

(Signature of the Head of the Department)

Annexure – G
[see Clause XIII.2 (b) (v)]

COPYRIGHT TRANSFER CERTIFICATE

Title of the Thesis	:	"Effect of crop establishment methods and irrigation scheduling on growth, yield and water productivity of wheat in rice-wheat system"
Candidate's Name	:	Sanjeev Kumar Kashyap

COPYRIGHT TRANSFER

The undersigned hereby assigns to the Banaras Hindu University all rights under copyright that may exist in and for the above thesis submitted for the award of the Ph.D. degree.

(Sanjeev Kumar Kashyap)

Note: However, the author may reproduce or authorize others to reproduce material extracted verbatim from the thesis or derivative of the thesis for author's personal use provided that the source and the University's copyright notice are indicated.

Effect of crop establishment methods and irrigation scheduling on growth, yield and water productivity of wheat in rice-wheat system

By

Sanjeev Kumar Kashyap

Thesis submitted in the partial fulfilment of the requirement for the degree of "**DOCTOR OF PHILOSOPHY IN AGRONOMY**", Department of Agronomy, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi-221 005, Uttar Pradesh (INDIA), 2021.

APPROVED BY ADVISORY COMMITTEE

Chairman/Supervisor	**:**	**Dr. U. P. Singh** **(Professor)** Department of Agronomy
Co- supervisor	**:**	**Dr. V. K. Srivastava** **(Professor)** Department of Agronomy
DRC Nominee	**:**	**Dr. J. S. Bohra** **(Professor)** Department of Agronomy
Internal Subject Expert	**:**	**Dr. Ramesh Kumar Singh** **(Professor)** Department of Agronomy
External Subject Expert	**:**	**Dr. A. K. Ghosh** **(Professor)** Department of Soil Science and Agricultural Chemistry
External Examiner	**:**	

ACKNOWLEDGEMENT

Gratitude takes three forms "A feeling from heart; An expression in words and A giving in return". Gratitude cannot be seen or expressed it can only be felt deep in heart and is beyond description. I sincerely thank all those who directly made this thesis possible. Although thanks are poor expression of depth of gratitude one feel yet there is no better way to express it.

First of all, I pay obeisance to the Lord Vishwanath and am grateful to the almighty for providing me the golden opportunity to breathe in this holy city and enlighten my mind. I express my deepest sense of gratitude to Bharat Ratna Pandit Madan Mohan Malviya Ji, a man of great vision and founder of Banaras Hindu University, Varanasi, Uttar Pradesh, India where I receive knowledge and wisdom and inspire me to work for the betterment of the society like Malviya Ji, who sacrificed himself for establishing such a great temple of learning.

It gives me immense pleasure to avail this opportunity to express my immense sense of gratitude to a modest, generous and affable personality Dr. U. P. Singh, Professor, Department of Agronomy, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, my supervisor & Chairman of my advisory committee and Dr V. K. Srivastava, Professor, Department of Agronomy, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Co-Supervisor. It is beyond my apprehension to express my deep sense of gratitude to them for their skilful and noble guidance, vast experience, unrivalled knowledge, incessant inspiration, stimulating discussion, healthy criticism, unstinting moral support and above all his scientific and humanitarian approach which had left in an everlasting impression on the canvass of my mind and helped me in completing this research work on time. Throughout my study period, they sustained me with their parental care and thoughtful advice which helped me to cope with many problematic situations. It had indeed been my privilege to work under their supervision and I will remain indebted to them.

I am immensely grateful to the distinguished members of my advisory Committee Dr. J. S. Bohra, Professor and Former Head, Department of Agronomy, Dr. Ramesh Kumar Singh, Professor, Department of Agronomy, and Dr. A. K. Ghosh, Professor, Department of Soil Science & Agricultural Chemistry for their technical support and valuable guidance during the course of this investigation.

I also wish to thank Dr. Y. Singh, Professor and Head, Department of Agronomy for his valuable guidance, constant encouragement and facilitating the study and providing necessary facilities. I am highly thankful to Director and Dean, *Institute of Agricultural Sciences for providing the necessary facilities for successful completion of the research work.*

My ecstatic thanks to Prof. Avijit Sen, Prof. J. P. Singh, Prof. Ram Kumar Singh, Prof. S. P. Singh, Prof. M. K. Singh, Prof. J. K. Singh, Prof. Chandra Bhushan, Dr. M. K. Singh, Dr. R. N. Meena, Dr. Rajesh Kumar Singh, Dr. S. K. Prasad, Dr. R. S. Meena, Dr. S. K. Verma, Dr. Nikhil Singh, Dr. Sudhir Rajput, Dr. Pratik Sanodiya and other teachers and staff members of the Department of Agronomy, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi for their advice, moral support, inspiration and stimulating encouragement.

I owe my sincere thanks to Dr. Bhagat Singh, Farm superintendent and all the staff members and labourers of Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University for providing the necessary and timely research facilities throughout the work.

I am grateful to all the respondents who have wholeheartedly cooperated by sparing their valuable time and patiently responding to the enquiry.

I have no words to express my heartfelt gratitude to my seniors Dr, J. M. Sutaliya, Dr. H. S. Ravi, Dr. Himanshu Singh, Dr. Amol Dahiphale, Dr. Pravin Upadhyay and Dr. Uppu Sai Sravan, my company of my batchmate Hari Singh, Sandeep Kumar, Sunil Kumar, Sunil Kumar, Tejram, Hemraj, Sushil Kumar, Neha, Ardith, Rajni, Neelam, Hemlatha, Meena Rani, and my lovely juniors Kajal, Chandini, Anurag, Tikendra, Abhishek Shori, Ritesh, Kartikeya, Anoop, Aswin, and many well wishers for their everlasting, vibrant, encouragement, co-operation, moral support and valuable assistant at all times with cheerful smiling gestures.

I am also thankful to the non teaching staff of the department Mr. Manoj Yadav, Mr. Nandu, Mr. Tripathi, Mr. Vijay and Mr. Shyam Sunder for whole hearted co-operation.

I express my love and respect for my father, Late Shambhu Prasad Kashyap, Ex J.E, University work department, Banaras Hindu Universiry and Mother Smt. Nirmala Devi who nurtured me from my first moment on this earth till this day of happiness and joy and encouragement provided during the entire period of my study, without which I would not have been able to complete my doctorate degree in any case.

I am highly thankful to University Grants Commission and Banaras Hindu University for providing me financial assistance to complete this task.

Any omission in this brief acknowledgement does not mean lack of gratitude. My apologies to those that I have inadvertently overlooked or forgot to mention in my acknowledgements but who equally deserve.

Before doing pen down, I once again confess that I do not know how to acknowledge the help and co-operation of my supervisor, members of advisory committee, family members and relatives, seniors, juniors, colleagues but above feeling are followed from the core of my heart in the shape of words and as gospel truth.

The graces of the God are always blessed to me and give me patience and power to overcome the difficulties which came my way in accomplishment of this endeavour. I cannot dare to say thanks but only pray to bless me always.

*Lastly, I bow at the feet of "**Goddess Saraswati**" with whose omnipresent blessing today on the eve of completion of my thesis. This is a long adventurous journey to the unknown destination with a hope for future. I was not alone in this journey to accomplish this herculean task, and I am in a position to acknowledge all those who helped me a lot to cross the way in finishing the marathon work.*

Date:
Place: *Varanasi* ***(Sanjeev Kumar Kashyap)***

CONTENTS

ABBREVIATIONS

%	-	Percentage
&	-	And
°C	-	Degree centigrade
/	-	Or
:	-	Ratio
@	-	At the rate of
₹	-	Rupee
₹ ha^{-1} day^{-1}	-	Rupees per hectare per day
₹ ha^{-1}	-	Rupees per hectare
₹ kg^{-1}	-	Rupees per kilogram
+	-	Plus
=	-	Is equal to
>	-	Greater than
$annum^{-1}$	-	Per annum
ANOVA	-	Analysis of Variance
Approx.	-	Approximately
B: C ratio	-	Benefit cost ratio
BHU	-	Banaras Hindu University
CA	-	Conservation Agriculture
CE	-	Crop establishment
cm	-	Centimeter
cm^2	-	Square centimetre
CT	-	Conventional tillage
CTPTR	-	Conventional till pudduled transplanted rice
d.f	-	Degree of freedom
DAS	-	Days after sowing
DAT	-	Days after transplanting
D_b	-	Bulk density
dSm^{-1}	-	deci Siemen per meter
dSm^{-1}	-	Deci siemen per meter
DSR	-	Direct seeded rice
DTPA	-	Diethylenetriaminepentaacetic acid
E.C.	-	Electrical conductivity
et al.	-	and others (*et alibi*)
et. al.	-	And others (*et alibi*)
etc.	-	And so fourth(*et cetera*)
fb	-	Followed by
Fig.	-	Figure
g cm^{-3}	-	Gram per cubic centimetre
g ha^{-1}	-	Gram per hectare
g kg^{-1}	-	Gram per kilogram
g m^{-1}	-	Gram per meter
g	-	Gram
g	-	Gram

H_2SO_4	-	Sulphuric acid
ha	-	Hectare
ha^{-1}	-	Per hectare
HCl	-	Hydrochloric acid
$HClO_4$	-	Perchloric acid
HNO_3	-	Nitric acid
HP	-	Horsepower
hr.	-	Hours
hr^{-1}	-	Per hour
hrs day^{-1}	-	Hours per day
hrs	-	Hours
I	-	Irrigation
i.e.	-	That is (*id est*)
i.e.	-	That is (*id est*)
IGP	-	Indo Gangetic Plains
$irrigation^{-1}$	-	Per irrigation
IW	-	Irrigation water
K	-	Potassium (*Kallium*)
K_2O	-	Potassium oxide
kg ha^{-1}	-	Kilogram per hectare
kg	-	kilogram
kg	-	Kilogram
kg^{-1}	-	Per kilogram
l ha^{-1}	-	Litre per hectare
L or l	-	Litre or litre
L	-	Length
LAI	-	Leaf area index
m	-	Meter
M.D.I.	-	Moisture deficit index
m^{-2}	-	Per square meter
m^2	-	Square meter
Max.	-	Maximum
Max.	-	Maximum
mg kg^{-1}	-	Milligram per kilogram
mg	-	Milligram
Min.	-	Minimum
Min.	-	Minimum
mm day^{-1}	-	Millimeter per day
mm	-	Millimeter
MOP	-	Muriate of potash
MSL	-	Mean Sea Level
N	-	Nitrogen
$NaHCO_3$	-	Sodium bicarbonate
No.	-	Number
No.	-	Number (Numero)
NS	-	Non-significant
OC	-	Organic carbon

P	-	Phosphorus
P_2O_5	-	Phosphorus pent oxide
pH	-	Potential of hydrogen ion
Ph.D.	-	Doctor of Philosophy
R.H.	-	Relative humidity
RDF	-	Recommended dose of fertilizer
RR	-	Rice residue
R-W	-	Rice- wheat
RWR	-	Rice and Wheat residue
s	-	Significant
S.Em.±	-	Standard Error of Mean
SPAD	-	Soil plant analysis development
t ha^{-1}	-	Tonnes per hectare
U.P.	-	Uttar Pradesh
viz.	-	Namely (*videlicet*)
W	-	Weight
Zn	-	Zinc
ZT	-	Zero tillage

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

PREFACE OF THE THESIS

This thesis is written as the final document for doctoral degree in Agronomy to study the **"Effect of crop establishment methods and irrigation scheduling on growth, yield and water productivity of wheat in rice-wheat system"**. I hope its results will be interesting to agronomists, soil science researcher and also to farmers for enhance the crop productivity, profitability, soil health and water productivity of wheat through conservation agriculture based crop establishment methods and irrigation scheduling.

The aforesaid work described in the thesis was carried out during *Kharif* and *Rabi* season of 2016-17 and 2017-18, respectively at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University under the supervision of Dr. U. P. Singh, Professor, and Dr. V. K. Srivastava, Professor, Department of Agronomy, Institute of Agricultural Sciences, BHU, Varanasi.

***Chapter I* -** the introduction part which provides much of the general background and overview of residue burning and climate change issues and decline water resources, for increasing crop productivity, profitability, soil health and water productivity of wheat. This chapter justifies the reason for choosing this research topic, lastly the objectives of the research work.

***Chapter II* -** the review of literature deals with the important work done in the past because it provides a conceptual frame work for carrying out as well as understanding the outcome of present work.

***Chapter III* -** the materials and methods details the methodology employed for carrying the research work describing the materials and treatments and methods for statistical analysis.

***Chapter IV* -** the experimental findings deal with the results of the research work illustrated with help of tables figures and photographs.

***Chapter V* -** the discussion which explains the results obtained with appropriate reasons and support.

***Chapter VI* -** the summary and conclusion gives brief description of the results of the experiment.

In the last chapter, references which have been consulted during the course of investigation have been cited.

(Sanjeev Kumar Kashyap)

INTRODUCTION

India is an agrarian country and agriculture is the major field of employment for a large number of Indian people. Rice and wheat are the major cereal crops having 70-75% to the total food grain basket, play role as backbone in country's food security. Rice-wheat (R-W) cropping system is one of the most dominating cropping systems in South Asia, covering with 14 million hectares area (Singh *et al*., 2010) and feeding more than 400 million people. This system occupied about 10.5 million hectares in India and large area in Pakistan (2.2 million ha), Nepal (0.5 million ha) and Bangladesh (0.8 million ha). Wheat (*Triticum aestivum* L.) is the leading cereal crop in world, with area covering 220.06 m ha with 2^{nd} position after maize, accompanied by production of 763.2 m t and productivity of 3.47 t ha^{-1} (USDA, 2019). It is a major staple food in more than 40 countries, feeding about more than one third of world's population with contributing 35% of world's food basket and meets 20 % of the total food of the world population (DFI Committee Estimates, 2018). India is the 2^{nd} leading wheat producing country of the world after China (134.33 m t), followed by Russia (85.17 m t). However, India having rank first (30.79 m ha) in area followed by Russia (27.37 m ha) and China (24.51 m ha) (USDA, 2019). India contributes about 15.36% to the world wheat production (Commodity profile of wheat, 2018). In India, wheat is 2^{nd} most staple cereal food after rice and it's provide 20% of proteins and 19% calorie intake to insure food and nutrition security. It covers the 21% of cultivation area and contributes 35% of total food grain production of the India (DFI Committee Est., 2018). The biological composition of wheat is 12.1% protein, 59.2% starch, 70% total carbohydrates, 1.8% lipids, 2.0% reducing sugars, 1.8% ash, 6.7% pentoses. It also has several minerals and vitamins *viz.,* 37 mg calcium, 4.1 mg iron, 0.45 mg thiamine, 0.13 mg riboflavin, and 5.4 mg nicotinic acid in 100 g of wheat grain (Vaughan *et al*., 2003).

Recently, it has been seen that due to climate change and reduced soil fertility, rice and wheat productivity has stagnated, posing a serious threat to the sustainability of rice-wheat cropping system. Consequently the major challenge in farming is to raise the productivity for meeting food demand without adverse environmental impact. In the past two- three decade many research efforts has been made to increase the productivity of wheat yields, despite, there are still large gaps between biologically and climatically achievable potential yield at research station and on farm yield.

In R-W system, cultivation of rice is done by manual seedling transplantation in puddled field and succeeding wheat crop is cultivated with intensive tillage operations. The tillage and crop establishment accounts 25-30% of the total cost of production in rice–wheat cropping system (Saharawat *et al.*, 2011; Pathak *et al.*, 2011). Practice of puddling makes soil poor in physical condition for establishment and growing the succeeding crops. This practice not only requires high water, labour, capital and energy but it also leads to the formation of compact hard soil surface, ultimately deteriorates soil health and delays planting of succeeding wheat crop. Timely establishment of wheat is critical as yield reductions of 1-1.5% per day occur when delaying of wheat seeding each day after the optimum sowing date, November 15 in the Indo-Gangetic planes (IGP) (Hobbs and Morris, 1996). In addition, practicing of puddling and repeated tillage creates a hard-pan at shallow depths, which inhibits root elongation of the post-rice crop, ultimately reduce crop yield (Boparai *et al.*, 1992).

The mechanization of farm saves time and labor, but raises the energy bill for farmers. There will be more energy demand for agriculture in the coming years. Narrowing profit in the agriculture is the serious concern, not only farmers point of view but for scientific communities and policy makers as well. At present, the major challenge is to fulfill the increasing quality food demand from the decreasing land and water resources, in a sustainable manner. Thus, the major challenge for the scientific communities is to evolve an alternative production system that produce higher yield at a lower cost and also improves farm profitability and sustainability (Jat *et al.* 2011; Gathala *et al.* 2011). For the sort out of these challenges, agricultural systems need a combination of new technologies which gives more attention on issues of sustainability and profitability.

Published studies reported an 8% yield reduction of wheat, when sown after conventional tilled puddled transplanted rice as compared to wheat sown after direct seeded rice (DSR) in un-puddled situation (Kumar *et al*., 2008). In the conventional tillage systems, due to accelerated oxidation soil organic matter is gradually decline. The crop residues burning causes greenhouse gases emission, air pollution, loss of plant nutrients available in soil and disturb beneficial soil microorganism. Conservation agriculture (CA) practices are potential tool to address the issues regarding soil and environmental degradation. It has great ability to manage the degraded ecologies, where yield stagnation and farm profit have become major concern. CA based technologies involve minimum mechanical soil disturbance, maximum soil cover with crop residues or other cover crops and sensible crop diversification for enhancing productivity, profitability and soil health (Singh *et al.,* 2009). It has appeared as way for transition to the sustainability of intensive cropping systems. Thus, many long-term experiments have been conducted at global level to introduce conservation agriculture technologies in different cropping systems as a ways of enhancing crop yields, soil health and farm income, although reduction in energy requirement and environmental degradation. However, in India CA is adopted by many farmers and its success is more in irrigated areas. Despite, Zero Tillage (ZT) in wheat is widely adopted, rice is still cultivated by transplanting in conventionally puddled soil. Hence, the advantage of ZT gains during the wheat growing, loose during the rice season due to practicing puddled transplanting establishment methods. To attain the full benefits of ZT, both rice and wheat need to be grown under double zero tillage with residue retaintion (Singh *et al*., 2012). In addition, emerging labor and water shortages, increasing fuel prices and soil fertility issues have increased the interest in a switch from puddled transplanting to DSR (Kumar and Ladha, 2011). ZT reduces the yield losses due to delayed sowing as it ensures the wheat sowing early by 10-15 days and also conserve the time and money required for field preparation (Sharma *et al.,* 2002; Chandana *et al*., 2010). Soil moisture content in ZT or no-till systems is more than in conventional tillage system (Ussiri *et al.,* 2009). ZT wheat system has an advantage of early seeding, which avoid the terminal heat stress, ultimately better crop yield and profitability as comprising with convention till wheat. Various published studies (Hobbs *et al*., 2000; Gupta *et al*., 2002; Hobbs and Gupta, 2003) showed that 15-30% irrigation water (IW) saved when wheat was grown under ZT as compared to conventional tilled in the R-W system of IGP. Because ZT takes instant advantage of residual moisture from the previous rice crop by escaping field preparation time, as well as cutting down on subsequent irrigation requirements, irrigation water use is decreased by about 10 cm (Malik *et al.,* 2002). It is realizable that timely seeding of the conventional wheat with the same time as the ZT allowed better use of residual soil moisture for the wheat, which does not normally happen in field situation when conventional sowing is delayed.

Water is a precious and necessary input plays an important role to assured crop production since it control the maintenance of turgidity, nutrients absorption, metabolic process and photosynthesis in the plants. Hence, there is need to develop an optimum irrigation schedule to provide the adequate available soil moisture during the crop growth period for better crop yield potential. Among the several developed criteria of irrigation scheduling, meteorological based approach is very widely accepted by scientific communities all round the world. It is established fact that evapo-transpiration by a full crop cover is very similar with the evaporation from an open pan evaporimeter (Dastane, 1972). Parihar *et al.* (1976) recommended a relatively more practical meteorological technique of irrigation scheduling based on IW-CPE which is a ratio between given amount of applied irrigation water (IW) and cumulative pan evaporation (CPE) minus rain fall. The IW-CPE technique has its own merit of simple functioning operation and higher water use efficiency.

It is well known that in future, less and lesser amount of irrigation water will be available for agriculture sector due to raising water demand for domestic need, industrial and other purposes. It is considered that even after approaching the full irrigation potential, nearly 45% of the total cultivated area will remain rainfed (DFI Committee reports, 2017). Further, in view of continuous high consumption of ground water over a period of time, the water table is gradually declining at substantial rate and equilibrium must be maintained between rate of corresponding ground water recharge and withdrawals for future water security in agriculture. The IW-CPE ratio based approach can help to solve these issues. In cultivation of wheat, farmers usually adopts criteria for irrigation scheduling either based on physiological growth stages *viz.* CRI, tillering, jointing, flowering, milking and dough stages (coincide with the critical stages of crop) or on soil moisture condition.

Enhancing water productivity (WP) adopting different climatological approaches for boosting of crop can help in improving both water sustainability and food security for future generation in different parts of the world (Brauman *et al.*, 2013). Previously, with ample water supplies, our priority was to boost up the yield per unit land. Now, with shrinking freshwater availability, our goal has shifted to increase WP with less effect on the environment. Future of irrigated agriculture particularly in RW system is now threatened by serious groundwater depletion. Hence, there is a need to manage water efficiently by adopting high cost-effective and eco-friendly approaches. The WP can be increase by producing more with same water or producing the same yield with lesser water.

In recent years crises of water is a vital issue. Rational use of water is needed through adopting CA based resource conservation technologies (RCTs) for sustaining and improving the productivity of RW system. In addition to water management practices, crop establishment and residue retention options will influence the water use efficiency (WUE), productivity and profitability. Water management by proper irrigation scheduling in combination with appropriate CA based crop establishment techniques may be a potential solution to save water and increase WUE, WP and crop yield of wheat in RW system.

Considering the above facts in view present investigation entitled **"Effect of crop establishment methods and irrigation scheduling on growth, yield and water productivity of wheat in rice-wheat system"** was carried out at the Agricultural Research Farm, Institute of agricultural Sciences, Banaras Hindu University, Varanasi with the following objectives:

1. To study the effect of crop establishment methods and irrigation scheduling on growth and yield of wheat,
2. To determine the water productivity of different treatments,
3. To study the NPK uptake by crop in different treatments,
4. To workout economics of the treatments.

Chapter II

REVIEW OF LITERATURE

The soil-water-plant environment system have to be handle sensibly for ensuring a good crop-stand and to enhance resource-use efficiencies, where tillage of the has a important role. Proper tillage can reduces the soil associated constraints while improper tillage may increases deterioration of soil structure, accelerated erosion, decrease organic matter and nutrient status, and disturbance of water cycles, (Lal, 1996; Gathala *et al.*, 2011; Bhatt *et al.*, 2016). Intensive conventional tillage practices change these properties in every cropping cycle, ultimately the whole soil-plant system are affecting. To conflict the soil losses and preserve soil moisture, soil conservation tillage techniques have been introduces in USA known which call for minimize the disruption of soil, improve natural biodiversity in soil, through minimize soil erosion and degradation of soil health (Karunakaran and Behera, 2015).

In 1996, Hobbs and Morris observed that rice-wheat cropping system of Indo-Gangetic plains suffer with lower production of wheat due to poor plant stand which mainly results of late sowing and problem covers almost 12 million hectares area of the system. It also noted that there is a reduction of 1-1.5% yield potential ha^{-1} day^{-1} due to late planting of wheat i.e. after November. This delay occurs mainly because of late harvest of previous rice crop and longer field preparation time for wheat sowing with conventional method. The problem of late sowing and poor crop stands can be overcome with the minimizing tillage either zero tillage or no tillage options in Asia.

A brief synopsis of literature has been reviewed relevant to the field experiment entitled **"Effect of crop establishment methods and irrigation scheduling on growth, yield and water productivity of wheat in rice-wheat system**" under the following heads:

2.1 Effect of crop establishment methods on growth, yield and water productivity of wheat in rice-wheat system

2.1.1 Growth character

Ravi *et al.* (2019) noticed significant maximum plant height and dry matter accumulation of wheat with zero till wheat grown after zero till rice followed by zero till wheat grown after reduced till direct seeded rice over conventional practice, in 2012-13 and 2013-14 at Varanasi, Uttar Pradesh.

At Varanasi, the higher plant height, number of tiller and dry matter accumulation of wheat were observed by Kumar and Singh (2017) under the no till wheat with residue retention over the residue removal treatment.

Kumar *et al*. (2017) during their field study at Haryana (India) in *rabi*, 2014-15 and 2015-16 examined the impact of crop establishment methods on wheat growth and rivaled, zero tillage wheat with rice residue retention treatment recorded significantly higher growth parameters *viz*. numbers of tillers (m^{-2}), plant height, dry matter accumulation ($g\ m^{-2}$), as compared to conventional method of broadcasting. However, it remained at par with zero tillage without residue treatment.

Sharma *et al*. (2016) at Jammu observed higher growth of succeeding wheat crop sown in zero tillage condition as compare to conventionally sown wheat under rice-wheat cropping system.

On the basis of two year of experimentation Jat *et al*. (2016) reported that significantly maximum plant height, dry matter accumulation and number of tiller were recorded at harvest under no till permanent beds system than conventional tillage system.

According to Jat *et al*. (2009) dry matter accumulation and number of green leave $plant^{-1}$ was maximum in conservation agriculture based practices when it was practiced with residue retention and mulching than residue removal and conventional practices.

Higher plant height and number of tiller of wheat was observed by Yadav *et al.* (2005) under zero tillage system than conventional system.

2.1.2 Yield and yield attributes

Singh *et al*. (2020) investigated a series of field experiment at Bihar, India during 2013-14 to 2015-16 on crop establishment methods and alternative tillage practices in rice-wheat cropping systems and they found higher yield with zero till wheat than conventional till wheat when wheat was cultivated after non-puddled direct seeded rice than other practices.

Tomar *et al*. (2019) performed a three years study from 2015 in rice-wheat cropping system at Gorakhpur, U.P. and noticed higher yield and yield attributes with zero tillage wheat as compared to farmers practice.

Kumar *et al*. (2019) studied on tillage and crop establishment methods impacts on productivity of rice-wheat system at Varanasi and reported 30% higher grain yield under zero till wheat with residue after zero till direct seeded rice with residue than farmer practice of rice-wheat system.

Kumar *et al.* (2017) performed an experiment at Varanasi and reported that the rice residue retention with *Trichoderma* application produced significantly higher crop growth, yield attributes, grain (3321 and 3617 kg ha^{-1}) and straw yield as compared to residue retention alone (3264 and 3681 kg ha^{-1}) and residue removal (3069 and 3386 kg ha^{-1}).

Kumar *et al*. (2017) observed that zero tillage wheat with rice residue retention resulted significantly higher yield attributes and grain yield (kg ha^{-1}) as compared to conventional method of broadcasting. However, it remained at par with zero tillage without residue.

Singh *et al*. (2017) determined impacts of establishment methods on wheat productivity and noticed that happy seeder planted wheat recorded higher grain yield than bed planted wheat, zero-till wheat and conventional till wheat.

Nagargade *et al*. (2016) recorded highest earhead length (cm), earhead weight (g), number of grains earhead^{-1}, grain yield and straw yield with zero-till wheat sown after conventional till rice (Puddled transplanted) followed by zero till wheat-reduced till DSR system. However, Bohra and Kumar (2015) also noticed that zero till drill wheat sowing had higher grain yield at Varanasi (U.P.). Accordingly, Singh *et al.* (2009) concluded based on three years of on-farm evaluations (2005-2008) that ZT wheat and bed planted wheat are the appropriate crop establishment system in Eastern UP for reducing cost and enhancing yield and profitability over conventional till wheat.

Wheat grown under rice wheat cropping system with residue retention with *Trichoderma* application produced 8.2 and 6.8% higher grain and 7.3 and 6.2% straw yield over residue removal treatment as reported by Kumar *et al.* (2019). Similarly Singh *et al*. (2015) noticed the higher yield under ZT wheat with full residue (anchored + loose) with and without *Trichoderma* as compared to residue removal.

Kumar *et al.* (2013) reported highest yield of wheat under ZT system among the five tillage system *viz.* conventional, reduced, rotavator, bed planting and zero tillage,

Gathala *et al*. (2011) carried out a series of field studied upto 7 years to determine various tillage and crop establishment methods impacts on soil physical properties and observed that long term improvement in soil physical properties in zero tillage system improved wheat yield. The highest bulk density of the 10-20 cm soil layer was under puddled treatments whereas, lowest under zero till treatments.

Maximum average grain yield (4237 kg ha^{-1}) and straw yield (6235 kg ha^{-1}) of wheat were reported by Saini *et al. (*2011) at Pantnagar, Uttarakhand, when wheat was sown after direct seeded rice. They also found maximum number of grains per ear under zero till wheat which were 0.79, 6.93 and 4.9% higher than that of strip till drill, bed planted and conventional till wheat, respectively.

Singh *et al.* (2012) conducted a field trial in 2009-10 and 2010-11 and noted 10% higher yield in double no-till, 20% lower production cost and 34% higher net return than conventional farmer practice.

Higher yield of wheat is reported by Ram *et al.* (2010) in ZT wheat with residue because of cumulative effect of better light interception, more dry matter production, lower soil and canopy temperature, higher soil moisture, tillers, grains per ear and test weight compared to ZT practices without residue as well as conventional practices. Accordingly, Jat *et al.* (2009) stated that Zero tillage in wheat can provide better yield if it is taken after direct seeded rice as compared to conventional system.

Bakht and his coworker in 2009 recorded 1.31 times higher wheat grain yield and 1.39 times straw yield by crop residue incorporation. However, Sidhu *et al*. (2007) recorded an average higher wheat grain yield by 9-15% with happy seeder sowing with rice residue retention as compared to convention tillage after residue burning. According to Singh *et al.* (2016), double ZT and bed planted wheat gave higher yield lower cost and higher net return over conventional system, which minimize the use of external costly inputs production cost and enhanced nutrient use efficiency and profitability.

Bohra *et al.* (2006) at Varanasi reported significantly higher grain yield with sowing of wheat by zero till drill over other crop establishment methods. This yield increase was attributed due to more favorable soil physical condition under zero tillage system over conventional system.

Singh *et al.* (2018) observed that ZTDSR-ZT wheat with residue retained and RWCM based nutrient approaches is a potential CA based system for better growth, yield, system productivity and profitability in wheat under rice-wheat system.

Sayre *et al.* (2005) carried out an experiment to know the effect tillage practices on wheat and they found 25-30% improvement in grain yield under wheat shown in zero till condition with residue retention as compared to other shown conditions *i.e.* heavy tillage practices before sowing, mono cropping and residue removal.

Malik *et al.* (2004) observed an increment in wheat yield under ZT condition at farmers' fields ranging from 1% in Punjab to 12% in Bihar. On an average 280 kg ha^{-1} increase was recorded in 112 farm trials (46 in 2000-01 and 66 in 2001-02) across five states in the IGP. Dhiman *et al*. (2003) observed an average yield increase ranging from 110 kg ha^{-1} in Punjab to 490 kg ha^{-1} in Bihar. Significantly higher grain yield was recorded at either on-station or on-farm trials under ZT with an increasing trend from Punjab towards the middle Gangetic plains.

2.1.3 Economics

Singh *et al*. (2020) during 2013-14 to 2015-16 conducted a series of field investigations at Bihar, India and noticed that production costs were reduced with zero till wheat resulted into higher gross margin and B:C ratio as compared to system of wheat intensification and conventional till wheat. As a system, machine till rice or direct seeded rice followed by zero till wheat recorded higher gross margins than other practices. However, on the basis of two years of experimentation Ravi *et al.* (2019) reported that Rice–wheat system (ZTR-ZTW) registered highest gross return, net return and B-C ratio of wheat among various crop establishment methods, while lowest values recorded with CTPTR-CTW. Double ZT (ZTR-ZTW) enhanced mean net return by 16% and benefit-cost ratio by 38.3% over CTPTR-CTW.

Tomar *et al*. (2019) conducted a three years study from 2015 to assess the impacts of crop establishment methods on productivity of rice-wheat cropping system at Gorakhpur, U.P. and noticed that maximum net return and B: C ratio was recorded with rice (DSR)-wheat (ZT) than the rice (DMS)-wheat (ZT) and rice (UPMTP)-wheat (ZT). Kumar *et al*. (2018) noticed maximum net returns with zero till wheat with residue after zero till direct seeded rice with residue among all the crop establishment methods.

Singh *et al*. (2017) during their field study to determine impacts of establishment methods in on wheat productivity and nutrient uptake and noticed that happy seeder planted wheat recorded higher net profit and benefit cost ratio than bed planted wheat, zero-till wheat and conventional till wheat.

Sharma *et al*. (2016) noted that net returns and benefit cost ratio were higher with zero tilled wheat and wet seeded rice in rice-wheat cropping system at Jammu. According to Bohra and Kumar (2015), at Varanasi (U.P.) zero till drill wheat was the most cost effective crop establishment which gave maximum net return and B:C ratio.

Jat *et al.* (2014) observed CA based practices in rice-wheat cropping system as superior over CT based practices in term of economics in a smallholder production system of Eastern IGP of South Asia.

Kumar *et al.* (2013) noticed that operational field capacity, specific energy and energy usage efficiency has increased by 81%, 17% and 13% respectively in zero tillage as compared to the conventional tillage. Zero tillage establishment method also recorded enhanced net income by 33% in ZT and by 20% in reduced tillage in comparison to conventional tillage. Saharawat *et al*. (2010) noticed 6% more profit with no-till wheat system than the conventional practice.

Erenstein and Laxmi (2008) found lower input cost for production of wheat in zero tillage condition in comparison to conventional tillage system because of no requirement of cost of land preparation in ZT.

2.1.4 Nutrient content and uptake

Shahane *et al*. (2020) at IARI, New Delhi noticed maximum system N, P, K and Zn uptake in aerobic rice system followed by zero tillage wheat than other crop establishment methods during 2013-14 and 2014-15.

On the basis of six years of research, Nandan *et al*. (2019) concluded that Zero till crop establishment method in rice based system (ZTTPR-ZTW and ZTDSR-ZTW) recorded better soil organic C-pool macro-aggregate formation and carbon stock in aggregates and conservation tillage increased the stabilization of residue C-input compared to conventional CTTPR- CT. Similarly Malhi and Lemke (2007) stated that crop residue is a good source of organic matter and its improve the soil organic matter when added back to soil as residue and ultimately its increases organic carbon and N content in soil. There was substantial loss of organic C and N when residue removed from soil system.

Singh *et al*. (2017) determined impacts of establishment methods on wheat productivity and nutrient uptake and noticed that happy seeder planted wheat recorded higher nutrient (N, P and K) uptake in wheat grain than bed planted wheat, zero-till wheat and conventional till wheat. However Nagargade *et al*. (2016) studied the impact of crop establishment methods on wheat in rice-wheat cropping system at Varanasi (U.P.) and observed highest N, P, K content and removal with zero till wheat-reduced till DSR than zero-till wheat-conventional till rice (Puddled transplanted)

Saini *et al.* (2011) noted that ZT drill wheat showed significantly higher nutrient uptake than that of conventional, bed planted and strip till drill wheat.

2.1.5 Water productivity

Parihar *et al*. (2019) investigated the impact of tillage and crop establishment methods on crop and water productivity and noticed that CA-based permanent raised bed with residue and zero tillage with residue practices decreases the total system water use in maize-wheat and maize-chickpea rotations which enhanced system water productivity than conventional till with residue system. Irrespective of crop rotations and tillage and crop establishment practices residue management treatments increases the soil moisture and also moderates the soil temperatures.

Sharma *et al*. (2019) concluded his research experiment on the basis of mean data of two years, that Full conservation agriculture based ZTDSR-ZTW system required lowest irrigation water use (182.2 cm ha^{-1}) in comparison to TPR-CTW (251.4 cm ha^{-1}) and there was 27.5% saving in irrigation water use under full CA based rice-wheat system (ZTDSR-ZTW) over farmer’s practice (TPR-CTW).

Devkota *et al*. (2019) studied a case on crop establishment impact on wheat and they submitted their reports with significantly 9% higher grain yield 24% average water productivity of wheat and less irrigation water under zero tillage compared to conventional sowing system.

Jat *et al*. (2018) analyzed the tillage and crop establishment method impacts on yield and water productivity of maize-wheat system found permanent bed with mungbean integration superior as system water use efficiency than conventional tillage. However, Punia *et al*. (2016) reported Zero till rice-zero till wheat (ZTR-ZTW) crop establishment method had better temperature modulation and less water consumption in comparison to conventional system. Accordingly Gathala *et al*. (2011) concluded that water productivity and infiltration rate was higher under double zero till system compared to conventional system of tillage, on the basis of seven years of rice-wheat rotation in Indo-Gangetic plains.

2.2 Effect of irrigation scheduling on growth, yield and water productivity of wheat in rice-wheat system

2.2.1 Growth character

The growth of a plant is a complex and dynamic function of internal plant factors and environmental conditions. The criteria for assessing vegetative growth of wheat crop in terms of stem elongation, tillering, height and leaf production was studied by different researchers. Generally, up to ear emergence, vegetative growth of wheat is continuous process. Irrigation application at 1.0 IW/CPE was found optimum for obtaining increased height of wheat plant (Sarel, 2015; Singh *et al*., 2013; Singh *et al*., 2012). Initiation of second physiological development phase *i.e* tillering in wheat is started in third week after sowing which increased tillers in plant upto 45 days and after that some tiller mortality occurs up to harvest. The application of irrigation at 1.25 to 1.0 IW/CPE has been found optimum for better tillering (Yaghobi, 2008; Behera, 2002). Irrigation at 0.9 IW/CPE was found optimum for satisfactory number of leaf in wheat (Singh *et al*., 2005; Angadi and Janawade, 2001). Many researchers studied the pattern of dry matter accumulation in wheat growth. It is the product of net assimilation. Initially, accumulation of dry matter was slow up to 45 days, however, it increased rapidly during panicle initiation to complete flowering (Jadhav, 1978; Singh and Singh, 1973; Ghos *et al*., 1975). Many workers reported that dry matter accumulation rate from flowering to maturity was increasing but varied slightly. An increased accumulation of dry matter after flowering was observed by Pal (1966), Singh and Singh (1973) and Jadhav (1978) than that observed by Ghos *et al*. (1975).

Khan *et al*. (2020) noticed that crop irrigated at 1.0 ET_0 (according to farmer's practice) recorded maximum number of leaves plant^{-1}, tillers and dry matter accumulation than 0.5 ET_0: deficit irrigation and 1.5 ET_0: over irrigation. Kaur *et al*. (2018), at Panjab, noticed that the growth parameters *viz*. Plant height (cm), leaf area index, number of tillers in running meter and dry matter accumulation (g m^{-1}) were highest with irrigation of the crop at CRI, maximum tillering and flowering stage which was followed by crop irrigation at CRI, maximum tillering, jointing and milking stage.

At Meerut, U.P., Singh *et al*. (2018) reported that irrigation scheduling at CRI + 50 mm CPE gave highest net photosynthesis rate, net transpiration rate and lowest canopy temperature of wheat leaves as compared to conventional irrigation.

Gupta *et al*. (2016) at Faizabad (U.P.) noticed that irrigation scheduling at IW/CPE ratio of 1.2 recorded significantly maximum plant height, dry matter accumulation (gm^{-1}) and number of shoots m^{-1} over other irrigation treatments except irrigation scheduling at IW/CPE ratio of 1.0 and five irrigation each at CRI, tillering, late jointing, flowering and milking stage.

Narolia *et al*. (2016) assessed the irrigation scheduling impacts on wheat and observed significantly increased plant height, leaf-area index and dry-matter accumulation (g m^{2}) with irrigation scheduling at IW/CPE ratio of 1.0 than other treatments. Accordingly, Sarel (2015) noticed higher plant height and dry matter accumulation of wheat with IW/CPE ratio of 1.0 over IW/CPE ratios of 0.25, 0.50 and 0.75.

Singh *et al*. (2013) performed a field experiment at Ludhiana and reported that IW/CPE ratio of 1.0 gave the highest plant height and dry matter accumulation, which was significantly higher than 0.75 IW/CPE ratio and 0.50 IW/CPE ratio in barley crop. These results are similar to those of Elmobarak *et al*. (2007).

Singh *et al*. (2012) carried out a field experiment at Faizabad in *Rabi* 2007-08 to assess the wheat performance under various irrigation supplementation and found that plant height and dry matter accumulation of wheat crop were significantly increased when crop was irrigated at IW/CPE ratio of 1.0 over lower IW/CPE ratios. This trend was similar for recovery and yield of malt during both the crop season. Similarly Singh *et al*. (2012) at Ludhiana, noticed that malt barley crop irrigated at IW/CPE ratio of 1.0 gave maximum plant height and dry matter accumulation over IW/CPE ratio of 0.75 and 0.50.

Idnani and Kumar (2012) find out the response of irrigation schedules on the growth of wheat and revealed that highest plant height, leaf area index and dry matter accumulation were obtained when wheat crop was irrigated at CRI + 100 mm CPE than irrigation at CRI + 200 mm CPE and CRI + 150 mm CPE.

Yaghobi (2008) observed the response of irrigation levels on wheat productivity (*Triticum aestivum* L.) under zero tillage and reported higher dry matter accumulation, number of tillers, plant height in crop irrigated at 1.25 and 1.0 treatment, 0.75 and 0.5. IW/CPE ratios. Similarly, Nadeem *et al*. (2007) noted maximum vigorous growth component of wheat with irrigation of crop at 1.25 IW/CPE. Similarly, Singh and Sheoran (2006) recorded the maximum plant height and plant dry matter (g m^{-2}) in late sown wheat with irrigation at 0.9 IW/CPE ratio among three levels of irrigation (0.5, 0.7 and 0.9 of IW/CPE).

Parashar and Thaman (2005) assessed the irrigation requirements of late sown wheat (*Triticum aestivum*) at Ludhiana (Punjab) and observed significantly higher plant height and yield attributes when irrigation scheduling was done at 40 and 50 mm CPE as compared to 65 and 80 mm CPE. According to Singh *et al*. (2005), significantly maximum leaf, stem, spike and total dry weight of wheat was noticed with irrigation at IW/CPE ratio of 0.9 over IW/CPE ratio of 0.5 and 0.7.

Saren *et al*. (2004) evaluated the impact of irrigation on wheat and revealed that the highest plant height, leaf area index, dry matter accumulation and crop growth rate of wheat was observed with the treatment, four irrigations given at root initiation, tillering, flowering and grain development stages.

Singh *et al*. (2003) reported from their field trial on effect of irrigation scheduling in wheat that an increased plant height with treatment 1.0 IW/CPE ratio over 0.6, which was at par with 0.8 IW/CPE. However, Mahmood and coworkers (2002) reported highest plant height (cm) and tillers (m^{-2}) at IW/CPE ratio of 0.9 which was superior over IW/CPE ratio of 0.7.

Behera (2002) at IARI, observed crop irrigated at IW/CPE ratio of 1.0 performs better for higher effective tillers $plant^{-1}$ in wheat. However, Angadi and Janawade (2001) studied the influence of irrigation schedules on wheat and noted higher plant height, number of tillers $plant^{-1}$ and number of functional leaves when irrigation scheduling was done at 0.9 IW/CPE ratio.

Jana *et al*. (2001) assessed the impact of irrigation regimes from 0.7 to 0.9 IW/CPE ratio on wheat and recorded increased plant height, number of tillers m^{-1} and dry matter accumulation in treatment IW/CPE ratio 0.9. Whereas, Pal *et al*. (2001) evaluated the response of wheat under various irrigation regimes and found that irrigation level at IW/CPE ratio of 1.2 is suitable to achieve highest plant height, dry matter and leaf area. Although Thakur *et al*. (2000) evaluated performance of wheat as influenced by various irrigation levels and reported increasing irrigation from 0.8 to 1.0 IW/CPE ratio increased growth characters *viz*., plant height, effective tillers $plant^{-1}$, number of functional leaves and dry matter.

2.2.2 Yield and yield attributes

Various management practices including scheduling of irrigation influence yield attributes *viz*. weight of panicle, length of panicle, number of spikeletspanicle^{-1}, number of panicles $plant^{-1}$, number of grains $panicle^{-1}$, weight of grains $panicle^{-1}$, test weight and finally yield. As reported by various researchers, Sarel (2015), Singh *et al*.

(2012), Yadav (1978), Tomer *et al*. (1976), available soil moisture above 60 to 75 per cent or irrigation scheduling at 0.9 to 1.1 IW/CPE ratio were found optimum to improve the yield components significantly.

Khan *et al*. (2020) investigated the impact of various irrigation rates on yield of wheat at Faisalabad, Pakistan. They found irrigation scheduling at 1.0 ET_0 (according to farmer's practice) recorded highest 1000-grain weight and grain yield.

In Egypt, Moursi *et al*. (2019) observed that irrigation scheduling at 40% ASMD (irrigation scheduling by PEM) recorded higher wheat yield components as well as grain yield than the other irrigation treatments.

Kaur *et al*. (2018) during their field experiment at Punjab noticed highest yield attributes and yield with the irrigation application at CRI, maximum tillering and flowering stage which was at par with irrigation scheduling at CRI, maximum tillering, jointing and milking stage.

Singh *et al*. (2018) concluded from their experiment that irrigation of the crop at CRI + 50 mm CPE recorded significantly higher grain yield by 12-19%.

Gupta *et al*. (2016) during their field investigation in 2013-14 to evaluate the irrigation scheduling impacts on the growth and yield of wheat at Faizabad (U.P.) noticed that significantly higher yield and yield attributes were recorded with irrigation scheduling at IW/CPE ratio of 1.2 which remained at par with irrigation scheduling at IW/CPE ratio of 1.0 and the treatment with five irrigations each at CRI, tillering, late jointing, flowering and milking stage.

Narolia *et al*. (2016) conducted a series of field investigations at Kota, Rajasthan during *Rabi*, 2011-12, 2012-13 and 2013-14 to find out the irrigation scheduling impacts on productivity, profitability and nutrient uptake of wheat. They observed that crop irrigated at IW/CPE ratio of 1.0 recorded significantly maximum number of effective tillers m^{-2}, ear length (cm), grains ear^{-1} and 1,000-seed weight (g), grain yield (t ha^{-1}), straw yield (t ha^{-1}). However, IW/CPE ratio of 0.8 recorded maximum harvest index.

At Udaipur (Rajasthan), Sarel (2015) studied the effect of nitrogen and irrigation levels on wheat productivity during *Rabi*, 2013-14. The experimental findings indicated that crop irrigated at IW/CPE ratio of 1.0 recorded highest yield attributes *viz*. total number of tillers of wheat m^{-1} row length, number of grain ear^{-1}, grain yield, straw yield and harvest index than IW/CPE ratios of 0.25, 0.50 and 0.75.

Shamsi and Kobraee (2013) at Iran in 2010-11, evaluating through their field experiment on wheat to find out impact of water deficit stress on yield and water use efficiency that among the three cultivars the Roshan-Back Cross cultivar recorded higher yield stability and lower yield reduction under treatments of stress conditions.

Chouhan *et al*. (2012) noted significantly higher grain yield (45.09 q ha^{-1}) of wheat with higher irrigation frequency of 1.0 IW/CPE ratio.

Singh *et al*. (2012) noticed significantly maximum effective tillers, grains ear^{-1}, 1000-grain weight, grain yield (5.3 t ha^{-1}) and straw yield (7.35 t ha^{-1}) were recorded with irrigation scheduling at IW/CPE ratio of 1.0 than IW/CPE ratios of 0.75 and 0.50. This trend was also similar for recovery and yield of malt in barley crop.

Idnani and Kumar (2012) conducted field experiments during the *Rabi* seasons 2007-08 and 2008-09 on sandy loam soil of IARI field, in Delhi and found irrigation at CRI + 100 mm CPE recorded significantly higher number of effective tillers m^{-1}, ear length, spikelet's $spike^{-1}$, grains $spike^{-1}$, grain weight $spike^{-1}$, 1000-grain weight, grain yield, straw yield and harvest index in wheat crop over CRI + 200 mm CPE and CRI + 150 mm CPE. However, Singh and coworkers (2011) laid out a field trial to determine the impact of rice straw mulch and irrigation schedules on growth, yield and water productivity of zero-till wheat at Panjab, India and found that decreased and delay in irrigation numbers also decreased the grain yield of wheat between crown root initiation and grain filling stages.

Rahim *et al*. (2010) reported from their field trial that maximum yield of the crop was with application of three irrigations once at crown roots, booting and grain development stages.

Khokar *et al*. (2010) observed maximum spike length, number of grains and grain yield of wheat, when irrigation scheduling was done at five different wheat growth stages over three and four irrigation respectively. Similarly, El Afandi and coworkers (2010) noticed improved yield by 8% when crop was irrigated at every 21 days interval after germination of wheat with higher water productivity. However, Khang *et al*. (2010) reported highest yield and water use efficiency of the crop when irrigation scheduling was done at 3 weeks after planting than 2 and 4 weeks after planting.

Bandyopadhyay *et al*. (2009) investigated the effects of irrigation scheduling and nutrient management on yield, root growth and water use efficiency of wheat under different cropping systems and observed wheat grain yield was significantly increased when crop was irrigated at 0.8 IW/CPE over irrigation at 0.6 IW/CPE.

Masanta *et al*. (2009) obtained enhanced wheat productivity with application of four irrigations each at CRI, maximum tillering, flowering and milking stage over irrigation application at CRI stage.

Mahbod *et al*. (2009) concluded from their study that significantly increased growth and yield of wheat was recorded when number of irrigation increased from 3 to 6. However, Rahim and Rahamtullah (2010) noticed improved yield with three irrigations at crown roots, booting and gain development stages than other irrigation scheduling.

At Algeria, Bouthiba and coworkers (2008) observed that the grain yield was increased by 27%, 10.7% and 6.7% with the treatments, FI (full irrigation, over the entire season), EI (early irrigation, up to heading) and LI (late irrigation, from heading), respectively.

At Kumarganj, Uttar Pradesh, Maurya and Singh (2008) worked on wheat assessed observed that IW/CPE ratio of 1.0 recorded maximum grain yield of 3.87 t ha^{-1} which was followed by under IW/CPE ratio of 0.80 and 0.60.

Yaghobi (2008) observed irrigation scheduling at IW/CPE ratio of 1.25, being at par IW/CPE ratio of 1.0 recorded maximum number of effective tillers, grains ear^{-1}, test weight of grain, grain yield and biological yield over IW/CPE at 0.5 and at 0.75.

Patel *et al*. (2008) revealed that nutrient uptake and forage yield of oats increased with each successive increase in irrigation frequency and significantly higher green forage and dry matter yields was recorded with frequent irrigations at 1.1 IW/CPE ratio.

Khan *et al*. (2007) observed that irrigation of the crop after five weeks interval gave maximum number of grain spike^{-1} and grain weight spike^{-1}, grain yield and water use efficiency.

In China, Huo and Shang (2007) reported that irrigation scheduling at the early heading stage was most efficient irrigation followed by the irrigation at early shooting stage. Similarly, Nadeem *et al*. (2007) reported that irrigation of the crop at 1.25 IW/CPE ratio gave highest yield attributes *viz*. 1000 grain weight and grains spike^{-1} and grain yield.

Higher grain yield was noticed by Singh *et al*. (2007) with four irrigations application of 0.95 and 1.1 IW/CPE ratio and three irrigations of 1.1 IW/CPE ratio over three irrigations of 0.65 IW/CPE ratio.

Singh and Sheoran (2006), noticed that significantly highest number of grains ear^{-1}, test weight, grain yield and straw yield were recorded when crop was irrigated at IW/CPE ratio of 0.9. However, increasing irrigation levels from 0.5, 0.7 and 0.9 of IW/CPE gave significant increase in number of effective tillers.

Singh *et al*. (2006) at Patna (Bihar) found that irrigation at 7 cm water depth gave highest grain and straw yields and bed planting of wheat gave highest water-use efficiency. A significant positive linear relationship was observed between irrigation depths and root growth and yield.

Parashar and Thaman (2005) reported significantly higher grains ear^{-1} and 1000-grain weight with irrigation at 40 and 50 mm CPE than 65 and 80 mm CPE. However, highest grain yield was recorded with irrigation at 50 mm CPE which was followed by irrigation at 40 mm CPE.

Singh *et al*. (2005) revealed that significantly higher grain yield was obtained with when crop was irrigated at IW/CPE ratio of 0.9 than IW/CPE ratio of 0.7 and 0.5.

In middle Gujrat, Rathod and Vadodaria, (2004) noticed that irrigation at 0.9 IW/CPE ratio gave significantly highest grain yield followed by irrigation at critical crop growth stages and were significantly superior to 0.7 IW/CPE ratio.

Muhammad *et al*. (2003) reported that increasing irrigation levels from 0.65 to 1.0 IW/CPE ratio significantly increased grain yield plant^{-1}, effective tillers plant^{-1}, test weight, number of spikelets panicle^{-1} and weight of grain panicle^{-1} of wheat.

Parihar and Tiwari (2003) recorded that each increasing irrigation levels significantly increased the effective tillers m^{-1} row and the highest number of effective tillers, test weight and grain yield was noted at IW/CPE ratio of 1.2. However Singh *et al*. (2003) stated that IW/CPE ratio of 1.25 gave the highest number of effective tillers, test weight and grain yield than IW/CPE ratio of 0.6 and 0.9.

In north western Rajasthan, Singh *et al*. (2003) observed that in first year maximum number of grains per ear^{-1}, grain yield and straw yield among the three levels of irrigation (0.6, 0.8 and 1.0 of IW/CPE ratios) was noted irrigation at IW/CPE ratio of 1.0, however, in second year highest yield was recorded with IW/CPE ratio of 0.8.

Singh *et al*. (2003) laid out a field experiment to find out water use and yield response of wheat to irrigation in North India and recorded that maximum yield with IW/CPE ratio of 0.75, also maximum number of effective tillers plant^{-1}, number of spikelets panicle^{-1}, test weight and weight of grain panicle^{-1}.

Bandopadhyay and Mallik (2003) observed that increasing levels of irrigation increased the yield of crop by 13% and 21% with IW/CPE ratio of 1.2 over IW/CPE ratio of 0.9 and 0.6.

Ibragimov *et al*. (2003) noticed that irrigation scheduling at 75 and 60% soil moisture levels of field capacity at critical crop growth stages gave optimal development and high crop productivity of winter wheat. More irrigation did not result in additional yield from the crop.

In Pakistan, Mahmood *et al*. (2002) found highest grains spike^{-1}, 1000 grain weight, grain and straw yield were recorded when crop was irrigated at 0.9 IW/CPE ratio which is significantly superior than IW/CPE ratio of 0.7. Similarly Behera *et al*. (2002) reported irrigation at IW/CPE ratio of 1.0 gave highest grain and straw yield.

Takate *et al*. (2002) reported from their field investigation that crop irrigated at 60 mm CPE recorded maximum grain yield of wheat than 80, 100 and 120 mm CPE, respectively.

Gadoury and Hess (2002), concluded that significantly increased average yields of 7.00 and 6.32 t ha^{-1} were noticed with irrigation amount that the full and 50% irrigation treatments, respectively.

Kang *et al*. (2002) worked at Loess Plateau of China to study the responses of limited irrigation on water use efficiency and yield in wheat noticed that maximum biomass production and grain yield with high moisture treatment than the lower moisture range.

At Kalyani, West Bengal, Saren and Jana (2001) carried out a field study in winter season to analyze the performance of wheat in response to irrigation depths, nitrogen and its time of application. They reported that significantly higher yield attributes and grain and straw yields of wheat were recorded at irrigation level up to 1 field capacity (FC) than 3/4 FC, 3/2 FC and 2 FC.

Hati *et al*. (2001) during the winter season laid out a field investigation to find out the responses of irrigation levels on yield of wheat and found that with increasing irrigation frequency from IW/CPE ratio of 0.8 to 1.2 increased length of panicle, number of grain panicle^{-1}, weight of grain panicle^{-1}, number of spikelet panicle^{-1}, test weight and grain yield plant^{-1} of wheat with increased irrigation frequency.

Khatri *et al*. (2001) at Karnal (Haryana) studied the impacts of irrigation levels on water use efficiencies in wheat. The results indicated that irrigation at IW/CPE ratio of 1.0 gave highest grain and straw yields over other treatments.

Angadi and Janawade (2001) observed that crop irrigated at IW/CPE ratio of 0.9 gave maximum tillers m^{-1} row length, 1000 grain weight, grains ear^{-1} and grain yield at 0.9 IW/CPE over IW/CPE ratio of 0.5 and remained at par with IW/CPE ratio of 0.7.

2.2.3 Economics

Moursi *et al*. (2019) conducted field trials in Egypt to evaluate the irrigation scheduling impacts on wheat during 2016-2017 and 2017-2018. They used 40, 50, 60 and 70% of available soil moisture depletion (ASMD) denoted as I_1, I_2, I_3 and I_4, respectively and obtained that irrigation scheduling at 40% ASMD gave the higher total seasonal return, net seasonal revenue and benefit cost ratio than the other irrigation treatments.

Kaur *et al*. (2018) conducted a field investigation in *Rabi*, 2017 at Panjab to find out the impact of mulching and irrigation scheduling on wheat and noticed that irrigation scheduling at CRI, maximum tillering and flowering stage gave the maximum net return and benefit: cost ratio.

At Kota, Rajasthan, Narolia *et al*. (2016) carried out a series of field investigations during *Rabi*, 2011-12, 2012-13 and 2013-14 to assess the irrigation scheduling impacts on productivity, profitability and nutrient uptake of wheat and noticed that crop irrigated at IW/CPE ratio of 1.0 significantly recorded highest net returns and benefit: cost ratio, production efficiency and economic efficiency than IW/CPE ratio of 0.8.

Sarel (2015), at Udaipur (Rajasthan) studied the effect of nitrogen and irrigation levels on wheat productivity during *Rabi*, 2013-14. The experimental findings indicated that highest net return and benefit-cost ratio was recorded with IW/CPE ratio of 1.0 over IW/CPE ratios of 0.75, 0.50 and 0.25.

Yaghobi (2008) from their field investigation at Udaipur (Raj) to assess the irrigation levels and weed management response on wheat productivity under zero tillage noticed that highest net return was recorded when the crop was irrigated at 1.25 IW/CPE ratio with 6 cm irrigation water followed by irrigation at IW/CPE ratio of 1.0 than IW/CPE ratio of 0.5 and 0.75.

Zhang (2002) reported from their study on irrigation scheduling that maximum profit from a crop was obtained using less water than was needed for maximum yield. High yield, efficient use of water and a net profit from winter wheat were achieved using one, two and three irrigations (60 mm of water irrigation^{-1}) in wet, normal and dry years, respectively.

2.2.4 Nutrient content and uptake

Narolia *et al*. (2016) assessed the irrigation scheduling impacts on productivity, profitability and nutrient uptake of wheat and reported that irrigation scheduling at IW/CPE ratio of 1.0 recorded maximum N, P and K uptake by grain and straw, respectively and protein content than the IW/CPE ratio of 0.8.

Sarel (2015) observed that IW/CPE ratio of 1.0 gave significantly higher nitrogen, phosphorus and potassium content and uptake in wheat grain and straw over IW/CPE ratios of 0.75, 0.50 and 0.25.

Yaghobi (2008) from their field trial at Udaipur (Raj) to find out the irrigation levels and weed management response on wheat productivity and observed that irrigation of the crop at IW/CPE ratios of 0.75, 1.0 and 1.25 were found at par in respect of nitrogen content and uptake in grain but gave significantly higher nitrogen content and uptake in grain over irrigation at IW/CPE ratio of 0.5. In respect to nitrogen content in straw and total nitrogen uptake by the crop, irrigation scheduling at IW/CPE ratio of 1.25 followed by IW/CPE ratio of 1.0 recorded the highest nitrogen content in straw, both theses recorded significantly higher nitrogen content in straw than IW/CPE ratios of 0.5 and 0.75.

Patel *et al*. (2008), at Anand, conducted a field investigation to evaluate the effect of irrigation levels (0.7, 0.9 and 1.1 IW/CPE) in oat and the results showed that significantly increased nutrient uptake of oat was noticed with successive increase in irrigation frequency and frequent irrigations at IW/CPE of 1.1 gave significantly higher N,P and K uptake.

Singh and Sheoran (2006), at Sirsa, Haryana, conducted an field experiment in *Rabi*, 2001-02 to find out the effect of different irrigation regimes on growth, yield and nutrient uptake in wheat and revealed that increased N uptake by the grain was recorded with increasing level of irrigation. Crop irrigated at IW/CPE ratio of 0.9 gave 14% and 22% more nitrogen uptake than IW/CPE ratios of 0.7 and 0.5. However, Parihar and Tiwari (2003) observed a reverse relationship between nitrogen content and higher level of irrigation. They noticed higher N content under lower moisture regime to lower total dry matter production of grain.

2.2.5 Water productivity

Moursi *et al*. (2019) during 2016-17 and 2017-18 carried out two field trials in Egypt to evaluate the irrigation scheduling impacts on wheat. They observed that 60% ASMD recorded the maximum amount of seasonal water applied, actual water consumptive use and water stored and lowest with 70% ASMD. However, the highest water application efficiency values were achieved with 70% ASMD. Irrigation scheduling at 40% ASMD recorded higher water productivity, productivity of irrigation water than the other irrigation treatments.

Singh *et al*. (2018) carried out a field experiment during 2014-15 and 2015-16 at Meerut, U.P. to examine the irrigation schedules effects on biomass, yield, physiological processes, IPAR, RUE and water productivity of wheat and observed that irrigation of the crop at CRI + 50 mm CPE recorded highest water use efficiency and water productivity with minimum water used during both the crop seasons than the other treatments.

Gupta *et al*. (2016) during their field investigation in 2013-14 to assess the irrigation scheduling impacts on the growth and yield of wheat at Faizabad (U.P.) noticed that significantly maximum water use efficiency (161.11 kg $ha^{-1}cm^{-1}$) was recorded with irrigation scheduling at IW/CPE ratio of 1.2 which remained at par with irrigation scheduling at IW/CPE ratio of 1.0 and two irrigations each at CRI and milking stage.

At Kota, Rajasthan, Narolia *et al*. (2016) assessed the irrigation scheduling impacts on productivity, profitability and nutrient uptake of wheat and noticed that crop irrigated at IW/CPE ratio of 1.0 recorded maximum water-use efficiency (kg ha^{-1}-cm) than IW/CPE of ratio of 0.8. However, maximum water productivity was observed with IW/CPE ratio of 0.8.

Sarel (2015) studied the effect of nitrogen and irrigation levels on wheat productivity at Udaipur (Rajasthan) observed that the consumptive use and water use efficiency of wheat at IW/CPE ratio of 1.0 registered significantly higher value than other IW/CPE ratios of 0.25, 0.50 and 0.75.

Shamsi and Kobraee (2013) evaluated a field experiment on wheat and noticed that harvest index and water use efficiency were decreased with increasing drought stress but evapotranspiration efficiency (ETE) was increased. The value of WUE under control conditions, was 1.27 kg m^{-3} for all cultivars and equal to 1.11, 0.91 and 0.73 kg m^{-3} for stress treatments I_2, I_3, and I_4, respectively.

Chouhan *et al*. (2012) assessesed the effect of integrated nutrient management and irrigation on wheat and concluded that significantly higher water use efficiency (47.5 kg ha^{-1} mm) was recorded with higher irrigation frequency of IW/CPE ratio of 1.0.

Idnani and Kumar (2012) observed highest water use efficiency and consumptive use were recorded when crop was irrigated at CRI + 100 mm CPE than CRI + 200 mm CPE and CRI + 150 mm CPE.

At Kumarganj, Faizabad, Singh *et al*. (2012) reported that application of IW/CPE ratio of 1.0 recorded highest consumptive use and lowest water use efficiency.

Bandyopadhyay *et al*. (2010) in their field study on impact of enhanced water use efficiency on agricultural productivity found that significantly increased soil water extraction and water use efficiency of wheat was recorded when crop was irrigated at IW/CPE ratio of 0.8 than IW/CPE ratio of 0.6. Similarly, Khang *et al*. (2010) reported that crop irrigation at IW/CPE ratio of 1.2 gave maximum water consumption and water use efficiency.

At Kumarganj, Uttar Pradesh, Maurya and Singh (2008) observed maximum consumptive use (33.91 and 28.49 cm) with IW/CPE ratio of 1.2 with 6 cm irrigation. However, irrigation of the crop at IW/CPE ratio of 0.80 recorded significantly higher irrigation water productivity but it was highest with IW/CPE 0.60 as reported by Jat *et al*. (2008). Similarly, Nadeem *et al*. (2007) found maximum water use efficiency with irrigation scheduling at IW/CPE ratio of 1.25. However, Parashar and Thaman (2005) reported that increasing volume of water decreased water use efficiency in wheat crop. Similarly, Ingle and Shelke (2007) found that increasing in number of irrigations in wheat increased the total consumptive use (CU) *i.e.*, five irrigation followed by four and three irrigations.

In middle Gujarat, Rathod and Vadodaria (2004) observed that irrigation of the crop at IW/CPE ratio of 0.7 gave significantly highest water use efficiency (20.28 and 24.07 kg ha^{-1} mm) than irrigation at critical crop growth stages and IW/CPE ratio of 0.9 during both years. Similarly, Bandopadhyay and Mallik (2003) observed 8% and 14% increased water use efficiency at IW/CPE ratio of 1.2 than IW/CPE ratio of 0.9 and 0.6.

Bharambe *et al*. (2003) observed that irrigation scheduled at IW/CPE ratio of 0.75 was found to be economically optimum.

Singh *et al*. (2003) studied water use and yield response of wheat to irrigation and found maximum water use efficiency at 0.75 IW/CPE ratio. Water use efficiency decreased with increase in irrigation frequency.

In north western Rajasthan, Singh *et al*. (2003) observed that with increase in irrigations levels, consumptive use of water (cm) also increased. But the reverse relation was observed with water use efficiency, which decreased with increasing irrigation level in late sown wheat.

Gadoury and Hess (2002), concluded their experiment that with 50% irrigation, seasonal water use efficiency averaged 0.95 kg m^{-3} and spring irrigation water use efficiency averaged 1.70 kg m^{-3}. However Mahmood *et al*. (2002) found highest water use efficiency when crop was irrigated at IW/CPE ratio of 0.7, than IW/CPE ratios of 0.9, 1.1 and 1.3.

MATERIALS AND METHODS

The present study entitled "**Effect of crop establishment methods and irrigation scheduling on growth, yield and water productivity of wheat in rice-wheat system**" was carried out at the Agricultural Research Farm, Institute of agricultural Sciences, Banaras Hindu University, Varanasi during two successive *Kharif* and *Rabi* seasons of 2016-17 and 2017-18. A thorough detail of the materials used, methodology employed and the techniques followed during investigation period have been described in this chapter.

3.1 Experimental site

The site of experiment was Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, is situated at about 10 km away from Varanasi railways station in the South-East direction. The farm is located geographically at 25° 15′N latitude, 82°59′E longitude and 75.7 meters altitude above the mean sea level in the Northern Gangetic Alluvial plains of Uttar Pradesh. The same location was used for both the years of experimentation. The experimental field was homogeneous in fertility with uniform topography and textural make up and well connected with tube well for timely and systematic irrigation. The drainage channel was assured for withdraw excess water from the experimental field.

3.2 Climate and weather

Varanasi district has predominantly a subtropical climate (semi-arid to sub-humid) and is subjected to extremes of hot summer and cold winter. Normally, the onset of monsoon in this region comes in third week of June and withdrawal of monsoon occurs by the end of September or sometimes extends up to the first week of October. Also in this area, irregularly winter shower can be seen resulting from the cyclone during December to February and the period during March to May is generally dry. The average annual rainfall of Varanasi is 1081.5 mm, out of which

87.33% (944.5 mm) is, occurs during the monsoon or rainy season (June to September) and 12.67% (137.0 mm) during post monsoon season. The annual potential evapo-transpiration (PET) mean of this region is 1525 mm. From second forth night of February, temperature starts to rise and touches to its maximum level by May-June and starts to decrease from July onwards and touches lowest level by in December-January. The maximum temperature generally fluctuates between 22°C and 45°C while minimum temperature varies from 5 to 28.5°C and occasionally extreme of minimum (2°C) and maximum (47°C) temperature are noticed.

The standard week-wise whether data recorded during the period of experimentation at meteorological observatory, Department of Agronomy, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi are given in Tables 3.1 and 3.2 and also expressed graphically in Figures 3.1 and 3.2.

3.2.1 Rainfall (mm)

The experimental years, 2016-17 and 2017-18 was not received rainfall during the crop growth period, except 1.0 mm in 2016-17 and 9.4 mm in 2017-18 (Table 3.1 and 3.2). Therefore, the rainfall was not given any impact in both the crop seasons. Although, in 2018, rainfall experienced during 14^{th} SMW (9.2 mm) at the time of harvesting of crop, which had no impact on need of irrigation in both the year of experimentation.

3.2.2 Temperature (°C)

During the crop growing period, the weekly mean maximum temperature varied from 20.1 to 39.4°C with an average of 27.4°C in 2016-17 and 16.1°C to 39.0°C with an average of 27.6°C in 2017-18. In 2016-17 the weekly mean minimum temperature was ranged from 8.2 to 24.8°C with an average of 13.9°C and in 2017-18, it was fluctuated from 5.9 to 21.9°C with an average of 12.1°C. The mean maximum and minimum temperature were almost similar during both the years of study. In conclusion the mean maximum and minimum temperature fluctuation was almost normal during both the crop growing season.

Table 3.1: Standard mean week wise meteorological observation recorded at agricultural research farm during *Rabi* season 2016-17

Week No.	Month & Date	Rainfall (mm)	Temperature (°C)		R.H. (%)		Wind Speed (km hr^{-1})	Sunshine (hrs)	Evaporation (mm)
			Max	Min	Morn.	Even.			
47	18-24	0.0	27.3	11.7	72	42	1.8	4.7	1.7
48	25-01	0.0	25.4	13.2	79	56	2.0	3.7	1.8
49	Dec 02-08	0.0	20.3	16.3	94	78	1.0	0.2	0.8
50	09-15	0.0	20.2	10.0	94	73	0.8	1.2	0.7
51	16-22	0.0	23.3	9.8	89	50	2.4	3.2	1.8
52	23-31	0.0	20.5	10.9	94	69	1.4	0.2	0.9
1	Jan 1-7	0.0	20.1	11.6	95	76	2.2	0.2	0.8
2	8-14	0.0	20.7	8.2	91	44	2.0	3.2	1.6
3	15-21	0.0	23.0	8.8	90	49	1.3	1.0	1.6
4	22-28	1.0	24.4	10.9	90	58	1.8	1.8	2.4
5	29-04	0.0	23.8	14.1	94	57	1.9	4.1	1.5
6	Feb 05-11	0.0	25.4	10.8	91	47	2.4	7.1	2.3
7	12-18	0.0	26.2	12.3	87	53	1.2	4.6	2.3
8	19-25	0.0	27.7	13.0	81	41	3.1	6.4	3.3
9	26-04	0.0	29.7	13.1	83	43	2.3	7.4	3.3
10	March 05-11	0.0	29.6	14.6	71	38	3.1	5.7	3.8
11	12-18	0.0	28.7	12.3	81	39	2.7	7.6	4.0
12	19-25	0.0	33.2	17.6	81	36	2.7	6.2	4.3
13	26-01	0.0	38.5	20.1	64	30	4.1	7.1	6.6
14	April 02-08	0.0	38.8	22.4	70	37	4.4	6.7	7.7
15	09-15	0.0	39.4	20.2	48	26	3.4	6.7	7.7
16	16-22	0.0	37.3	24.8	74	49	4.9	9.0	7.2

Table 3.2: Standard mean week wise meteorological observation recorded at agricultural research farm during *Rabi* season 2017-18

Week No.	Month & Date	Rainfall (mm)	Temperature (^0C)		R.H. (%)		Wind Speed (km hr^{-1})	Sunshine (hrs)	Evaporation (mm)
			Max	Min	Morn.	Even.			
48	26-02	0.0	26.4	8.5	91	37	0.9	7.6	1.7
49	Dec 03-09	0.0	25.7	9.3	90	54	0.6	7.6	1.8
50	10-16	0.0	26.2	11.2	86	46	1.1	7.2	1.8
51	17-23	0.0	23.5	8.8	84	50	1.8	4.3	1.4
52	24-31	0.0	21.2	8.2	92	61	1.4	5.4	1.2
1	Jan 1-7	0.0	16.1	6.2	93	69	0.8	0.8	0.7
2	8-14	0.0	19.4	5.9	96	57	1.6	5.7	1.0
3	15-21	0.0	23.1	6.4	94	49	1.3	8.0	1.2
4	22-28	0.0	24.4	7.7	94	60	1.7	7.3	2.1
5	29-04	0.0	24.9	9.1	86	47	2.5	8.8	2.3
6	Feb 05-11	0.0	24.4	9.5	80	38	2.2	7.0	2.5
7	12-18	0.0	24.6	11.8	87	55	2.3	6.7	2.4
8	19-25	0.0	29.6	13.2	90	42	1.0	8.6	2.6
9	26-04	0.0	30.0	14.9	88	43	2.6	9.3	3.5
10	March 05-11	0.0	30.4	13.8	82	36	2.4	7.9	3.9
11	12-18	0.0	33.1	15.7	72	28	2.2	8.5	4.5
12	19-25	0.0	34.1	15.6	73	27	1.8	8.8	4.8
13	26-01	0.0	35.4	16.8	69	24	3.7	9.0	6.6
14	April 02-08	9.4	33.8	20.0	70	42	3.2	7.9	6.4
15	09-15	0.0	34.8	20.2	72	35	2.6	8.8	5.8
16	16-22	0.0	39.0	21.9	55	25	2.2	9.6	7.9

3.2.3 Relative humidity (%)

The weekly mean maximum relative humidity during 2016-17 fluctuated from 64 to 95% with an average of 82.4%, whereas, in 2017-18, it varied from 69 to 96% with an average of 83.0%. The weekly mean minimum relative humidity during 2016-17 ranged from 26% to 78% with an average of 49.0%, whereas, in 2017-18, it varied from 24 to 69% with an average of 40.0%. The relative humidity show sizeable variation throughout the investigation period during both the year of study. Also, we can say from the data that the first year was more humid in as compared to the second year.

3.2.4 Sunshine duration (hrs)

The weekly mean bright sun-shine duration varied from 0.2 to 9 hrs (average 4.5 hrs) in 2016-17 and 0.8 to 9.6 hrs (average 7.4) in 2017-18. From the data we can conclude that the day time of second year was brighter as compared to the first year during crop growing period.

3.2.5 Evaporation (mm day^{-1})

The weekly mean evaporation fluctuated between 0.7 to 7.7 mm with an average of 3.1 mm in 2016-17 and in 2017-18, it ranged from 0.7 to 7.9 mm with a mean of 3.1 mm. Meteorological data revealed that the average evaporation was similar in both the year of experimentation, but in second year, evaporation was more distributed as compare to first year.

3.2.6 Wind speed (km hrs^{-1})

The weekly mean wind speed during crop growing period of 2016-17 ranged from 0.8 to 4.9 km hrs^{-1} with an average of 2.4 km hrs^{-1} while it was varied from 0.6 to 3.7 km hrs^{-1} with an average of 1.9 km hrs^{-1}. The wind speed during the crop growing period was normal in both the years of experiment.

3.3 Cropping history of the experimental field

The fertility and productivity of an experimental field can be assessed from the cropping history. The cropping history of the present experimental field for last four years prior to experimentation is given below in Table 3.3.

Table 3.3: Cropping history of the experimental field

Year	Season			Remarks
	Rainy (*Kharif*)	**Winter (*Rabi*)**	**Summer**	
2011-12	Rice	Wheat	Fallow	-
2012-13	Rice	Wheat	Fallow	-
2013-14	Rice	Wheat	Fallow	-
2014-15	Rice	Wheat	Fallow	-
2015-16	Rice	Wheat	Fallow	-
2016-17	Rice	Wheat*	Fallow	Experimental year
2017-18	Rice	Wheat*	Fallow	Experimental year

3.4 Soil analysis

The physico-chemical properties of the soil of experimental field were analyzed by adopting suitable procedures. Before run the experiment, soil samples were taken from the depth of 0-15 cm following the appropriate sampling technique of whole experimental field described by Black *et al*. (1967). The soil samples taken from experimental field were further proceed in the laboratory by air drying, crushing and pass through 2 mm mesh sieve. After preparing the soil sample appropriate method were used to assess the mechanical, physical and chemical properties of the experimental field. The results of those samples are listed in Tables 3.4(a) and 3.4(b).

Table 3.4(a): Physical properties of the experimental soil

	Particulars	Value 2016	Method employed
1.	**Mechanical analysis**		
	Soil separates (%)		
	Sand	46.27	Hydrometric method (Bouyoucos, 1962)
	Silt	30.65	
	Clay	23.08	
	Textural class	Sandy clay loam	
2.	**Physical constant**		
	Bulk density (g cc^{-1}) Depth (cm) 0-30	1.37	Core sampler method (Piper, 1966)

Table 3.4(b): Chemical properties of the experimental soil

Parameters	Initial value	Method employed
Soil organic carbon (%)	0.42	Wet digestion method (Walkley and Black,1934)
Soil pH (1:2.5 Soil : water suspension)	7.32	Glass electrode digital pH meter (Jackson, 1973)
Soil electrical conductivity (1:2 Soil : water suspension) (dSm^{-1}) at 25°C	0.25	Systronics electrical conductivity meter (Jackson, 1973)
Available N (kg ha^{-1})	206.49	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P_2O_5 (kg ha^{-1})	21.77	0.5 N $NaHCO_3$ extractable Spectrophotometer (Olsen *et al*., 1954)
Available K_2O (kg ha^{-1})	220.21	Ammonium acetate extractable Flame photometer (Jackson, 1973)

3.5 Experimental design and layout

The experiment was lead out in split plot design combining four main plot treatments and four sub plot treatments with three replications. The main plot treatments were crop establishment method *i.e.* CE_1-Conventional till puddled transplanted rice-conventional till wheat (CTPTR-CTW), CE_2-Conventional till direct seeded rice (DSR)-conventional till wheat (CTDSR-CTW), CE_3-Conventional till DSR-Zero till wheat with rice residue retention [CTDSR-ZTW (RR)], and CE_4-Zero till DSR-Zero till wheat with residue retention in rice & wheat [ZTDSR-ZTW(RWR)] whereas, sub plot treatments were irrigation scheduling based on IW/CPE *viz.* (I_1) IW/CPE ratio=0.75, (I_2) IW/CPE ratio=1.0, (I_3) IW/CPE=1.25 and (I_4) Farmer's practice (need based irrigation). The anchored crop residue was retained as per treatment requirement in rice and wheat by harvesting of crop from 40 cm height during both the years of experimentation. The crop establishment methods in main plot are continuing since 2012. The initial organic carbon was 0.42%, and available N P & K was 206.59, 25.10 and 219.60 kg ha^{-1} at the time of establishment of main plot treatment. Present experiment was carried out in 2016-17 and 2017-18. In total, there were sixteen (4 main plots × 4 sub-plots) treatment combinations and 48 plots (experimental units) in the experiment. This entire set-up was carried in the 2^{nd} year to confirmation of outcomes. The randomization principles were applied to assign the treatments among experimental units. Block border effect, field border effects, plot border effect and irrigation channel effect are taken into account.

The detail information about the experiment is given in Table 3.5, 3.6, 3.7, 3.8 and layout plan is illustrated in Figure 3.3.

Table 3.5: Treatment details with symbols

Treatments	**Symbol used**
A. Main plot (Crop Establishment methods)	
Conventional till rice (puddled transplanted)-conventional till wheat [CTPTR-CTW]	**CE_1**
Conventional till direct seeded rice (DSR)-conventional till wheat [CTDSR-CTW]	**CE_2**
Conventional till DSR-zero till wheat (rice residue retention) [CTDSR-ZTW (RR)]	**CE_3**
Zero till DSR-zero till wheat (residue retention in rice and wheat) [ZTDSR-ZTW(RWR)]	**CE_4**
B. Sub plot (Irrigation Scheduling in wheat)	
IW/CPE=0.75	**I_1**
IW/CPE=1.0	**I_2**
IW/CPE=1.25	**I_3**
Farmer's practice (need based irrigation)	**I_4**

* *Recommended nutrient and weed management practices was followed as per requirement of crop*

Table 3.6: Details of treatment combinations and their symbols

CE_1 I_1	**CE_2 I_1**	**CE_3 I_1**	**CE_4 I_1**
CE_1 I_2	**CE_2 I_2**	**CE_3 I_2**	**CE_4 I_2**
CE_1 I_3	**CE_2 I_3**	**CE_3 I_3**	**CE_4 I_3**
CE_1 I_4	**CE_2 I_4**	**CE_3 I_4**	**CE_4 I_4**

3.6 Lay out plan

The details of layout are given below and graphically represented in figure 3.3.

Table 3.7: Layout details

Design	Split plot
Replications	3
Treatments combinations	4 x 4= 16
Total number of plots	16 x 3 = 48
Gross Plot size	4.5 m x 4.0 m = 18 m^2
Net plot size	3.5 m x 3.2 = 11.2 m^2
Row spacing	20 cm
Seed rate	100 kg ha^{-1}
Main irrigation channel cum replication border	1.5 m
Plot border	0.8 m
Variety	Rice: Sarajoo-52 Wheat: HD 2967

3.7 Crop and variety

The variety Sarajoo-52 and HD 2967 were used for rice and wheat, respectively. Wheat variety HD 2967 was released from IARI, New Delhi for North-Western Plains Zone in the year of 2011. Its grains are medium bold, hard and shining. HD 2967 is a double dwarf and medium duration (130-140 days) variety. It has the excellent *chapati* making quality and good content of iron and zinc with yield potential of 55-60 q ha^{-1}. It is yellow rust resistance and less suffered from Karnal bunt and loose smut diseases as compared to other wheat varieties.

3.8 Residue retention

The anchored crop residue was retained as per treatment requirement in rice and wheat by harvesting of crop from 40 cm height during both years of the experimentation.

3.9 Calendar of operation and cultural practices

Field operations carried out during the cultivation of wheat and rice during investigation period are summarizing below and the calendar of the operations is given in Table 3.8.

3.9.1 Field preparation

A rectangular piece of land with even topography and uniform fertility having well irrigation facility was chosen and undisturbed layout was carried out according to the main plot treatments (crop establishment methods) since 2012. During *Kharif* season in conventional till paddled transplanted rice (CTPTR) treatment field was ploughed twice in dry condition followed by wet ploughed under water (puddling), whereas in conventional till direct seeded rice (CTDSR) field was ploughed twice with tractor drawn cultivator. In zero till direct seeded rice (ZTDSR) treatment, crop was established with zero till seed drill without any preparatory tillage. Need based application of Glyphosate @1 kg *a.i.* ha^{-1} was done seven days before the seeding in ZT treatments to knock down the weeds. In *Rabi* season for convention till wheat (CTW) plots, the field was ploughed twice with cultivator and seeding was with seed drill. In zero till wheat (ZTW) treatment, seeding was done with ZT seed drill without any preparatory tillage. Need based Glyphosate @1 kg *a.i.* ha^{-1} was applied in all ZTW treatments before seeding. Subsequently, implementation of layout was done as per pre-decided plan of the experimental design described in Figure 3.3.

3.9.2 Fertilizers application

The recommended dose of 150 kg N, 60 kg P_2O_5, 60 kg K_2O and 5 kg Zn ha^{-1} was applied for rice crop in all the treatments through Urea, DAP, muriate of potash (MOP) and $ZnSO_4$ respectively.

Table 3.8: Calendar of operation and cultural practices

S. No.	Operations	2016-17	2017-18
1	Glyphosate spray in no-till plots In CE_3 & CE_4 treatment	 16.11.2016	 24.11.2017
2	Field preparation CE_1 & CE_2 (CT wheat)	 21.11.2016	 29.11.2017
3	Sowing	23.11.2016	01.12.2017
4	Herbicides application Post-Emergence	 23.12.2016	 30.12.2017
5	Top dressing of N First top dressing Second top dressing	 After 1st irrigation After 2nd irrigation	 After 1st irrigation After 2nd irrigation
6	Irrigation		
	IW/CPE=0.75	15.12.2016 06.02.2017 06.03.2017 26.03.2017	22.12.2017 17.02.2018 11.03.2018 28.03.2018
	IW/CPE=1.0	15.12.2016 25.01.2017 22.02.2017 11.03.2017 26.03.2017	22.12.2017 03.02.2018 28.02.2018 15.03.2018 30.03.2018
	IW/CPE=1.25	15.12.2016 20.01.2017 12.02.2017 28.02.2017 14.03.2017 26.03.2017	22.12.2017 29.01.2018 19.02.2018 07.03.2018 18.03.2018 28.03.2018
	Farmer's practice (need based)	15.12.2016 23.01.2017 25.02.2017 20.03.2017	22.12.2017 31.01.2018 02.03.2018 28.03.2018
7	Harvesting CE_3 & CE_4 treatments In CE_1 & CE_2 treatments	 12.04.2017 08.04.2017	 13.04.2018 07.04.2018
8	Threshing and winnowing In CE_1 & CE_2 treatments In CE_3 & CE_4 treatments	 14.04.2017 16.04.2017	 15.04.2018 17.04.2018

In wheat recommended dose of NPK (150-60-60) was applied in all the treatments through Urea, DAP and MOP sources, respectively. The full dose of phosphorus & potash and half of total nitrogen were applied as basal at the time of seeding and remaining half of nitrogen was top dressed in two equal splits after first irrigation (at crown root initiation) and second irrigation (at spike emergence) in optimum soil moisture condition.

3.9.3 Seed and sowing

A seed rate of 100 kg ha^{-1} was used. Sowing was done on 23rd November in 2016-17 and 1st December in 2017-18. The sowing was done with the tractor drawn zero till fertilizer-seed drill. The seeding depth was maintained 3-4 cm by the depth control wheel.

3.9.4 Weed management

The post-emergence herbicide Sulfosulfuron + Metsulfuron (Total) 40 g ha^{-1} *a.i.* was applied by using knap sack sprayer with flat fan nozzle with 400 liter water after 30 DAS. Herbicide surfactant was also used to minimize the herbicide wastage and better efficacy.

3.9.5 Irrigation

The tube well water was used for irrigation. The details of irrigation applied for different treatments are given in Table 3.8. Irrigation was scheduled as per the treatments, when pan evaporation recorded values of 80, 60, & 48 mm for I_1, I_2 & I_3 respectively and for I_4 (farmer's practice) need based irrigation was applied. Irrigation water depth was maintained 6.0 cm for all treatments at every irrigation time. The daily evaporation was noted from the US Weather Bureau Class A Open Pan Evaporimeter installed in the Meteorological Observatory of Agricultural Research Farm, BHU. Cumulative pan evaporation was calculated on the basis of daily evaporation minus the precipitation since the previous irrigation. A buffer channel of 0.25 m width between plots was carried out in order to prevent the seepage and overflow of water from the main and sub irrigation channel. Strong bunds were made around all the plot sides. The Parshal flume was used at the plot head to measure the amount of irrigation water. Irrigation treatments were applied according to the pre-plan layout.

3.9.6 Harvesting

The crop was harvested at maturity, when the stem becomes dry and panicles were turned golden yellow. First the border rows were harvested with the help of sickle to remove the border effect. Then, net plot was harvested and sun dried. The harvested crop from every net plot bundled carefully, tagged and carried to the threshing floor for threshing.

3.10 Sampling procedure and observation

A good sample is one that provides an estimate or a standard value as close as possible to the real value that would have been acquired by all plants in the plot. This standard value may be used for calculate the sampling error between the sample value and plot value. Therefore a good sampling technique can provides small sampling error. Nevertheless, the cost of experimentation will increase with increase in either number or size of sampling unit. Accordingly, to get the higher precision with minimum cost, appropriate sampling techniques are mainly taken into consideration. A single plot is considered as a sampling unit and appropriate number of plant are taken (per meter row length or five plants plot^{-1}) according to requirement for experimental plot as a sample size and random sampling techniques (Gomez and Gomez, 1984) were followed to measurement of plant growth and yield of test crops. Destructive method was used for dry matter studies.

3.11 Biometric observations

3.11.1 Wheat

3.11.1.1 Growth characters

Observations on growth parameter *viz*. plant height, number of tiller and dry weight, at 30, 60, 90 DAS and at harvest, number of leaf and leaf chlorophyll content

(SPAD value) at 30, 60 and 90 DAS, were taken during both the years of experimentation.

3.11.1.1.1 Plant height (cm)

Five plants were selected randomly and tagged from each experimental plot for the measurement of plant height. Plant height of the wheat was observed at 30, 60, 90 DAS and at harvest with the help of metre scale from base of the plant to the tip of the plant before spike emergence and upto the tip of spike after heading then average height was calculated and given in centimeter.

3.11.1.1.2 Dry matter accumulation (g m^{-1} row length)

For estimation of dry matter accumulation (m^{-1} row length), plants were cut from the border rows in each plot from four places of 0.25 m area at 30, 60, 90 DAS and at harvest. These samples were first sun dried then dried at 70°C in oven till constant weight and weighed to work out the dry matter accumulation g m^{-1} row length.

3.11.1.1.3 Number of tiller (m^{-1} row length)

The number of tiller (m^{-1} row length) were taken at 30, 60, 90 DAS and at harvest from the randomly tagged area of 0.25 m in crop rows at four places in net plot area and added all to expressed as number of tiller m^{-1} row length.

3.11.1.1.4 Number of green leaf (m^{-1} row length)

The number of leaf m^{-1} row length were noted at 30, 60 and 90 DAS from randomly tagged area of 0.25 m row at four places in net plot area. Then pooled all and show as number of leaf m^{-1} row length.

3.11.1.1.5 Chlorophyll content (SPAD value)

Chlorophyll content (SPAD value) was recorded with non-destructive and quick estimation of extractable chlorophyll method by hand held SPAD (soil plant analysis development-502 meter) at 30, 60 and 90 DAS. For estimation of chlorophyll, the five top most fully developed leaves were taken from five randomly selected plants in net plot area then SPAD reading was observed, and averaged of all values to express in SPAD unit.

3.11.1.2 Yield and yield attributes

3.11.1.2.1 Number of spike (m^{-1} row length)

The number of spike **(**m^{-1} row length) were noted at the time of harvesting from the randomly selected area of 0.25 m row at four places in net plot, then added all to indicate as number of spike m^{-1} row length.

3.11.1.2.2 Spike length (cm)

For the measurement of spike length the randomly selected 10 spikes were taken from the marked area of 0.25 m at four places in net plot. Then length of spikes was measured with the help of meter scale and their average was calculated and depicted in centimeter.

3.11.1.2.3 Number of grain spike^{-1}

The ten spikes was selected for measuring number of grain spike^{-1} and separately threshed for counting of grain in each spike, after counting, their average was work out to express as number of grain spike^{-1}.

3.11.1.2.4 Test weight (g)

After threshing of each net plot, the produce grain was sun dried, after that 1000 grains were counted, weighed and depicted as test weight (g 1000^{-1} grains).

3.11.1.2.5 Grain yield (kg ha^{-1})

After threshing and winnowing, the produce grain from each net plot was sun dried, weighed on electronic balance and expressed as grain yield kg ha^{-1}.

3.11.1.2.6 Straw yield (kg ha^{-1})

For obtaining the straw yield, the grain yield was subtracted per plot from the respective biological yield per plot. The straw yield was computed and expressed as kg ha^{-1}.

3.11.1.2.7 Harvest index (%)

For calculation of harvest index, the following formula was used:

$$\text{Harvest index (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

3.11.1.3 Water use studies

3.11.1.3.1 Irrigation water use efficiency (kg ha^{-1}-cm)

Irrigation water-use efficiency (IWUE) is defined as the yield obtained per unit of irrigation water applied to field. The IWUE was calculated as follow:

$$\text{Irrigation water use efficiency (kg ha}^{-1}\text{ -cm)} = \frac{\text{Yield (kg ha}^{-1}\text{)}}{\text{Irrigation water supplied (cm)}}$$

3.11.1.3.2 Water productivity (kg m^{-3})

Water productivity (WP) was computed by dividing grain yield (kg) with the total volume of water supplied to the field, whether from irrigation or total rainfall received including the precipitation (m^{-3}). It is expressed as kg m^{-3} of water. WP is calculated by following equation:

$$\text{Water productivity (kg m}^{-3}\text{)} = \frac{\text{Yield (kg)}}{\text{Volume of water (m}^{3}\text{)}}$$

3.12 Soil analysis

For assessment of soil physico-chemical properties, soil samples were collected from 0-15 cm depth just before sowing and after harvesting of wheat. These samples were carefully dried in shed on polythene sheet and grinded with roller followed by sieved through 2 mm mesh sieve.

3.12.1 Physico-chemical properties of soil

3.12.1.1 Soil bulk density

Bulk density was studied with a cylindrical core sampler (5.1 cm diameter and 12.5 cm length) by inserting into the soil (Piper, 1966). The soil hold in the core sampler was carried into moisture box and then dried at 105°C till constant oven dry soil weight obtained. Following formula was used to measure the bulk density:

$$\text{Bulk density (Mg m}^{-3}\text{)} = \frac{\text{Weight of soil}}{\text{Volume of the cylinder}}$$

3.12.1.2 Soil electrical conductivity (dS m^{-1})

Electrical conductivity (EC) was observed with making a soil water suspension (1:2.5 soil water suspension) from earlier processed soil sample. The EC of this soil water suspension was measured with the help of electrical conductivity bridge (Jackson, 1973).

3.12.1.3 Soil pH

For measuring the soil pH, a glass electrode digital pH meter was used with making saturation soil extract, obtained from 1:2.5 soil water suspension as described by Jackson, 1973.

3.12.1.4 Soil organic carbon

After the harvest of test crop wheat the soil organic carbon was assessed by Walkley and Black’s method (1934).

3.12.1.5 Available nitrogen in soil

Available nitrogen in the soil was analyzed by alkaline permanganate method of Subhiah and Asija (1956) with Kjeldahl distillation unit.

3.12.1.6 Available phosphorus in soil

For estimation of available phosphorus in soil, sodium bicarbonate ($NaHCO_3$) method suggested by Olsen *et al*. (1954) was used. In this method, 2 g of processed soil is taken and extracted with 40 ml of 0.5 N $NaHCO_3$ solution (pH adjusted to 8.5) on mechanical shaker for 30 minutes. After filtration of the suspension, the blue color was developed and this blue color was measured with spectrophotometer at 760 nm to find out the phosphate concentration in the soil and expressed as available P kg ha^{-1}.

3.12.1.7 Available potassium in soil

Available potassium in the soil was determined by making soil and normal NH_4AOC suspension, which was buffered at pH 7.0. The concentration of potassium in the solution was measured with flame photometer method (Jackson, 1973) and the data were presented as available K in kg ha^{-1}.

3.13 Nutrient content and their uptake

3.13.1 N, P and K content (%) in plants

The plant samples were collected for analysis of N, P and K content in plants, at harvest of crop. The samples of grain and straw were taken carefully from each net plot area and dried at 65 ± 5 ^{0}C for 48-72 hours in oven. These dried samples were processed with grounding thoroughly in a Willey mill to pass through a 35 mm mesh sieve and then sealed in labeled polythene bags. These processed samples were used for further analysis in the laboratory for nutrient content & uptake as per respective methods.

3.13.1.1 Nitrogen content (%) in grain and straw

For estimation of nitrogen content in grain and straw, the micro-Kjeldahl method (A.O.A.C., 1995) was used.

3.13.1.2 Phosphorus content (%) in grain and straw

Phosphorus content in grain and straw was analyzed with using the Barton's reagent from Vandomolybdo-phosphoric acid yellow color method suggested by Bhargava and Raghupathi, 1993).

3.13.1.3 Potassium content (%) in grain and straw

The potassium content was determined from grain and straw of wheat, after making appropriate dilutions by using Flame photometer (Bhargava and Raghupati, 1993).

3.13.2 Nutrient uptake (kg ha^{-1})

The uptake of N, P and K by grain and straw was estimated by multiplying grain and straw yield with their respective nutrient content in grain and straw (Black *et al*., 1965) and expressed as N, P & K uptake by crop in kg ha^{-1}.

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient content (\%) in grain or straw}}{100} \times \text{Grain or straw yield (kg ha}^{-1}\text{)}$$

3.14 Economics

The economics of each treatment was estimated separately for both the years of experimentation by taking into account the existing price of inputs and produce. The labour cost, fertilizers and power for carrying out different experimental operations *viz*. tillage, seeding, irrigation, weeding, harvesting, threshing etc. were computed per hectare as per present market price of Varanasi region. For estimating economics of treatments, the particular cultivation cost was taken into account and economics of treatments are showed as gross returns (₹ ha^{-1}), net returns (₹ ha^{-1}) and benefit cost ratio.

3.14.1 Gross returns (₹ ha^{-1})

On the basis of minimum support price of wheat grain and existing market price of straw, the grain and straw yield were computed as gross returns in ₹ ha^{-1}.

3.14.2 Net returns (₹ ha^{-1})

The net returns from various treatments were calculated by subtracting cost of cultivation from their respective gross returns with using the following formula:

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

3.14.3 Benefit cost ratio

The calculation of benefit cost ratio (B:C) was done with the help of following formula:

$$\text{Benefit cost ratio} = \frac{\text{Net returns (₹ ha}^{-1}\text{)}}{\text{Cost of cultivation (₹ ha}^{-1}\text{)}}$$

3.15 Statistical analysis

The data generated from various observations during investigation period were tabulated and analyzed statistically for establishing the significance of difference between the treatments and to draw out a valid conclusion by adopting proper method of 'Analysis of Variance, F and t tests' described by Gomez and Gomez (1984) for split plot design at the level of significance of p=0.05. Whenever F test was found significant, then calculation of critical difference (CD) was work out. Based on the two years data (2016-17 and 2017-18) of experimentation, results have been interpreted and discussed.

Table 3.9: Analysis of variance (ANOVA) for wheat

Source of variance	d.f.	SS	MSS	Calculated 'F' Value	Tabulated 'F' value at 5%
Replication	2				5.14
Crop establishment	3				4.75
Error(a)	6				
Irrigation	3				3.00
CE x I	9				2.30
Error (b)	24				
Total	47				

3.16 Elimination of mechanical errors

Error that happens in the implementation of an experiment is called mechanical error. During field experimentation, it may occur when plots that are carried out *viz*. errors in plot measurement, use of impure seed, fertilizer and during observation of data. Mechanical error can affects on experimental results, especially, if the errors are happened during critical period of the experimentation. The most effective precaution of mechanical error is awareness of researcher to manage the potential error in relation to various objectives of the experiment such as following:

i. Row to row and plant to plant spacing

ii. Gap filling

iii. Fertilizer management

iv. Plot layout and leveling

v. Measurement error like height, weight and other physical measurement

vi. Transcription of data

In view of the above, precaution was taken to keep 100% precision during executing all operations to eliminate error or keep it to the minimum possible.

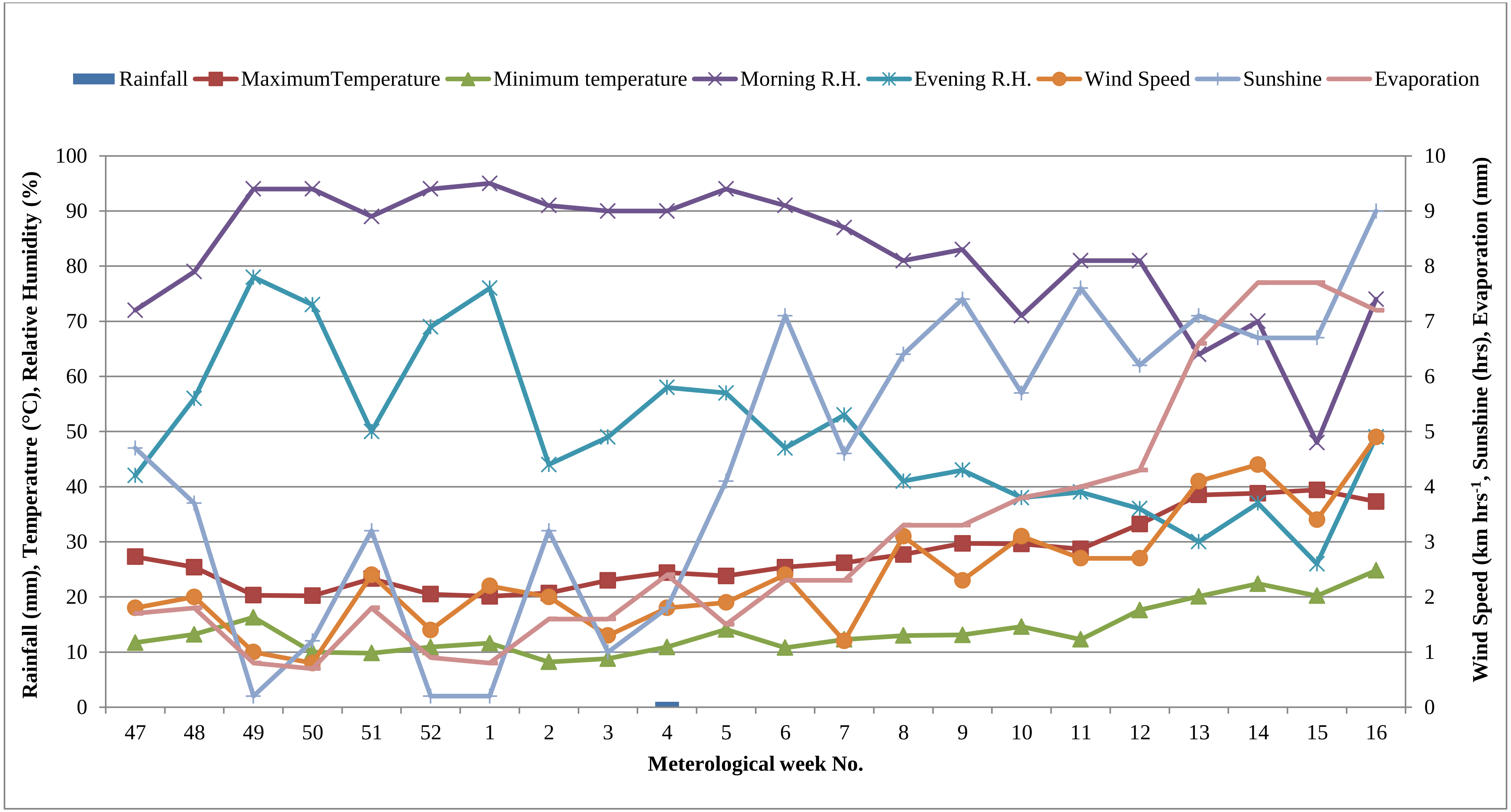


Figure 3.1: Standard weekly meteorological data during crop season (*Rabi* 2016-17)

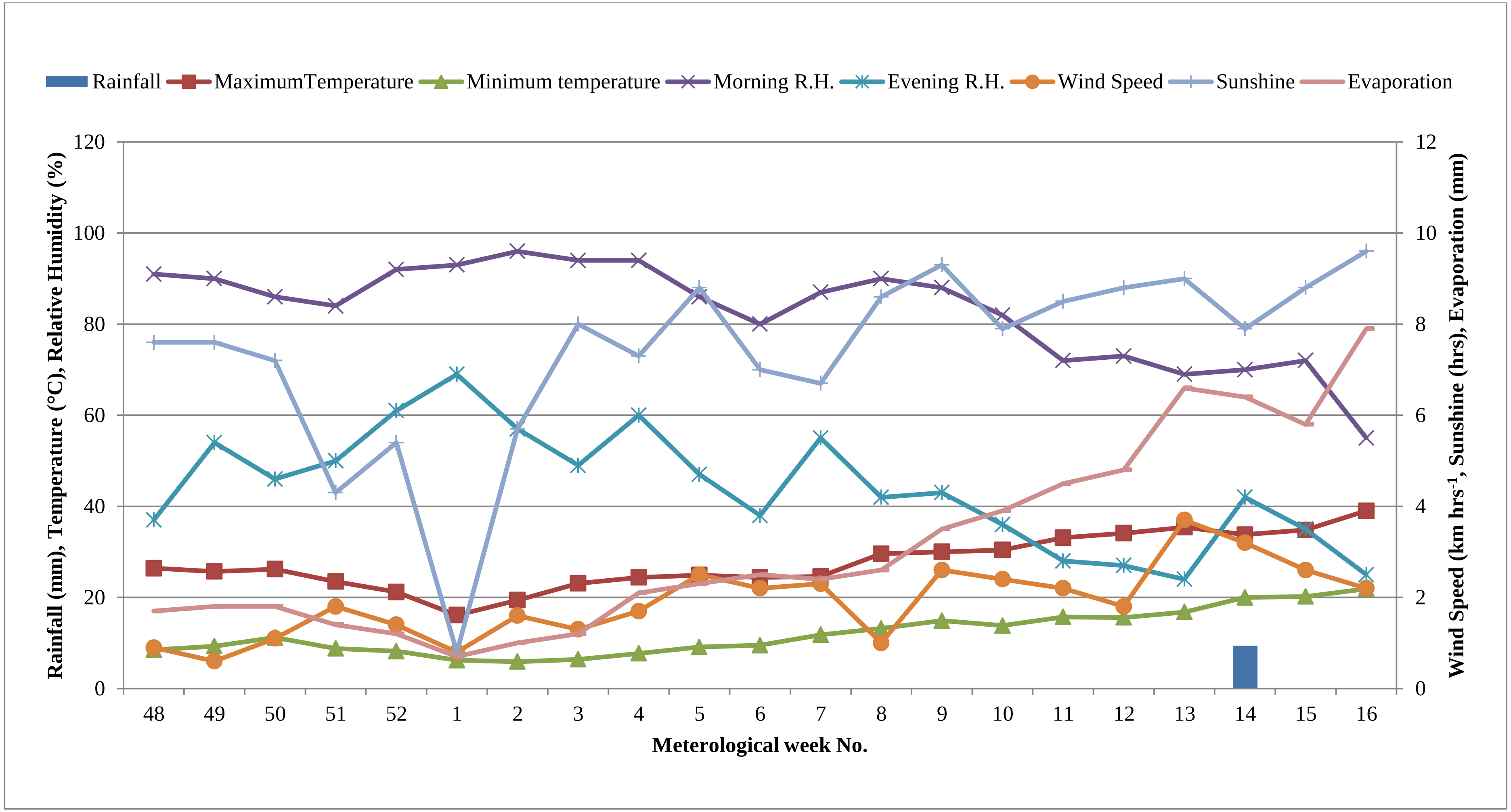
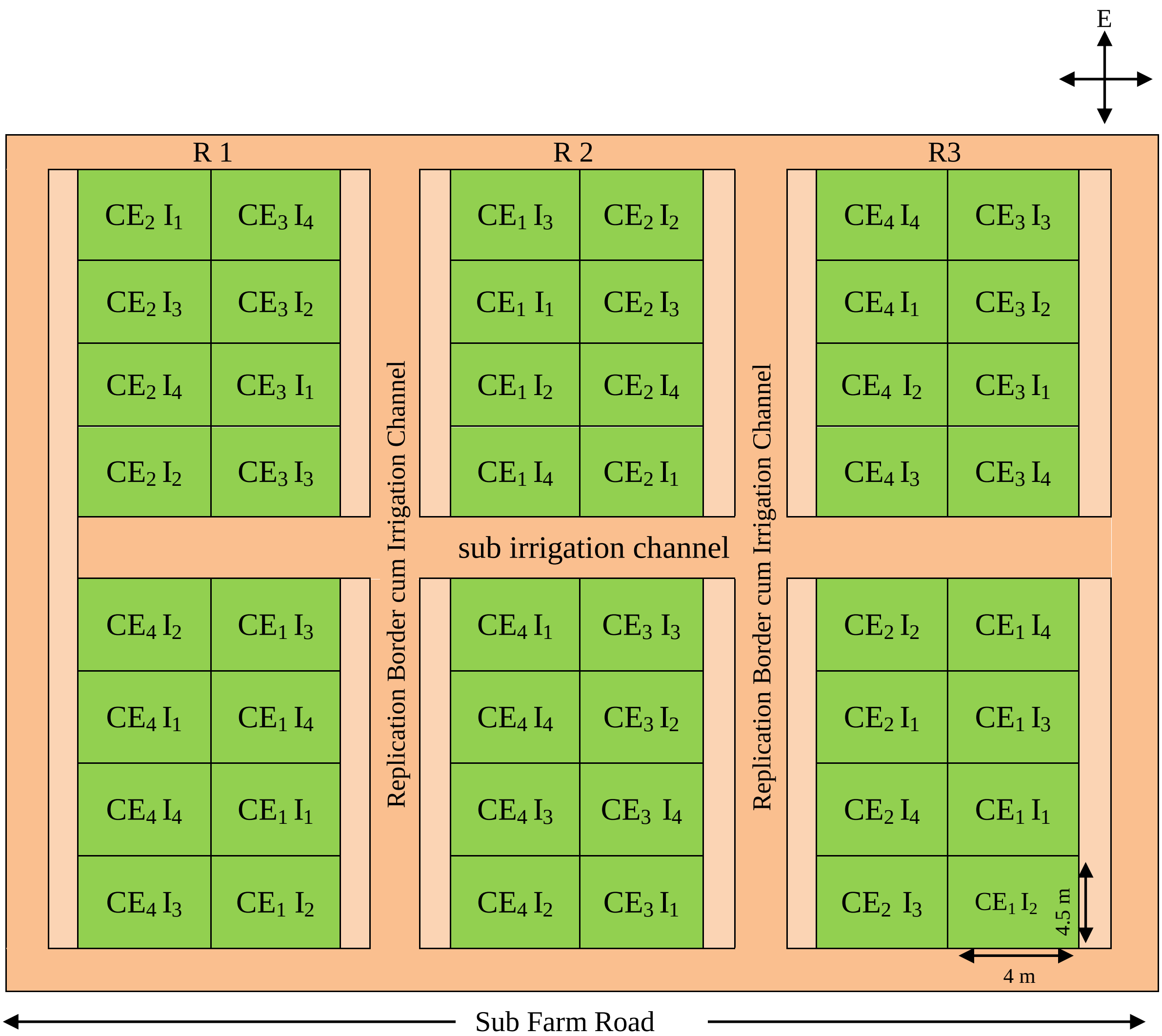


Figure 3.2: Standard weekly meteorological data during crop season (*Rabi* 2017-18)



Design	Split plot	Row spacing	20 cm
Replications	3	Seed rate	100 kg ha^{-1}
Treatments combinations	4 x 4= 16	Main irrigation channel cum replication border	1.5 m
Total number of plots	16 x 3 = 48	Plot border	0.8 m
Gross Plot size	4.5 m x 4.0 m = 18 m^2	Variety	Rice: Sarajoo-52
Net Plot size	3.5 m x 3.2 m = 11.2 m^2		Wheat: HD 2967

Treatments	**Symbol used**
A. Main plot (Crop Establishment methods)	
Conventional till rice (puddled transplanted)-conventional till wheat [CTPTR-CTW]	**CE_1**
Conventional till direct seeded rice (DSR)-conventional till wheat [CTDSR-CTW]	**CE_2**
Conventional till DSR-zero till wheat (rice residue retention) [CTDSR-ZTW (RR)]	**CE_3**
Zero till DSR-zero till wheat (residue retention in rice and wheat) [ZTDSR-ZTW(RWR)]	**CE_4**
B. Sub plot (Irrigation Scheduling in wheat)	
IW/CPE ratio = 0.75	**I_1**
IW/CPE ratio = 1.0	**I_2**
IW/CPE ratio = 1.25	**I_3**
Farmer's practice (need based irrigation)	**I_4**

Figure 3.3: Layout of the experiment

EXPERIMENTAL FINDINGS

The present study entitled **"Effect of crop establishment methods and irrigation scheduling on growth, yield and water productivity of wheat in rice-wheat system"** was carried out at the Agricultural Research Farm, Institute of agricultural Sciences, Banaras Hindu University, Varanasi during two successive *Kharif* and *Rabi* seasons of 2016-17 and 2017-18. In this chapter, attempt has been made to elucidate the effect of experimental variables on the growth characters, yield attributes and yield of wheat crop, nutrient content and uptake, water productivity of wheat and economics, soil physico-chemical properties as well as nutrient balance in soil of different crop establishment methods and irrigation scheduling during the study period. The observations were noted at different growth stages and maturity of wheat crop. Hence, the data produced during the study period were subjected to analysis statistically to assess the degree of variance to portray the trends of response statistically; significant differences have been emphasized in order to provide a quick trend betray by experimental variables on various attributes. The major effects have been described however the interaction effects were not significant, hence not presented.

4.1 Effect of crop establishment and irrigation scheduling on wheat

4.1.1 Growth characters

The data related to growth parameter *viz*. plant height (cm), number of tiller (m^{-1} row length), dry matter accumulation (g m^{-1} row length) at 30, 60, 90 DAS and at harvest and chlorophyll content (SPAD value) & number of green leaf (m^{-1} row length) at 30, 60 and 90 DAS were recorded and presented in Tables 4.1 to 4.5.

4.1.1.1 Plant height (cm)

The observation related to plant height as influenced by different crop establishment methods and irrigation scheduling recorded at 30, 60, 90 DAS and at harvest presented in Table 4.1 and Figure 4.1 reflected the steady increment in plant height with advancement of crop growth stages up to 90 DAS and then, it practically stagnated at maturity during both the years.

A perusal of the data revealed, significant increment in plant height due to CA based crop establishment methods at all the growth stages except 30 DAS. Maximum plant height was observed with ZTDSR-ZTW (RWR) establishment method which was significantly higher than CTPTR-CTW and CTDSR-CTW, but it was remained at par to CTDSR-ZTW (RR) at all the growth stages during both the years. At 30 DAS differences in plant height due to crop establishment method did not had remarkable significance.

The data given in Table 4.1 further revealed that irrigation scheduled at different IW/CPE ratio had marked effect on plant height during both the years of experimentation. Water applied based on IW/CPE=1.25 (I_3) produced significantly taller plant of wheat over IW/CPE=1.25 (I_1). However I_3 was at par with IW/CPE=1.0 and Farmer's Practice (need based application) at all the stages of observation except 30 DAS, at which the plant height had not varied significantly due to irrigation scheduling, during both the years of investigation.

None of the interactions due to crop establishment methods and irrigation scheduling gave significant impact on height of wheat at any stages of observation during both the years.

4.1.1.2 Number of tiller (m^{-1} row length)

The data on number of tiller m^{-1} row length as influence by different crop establishment methods and irrigation scheduling are listed in Table 4.2. The data showed the continuous enhancement in number of tiller m^{-1} row length up to 90 DAS and thereafter, it slightly curtailed.

The values listed in Table 4.2 clearly indicated that CA based crop establishment methods significantly enhanced number of tiller m^{-1} row length. Among the crop establishment methods treatment ZTDSR-ZTW (RWR) recorded significantly higher number of tiller m^{-1} row length, but it was remained comparable with CT DSR-ZT Wheat (RR) at all the growth stages during both experimental years. Minimum number of tiller m^{-1} row length was registered with CTPTR-CT Wheat.

As regards to irrigation scheduling, significant variations were found in respect to tiller production during both the years. The irrigation scheduled on IW/CPE=1.25 produced highest tillers m^{-1} row length followed by IW/CPE=1.0 and farmer's practice. However, they were being comparable, significantly superior to IW/CPE=0.75) at all the growth stages except 30 DAS, during both the years of study. At 30 DAS the variation in number of tiller m^{-1} row length was not significant.

The interactions due to various crop establishment methods and irrigation scheduling had no significant impact on tillers m^{-1} row length at any of the growth stage in any of investigation year.

4.1.1.3 Number of green leaf (m^{-1} row length)

The data on number of green leaf m^{-1} row length as influenced by different crop establishment methods and irrigation scheduling in wheat are presented in Table 4.3. The data revealed the continuous increment in number of leaf m^{-1} row length up to 90 DAS during both the experimenting years.

A critical analysis of data showed prominent effect of crop establishments methods on green leaf m^{-1} row length and the maximum value was recorded with CE_4-ZTDSR-ZT wheat (RWR), which found statistically superior over CE_1-CTPTR-CTW and CE_2-CTDSR-CTW, however, CE_4 was statistically at par to CE_3-CTDSR-ZTW (RR) at 30, 60 and 90 DAS, during both the years.

The data noted on various irrigation scheduling in wheat distinctly indicated that increasing number of irrigation noticeably increased number of green leaf m^{-1} row length at all the growth stages during both the year of experiment (Table 4.3). Amongst the irrigation scheduling in wheat, IW/CPE=1.25 recorded significantly higher total green leaf m^{-1} row length followed by IW/CPE=1.0, Farmer's practice (need based) and IW/CPE=0.75 at 60 and 90 DAS. However, at 30 DAS number of green leaf m^{-1} row length did not differ statistically due to irrigation scheduling in wheat during both the years of study.

No interaction effect was found as regard to green leaves m^{-1} row length due to various crop establishment methods and irrigation scheduling in wheat in rice-wheat system, during both the year of experimentation.

4.1.1.4 Dry matter accumulation (g m^{-1} row length)

Careful appraisal of the data tabulated in Table 4.4 and illustrated in Figure 4.2 showed that dry matter accumulation m^{-1} row length was continued to accumulate with advancement of growth period till maturity of crop throughout the research period during both the years.

Amongst the crop establishment methods, CE_4-zero till direct seeded rice-zero till wheat with rice and wheat residue recorded significantly higher dry matter accumulation than CE_1-conventional till pudduled transplanted rice-conventional till wheat and conventional till direct seeded rice-conventional till wheat, but it was remained statistically comparable with CE_3-conventional till direct seeded rice-zero till wheat with rice residue in rice wheat system at all the observation stages during both the years of investigation.

Data pertaining to irrigation scheduling indicated that increasing number of irrigation markedly enhanced dry matter m^{-1} row length at all the growth stages during both the years of experimentation. Dry matter m^{-1} row length increased significantly with irrigation scheduled on IW/CPE=1.25 over other IW/CPE ratio and farmer's practice at 60 DAS. Although at 90 DAS and at harvest it was at par with IW/CPE=1.0 and farmer's practice. However, dry matter accumulation did not differ significantly at 30 DAS.

The interaction on dry matter accumulation m^{-1} row length was not significant at any of the observation stages during both the years of study.

4.1.1.5 Chlorophyll content (SPAD value)

Data on leaf chlorophyll content (SPAD value) at 30, 60 and 90 DAS are presented in Table 4.5. The values were relatively little with higher in second year as compared to the first year.

A critical analysis of the data clearly pointed out that there was significant variation in chlorophyll content (SPAD value) of wheat in response to different crop establishment methods and the highest values was obtained with CE_4-ZTDSR-ZT wheat (RWR), which found comparable with ZTDSR-ZT wheat at 60 and 90 DAS. However, at 30 DAS, no substantial variation in chlorophyll content of wheat was observed due to different crop establishment methods during both the years of study.

It is evident from the data (Table 4.5) that increasing number of irrigation distinctly improved chlorophyll content and the higher SPAD value was noted with irrigation scheduled at IW/CPE=1.25 followed by IW/CPE=1.0 and farmer’s practice, they all being at par distinct showed superiority over IW/CPE=0.75 at 60 and 90 DAS during both the years of experimentation. Although, at 30 DAS, the differences in chlorophyll content influence by irrigation scheduling did not touch the level of significance.

Interactions of different treatments did not left any significant impact on leaf chlorophyll content (SPAD value) of wheat during both the years of investigation.

4.1.2 Yield attributes

4.1.2.1 Spikes (m^{-1} row length)

Data pertaining to Spikes m^{-1} row length at harvest are showed in Table 4.6. The values were little with higher in second year as compare to first year.

It was noticed that different crop establishment methods had significant impact on number of spike m^{-1} row length. Amongst different crop establishment methods, zero till direct seeded rice - zero till wheat with anchored rice & wheat residue resulted in higher spikes m^{-1} row length which was statistically comparable to conventional till direct seeded rice - zero till wheat with anchored rice residue. The minimum number of spike m^{-1} row length was in conventional till puddled transplanted rice-conventional till wheat during both the year of study.

The interpretation of data revealed that, irrigation scheduling in wheat influenced significantly on Spikes m^{-1} row length at harvest stage during both the years. Highest number of spike m^{-1} row length was recorded in irrigation scheduled based on IW/CPE=1.25 which was at pat to IW/CPE=1.0 and farmer's practice. However lowest number of spike m^{-1} row length was with irrigation scheduled with IW/CPE=0.75.

None of significant interactions was found as regard to number of spike m^{-1} row length due to various crop establishment methods and irrigation scheduling during the both the years of study.

4.1.2.2 Spike length (cm)

Data pertaining to spike length (cm) are presented in Table 4.6. A critical evaluation of the data clearly indicated that spike length was statistically differing due to different crop establishment methods. Amongst the crop establishment methods, ZTDSR-ZTW (RWR) being at par with CTDSR-ZTW (RR) produced longest spike followed by CTDSR-CTW and CTPTR-CTW during both the years of investigation.

As regard to irrigation scheduling in wheat, marked differences were noticed in spike length (Table 4.6). In relation to irrigation scheduling treatment, IW/CPE=1.25 being comparable to IW/CPE=1.0 and farmer's practice recorded significantly longer spike, all treatments showed superiority over IW/CPE=0.75 during both the years of experimentation.

Interactions between crop establishment methods and irrigation scheduling didn't show any significant effect on spike length in any of the experimenting years.

4.1.2.3 Grains spike^{-1}

Detailed perusal of the data regarding number of grain spike^{-1} as influenced by different treatments (Table 4.6) revealed that number of grain spike^{-1} statically differed due to crop establishment methods and irrigation scheduling in both the years.

Among the crop establishment methods treatment CE_4-ZTDSR-ZTW (RWR) recorded highest grains spike^{-1} which was significantly higher over CE_2-CTDSR-CTW and CE_1-CTPTR-CTW, but it was at par to CE_3-CTDSR-ZTW (RR) during both the years of experimentation.

While examining of data showed in Table 4.6, it could be noticed that the maximum number of grain spike^{-1} was recorded with irrigation scheduled on IW/CPE=1.25 followed by IW/CPE=1.0 and farmer’s practice. Nonetheless, the differences did not touch the level of significance in between these treatments. However, these treatments were statistically superior to IW/CPE=0.75 during both the years of experiment.

Interactions did not left any significant effect on grains spike^{-1} during both the years of study period.

4.1.2.4 Test weight

The data on test weight of 1000-grains as influenced by different crop establishment methods and irrigation scheduling in wheat in rice-wheat system are tabulated in Table 4.6.

Close examination of data revealed that there were no significant differences in weight of 1000-grains of wheat under different establishment methods. However, CE_4-ZTDSR-ZTW (RWR) recorded comparatively higher test weight followed by CE_3-CTDSR-ZTW (RR) > CE_2-CTDSR-CTW > CE_1-CTPTR-CTW.

Irrigation scheduling in wheat failed to touch level of significance on 1000 grains test weight during both the years of investigation. Although, test weight was higher in IW/CPE=1.25 followed by IW/CPE=1.0 > farmer's practice > IW/CPE=0.75.

4.1.3 Yield

4.1.3.1 Grain yield (kg ha^{-1})

The pertaining to grain yield as influenced by crop establishment methods and irrigation scheduling are shown in Table 4.7. and Figure 4.3 Yield of grain was slightly higher during second year as compared to first year of experimentation.

Amongst the crop establishment methods, zero till direct seeded rice - zero till wheat with anchored rice & wheat residue produced maximum grain yield which was remained at par to conventional till direct seeded rice - zero till wheat with anchored rice residue. The treatment CE_4-ZTDSR-ZTW (RWR) gain an increment of 11.61% and 11.95% higher grain yield over CE_1-CTPTR-CTW during 2016-17 and 2017-18 respectively.

Similarly, the data distinctly indicated that irrigation scheduling markedly affected grain yield during both the years of study. The higher irrigation water statistically improved the wheat grain yield than the lower amount of irrigation water. The highest grain yield was obtained with irrigation applied on IW/CPE=1.25, however, being at par with IW/CPE=1.0, both treatment produced significantly higher grain yield over farmer's practice and IW/CPE=0.75 during both the years of study. Irrigation scheduling on IW/CPE=1.25 recorded 9.74% and 9.69% higher grain yield over IW/CPE=0.75 during 2016-17 and 2017-18, respectively.

None of the significant interactions effect was found due to crop establishment methods and irrigation scheduling on grain yield of wheat during both the years of experiment.

4.1.3.2 Straw yield (kg ha^{-1})

The data on straw yield as affected by different crop establishment methods and irrigation scheduling are listed in Table 4.7. and Figure 4.3. The data revealed continuous improvement in straw yield with moving from conventional crop establishment to CA based crop establishment as well as irrigation scheduling on higher IW/CPE ratio. Straw yield of wheat was slightly higher during second year of experimentation than the first year.

A crucial examine of data expressed that CA based crop establishment method CE_4-ZTDSR-ZTW (RWR), which was at par to CE_3-CTDSR-ZTW (RR), resulted significantly higher wheat straw over the conventional crop establishment methods CE_2-CTDSR-CTW and CE_1-CTPTR-CTW. The treatment CE_4-ZTDSR-ZTW (RWR) recorded 9.50 and 9.90% higher straw yield over CE_1-CTPTR-CTW during first year and second year of experiment, respectively.

Irrigation scheduling in wheat showed marked improvement in straw yield of wheat (Table 4.7). The maximum straw yield was recorded with the treatment IW/CPE=1.25, although, it remained at par to IW/CPE=1.0. However, both were statistically superior to IW/CPE=0.75 and farmer's practice (need based irrigation) during both the years of study. Irrigation scheduled on IW/CPE=1.25 resulted 12.85% and 10.94% higher straw yield over IW/CPE=0.75 during 2016-17 and 2017-18, respectively.

The interactions influenced by different crop establishment methods and irrigation scheduling had no significant effect on wheat straw yield during both the experimentation.

4.1.3.3 Harvest index (%)

The data related with harvest index as influenced by different crop establishment methods and irrigation scheduling is presented in Table 4.7.

The values revealed that different crop establishment methods failed to make the significant differences in harvest index during both the years of experimentation. However among the crop establishment methods CE_4-ZTDSR-ZTW (RWR) recorded maximum harvest index followed by CE_3-CTDSR-ZTW (RR) > CE_2-CTDSR-CTW > CE_1-CTPTR-CTW in either of the two years experiment.

Critical evaluation of the data showed that harvest index did not varied statistically in response to irrigation scheduling. Although, a little improvement in harvest index was noticed with increasing IW/CPE ratio. Highest harvest index was with treatment IW/CPE=1.25 followed by IW/CPE=1.0 > farmer's practice (need based irrigation) > IW/CPE=0.75.

The various interactions due crop establishment methods and irrigation scheduling in rice wheat system failed to express any significant effect on harvest index in any of the experimenting year.

4.1.4 Water studies

4.1.4.1 Irrigation water use efficiency (kg ha^{-1}-cm)

The data pertaining to irrigation water use efficiency under various crop establishment methods and irrigation scheduling tabulated in Table 4.8 and Figure 4.4.

The data revealed that irrigation water use efficiency differed significantly in response to different crop establishment methods in rice-wheat system during both the years of experimentation. However, treatment CE_4-ZTDSR-ZTW (RWR), being at par with CE_3-CTDSR-ZTW (RR) recorded highest irrigation water use efficiency. CA based crop establishment methods [CE_4-ZTDSR-ZTW (RWR) and CE_3-CTDSR-ZTW (RR)] both proved it's superiority over conventional crop establishment methods [CE_2-CTDSR-CTW and CE_1-CTPTR-CTW] during both the years.

An appraisal of data explicated that various IW/CPE ratio resulted significant differences in irrigation water use efficiency of wheat in rice-wheat system during both the experimentation years. Among the different irrigation scheduling, treatment farmer's practice (need based- 4 irrigation) resulted significantly higher irrigation water use efficiency followed by IW/CPE=0.75 > IW/CPE=1.0 > IW/CPE=1.25 during both the years of study.

No significant interactions effect was found due to crop establishment method and irrigation scheduling in respect to irrigation water use efficiency during any of experimenting year.

4.1.4.2 Water productivity (kg m^{-3} applied water)

The data pertaining to water productivity was set out in Table 4.8 and Figure 4.4 indicated that different crop establishment methods had marked impact on water productivity of wheat. Significantly higher water productivity was observed in CE_4-ZTDSR-ZTW (RWR) but it was remained at par to CE_3-CTDSR-ZTW (RR). However both were shown ascendancy over CE_2-CTDSR-CTW and CE_1-CTPTR-CTW during both the years.

Perusal of data (Table 4.8 & Fig. 4.4) reveals that water productivity of wheat was significantly affected in response to irrigation scheduling in rice wheat system. Among the irrigation scheduling treatment, water applied at farmer's practice (need based- 4 irrigation) registered maximum water productivity followed by IW/CPE=0.75 > IW/CPE=1.0 >IW/CPE=1.25.

None of the interactions influenced significantly by different treatment.

4.1.5 Nutrient content and uptake

4.1.5.1 N, P and K content (%) in wheat grain and straw

The data related to nitrogen (N), phosphorus (P) and potassium (K) content in wheat grain & straw at harvest as affected by crop establishment methods and irrigation scheduling are presented in Table 4.9 and 4.10. It is clear from the data that different crop establishment methods and irrigation scheduling failed to express any significant impact on N, P and K content in wheat grain and straw during both the year of experiment.

A precise analysis of the data revealed that there were little variations in N, P and K content in grain and straw of wheat influenced by different crop establishment methods. But the differences were not significant during both the years. The maximum N, P and K content was noticed with CE_4-ZTDSR-ZTW (RWR) followed by CE_3-CTDSR-ZTW (RR) > CE_2-CTDSR-CTW > CE_1-CTPTR-CTW during both the years.

In case of irrigation scheduling, the differences as regard to N, P and K content in grain and straw wheat were also not statistically comparable during both the year of experiment. Little higher N, P and K content was registered in irrigation scheduling on IW/CPE=1.25 followed by farmer's practice > IW/CPE=1.0 > IW/CPE=0.75.

The interactions effect on N, P and K content in wheat grain and straw were also not significant in any of investigating years.

4.1.5.2 N, P and K uptake by wheat grain and straw (kg ha^{-1})

The data on N, P and K uptake by grain and straw in context to different crop establishment methods and irrigation scheduling in rice-wheat system are presented in Table 4.11 and 4.12. The uptake was comparatively slightly higher in second year than the first year.

A deep investigation of the data showed that different crop establishment methods had effect on N, P and K uptake by wheat grain and straw during both the years of study. The crop established in CA based CE_4- ZTDSR-ZTW (RWR) method, being on par to CE_3-CTDSR-ZTW (RR) recorded statistically higher nitrogen, phosphorus and potassium uptake by grain as well as straw over crop established under conventional methods CE_2-CTDSR-CTW and CE_1-CTPTR-CTW during both the years.

Higher number of irrigation increased nutrient uptake by wheat grain and straw during both the years of experiment. The maximum nutrient (N, P and K) uptake by grain and straw was observed with irrigation scheduling at IW/CPE=1.25 which was at par to IW/CPE=1.0, however lowest nutrient uptake was observed under irrigation scheduling on IW/CPE=0.75.

The variations in interactions effect due to different treatments were not beyond the significant limits in relation to nutrient (N, P and K) uptake by grain and straw of wheat during two years of trial.

4.1.6 Physico-chemical properties of soil

4.1.6.1 Available N, P and K in soil (kg ha^{-1})

Summary of the data on available N, P and K in soil after harvest of wheat crop as influenced by different crop establishment methods and irrigation scheduling in rice-wheat system are presented in Table 4.13.

A rigorous inspection of the data given in Table 4.13 reviled that different crop establishment methods had marketable impact on available N, P and K in soil during both the year of study. CA based crop establishment methods provide significantly higher availability of N, P and K in the soil after harvest of crop. The maximum available N, P and K in soil after wheat harvest was noted in treatment CE_4-ZTDSR-ZTW (RWR) and it was at par to CE_3-CTDSR-ZTW (RR). The lowest available N, P and K in soil was found in conventional till based crop establishment methods CE_1-CTPTR-CTW followed by CE_2-CTDSR-CTW during both the years of investigation.

Among irrigation scheduling, IW/CPE=1.25 recorded higher available N, P and K in soil after harvest of wheat followed by IW/ CPE=1.0 > farmer's practice and IW/CPE=0.75. Even so, the differences unable to touch the significance level during both the years of evaluation.

Interactions could not left any significant impact on available N, P and K in soil after harvest of wheat in rice-wheat system due to different treatments in either of the years of investigation.

4.1.6.2 Soil pH, EC (dS m^{-1}), bulk density (g cm^{-3}) and organic carbon (%)

The data regarding to soil pH, EC, bulk density and organic carbon as influenced by different crop establishment and irrigation scheduling in rice wheat system are represented in Table 4.14. The scrutiny of data showed that the different treatment had no significant impact on pH, EC, bulk density and organic carbon of soil.

Among the crop establishment methods, CE_4-ZTDSR-ZTW (RWR) recorded slightly higher organic carbon and lower pH, EC and bulk density of soil followed by CE_3-CTDSR-ZTW (RR), CE2-CTDSR-CTW and CE_1-CTPTR-CTW. But the differences between highest and lowest value were not beyond the significant limit. However, the data on pH, EC and bulk density were little lower and slightly higher organic carbon in second year as compared to first year.

In case of irrigation scheduling, the pH, electrical conductivity, bulk density and organic carbon in soil after harvest of wheat were not differed statistically due to various irrigation scheduling. However, it seems from the data that lowest pH, EC and bulk density were in irrigation scheduled on IW/CPE=1.25 and highest values in IW/CPE=0.75. The organic carbon was little higher in IW/CPE=1.25 and lowest in IW/CPE=0.75 during both the year of investigation.

No interactions effect was found in case of soil pH, EC, bulk density and organic carbon after harvest of wheat crop during both the years.

4.1.7 Economics

Economics of different crop establishment methods and irrigation scheduling have been tabulated in Table 4.15. It was calculated on the basis of input-output analysis.. There was a notable variation in relation to cost of cultivation, gross returns, net returns and benefit cost ratio as influenced by crop establishment methods and irrigation scheduling during both the years of experiment.

4.1.7.1 Cost of cultivation (₹ ha^{-1})

The data on cost of cultivation as affected by various crop establishment methods and irrigation scheduling are summarized under Table 4.15. The cost of cultivation remained same during both the years.

The data presented in Table 4.15 clearly reflected that CA based crop establishment methods markedly decreased the cost of cultivation. In general, CA based crop establishment methods CE_4-ZTDSR-ZTW (RWR) and CE_3-CTDSR-ZTW (RR) registered 14.73% (34345 ₹ ha^{-1}) lower cost of cultivation of wheat as compared to conventional crop establishment methods CE_2-CTDSR-CTW and CE_1-CTPTR-CTW (40281 ₹ ha^{-1}) during both the years of experiment.

Further, it can be noticed from the Table 4.15 that the lowest cost of cultivation was noted with irrigation scheduling on IW/CPE=0.75 (36836 ₹ ha^{-1}) and farmer's practice (need based - 4 irrigation) followed by IW/CPE=1.0 (37472 ₹ ha^{-1}) and IW/CPE=1.25 (38108 ₹ ha^{-1}) during both the years.

4.1.7.2 Gross returns (₹ ha^{-1})

Gross returns as influenced by different crop establishment methods and irrigation scheduling are summarized in Table 4.15. Slightly higher gross returns were found in second year than the first year.

A close scanning of the data revealed noticeable effect of crop establishment methods on gross returns. The highest gross returns were obtained from the CE_4-ZTDSR-ZTW (RWR) establishment method which was statistically at par to CE_3-CTDSR-ZTW (RR), nevertheless both proved superiority over CE_2-CTDSR-CTW and CE_1-CTPTR-CTW during both the years of experimentation. The CE_4-ZTDSR-ZTW (RWR) registered 11.18% and 11.54% more gross returns over CE_1-CTPTR-CTW during 2016-17 and 2017-18, respectively.

As regards the irrigation scheduling, data clearly reflected that the gross returns were markedly enhanced with increasing level of IW/CPE ratio from 0.75 to 1.25. The maximum gross returns were observed from irrigation scheduled on IW/CPE=1.25. But it remained comparable to IW/CPE=1.0 and minimum gross returns was associated with IW/CPE=0.75 during both the year of experimentation.

Interactions in response to crop establishment methods and irrigation scheduling did not had any significant impact on gross returns during both the years of study.

4.1.7.3 Net returns (₹ ha^{-1})

Data pertaining to net returns as influenced by different crop establishment methods and irrigation scheduling are set out in Table 4.15 and Figure 4.5. The net returns were little higher in second year in comparison to first year.

Analysis of data on net returns reviled that crop establishment markedly influenced net returns during both the years. CA based crop establishment CE_4-ZTDSR-ZTW (RWR), being at par with CE_3-CTDSR-ZTW (RR) resulted significantly higher net returns over conventional crop establishment method CE_2-CTDSR-CTW and CE_1-CTPTR-CTW. It was further noticed that CE_4-ZTDSR-ZTW (RWR) recorded 29.24% (average of two year) higher net returns on CE_1-CTPTR-CTW and 28% (average of two year) over CE_2-CTDSR-CTW.

The water application at different IW/CPE treatments distinctly affected net returns during both the years of experimentation. Scrutiny of the data manifested that IW/CPE=1.25 recorded highest net return during wheat crop experimentation. Treatment IW/CPE=1.25 accounted for additional net return of ₹ 13425, 6798 & 3133 ha^{-1} in 2016-17 and ₹ 11909, 6678 & 2910 ha^{-1} in 2017-18 over IW/CPE=0.75, farmer’s practice and IW/CPE=1.0 respectively. However, the significant additional net return was not observed between IW/CPE=1.25 and IW/CPE= 1.0 during both the years.

Interactions due to different crop establishment methods and irrigation scheduling on net returns were not significant during the both the years.

4.1.7.4 Benefit cost ratio (B:C)

The data on benefit cost ratio in respect to different crop establishment methods and irrigation scheduling are presented in Table 4.15 and Figure 4.5. Benefit cost ratio was little higher during second year than the first year.

A superficial view over the data reflected that CA based crop establishment methods distinctly enhanced the benefit cost ratio during both the year of study. Treatment CE_4-ZTDSR-ZTW (RWR) (2.20 & 2.22) recorded highest benefit cost ratio which was significantly superior over CE_2-CTDSR-CTW (1.46 & 1.49) and CE_1-CTPTR-CTW (1.45 & 1.47) but remained comparable to CE3-CTDSR-ZTW (RR) (2.11 & 2.18) during 2016-17 and 2017-18, respectively.

Further examination of data confirmed that benefit cost ratio also touched the level of significance in case of irrigation scheduling during the course of study. Irrigation scheduling at IW/CPE=1.25 (1.92 & 1.95) recorded maximum B:C followed by IW/CPE=1.0 (1.87 & 1.90), farmer's practice (1.81 & 1.83) and IW/CPE=0.75 (1.62 &1.68). However, the difference between IW/CPE=1.25 and IW/CPE=1.0 remained comparable during both the year of study. While during 2016-17 the farmer's practice also at par to IW/CPE=1.25 in respect of benefit cost ratio.

The interactions due to different crop establishment methods and irrigation scheduling in rice-wheat system had no significant impact on benefit cost ratio during both the years.

Table 4.1: Plant height of wheat at different growth stages as influenced by crop establishment methods and irrigation scheduling in rice-wheat system

Treatments	Plant height (cm)							
	30 DAS		60 DAS		90 DAS		At harvest	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Crop Establishment*								
CT PTR-CT Wheat	25.92	26.05	51.18	51.22	93.05	94.88	93.40	94.75
CT DSR-CT Wheat	26.19	26.32	52.42	52.60	93.96	95.34	93.70	95.17
CT DSR-ZT Wheat (RR)	26.63	26.68	53.88	54.89	96.77	97.77	98.35	97.82
ZT DSR-ZT Wheat (RWR)	27.03	27.15	54.48	55.16	99.17	100.39	99.33	99.96
SEm ±	**0.60**	**0.33**	**0.58**	**0.64**	**1.14**	**1.12**	**1.23**	**1.11**
CD (*p=0.05*)	**NS**	**NS**	**2.02**	**2.21**	**3.96**	**3.88**	**4.25**	**3.86**
Irrigation Scheduling in wheat								
IW/CPE=0.75	26.40	26.44	51.58	52.57	92.92	94.88	94.10	94.86
IW/CPE=1.0	26.40	26.57	53.79	53.74	96.73	97.69	97.23	97.36
IW/CPE=1.25	26.49	26.58	54.07	54.00	97.23	98.40	97.25	98.09
Farmer's Practice	26.48	26.61	52.53	53.56	96.06	97.42	96.18	97.39
SEm ±	**0.25**	**0.36**	**0.54**	**0.36**	**0.94**	**0.86**	**0.82**	**0.70**
CD (*p=0.05*)	**NS**	**NS**	**1.59**	**1.04**	**2.73**	**2.50**	**2.39**	**2.04**

*CTPTR-CTW - Conventional till rice (puddled transplanted)-conventional till wheat
CTDSR-CTW - Conventional till direct seeded rice (DSR)-conventional till wheat
CTDSR-ZTW (RR) - Conventional till DSR-zero till wheat (rice residue retention)
ZTDSR-ZTW(RWR) - Zero till DSR-zero till wheat (residue retention in rice and wheat)

Table 4.2: Number of tiller of wheat at different growth stages as influenced by crop establishment methods and irrigation scheduling in rice-wheat system

Treatments	Number of tiller (m^{-1} row length)							
	30 DAS		60 DAS		90 DAS		At harvest	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Crop Establishment								
CT PTR-CT Wheat	75.17	75.58	103.83	102.25	108.25	108.00	99.50	99.25
CT DSR-CT Wheat	76.17	76.08	104.83	105.08	110.17	110.83	101.17	102.25
CT DSR-ZT Wheat (RR)	79.42	78.58	111.67	112.33	113.67	116.17	107.33	108.42
ZT DSR-ZT Wheat (RWR)	80.33	81.08	114.75	115.67	117.67	118.08	109.92	111.08
SEm ±	**1.13**	**1.14**	**2.29**	**2.03**	**1.85**	**1.95**	**2.07**	**2.03**
CD (*p=0.05*)	**3.91**	**3.95**	**7.92**	**7.03**	**6.42**	**6.76**	**7.15**	**7.02**
Irrigation Scheduling in wheat								
IW/CPE=0.75	76.92	76.58	97.92	100.17	106.33	108.00	95.92	100.58
IW/CPE=1.0	77.83	78.08	111.75	112.08	115.42	115.08	106.83	106.33
IW/CPE=1.25	78.42	78.75	114.92	114.25	115.92	116.58	108.83	107.58
Farmer's Practice	77.92	77.92	110.50	108.83	112.08	113.42	106.33	106.50
SEm ±	**0.80**	**1.08**	**2.20**	**1.56**	**1.63**	**1.22**	**1.79**	**1.33**
CD (*p=0.05*)	**NS**	**NS**	**6.41**	**4.56**	**4.75**	**3.57**	**5.23**	**3.87**

Table 4.3: Number of green leaf (m^{-1} row length) of wheat at different growth stages as influenced by crop establishment methods and irrigation scheduling in rice-wheat system

Treatments	Number of green leaf (m^{-1} row length)					
	30 DAS		60 DAS		90 DAS	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Crop Establishment						
CT PTR-CT Wheat	258.00	259.83	478.33	490.92	422.08	429.33
CT DSR-CT Wheat	261.33	264.83	494.92	503.92	425.08	431.67
CT DSR-ZT Wheat (RR)	270.67	270.00	513.00	523.67	442.83	443.42
ZT DSR-ZT Wheat (RWR)	273.75	278.83	522.75	531.75	452.25	461.83
SEm ±	**3.17**	**3.44**	**7.74**	**7.46**	**6.33**	**6.25**
CD (*p=0.05*)	**10.98**	**11.91**	**26.77**	**25.83**	**21.89**	**21.62**
Irrigation Scheduling in wheat						
IW/CPE=0.75	263.33	267.25	461.67	486.33	395.92	399.00
IW/CPE=1.0	266.92	268.33	512.33	521.08	449.67	454.25
IW/CPE=1.25	267.67	269.75	532.50	530.08	462.75	468.50
Farmer's Practice	265.83	268.17	502.50	512.75	433.92	444.50
SEm ±	**2.75**	**0.62**	**5.82**	**3.33**	**5.85**	**3.96**
CD (*p=0.05*)	**NS**	**NS**	**16.98**	**9.71**	**17.09**	**11.56**

Table 4.4: Dry matter accumulation (g m^{-1} row length) of wheat at different growth stages as influenced by crop establishment methods and irrigation scheduling in rice-wheat system

Treatments	Dry matter (g m^{-1} row length)							
	30 DAS		60 DAS		90 DAS		At harvest	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Crop Establishment								
CT PTR-CT Wheat	13.17	13.53	80.15	82.76	208.25	212.42	269.08	272.67
CT DSR-CT Wheat	13.64	14.01	82.48	85.92	212.12	214.95	271.62	274.83
CT DSR-ZT Wheat (RR)	13.90	14.27	89.77	91.59	222.45	225.27	285.75	286.00
ZT DSR-ZT Wheat (RWR)	14.66	15.04	95.13	96.65	225.73	230.03	290.13	295.00
SEm ±	**0.28**	**0.23**	**2.71**	**1.67**	**3.73**	**3.70**	**4.41**	**4.36**
CD (*p=0.05*)	**0.95**	**0.81**	**9.37**	**5.79**	**12.90**	**12.82**	**15.25**	**15.09**
Irrigation Scheduling in wheat								
IW/CPE=0.75	13.52	13.96	74.85	79.32	208.83	214.92	270.92	274.25
IW/CPE=1.0	14.08	14.23	90.95	91.73	218.30	221.80	282.37	283.58
IW/CPE=1.25	14.33	14.50	96.42	96.44	223.82	224.70	283.70	287.42
Farmer's Practice	13.45	14.17	85.31	89.44	217.60	221.25	279.60	283.25
SEm ±	**0.25**	**0.21**	**1.86**	**1.58**	**2.22**	**1.59**	**3.30**	**2.85**
CD (*p=0.05*)	**NS**	**NS**	**5.42**	**4.60**	**6.49**	**4.64**	**9.62**	**8.31**

Table 4.5: Chlorophyll content (SPAD value)of wheat at different growth stages as influenced by crop establishment methods and irrigation scheduling in rice-wheat system

Treatments	Chlorophyll content (SPAD value)					
	30 DAS		60 DAS		90 DAS	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Crop Establishment						
CT PTR-CT Wheat	37.03	38.16	40.28	40.72	42.35	43.09
CT DSR-CT Wheat	37.06	38.38	40.94	41.84	43.30	43.64
CT DSR-ZT Wheat (RR)	37.29	38.74	42.28	42.72	44.15	45.42
ZT DSR-ZT Wheat (RWR)	37.86	39.14	43.18	43.53	45.79	46.46
SEm ±	**0.59**	**0.59**	**0.59**	**0.55**	**0.66**	**0.64**
CD (*p=0.05*)	**NS**	**NS**	**2.04**	**1.91**	**2.29**	**2.21**
Irrigation Scheduling in wheat						
IW/CPE=0.75	36.92	38.31	40.48	41.27	43.19	43.69
IW/CPE=1.0	37.15	38.48	42.12	42.32	43.75	44.57
IW/CPE=1.25	37.82	38.86	42.53	42.86	44.65	45.31
Farmer’s Practice	37.36	38.78	41.55	42.34	44.00	45.04
SEm ±	**0.50**	**0.37**	**0.36**	**0.36**	**0.34**	**0.33**
CD (*p=0.05*)	**NS**	**NS**	**1.04**	**1.04**	**0.98**	**0.95**

Table 4.6: Yield attributes of wheat as influenced by crop establishment methods and irrigation scheduling in rice-wheat system

Treatments	Yield attributes							
	Spikes (m^{-1} row length)		Spike length (cm)		Grains $spike^{-1}$		Test weight (g)	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Crop Establishment								
CT PTR-CT Wheat	84.20	85.33	12.23	12.39	49.03	50.42	37.11	37.25
CT DSR-CT Wheat	85.08	87.58	12.33	12.46	50.17	51.67	37.30	37.38
CT DSR-ZT Wheat (RR)	90.10	91.08	12.88	13.25	52.75	54.17	37.88	38.29
ZT DSR-ZT Wheat (RWR)	92.85	94.25	13.15	13.37	54.50	54.75	38.28	38.54
SEm ±	**1.64**	**1.61**	**0.18**	0.18	**1.08**	**0.88**	**0.44**	**0.38**
CD (*p=0.05*)	**5.66**	**5.56**	**0.63**	0.63	**3.74**	**3.06**	**NS**	**NS**
Irrigation Scheduling in wheat								
IW/CPE=0.75	83.33	85.33	11.97	12.40	49.69	51.13	37.06	37.36
IW/CPE=1.0	89.87	90.58	12.79	12.87	51.75	53.18	37.75	37.86
IW/CPE=1.25	90.62	91.83	13.02	13.12	52.83	53.83	38.07	38.16
Farmer's Practice	88.42	90.50	12.81	13.09	52.17	52.86	37.69	38.08
SEm ±	**1.22**	**0.93**	**0.11**	0.09	**0.57**	**0.52**	**0.31**	**0.23**
CD (*p=0.05*)	**3.57**	**2.72**	**0.33**	0.26	**1.66**	**1.53**	**NS**	**NS**

Table 4.7: Grain yield, straw yield and Harvest index of wheat as influenced by crop establishment methods and irrigation scheduling in rice-wheat system

Treatments	**Grain yield ($kg\ ha^{-1}$)**		**Straw yield ($kg\ ha^{-1}$)**		**Harvest index (%)**	
	2016-17	**2017-18**	**2016-17**	**2017-18**	**2016-17**	**2017-18**
Crop Establishment						
CT PTR-CT Wheat	4392	4418	6584	6603	40.01	40.07
CT DSR-CT Wheat	4409	4459	6589	6624	40.08	40.25
CT DSR-ZT Wheat (RR)	4767	4872	7033	7149	40.37	40.48
ZT DSR-ZT Wheat (RWR)	4902	4946	7210	7257	40.46	40.52
SEm ±	**79**	**73**	**116**	**101**	**0.18**	**0.24**
CD (*p=0.05*)	**272**	**253**	**402**	**351**	**NS**	**NS**
Irrigation Scheduling in wheat						
IW/CPE=0.75	4244	4347	6408	6533	39.83	39.97
IW/CPE=1.0	4747	4799	7035	7028	40.29	40.56
IW/CPE=1.25	4923	4960	7232	7248	40.49	40.60
Farmer's Practice	4557	4589	6741	6824	40.31	40.19
SEm ±	**64**	**50**	**94**	**58**	**0.17**	**0.20**
CD (*p=0.05*)	**188**	**146**	**275**	**169**	**NS**	**NS**

Table 4.8: Irrigation water use efficiency and water productivity of wheat as influenced by crop establishment methods and irrigation scheduling in rice-wheat system

Treatments	Irrigation water use efficiency (kg ha^{-1}-cm)		Water productivity (kg m^{-3} applied water)	
	2016-17	**2017-18**	**2016-17**	**2017-18**
Crop Establishment				
CT PTR-CT Wheat	157.37	158.49	1.57	1.58
CT DSR-CT Wheat	158.02	160.21	1.58	1.60
CT DSR-ZT Wheat (RR)	170.22	174.04	1.70	1.74
ZT DSR-ZT Wheat (RWR)	176.04	177.31	1.76	1.77
SEm ±	**2.71**	**2.37**	**0.03**	**0.02**
CD (*p=0.05*)	**9.39**	**8.19**	**0.09**	**0.08**
Irrigation Scheduling in wheat				
IW/CPE=0.75	176.82	181.11	1.77	1.81
IW/CPE=1.0	158.22	159.98	1.58	1.60
IW/CPE=1.25	136.75	137.77	1.37	1.38
Farmer's Practice	189.86	191.19	1.90	1.91
SEm ±	**2.32**	**1.70**	**0.02**	**0.02**
CD (*p=0.05*)	**6.77**	**4.96**	**0.07**	**0.05**

Table 4.9: NPK content in wheat grain as influenced by crop establishment methods and irrigation scheduling in rice-wheat system

Treatments	N Content (%)		P Content (%)		K Content (%)	
	2016-17	**2017-18**	**2016-17**	**2017-18**	**2016-17**	**2017-18**
Crop Establishment						
CT PTR-CT Wheat	1.740	1.748	0.329	0.330	0.481	0.487
CT DSR-CT Wheat	1.743	1.754	0.331	0.333	0.490	0.492
CT DSR-ZT Wheat (RR)	1.749	1.759	0.340	0.342	0.502	0.504
ZT DSR-ZT Wheat (RWR)	1.758	1.763	0.345	0.347	0.512	0.518
SEm ±	**0.028**	**0.027**	**0.009**	**0.006**	**0.012**	**0.010**
CD (*p=0.05*)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Irrigation Scheduling in wheat						
IW/CPE=0.75	1.743	1.756	0.335	0.336	0.493	0.494
IW/CPE=1.0	1.747	1.755	0.337	0.339	0.496	0.499
IW/CPE=1.25	1.753	1.757	0.338	0.338	0.499	0.505
Farmer’s Practice	1.747	1.756	0.335	0.339	0.497	0.503
SEm ±	**0.015**	**0.009**	**0.006**	**0.006**	**0.010**	**0.006**
CD (*p=0.05*)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 4.10: NPK content in wheat straw as influenced by crop establishment methods and irrigation scheduling in rice-wheat system

Treatments	N Content (%)		P Content (%)		K Content (%)	
	2016-17	**2017-18**	**2016-17**	**2017-18**	**2016-17**	**2017-18**
Crop Establishment						
CT PTR-CT Wheat	0.437	0.445	0.057	0.056	1.371	1.373
CT DSR-CT Wheat	0.443	0.447	0.058	0.057	1.374	1.379
CT DSR-ZT Wheat (RR)	0.446	0.450	0.059	0.059	1.400	1.410
ZT DSR-ZT Wheat (RWR)	0.452	0.458	0.060	0.060	1.407	1.418
SEm ±	**0.009**	**0.008**	**0.001**	**0.001**	**0.022**	**0.022**
CD (*p=0.05*)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Irrigation Scheduling in wheat						
IW/CPE=0.75	0.443	0.445	0.057	0.056	1.380	1.384
IW/CPE=1.0	0.445	0.450	0.059	0.058	1.393	1.397
IW/CPE=1.25	0.446	0.454	0.059	0.059	1.399	1.401
Farmer's Practice	0.445	0.451	0.059	0.058	1.379	1.399
SEm ±	**0.005**	**0.005**	**0.001**	**0.001**	**0.015**	**0.013**
CD (*p=0.05*)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 4.11: NPK uptake by wheat grain as influenced by crop establishment methods and irrigation scheduling in rice-wheat system

Treatments	N Uptake (kg ha^{-1})		P Uptake (kg ha^{-1})		K Uptake (kg ha^{-1})	
	2016-17	**2017-18**	**2016-17**	**2017-18**	**2016-17**	**2017-18**
Crop Establishment						
CT PTR-CT Wheat	76.48	77.23	14.43	14.57	21.14	21.52
CT DSR-CT Wheat	76.84	78.22	14.62	14.86	21.45	21.94
CT DSR-ZT Wheat (RR)	83.33	85.64	16.19	16.66	23.93	24.57
ZT DSR-ZT Wheat (RWR)	86.18	87.16	16.91	17.15	25.10	25.65
SEm ±	**1.82**	**1.61**	**0.41**	**0.32**	**0.69**	**0.65**
CD (*p=0.05*)	**6.29**	**5.58**	**1.42**	**1.10**	**2.40**	**2.27**
Irrigation Scheduling in wheat						
IW/CPE=0.75	74.02	76.35	14.22	14.62	20.83	21.51
IW/CPE=1.0	82.91	84.24	16.01	16.27	23.57	24.00
IW/CPE=1.25	86.30	87.08	16.64	16.79	24.59	25.06
Farmer's Practice	79.60	80.58	15.29	15.56	22.62	23.12
SEm ±	**1.28**	**0.85**	**0.38**	**0.30**	**0.65**	**0.43**
CD (*p=0.05*)	**3.74**	**2.48**	**1.11**	**0.89**	**1.88**	**1.27**

Table 4.12: NPK uptake by wheat straw as influenced by crop establishment methods and irrigation scheduling in rice-wheat system

Treatments	N Uptake (kg ha^{-1})		P Uptake (kg ha^{-1})		K Uptake (kg ha^{-1})	
	2016-17	**2017-18**	**2016-17**	**2017-18**	**2016-17**	**2017-18**
Crop Establishment						
CT PTR-CT Wheat	28.76	29.41	3.70	3.75	90.25	90.67
CT DSR-CT Wheat	29.22	29.61	3.73	3.82	90.66	91.38
CT DSR-ZT Wheat (RR)	31.56	32.19	4.14	4.24	98.56	100.87
ZT DSR-ZT Wheat (RWR)	32.77	33.29	4.30	4.37	101.38	102.97
SEm ±	**0.83**	**0.72**	**0.08**	**0.08**	**2.40**	**2.28**
CD (*p=0.05*)	**2.89**	**2.50**	**0.29**	**0.29**	**8.31**	**7.89**
Irrigation Scheduling in wheat						
IW/CPE=0.75	28.41	29.10	3.59	3.73	88.45	90.50
IW/CPE=1.0	31.53	31.67	4.12	4.13	98.09	98.27
IW/CPE=1.25	32.24	32.94	4.24	4.31	101.28	101.59
Farmer's Practice	30.13	30.79	3.92	4.01	93.03	95.54
SEm ±	**0.59**	**0.47**	**0.08**	**0.07**	**1.83**	**1.37**
CD (*p=0.05*)	**1.73**	**1.36**	**0.24**	**0.20**	**5.34**	**4.00**

Table 4.13: Available N, P and K in soil after harvesting of wheat as influenced by crop establishment methods and irrigation scheduling in rice-wheat system

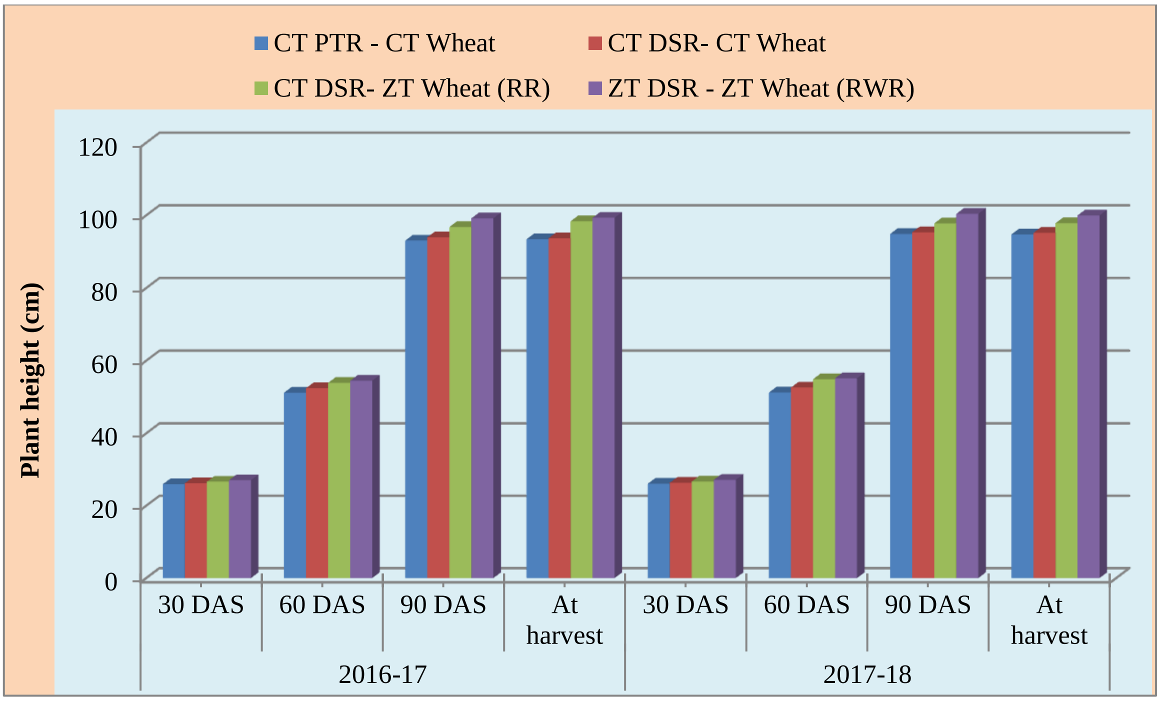
Treatments	Available N (kg ha^{-1})		Available P (kg ha^{-1})		Available K (kg ha^{-1})	
	2016-17	**2017-18**	**2016-17**	**2017-18**	**2016-17**	**2017-18**
Crop Establishment						
CT PTR-CT Wheat	205.41	206.00	22.93	23.213	217.33	217.91
CT DSR-CT Wheat	209.70	209.83	24.05	24.883	218.82	219.53
CT DSR-ZT Wheat (RR)	215.29	217.58	27.26	28.442	228.55	229.90
ZT DSR-ZT Wheat (RWR)	222.33	224.12	28.15	29.474	229.07	230.73
SEm ±	**3.302**	**2.93**	**0.57**	**0.374**	**2.62**	**2.54**
CD ($p=0.05$)	**11.426**	**10.15**	**1.97**	**1.293**	**9.06**	**8.80**
Irrigation Scheduling in wheat						
IW/CPE=0.75	209.58	212.87	25.29	26.167	222.57	223.93
IW/CPE=1.0	214.54	214.08	25.70	26.601	223.62	224.89
IW/CPE=1.25	214.58	215.83	26.04	26.742	224.13	224.56
Farmer’s Practice	213.00	214.75	25.38	26.503	223.45	224.68
SEm ±	**2.32**	**2.30**	**0.22**	**0.254**	**1.26**	**0.76**
CD ($p=0.05$)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

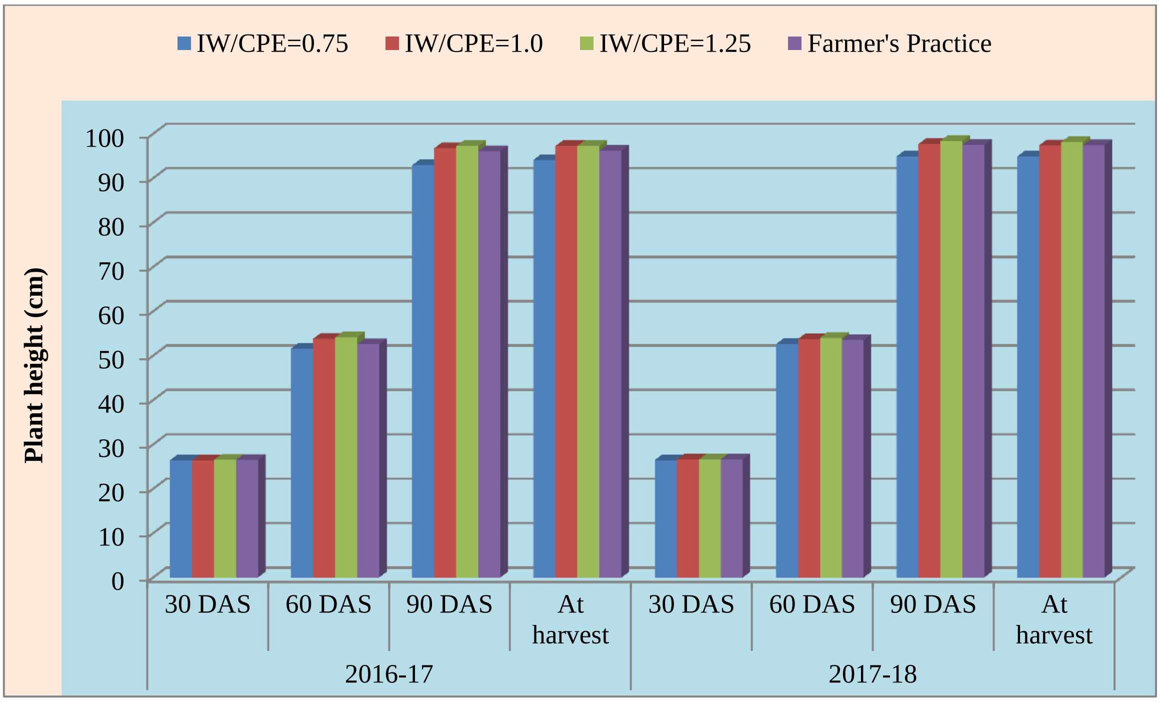
Table 4.14: Soil pH, EC (dS m^{-1}), bulk density (g cm^{-3}) and organic carbon (%) as influenced by crop establishment methods and irrigation scheduling in rice-wheat system

Treatments	Soil pH		EC (dS m^{-1})		Bulk density (g cm^{-3})		Organic carbon (%)	
	2016-17	**2017-18**	**2016-17**	**2017-18**	**2016-17**	**2017-18**	**2016-17**	**2017-18**
Crop Establishment								
CT PTR-CT Wheat	7.31	7.29	0.24	0.24	1.34	1.34	0.42	0.43
CT DSR-CT Wheat	7.31	7.29	0.23	0.24	1.34	1.32	0.42	0.43
CT DSR-ZT Wheat (RR)	7.29	7.25	0.22	0.22	1.33	1.32	0.42	0.44
ZT DSR-ZT Wheat (RWR)	7.27	7.24	0.22	0.22	1.33	1.31	0.43	0.44
SEm ±	0.05	0.05	0.01	0.01	0.02	0.03	0.01	0.01
CD (*p=0.05*)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Irrigation Scheduling in wheat								
IW/CPE=0.75	7.30	7.27	0.22	0.23	1.33	1.32	0.42	0.43
IW/CPE=1.0	7.29	7.25	0.22	0.23	1.33	1.32	0.42	0.44
IW/CPE=1.25	7.29	7.28	0.22	0.23	1.34	1.33	0.42	0.44
Farmer's Practice	7.29	7.27	0.22	0.23	1.33	1.31	0.42	0.43
SEm ±	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01
CD (*p=0.05*)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 4.15: Economics of wheat as influenced by crop establishment methods and irrigation scheduling in rice-wheat system

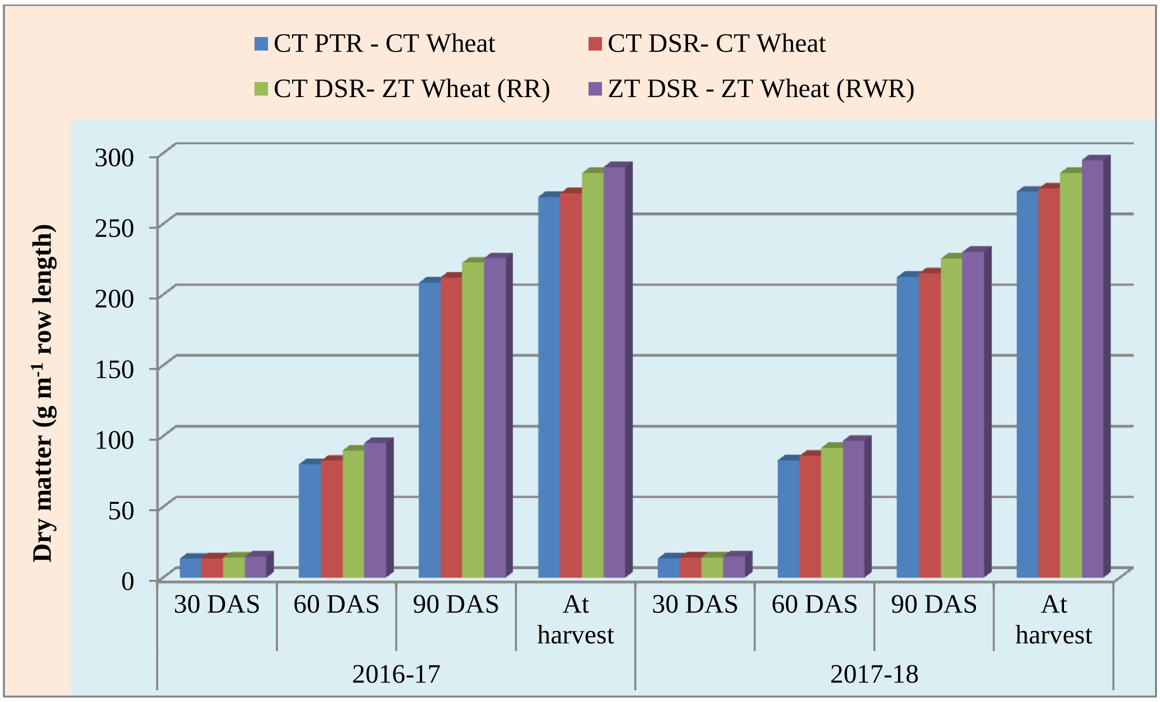
Treatments	Cost of cultivation (₹ ha^{-1})		Grass return (₹ ha^{-1})		Net return (₹ ha^{-1})		Benefit cost ratio (B:C)	
	2016-17	**2017-18**	**2016-17**	**2017-18**	**2016-17**	**2017-18**	**2016-17**	**2017-18**
Crop Establishment								
CT PTR-CT Wheat	40281	40281	98812	99325	58531	59044	1.45	1.47
CT DSR-CT Wheat	40281	40281	99125	100137	58844	59856	1.46	1.49
CT DSR-ZT Wheat (RR)	34345	34345	106902	109139	72556	74794	2.11	2.18
ZT DSR-ZT Wheat (RWR)	34345	34345	109865	110794	75520	76449	2.20	2.22
SEm ±	-	-	**1737**	**1570**	**1737**	**1570**	**0.05**	**0.04**
CD ($p=0.05$)	-	-	**6011**	**5433**	**6011**	**5433**	**0.16**	**0.15**
Irrigation Scheduling in wheat								
IW/CPE=0.75	36836	36836	95613	97837	58777	61001	1.62	1.68
IW/CPE=1.0	37472	37472	106541	107472	69069	70000	1.87	1.90
IW/CPE=1.25	38108	38108	110310	111018	72202	72910	1.92	1.95
Farmer’s Practice	36836	36836	102240	103068	65404	66232	1.81	1.83
SEm ±	-	-	**1408**	**1019**	**1408**	**1019**	**0.04**	**0.03**
CD ($p=0.05$)	-	-	**4108**	**2974**	**4108**	**2974**	**0.11**	**0.08**





CTPTR-CTW	-	Conventional till rice (puddled transplanted) - conventional till wheat
CTDSR-CTW	-	Conventional till direct seeded rice (DSR) - conventional till wheat
CTDSR-ZTW (RR)	-	Conventional till DSR - zero till wheat (rice residue retention)
ZTDSR-ZTW(RWR)	-	Zero till DSR - zero till wheat (residue retention in rice and wheat)

Figure 4.1: Plant height of wheat at different growth stages as influenced by crop establishment methods and irrigation scheduling in rice-wheat system.



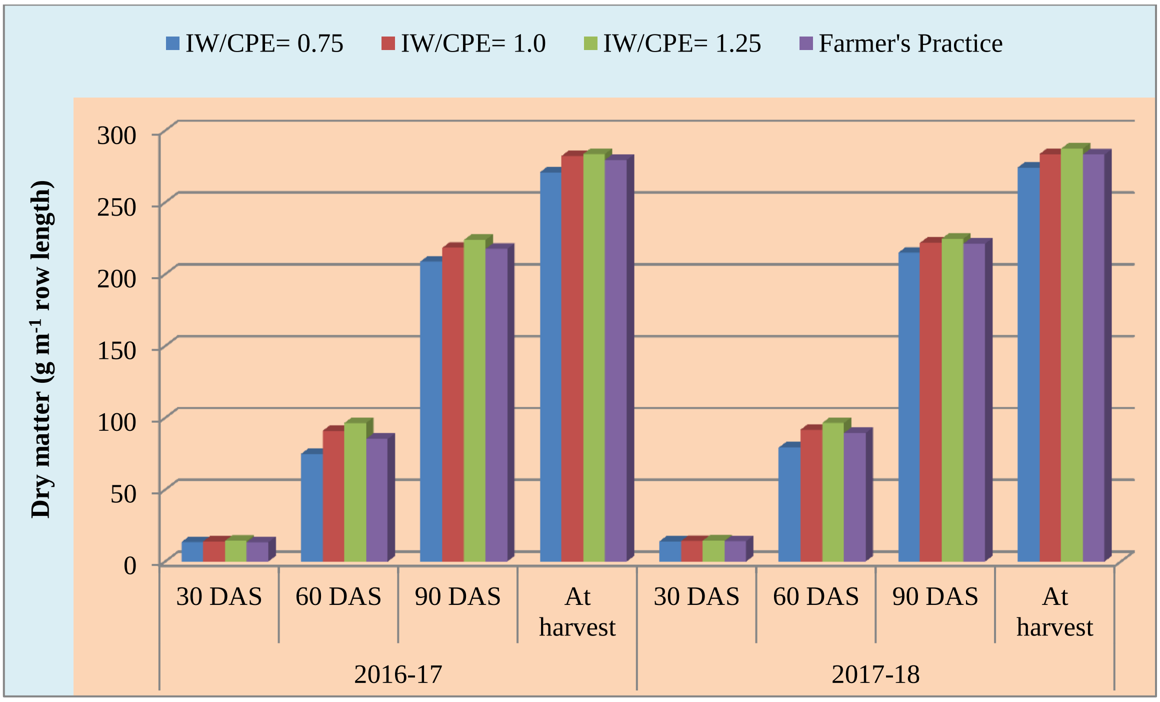
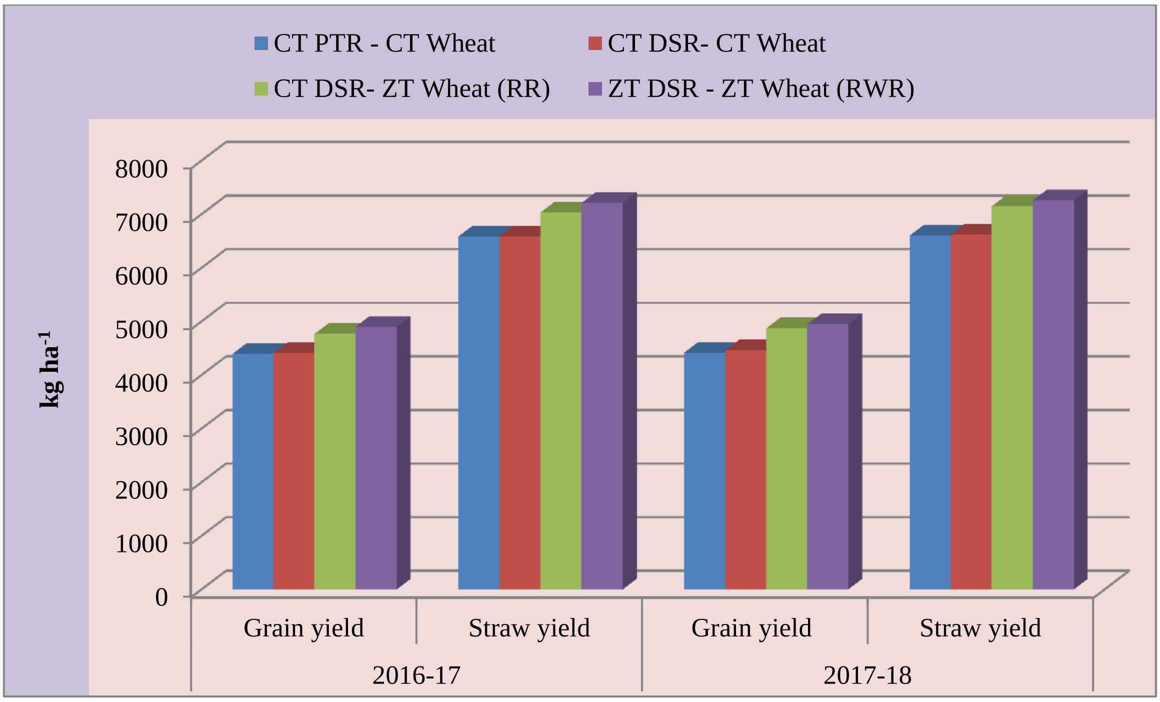


Figure 4.2: Dry matter accumulation (g m^{-1} row length) of wheat at different growth stages as influenced by crop establishment methods and irrigation scheduling in rice-wheat system.



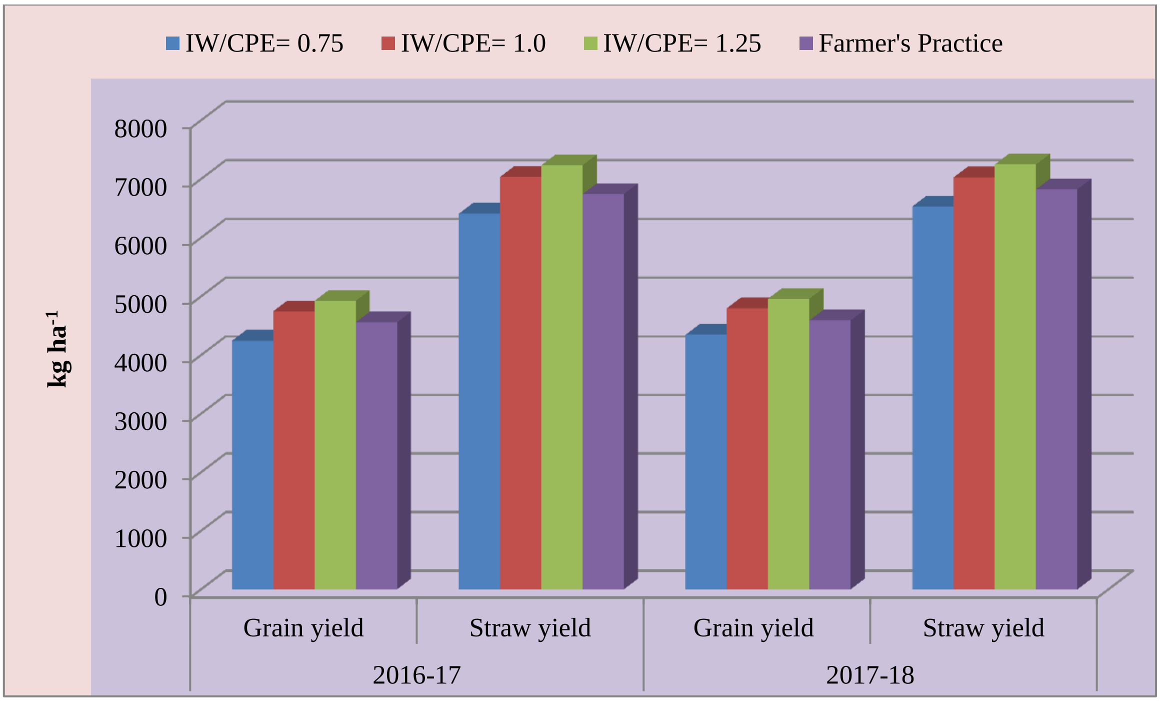
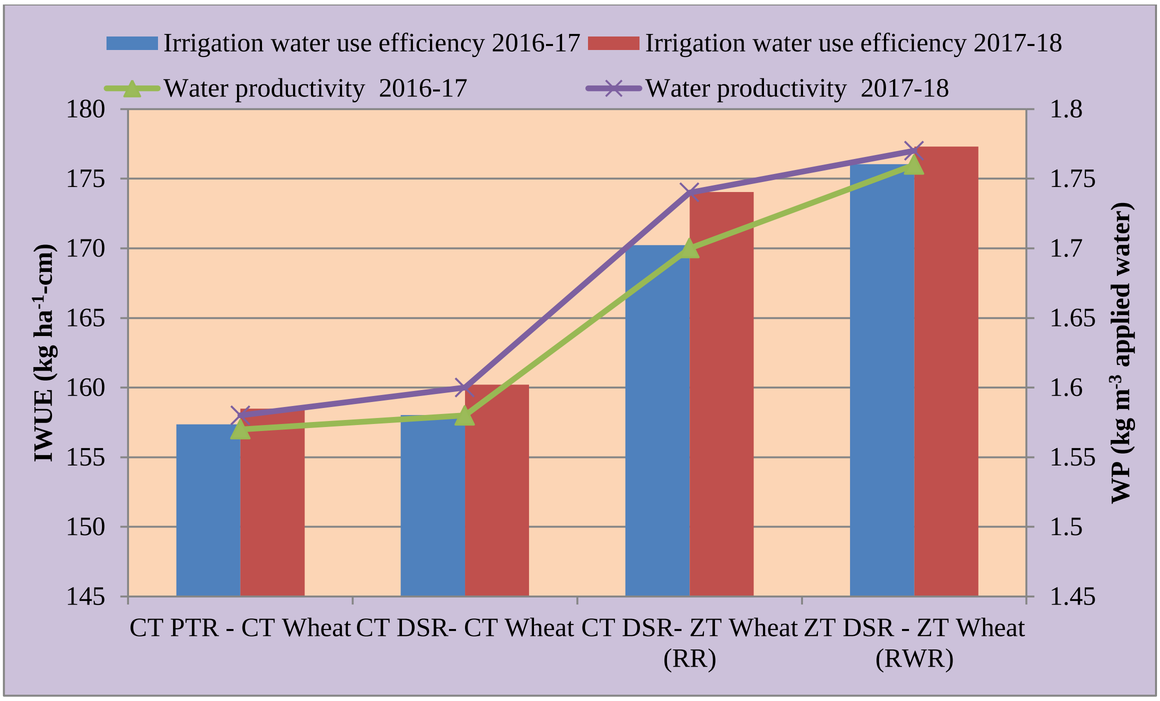


Figure 4.3: Grain yield and straw yield of wheat as influenced by crop establishment methods and irrigation scheduling in rice-wheat system.



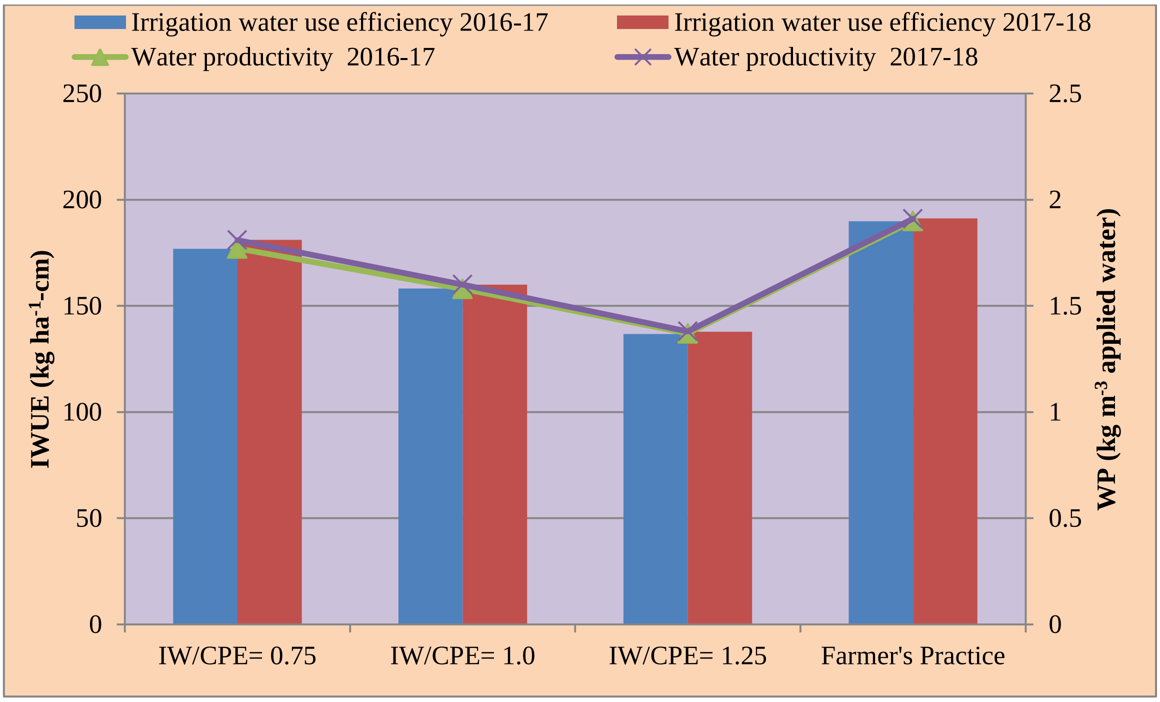
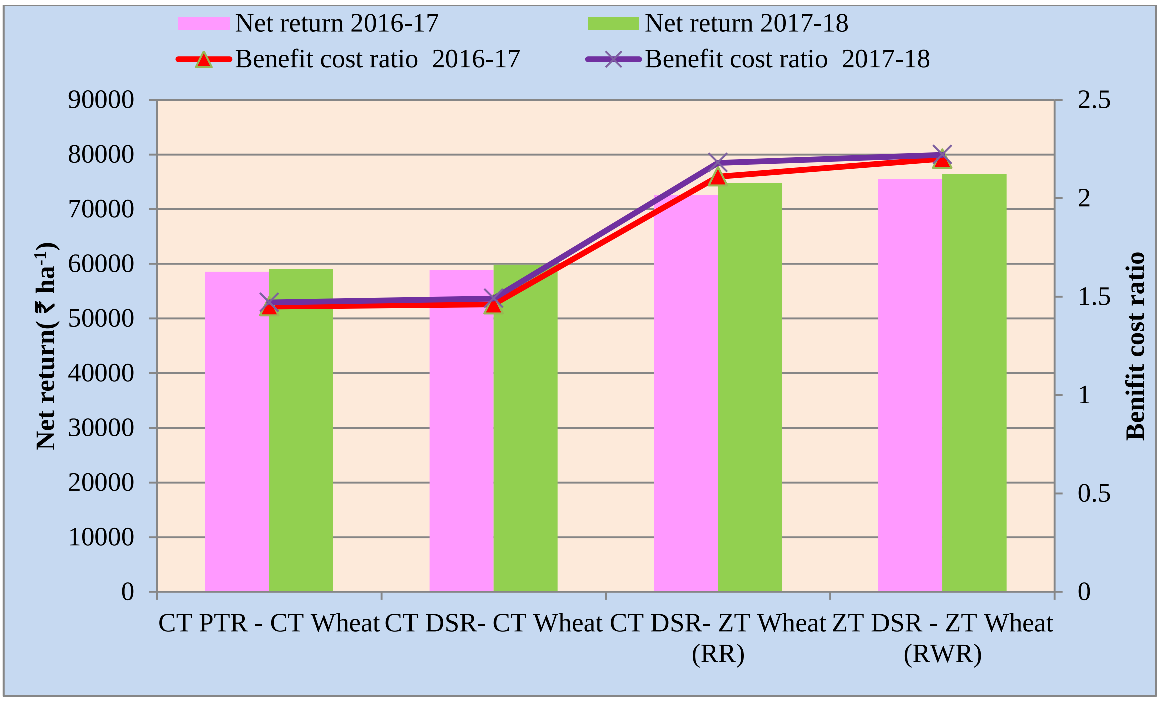


Figure 4.4: Irrigation water use efficiency and water productivity of wheat as influenced by crop establishment methods and irrigation scheduling in rice-wheat system.



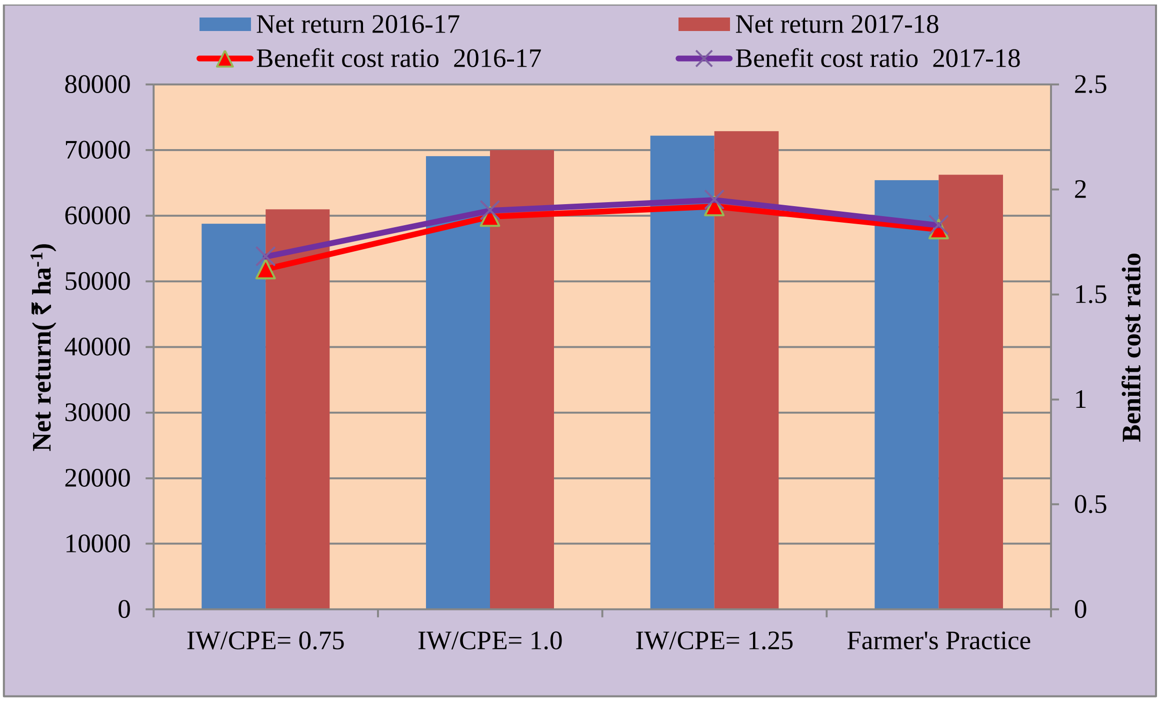


Figure 4.5: Net return and benefit cost ratio of wheat as influenced by crop establishment methods and irrigation scheduling in rice-wheat system.

Plate 4.1: Performance of wheat crop as influenced by different crop establishment methods and irrigation scheduling in wheat under rice-wheat system.

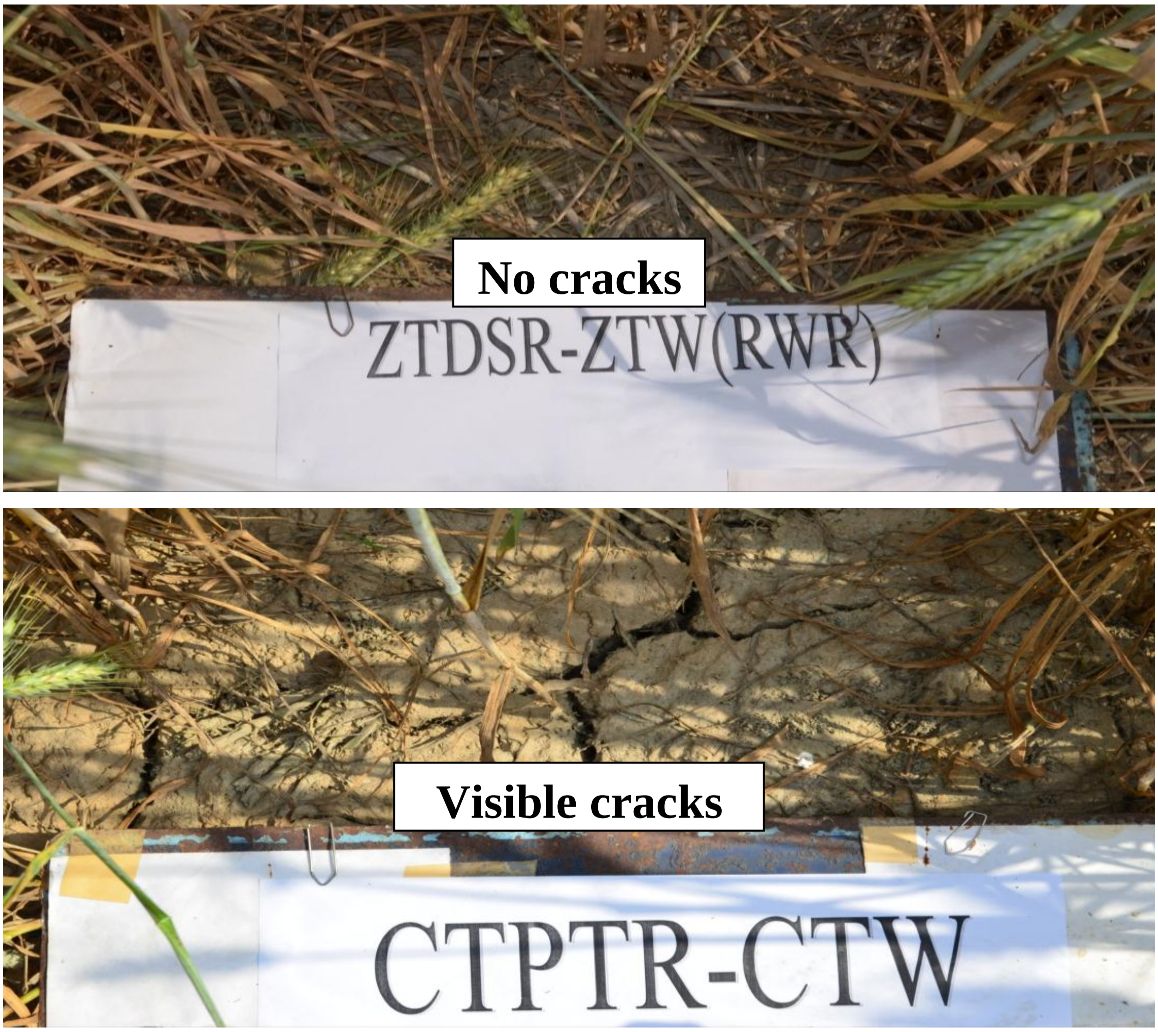


Plate 4.2: **Effect of ZDSR- ZTW (RWR) and CTPTR-CTW on cracks development in soil.**

Plate 4.3: **Performance of ZDSR- ZTW (RWR) and CTPTR-CTW on grain development of wheat.**

Plate 4.4: **Photographs showing visible enforce maturity under CTPTR-CTW in comparison of ZTDSR-ZTW crop establishment system.**

Plate 4.5: General experimental view

Plate 4.6: Discussion with students as response of variables during experimentation.

Plate 4.7: Seeding of wheat with zero-till ferti-seed drill.

Plate 4.8: **Estimation of nutrient content in grain and straw of the experimental samples.**

DISCUSSION

The present study entitled "**Effect of crop establishment methods and irrigation scheduling on growth, yield and water productivity of wheat in rice-wheat system**" was carried out at the Agricultural Research Farm, Institute of agricultural Sciences, Banaras Hindu University, Varanasi during two successive *Kharif* and *Rabi* seasons of 2016-17 and 2017-18. The results of the field experiment are given earlier in chapter IV. In this chapter, an effort has been made to assess and explore the variation among these results critically influenced by treatment differences to appraise cause and effect correlation through either general agronomic principles or physiological and biochemical processes. The references related to the present study have been taken into consideration from earlier studies, as and where required to support the findings of the current study while discussion.

It is well known fact, that the growth and development of a plant are governs by genetic factor, but it can expanse by the environment and cultural operation through their direct and indirect impact on different biochemical action of the plants. Plant genetic composition develops specific character of plant, whereas, the soil physiological and biochemical constitution accompanying climatological characters *viz*. rainfall, temperature, wind speed, relative humidity etc. are accounted under environmental factors in a particular set of agro-climatic circumstance. Improving crop productivity and sustainability, sensible and scientific manipulation is required, thoughtfully and scientifically. Hence, to explore the maximum crop potential, there is a need of appropriate agronomic approach of micro environment under sustainable intensification, ultimately for climate mitigation.

To achieving highest wheat genetic potential and enhancing the productivity, it is quite crucial to successful completion of crop growth period, meshed with appropriate environmental situations in which the crop is grown. However, the role of crop establishment and water considered as a most important factors to reach maximum yield potential of wheat. Successful and sustainable production of wheat through different cost effective agronomic approaches *viz* CA based crop establishment options, evolving rational crop residue management practices and smart water management technique are thus recognized as most vital factors.

5.1 Effect of weather conditions on crop

Crop growing in natural environmental condition are usually prevented from manifesting their full genetic production potential and these are by various biotic and abiotic stresses. Amidst abiotic stresses, the unfavourable weather conditions are widely considered. Every plant needs a specific set of favourable environment for normal growth and development. Suitability of the climatic environment with crop phenology during growing period is an important facet to explore full genetic potential. If weather component exceed beyond the upper and lower limit and fluctuation are too wide, plants may fail to maintain the rhythm of growth and thereby yield will affect.

Outcomes of field experiment are ultimately influenced by weather condition and magnitude of their fluctuation. Any discussion of the findings would not be appropriate without taking into consideration the plant - weather relationship to reach at correct evaluation and conclusion. The climatic elements like, rainfall, humidity, temperature, etc. play vital role, when crop is under vegetative growth period and sun-shine hours at the time of reproductive phase for maximum productivity. Despite of steadiness of cultivation practices and other inputs, weather is the most important factor behind the variation in crop performance. Accordingly, weather conditions during wheat growing period were deeply analyzed.

The meteorological observation *viz*. rainfall, temperature, relative humidity, evaporation and sunshine hours during the present study are tabulated in Tables 3.1 and 3.2 and illustrated in Figures 3.1 and 3.2. The experimental years, 2016-17 and 2017-18 was not received rainfall during the wheat crop growth period, except 1.0 mm in 2016-17 and 9.4 mm in 2017-18. Therefore, the rainfall had no much impact on crop during both the crop seasons. Although, in 2018, rainfall experienced during 14^{th} SMW (9.2 mm) at the time of harvesting of crop, which also not impacted to ether crop growth or development in both the year of experimentation. The mean maximum and minimum temperature were almost similar during both the years of study. In conclusion the mean maximum and minimum temperature fluctuation was almost normal during both the crop growing season. The relative humidity show sizeable variation throughout the investigation period during both the year of study. Also, we can say from the data that the first year was more humid in as compared to the second year. From the data we can conclude that the day time of second year was brighter as compared to the first year during crop growing period. Meteorological data revealed that the average evaporation was similar in both the year of experimentation, but in second year, evaporation was more distributed as compare to first year. Hence, during second year of wheat growing season, temperature and fairly bright sunshine created suitable weather situation which enhanced photosynthetic efficiency of crop ultimately resulted in better crop performance as regard of growth and yield.

5.2 Effect of crop establishment methods and irrigation scheduling on crop

5.2.1 Effect on growth and development

The obsevation related to growth parameter *viz*. plant height (cm), number of tiller (m^{-1} row length), dry matter accumulation (g m^{-1} row length) and chlorophyll content (SPAD value) number of green leaf (m^{-1} row length) presented in Tables 4.1 to 4.5. These growth characters of wheat were distinctly affected due to different crop establishment methods during both the years of experimentation. Among the crop establishment methods, CE_4-ZTDSR-ZTW significantly improved growth parameters *viz*. plant height, number of tiller, number of green leaf and dry weight m^{-1} row length, leaf chlorophyll content over the CE_1-CTPTR-CTW and CE_2-CTDSR-CTW and it was at par with CE_3-CTDSR-ZTW at all the growth stages except at 30 DAS, where plant height and chlorophyll content was not influenced significantly during both the years. This can explained in light of the fact that due to continuous adoption of conservation agriculture based management practices creates better micro-environment and good soil health which provide good opportunity to better crop stand at earlier stage ultimately develops vigorous plants. These findings are in accordance with the observations of Ravi *et al.* (2019); Jat *et al.* (2016) and Gathala *et al*. (2011).

In the growth parameters of crop, plant height is most important parameter which is subjected to the function of internodes and leaf emergence. The leaves are develops from stem node and dry matter accumulation is closely associate with leaf area development and plant height. After analysis of the data in Table 4.1 and Figure 4.1, it can be seen that the plant height of wheat was continuously increased with advancement in crop growth up to 90 DAS. Their after little decrement in the growth rate may be due to senescence towards maturity and plants moved to reproductive phase, hence, food material produced by the plant which was being used for growth yet, shifted to grain development. The leaves and photosynthesis relationship are closely associated with the yield of plant. Thus, higher leaves are favorable for high dry matter accumulation and ultimately resulting of higher economic yield crops.

Data furnished in Table 4.1 to 4.5 clearly reflected that water application on IW/CPE ratios 1.25 significantly outperformed, but remained at par with IW/CPE ratio of 1.0 and farmers practice during 2016-17 and 2017-18. The growth performance of wheat crop were higher in terms of plant height (cm), number of tiller (m^{-1} row length), dry matter accumulation (g m^{-1} row length), chlorophyll content (SPAD value) and number of green leaf (m^{-1} row length) with irrigation scheduling at IW/CPE=1.25. Hence, above resulted distinctly confirm that IW/CPE=1.25 provided most favorable and adequate moisture status in soil during entire growth period of wheat crop as well as critical crop stages in Varanasi region of Eastern Uttar Pradesh. Sufficient supply of moisture regulates various metabolic in the plant and maintains the turgidity of plant cells and processes keeps on unintereptivly which results in higher cell division and greater cell elongation. Apart from, water plays a vital role in plant system by regulating the nutrients availability in soil solution through their movement and distribution in soil, eventually leading to higher nutrients uptake by plants. Finding of the present experiment are well in conformity with the results of Gupta *et al*. (2016) and Khan *et al*. (2020).

In fact, the uptake of water at certain lower moisture level, gradually decreases soil moisture status due to plant energy consuming process, and non osmotic water uptake happens under less or no osmotic potential difference between soil solution and root xylem sap (Mukharjee and Ghosh, 2006). The moisture deficit situation force to plant for more energy expenditure in extraction water from soil moisture which decelerate the plant growth. Results of present experiment also justified that the soil moisture deficit in the root zone was minimal at higher IW/CPE =1.25, thus, there was least expenditure of plant energy in moisture extraction from soil, ultimately validated by the maximum growth performance under this treatment. Since, uptake of nutrients and their translocation in the plant systems are directly related with moisture uptake as well as functioning of various physiological and metabolic processes in the plant at optimum moisture level, thus, it can be said that sufficient soil moisture availability at IW/CPE=1.25, 1.0 and farmer's practice (need based) resulted statistically higher growth of wheat in this experiment. Beside this, water permits a high transmission of visible light which plays vital role in photosynthesis by plants.

IW/CPE ratios 0.75 obviously experienced a soil moisture deficit as confirmed by noticeably lower plants growth of wheat. This might be due to insufficient moisture uptake creates internal water deficit situation in the plants that impede the translocation of metabolites and assimilates in the plant system. It adversely affects various physiological and metabolic processes by gradual loss of turgor and water potential within the plants which results in stagnated plant growth. Hence, in this study the optimum level of soil moisture at IW/CPE=1.25 might have maintained the different metabolic and physiological activities in wheat plants at an ideal rate/ order. Findings of the present study are agreed with results of Nadeem *et al.* (2007); Idnani and Kumar (2012); Singh *et al.* (2012) and Sarel (2015).

5.2.2 Effect on yield attributes and yield

Yield is the end product of the vegetative development of a crop which is function of yield attributes. During both the years of study, crop establishment methods distinctly affected to yield attributes of wheat *viz*. number of spike m^{-1} row length, spike length, and grains $spike^{-1}$, however, weight of 1000-grain did not differ statistically (Table 4.6).

The number of spike, spike length and grains spike^{-1} are the complex physiological composite results of all morpho-physiological character in respect of plant height, leaves, total dry matter production and number of tiller and it totally depends upon source sink relationship. Yield attributes of wheat *viz*. number of spike m^{-1} row length, spike length, number of grain spike^{-1} were significantly superior with CA crop establishment method i.e. zero till direct seeded rice - zero till wheat with anchored rice and wheat residue over the conventional till puddled transplanted rice-conventional till wheat and conventional till direct seeded rice-conventional till wheat and it was at par with conventional till direct seeded rice-zero till wheat with anchored rice residue. However, test weight and harvest index did not differ significantly during both the years of investigation. This may be attributed to CA based crop establishment methods which would have help in improving the soil health, better availability of nutrient to the plant and soil temperature moderation because crop residue retention favors to create good micro-environment. Healthy soil provides a favorable environment for microorganism in the root zone to increase the nutrients availability to crop. Hence, better availability of nutrients and favorable environment increased possibly sink capacity which enhanced source capacity of the plant *viz*, leaf area index, net assimilation rate and photosynthetic efficiency which eventually improved transportation of photosynthates from source to sink (yield contributing characteristics) for the formation of spike, number of grain spike^{-1} and test weight. Similarly, higher yield attributes of wheat with CA based crop establishment methods were also reported earlier by many researches Kumar *et al*. (2018); Saini *et al.* (2011); Kumar *et al.* (2013) and Ram *et al.* (2010).

It is obvious from the value presented in Table 4.7 and Figure 4.3 that grain and straw yield of the wheat crop were significantly affected by various crop establishment methods during the both the years of experiments. The growth characters like plant height, number of green leaf m^{-1} row length, and dry matter accumulation m^{-1} row length, number of tiller m^{-1} row length plays a vital role in the expression of yield attributes. The economic yield of wheat is the function of yield attributing traits *viz.* number of spike m^{-1} row length, length of spike, number of grain spike^{-1} and test weight. Accordingly, to tackle the maximum yield potential of a crop, good growth and development of a crop is essential. Amongst the crop establishment methods, zero till direct seeded rice - zero till wheat with anchored rice & wheat residue produced maximum grain yield which was remained at par to conventional till direct seeded rice-zero till wheat with anchored rice residue. The treatment CE_4-ZTDSR-ZTW (RWR) gained an average increment of 11.78 higher grain yield over CE_1-CTPTR-CTW during both the year. Here it seems possible that conservation agriculture based crop establishment methods might have improved the growing environment, soil structure and availability of essential nutrient on account of residue retention and minimum tillage that accelerate higher biomass production resulting into better source and sink relationship leading to the higher production of yield traits which ultimately enhanced economic yield of wheat. The findings of the present investigation are in conformity with those of Nagargade *et al*. (2016); Bohra and Kumar (2015); Kumar *et al.* (2013) and Saini *et al.*, (2011).

Results affix to Table 4.6 and 4.7 showed that IW/CPE=1.25 registered appreciably higher yield attributes *viz.* number of spike m^{-1} row length, spike length, and grains $spike^{-1}$. However test weight did not touch the level of significance. The higher yield attributes at high IW/CPE ratio confirms to the adequate soil moisture availability for wheat crop during whole crop growing period specifically on critical stages at irrigation scheduling at IW/CPE=1.25, IW/CPE=1.0 and farmer's practice over lower IW/CPE=0.75. Significantly higher yield attributes of wheat at IW/CPE=1.25 is also well supported by better performance of various growth parameters of wheat plants. Reviewing of data (Table 4.7 and Fig. 4.3) further illustrates that water application at IW/CPE=1.25 resulted an average of 9.72% higher grain and 11.90% straw yield over IW/CPE=0.75 during both of years. This might be due to more frequently water application at higher IW/CPE ratio maintained adequate soil moisture at various critical stages of wheat which meet out the water requirements for metabolic, structural and physiological activity of wheat plants, beside meeting out the evapo-transpiration demand. Appreciable increments in performance of yield attributes were directly linked with corresponding performance of growth component. It can be assigned to greater availability of nutrients, photo-synthates and metabolites and their translocation towards the re-productive traits which help in formation of more spike plant^{-1} and also significantly improved the spike and grain health. (Effective tiller m^{-1}row length, higher grain spike^{-1} and 1000-grain weight) and ultimately the grain yield. This is well known fact that availability of photosynthesis (sources) and capacity of storage organs (sink) regulates the function of complex process of yield formation. Significantly higher yield attributes and yield of wheat crop at IW/CPE=1.25 are well corroborate the results of Nadeem *et al.* (2007); Singh *et al.* (2012); Singh and Sheoran (2006); Idnani and Kumar (2012) and Meena (2015).

5.2.3 Effect on nutrient content and their uptake

After critically examine of the data in Table 4.9 to 4.12 and it was observed that different crop establishment methods failed to express any significant impact on N, P and K content in wheat grain and straw during both the year of experiment. However, uptake of N, P and K e by wheat grain and straw were significantly affected due to crop establishment options on during both the years of study. The crop established in CA based CE_4-ZTDSR-ZTW (RWR) method, being on par to CE_3-CTDSR-ZTW (RR) recorded statistically higher nitrogen, phosphorus and potassium uptake by grain as well as straw over crop established under conventional methods CE_2-CTDSR-CTW and CE_1-CTPTR-CTW during both the years. This is the well established fact that in a healthy soil, capacity of nutrients supply is higher due to better microbial activity and high organic carbon soil which favors the higher availability of these nutrients in soil solution for their effective uptake by crop. The higher N, P and K uptakes in under zero till DSR-Zero-till wheat with residue retained in rice and wheat both, might be due to increased favourable environment for higher microbial activity and extra supply of nutrients through residue which lead to better root growth, leading to high extraction of nutrient from soil root zone, higher moisture availability as well as high biomass production, better crop performance. Therefore all these factors might be responsible for higher removal of nutrients under wheat established in ZTDSR-ZTW (RWR) system. Lower nutrients removal under conventional till pudduled transplanted rice-conventional tilled wheat, might be ascribed to poor soil structure due to puddling and extreme tillage, poor root growth, high bulk density and compaction of soil and poor biomass production. These results were close proximity with Saini *et al.* (2011); Shahane *et al*. (2020); Singh *et al*. (2017) and Behera *et al.* (2007).

In case of irrigation scheduling, the differences as regard to N, P and K content in grain and straw of wheat were not statistically comparable during both the year of experiment. Little higher N, P and K content was registered in irrigation scheduling on IW/CPE=1.25 followed by farmer's practice > IW/CPE=1.0 > IW/CPE=0.75. This might be due to sufficient moisture supply had maintained in higher IW/CPE ratio which lead to higher nutrients availability for their uptake by plant. A deep investigation of the data (Table 4.9 to 4.12) unveiled that increasing number of irrigation lucidly increased nutrient uptake by wheat grain and straw during both the years of experiment. The maximum nutrient (N, P and K) uptake by grain and straw was observed with irrigation scheduling at IW/CPE=1.25 which was at par to IW/CPE ratio 1.0, however lowest nutrient uptake had seen under irrigation scheduling on IW/CPE ratio 0.75. These findings showed that nutrient availability and their mining by wheat crop consistently improved up to IW/CPE=1.25 which can, be regarded as the most optimum irrigation scheduling level in wheat crop on Varanasi region of Eastern Uttar Pradesh. Hence, IW/CPE ratio of 1.25 may have minimal plant energy expenditure in extraction of moisture from soil. This led to more availability and uptake of labile and non-labile nutrients, otherwise, higher nutrient mining can be linked with higher root biomass/ root length which is a matter of future investigation. Apart from this, higher N, P and K uptake in higher water application are directly correlated with the better crop growth character and high biomass production in this treatment. Significantly higher nutrient uptake by wheat crop under higher IW/CPE ratio levels have also been reported by Narolia *et al*. (2016); Yaghobi (2008); Idnani and Kumar (2012) and Sarel (2015).

5.2.4 Effect on water productivity and irrigation water use efficiency

The data presented in Table 4.8 and Fig. 4.4, revealed that irrigation water use efficiency and water productivity of wheat differed significantly due to different crop establishment methods in rice-wheat system during both the years of experimentation.

Treatment CE_4-ZTDSR-ZTW (RWR), being at par with CE_3-CTDSR-ZTW (RR) resulted highest irrigation water use efficiency and water productivity of wheat. CA based crop establishment methods [CE_4-ZTDSR-ZTW (RWR) and CE_3-CTDSR-ZTW (RR)] both proved it's superiority over conventional crop establishment methods [CE_2-CTDSR-CTW and CE_1-CTPTR-CTW] during both the years. The high irrigation water use efficiency and water productivity of wheat in CA based crop establishment methods, might be due to improved water holding capacity of soil on account of high organic carbon content due to crop residue retention, and the better micro-environment, better soil temperature moderation and lower temperature in root zone. The higher moisture availability and lower temperature farms the good micro-climate, which provided longer opportunity to avoid the terminal heat stress at the time of maturity of crop. The higher irrigation water use efficiency and water productivity of wheat in CA based crop establishment method are agreement with the results of Sharma *et al*. (2019); Devkota *et al*. (2019); Jat *et al*. (2018) and Gathala *et al*. (2011).

An appraisal of data explicit that various IW/CPE ratio resulted significant differences in irrigation water use efficiency (IWUE) and water productivity (WP) of wheat as influenced by irrigation scheduling in wheat in rice-wheat system during both the experimentation years. Among the different irrigation scheduling, treatment farmer's practice (need based- 4 irrigation) resulted significantly higher irrigation water use efficiency and water productivity of wheat followed by IW/CPE=0.75 > IW/CPE=1.0 > IW/CPE=1.25 during both the years of study. The IWUE and WP are directly associated with yield of crop and water applied to the crop. Therefore, number of irrigation was lower (4 irrigation) in farmer's practice and IW/CPE=0.75 as compared to IW/CPE=1.0 (5 irrigation) and IW/CPE=1.25 (6 irrigation). Apart from, water applied in farmer's practice was on crop demand basis and in other treatments it was on the basis of fix weather parameter. So, water applied on farmers practice resulted higher IWUE and WP. It is well known fact that under soil moisture deficit situation, crop roots tend to extend at deeper soil layer for search and extraction of water from beyond the wet zone of irrigation water which lead to higher water use efficiency at lower IW/CPE ratios. Thus, per unit productivity of applied water declined with rise in more frequently water application at each higher IW/CPE ratio. Similar results also reported in lower IW/CPE ratio by earlier researchers Singh and Sheoran (2006); Idnani and Kumar (2012); Singh *et al.* (2012) and Meena (2015)

5.2.5 Effect on soil physico-chemical properties

The treatment variable did not left any noticeable impact on Soil pH, EC, bulk density and organic carbon. This might be due fact that the present investigation was initiated only few years ago, these properties are not affected in short term duration of the experiment. However, the CA based crop establishment methods brought appreciable changes in available N, P and K in the soil. The maximum available N, P and K in soil after wheat harvest was noted in treatment CE_4-ZTDSR-ZTW (RWR) and it was on par to CE_3-CTDSR-ZTW (RR). This might be resulted due to minimal disturbance of soil along with addition of crop residue retention, enhanced the microbial activity which ultimately, increased the available nutrients in the soil solution by mineralization process. The lowest available N, P and K was found in conventional till based crop establishment methods CE_1-CTPTR-CTW followed by CE2-CTDSR-CTW during both the years of investigation. This might be possible, due to heavy tillage practices which destroyed the soil structure and microbial ecology in the root zone, and caused poor activity of beneficial soil microbes ultimately resulting the nutrients immobilization in the soil. Similar results are concluded by Scheer *et al.* (2009); Erenstein and Laxmi, (2008) and Malhi and Lemke (2007).

Among irrigation scheduling, IW/CPE=1.25 recorded higher available N, P and K in soil after harvest of wheat followed by IW/CPE=1.0 > farmer's practice and IW/CPE=0.75. Even so, the differences unable to touch the significance level during both the years of evaluation. Soil pH, EC, bulk density and organic carbon also not got the appreciable changes in response to irrigation scheduling. This might be due to change in these parameters did not happen in such a short time of study.

5.2.6 Effect on economics

Any new technology can only adopted by the farmers in current agriculture, when it is economically viable. The economic viability of technology is subjected to gain or loss, therefore, if any practice/technology enhances the profitability over its cost than only it can be adopted by the farmers. The cost of cultivation distinctly differed in response to various crop establishment methods and irrigation scheduling according to the tillage practice and number of irrigation applied in the wheat. The gross return, which is associated to economic yield and its market price, differed significantly as influenced by various treatments along with their cost of cultivation, which ultimately regulates the net return and benefit cost ratio.

Economics of different crop establishment methods and irrigation scheduling have been tabulated in Table 4.15. It was calculated on the basis of input-output analysis. There was a notable variation in relation to cost of cultivation, gross returns, net returns and benefit cost ratio as influenced by various treatments. The CA based crop establishment methods markedly decreased the cost of cultivation. In general, CA based crop establishment methods CE_4-ZTDSR-ZTW (RWR) and CE_3-CTDSR-ZTW (RR) registered an average of 14.73% (34345 ₹ ha^{-1}) lower cost of cultivation of as compared to conventional crop establishment methods CE_2-CTDSR-CTW and CE_1-CTPTR-CTW (40281 ₹ ha^{-1}) during both the years of experiment. These differences are due to cost of preparatory tillage, and saving in labor/man power is excluded in the zero tillage treatments. As there was reduction in cost of cultivation and higher yield, leading to the higher net returns and benefit cost ratio under CA based crop establishment CE_4-ZTDSR-ZTW (RWR) recorded higher net return (average 29.24%) and B:C ratio (average 51.36%) over CE_1-CTPTR-CTW. The lowest net return and benefit cost ratio were resulted under conventional till wheat, because of the higher cost of cultivation as preparatory tillage practices included in this treatment as well as lower yield than the CA system. These results are supported by Singh *et al*. (2020); Ravi *et al.* (2019); Tomar *et al*. (2019); Kumar *et al*. (2018) and Singh *et al*. (2017).

As regards the irrigation scheduling, data clearly reflected that the gross returns, net returns and benefit cost ratio were markedly enhanced with increasing level of IW/CPE from 0.75 to 1.25. The maximum gross returns, net returns and benefit cost ratio were observed with irrigation scheduled on IW/CPE=1.25. These results can be assigned due to statistically higher grain and straw yield of wheat under IW/CPE=1.25. The lowest cost of cultivation was noted with irrigation scheduling on IW/CPE=0.75 (36836 ₹ ha^{-1}) and farmer's practice (need based - 4 irrigation) (36836 ₹ ha^{-1}) as compared to IW/CPE=1.0 (37472 ₹ ha^{-1}) and IW/CPE=1.25 (38108 ₹ ha^{-1}) during both the years. Highest net return and B:C was associated with IW/CPE=1.25 on account of higher economic and biological yield. This deduction in the cost of cultivation at lower IW/CPE is due to, the reduction in number of irrigation in these treatments. These findings distinctly supports to suitability of IW/CPE=1.25 based on economic viability aside from significantly higher grain and straw yields over other lower IW/CPE under the Varanasi region of Eastern Uttar Pradesh. These findings are in conformity with of results Idanani and Kumar (2012) and Nadeem *et al*. (2007).

SUMMARY AND CONCLUSION

An effort has been made to summarize the findings of the current study and made justifiable conclusions based on the significant results of the current experiment. Present investigation entitled "**Effect of crop establishment methods and irrigation scheduling on growth, yield and water productivity of wheat in rice-wheat system**" was carried out at the Agricultural Research Farm, Institute of agricultural Sciences, Banaras Hindu University, Varanasi with the following objectives:

1. To study the effect of crop establishment methods and irrigation scheduling on growth and yield of wheat
2. To determine the water productivity of different treatments
3. To study the NPK uptake by crop in different treatments
4. To workout economics of the treatments

The present study was carried out at the Agricultural Research Farm Institute of Agricultural Sciences, Banaras Hindu University, Varanasi during two successive *Kharif* and *Rabi* seasons of 2016-17 and 2017-18. The farm is located geographically at 25°15′N latitude, 82°59′E longitude and 75.7 meters altitude above the mean sea level in the Northern Gangetic Alluvial plains of Uttar Pradesh. The same location was used for both the years of experimentation. The experimental field was homogeneous in fertility with uniform topography and textural make up and well connected with tube well for timely and systematic irrigation. The drainage channel was assured for withdraw excess water from the experimental field. The significant rainfall was not received during the growth period of wheat in both the years of experimentation. The soil of the experimental site was slightly alkaline (pH-7.32) having low organic carbon (0.42%) and available nitrogen (206.49 kg ha^{-1}) and medium available phosphorus (21.77 kg ha^{-1}) and available potassium (220.21 kg ha^{-1}). In both rice and wheat crop the recommended dose of fertilizer (150 kg N, 60 kg

P_2O_5, 60 kg K_2O and 5 kg $ZnSO_4$ ha^{-1}) were applied through Urea, DAP, MOP and $ZnSO_4$ respectively. The significant rainfall was not received during the growth period of wheat in both the years of experimentation.

The experiment was laid out in split plot design combining four main plot treatments and four sub plot treatments with three replications. The main plot treatments were crop establishment method *i.e.* CE_1-Conventional till (CT) puddled transplanted rice-conventional till wheat (CTPTR-CTW), CE2-Conventional till direct seeded rice (DSR)-conventional till wheat (CTDSR-CTW), CE3-Conventional till DSR-Zero till (ZT) wheat with rice residue retention [CTDSR-ZTW (RR)], and CE4-Zero till DSR-Zero till wheat with residue retention in rice & wheat [ZTDSR-ZTW(RWR)] whereas, in sub plot treatment were irrigation scheduling based on IW/CPE *i.e.* (I_1) IW/CPE=0.75, (I_2) IW/CPE =1.0, (I_3) IW/CPE =1.25 and (I_4) Farmer's practice (need based irrigation). The crop establishment methods in main plot are continuing since 2012. The initial organic carbon was .42 % and available N P & K was 206.59, 25.10 and 219.60 kg ha^{-1} at the time of establishment of main plot treatment. Present experiment was carried out in 2016-17 and 2017-18. The anchored crop residue was retained as per treatment requirement in rice and wheat by harvesting of crop from 40 cm height during both years of experimentation. The variety Sarajoo-52 and HD 2967 were used for rice and wheat, respectively. The post-emergence herbicide Sulfosulfuron + Metsulfuron (Total) 40 g ha^{-1} *a.i.* was applied after 30 DAS. Herbicide surfactant was also used to minimize the herbicide wastage and better efficacy.

Crop response to different treatments was recorded in terms of various quantitative and qualitative indices. Observations on growth parameter *viz*. plant height, number of tiller and dry weight, at 30, 60, 90 DAS and at harvest, number of green leaf and leaf chlorophyll content (SPAD value) at 30, 60 and 90 DAS, were taken. Yield and yield attributes *viz*. number of spike m^{-1} row length, length of spike, number of grain $spike^{-1}$, test weight (g), grain yield, straw yield and harvest index were recorded after harvesting of crop. The N, P and K content and their uptake by grain as well as straw were also estimated. Soil pH, EC (dSm^{-1}), OC (%), available N (kg ha^{-1}), P (kg ha^{-1}) and K (kg ha^{-1}) status of soil were analyzed before initiation of experiment and after harvesting of wheat. Economic analysis of treatments *i.e.* gross returns (₹ ha^{-1}), net returns (₹ ha^{-1}) and B: C ratio were worked out on the basis of current market prices. For water studies irrigation water use efficiency (kg^{-1} ha-cm) and water productivity (kg m^{-3}) was computed by their formula. The recorded data were subjected to statistical analysis as prescribed by Gomez and Gomez (1984). The interpretation of the treatment effects were made on the basis of Fisher's critical difference at p=0.05 level. The salient features of the experimental findings are summarized as under:

Experimental finding

Effect of treatment on growth parameter

The growth parameters of wheat were distinctly affected due to different crop establishment methods during both the years of experimentation. Among the crop establishment methods, CE_4-ZTDSR-ZTW significantly improved growth parameters *viz*. plant height, number of tiller, number of green leaf dry weight m^{-1} row length and leaf chlorophyll content over the CE_1-CTPTR-CTW and CE_2-CTDSR-CTW and it was at par with CE_3-CTDSR-ZTW at all the growth stages except at 30 DAS, where plant height and chlorophyll content was not influenced significantly during both the years.

Irrigation scheduled based on I_3 (IW/CPE=1.25) recorded significantly higher plant height, number of tiller, dry weight m^{-1} row length and leaf chlorophyll content as compared to I_1 (IW/CPE=0.75), however it was at par with I_2 (IW/CPE=1.0) and I_4 (farmer's practice) at all the growth stages except 30 DAS, where growth parameters did not differ significantly due to irrigation scheduling. Treatment I_3 (IW/CPE=1.25) gave significantly higher number of green leaf over the rest of treatments during both the years of investigation.

Effect of treatment on yield and yield attributes

Yield attributes and yield of wheat *viz*. number of spike m^{-1} row length, spike length, number of grain $spike^{-1}$ and grain yield and straw yield were significantly superior with CE_4-ZTDSR-ZTW crop establishment method over the CE_1 and $CE_{2,}$ and it was at par with CE_3. However, test weight and harvest index did not differ significantly during both the years of investigation.

Among the irrigation scheduling treatments, water applied based on IW/CPE=1.25 recorded significantly higher number of spike m^{-1} row length, spike length and number of grain $spike^{-1}$ over IW/CPE=0.75, which was at par with IW/CPE=1.0 and farmer's practice. Significantly higher grain yield and straw yield were observed with IW/CPE=1.25 as compared to IW/CPE=0.75 and farmer's practice, however it was at par with IW/CPE= 1.0. Test weight and harvest index was not significantly affected due irrigation scheduling.

Effect of treatment on NPK content and their uptake

The content of N, P and K in wheat grain and straw was not significantly affected due to crop establishment methods as well as irrigation scheduling. However, N, P & K uptake by wheat grain and straw showed noticeable variation in response to crop establishment methods and irrigation scheduling during both the years of experimentation. Moreover, among the crop establishment methods, CE_4-ZTDSR-ZTW recorded significantly higher N, P and K uptake by wheat grain and straw, which was at par to CE_3-CTDSR-ZTW.

Amongst irrigation scheduling treatment, highest N, P and K uptake by grain and straw was recorded with application of water at IW/CPE=1.25 followed by farmer's practice and IW/CPE=0.75, but it was remained at par with IW/CPE=1.0 during both the years of experiment.

Effect of treatment on Irrigation water use efficiency and water productivity

Distinct improvement was noticed in irrigation water use efficiency and water productivity due to CA based crop establishment methods and precise irrigation scheduling. In the crop establishment methods, treatment CE_4-ZTDSR-ZTW gave significantly higher irrigation water use efficiency and water productivity of wheat being at par with CE_3-CTDSR-ZTW over the CE_1-CTPTR-CTW and CE_2-CTDSR-CTW.

Among the irrigation scheduling, water application with I_4- Farmer's practice (need based irrigation) recorded significantly higher irrigation water use efficiency (IWUE) and water productivity (WP) over the rest of the treatments. I_4 was followed by IW/CPE=1.0, IW/CPE=0.75 and IW/CPE=1.25 in respect of IWUE and WP during both the years of investigation.

Effect of treatment on physico-chemical properties

The crop establishment methods diverting from conventional tillage to conservation tillage improved the physico-chemical properties of soil *viz.* pH, EC, bulk density, organic carbon as well as available N, P and K in soil after wheat harvest. In case of pH, EC, bulk density and organic carbon the differences failed to touch the level of significance during both the years. Available N, P and K in soil were significantly higher with CE_4-ZTDSR-ZTW followed by CE_3-CTDSR-ZTW. Nevertheless, both being comparable proved significantly superior over CE_1-CTPTR-CTW and CE_2-CTDSR-CTW.

Irrigation scheduling based on different IW/CPE was failed to give noticeable impact on physico-chemical properties of soil during both the years of study.

Effect of treatment on economics

Moving from conventional tillage to conservation agriculture based crop establishment options significantly enhanced the gross returns, net returns and benefit cost ratio, proving that no till system in wheat was more remunerative than traditional tillage system. Among the crop establishment methods, CE_4-ZTDSR-ZTW, being at par with CE_3-CTDSR-ZTW, recorded highest gross returns, net returns and benefit cost ratio and lowest cost of cultivation.

As regards the irrigation scheduling, gross returns, net returns and benefit cost ratio were maximum with IW/CPE=1.25, which was significantly superior over IW/CPE=0.75 and farmer's practice (need based irrigation), but it was at par to IW/CPE=1.0.

Conclusion

On the basis of these finding, it can be concluded that:

- Among the different crop establishment methods, ZTDSR-ZTW (CE_4), being at par with CTDSR-ZTW (CE_3), resulted higher growth, yield attributes and yield of wheat in rice wheat system. These treatments also recorded significantly higher nutrient uptake by crop.
- Treatment ZTDSR-ZTW (CE_4) recorded maximum irrigation water use efficiency and water productivity of wheat and it was at par with CTDSR-ZTW (CE_3). This treatment proved to be superior over CTPTR-CTW (CE_1) and CTDSR-CTW (CE_2)
- Irrigation scheduled based on IW/CPE=1.25 recorded maximum crop growth, yield attributes, yield and nutrient uptake by wheat crop, but it was at par with IW/CPE=1.0.
- Among the irrigation scheduling treatment, farmer's practice (need based irrigation- 4 irrigation) recorded highest irrigation water use efficiency and water productivity of wheat in rice-wheat system
- Highest NPK uptake by crop was observed with conservation agriculture based crop establishment, *i.e.* ZTDSR-ZTW (RWR), CTDSR-ZTW (RR) and IW/CPE=1.25 irrigation scheduling methods.
- ZTDSR-ZTW crop establishment method recorded highest gross returns, net returns and benefit cost ratio and lowest cost of cultivation which was at par with CTDSR-ZTW (CE_3).
- Irrigation scheduling based on IW/CPE=1.25 resulted highest gross returns, net returns and benefit cost ratio, though, it was at par to IW/CPE=1.0.

Recommendation

It can be recommended that zero till direct seeded rice- zero till wheat with residue retention in rice & wheat ZTDSR-ZTW (RWR) and irrigation scheduling based on IW/CPE=1.25 should be practiced to achieve better crop growth, higher yield, NPK uptake and profitability of wheat in rice wheat system. However, for obtaining higher irrigation water use efficiency and water productivity, ZTDSR-ZTW (RWR) crop establishment option and irrigation scheduling by farmer's practice (need based - 4 irrigation) should be followed in Varanasi region of Eastern Uttar Pradesh.

BIBLIOGRAPHY

Angadi, SA and Janawade, AD, Grain and yield attributes of dicoccum wheat as influenced by irrigation schedules and sowing dates invertisols, *Karnataka Journal of Agricultural Sciences*, 14 (3), 578-581, 2001.

Anonymous, 2017-18, World Agriculture Production, USDA, pp. 15, June, 2019.

AOAC, International, formerly the Association of Official Analytical Chemists, Official Methods of Analysis, Arlington, VA, AOAC International, 1995.

Bakht, J, Shafi, M, Jan, MT and Shah, Z, Influence of crop residue management, cropping system and N fertilizer on soil N and C dynamics and sustainable wheat (*Triticum aestivum* L.) production, *Soil and Tillage Research*, 104, 233-240, 2009.

Bandyopadhyay, KK, Gosh, PK, Hati, KM and Mistra, AK, Efficient utilization of limited available water in wheat through proper irrigation scheduling and integrated nutrient management under different cropping systems in a vertisol, *Journal of the Indian Society of Soil Science*, 57(2), 121-128, 2009.

Bandyopadhyay, KK, Singh, R and Kundu DK, Enhancing agricultural productivity through enhanced water use efficiency, *Journal of Agricultural Physics*, 10, 1-15, 2010.

Bandyopadhyay, PK, Mallic, S, Actual evapotranspiration and crop coefficient of wheat (*Triticum aestivum*) under varying moisture levels of humid tropical canal command area, *Agricultural water management*, 6 (4), 403-407, 2003.

Behera, UK, Sharma, AR and Pandy, HN, Sustaining productivity of wheat–soybean cropping system through integrated nutrient management practices on the Vertisols of central India, *Plant and Soil*, 297, 185-199, 2007.

Behera, UK, Water management of improving the productivity of durum and aestivum wheat in the vertisols of central India. *Indian Farming*, 2002.

Bhania, SR, and Singh,V, Scheduling of irrigation to wheat (*Triticum aestivum*) under shallow water table, *Indian Journal of Agricultural Sciences*, 70 (7), 494-495, 2000.

Bharambe, PR, Sondge, GS, Jadhav, Soil-Water balance components and water use efficiency of different crop sequences grown on a vertisol, *Journal of the Indian Society of Soil Science*, 51(e), 95-98, 2003.

Bhargava, BS and Raghupati, HB, Analysis of plant materials for macro and micro nutrients, Methods of Analysis of Soil, Plant, Water and Fertilizers, FDCO, (Eds), New Delhi, India, 49-82, 1993.

Bhatt, R, Kukal, SS, Arora, S, Busari, MA and Yadav, M, Sustainability issues on rice-wheat cropping system, *International Soil and Water Conservation Research*, 4(1), 68-83, 2016.

Black, CA, Evans, DD, White, JL, Ensminger, LE and Clark, FE, Methods of Soil Analysis, Part I- Physical and Mineralogical Properties, Including Statistic of Measurement and Sampling, *American Society of Agronomy*, 677 South Segoe Road Madison Wisconsin, USA, 53711, 1967.

Bohra, JS and Kumar, R, Effect of crop establishment methods on productivity, profitability and energetics of rice (Oryza sativa)-wheat (*Triticum aestivum*) system, *Indian Journal of Agricultural Sciences*, 85 (2), 217-23, 2015.

Bohra, JS, Verma, SK , R, Singh, RP, Singh, JP and Singh, Y, Crop establishment options in rice (*Oryza sativa*) - wheat (*Triticum aestivum*) system under irrigated conditions of Varanasi, National Symposium on Conservation Agriculture and Environment, October 26-28, BHU, Varanasi, 2006.

Boparai, BS, Yadvinder-Singh and Sharma, BD, Effect of green manuring with *Sesbania aculeate* on physical properties of soil and on growth of wheat in rice-wheat cropping systems in a semi-arid region of India, *Arid Soil Research & Rehabilitation*, 6, 135-143 1992.

Bouthiba A, Debaeke P and Hamoudi SA, Varietal differences in the response of durum wheat (*Triticum turgidum* L. var. *durum*) to irrigation strategies in a semi-arid region of Algeria, *Irrigation Science*, 26(3), 239-251, 2008.

Bouyoucos, GT, Hydrometer method for measuring particle size analysis of soil, *Agronomy Journal*, 5(4), 464-465, 1962.

Brauman, KA, Siebert, S, Foley, JA, Improvements in crop water productivity increase water sustainability and food security- a global analysis, *Environmental Research Letters*, 8, 24-30, 2013.

Chandna, P, Ladha, JK, Singh, UP, Punia M, Gupta, R and Sidhu, BS, Using remote sensing technologies to enhance resource conservation and agricultural productivity in underutilized lands of South Asia, *Applied Geography*, 32, 757-765, 2010.

Chauhan, DS, Sharma, RK, Tripathi, SC, Kharub, AS, Chhokar, RS and Dhillon, OP, Technology assessment and refinement through on farm participatory approach, Indian wheat Newsletter, pp. 1, 2000.

Chouhan, RPS, Bhunia, SR and Yadav, BS, Effect of irrigation and integrated nutrient management on productivity, monetary return, sustainability value index and water use efficiency of cluster bean (*Cyamopsis teragonoloba*)- Wheat (*Triticum aestivum*) cropping system under North-Western canal command area of Rajasthan, *The Journal of Rural and Agricultural Research*, 12, 7-10, 2012.

Dastane, NG, A Practical Manual for Water Use Research in Agriculture, Navbharat Prakashan, 702-Budhawar Path Poona-2, 1972.

Devkota, M, Devkota, KP, Acharya, S, & McDonald, AJ, Increasing profitability, yields and yield stability through sustainable crop establishment practices in the rice-wheat systems of Nepal, *Agricultural Systems*, 173, 414-423, 2019.

DFI committee estimates, Report of the Committee for Doubling Farmers' Income, Volume VIII "Production Enhancement through Productivity Gains", DAC&FW, MA&FW, February, 2018.

DFI committee reports, Report of the Committee on Doubling Farmers' Income Volume VI "Strategies for Sustainability in Agriculture" DAC&FW, MA&FW, November 2017.

Dhiman, SD, Kumar, S and Om, H, Shallow tillage and drill technology for wheat, *Indian Farming*, 53, 10-13, 2003.

El-Afandi G, Khalil, FA and Ouda SA, Using irrigation scheduling to increase water productivity of wheat-maize rotation under climate change condition, *Chilean Journal of Agricultural Research*, 70(3),474-484, *2010*.

Erenstein, O and Laxmi, V, Zero tillage impacts in India‘s rice-wheat systems- A review, *Soil and Tillage Research*, 100, 1-14, 2008.

Erenstein, O, Farooq, U, Malik, RK, Sharif, M, Adoption and impacts of zero-tillage as a resource conserving technology in the irrigated plains of South Asia, Colombo, Sri Lanka, International Water Management Institute, P 55, Comprehensive Assessment of Water Management in Agriculture. Research Report 19, 2007.

Gadoury, S and Hess, T, Improved irrigation scheduling for spring wheat grown under centre pivot irrigation in Zambia's sandy soil, In; Food production, poverty alleviation and environmental challenges as influenced by limited water resources and population growth, 18th International Congress on Irrigation and Drainage, Montreal, Canada (1 A),1-13, 2002.

Gathala, MK, Ladha, JK, Saharawat, YS, Kumar, V, Kumar, V and Sharma, PK, Effect of tillage and crop establishment methods on physical properties of a medium-textured soil under a seven-year rice-wheat rotation, *Soil Science Society of America Journal*, 75, 1851-1862, 2011.

Ghodpage, RM and Gawande, RL, Effect of scheduling of irrigation on yield of late sown wheat (*Triticum aestivum* L.) on Morna command area, *Annals of Plant Physiology*, 15(1),77-79, 2001.

Gomez, KA and Gomez, AA, Statistical Procedure for Agricultural Research, 2nd Edn, John Wiley and Sons, New York, pp 241-271, 1984.

Gupta, AK, Nainwal, RC, Singh, D and Singh, AK, Response of irrigation scheduling on growth and yield of late sown wheat, Progressive Research, 11 (Special-VIII), 5307-5310, 2016.

Gupta, RK, Naresh, RK, Hobbs, PR, Ladha, JK, Adopting conservation agriculture in the rice–wheat system of the Indo-Gangetic Plains: new opportunities for saving water. In: Bouman, BAM, Hengsdijk, H, Hardy, B, Bindraban, PS, Tuong, TP, Ladha, JK (Eds.), Water Wise Rice Production. Proceedings of the International Workshop on Water Wise Rice Production, Los Banos, Philippines, 8–11 April, International Rice Research Institute, Los Banos, Philippines, 207-222, 2002.

Hati, KM, Mandal, KG, Misra, AK, Ghosh, PK and CL Acharya, Effect of irrigation regimes and nutrient management on soil water dynamics, evapotranspiration and yield of wheat (*Triticum aestivum*) in vertisols, *Indian Journal of Agricultural Sciences*, 71 (9), 581-586, 2001.

Hobbs, P and Morris,M, Meeting South Asia's future food requirements from rice-wheat cropping systems: priority issues facing researchers in the post- Green Revolution era, NRG paper 96(01), 1996.

Hobbs, PR and Morris, M, Meeting South Asia‘s future food requirements from rice - wheat cropping systems: priority issues facing researchers in the Post-Green Revolution era, *NRG Paper*, 96–101, 1996.

Hobbs, PR, Gupta, RK, Resource-conserving technologies for wheat in the rice-wheat system, In: Improving the Productivity and Sustainability of Rice-wheat Systems: Issues and Impacts, 2003.

Hobbs, PR, Singh, Y, Giri, GS, Lauren, JG, Duxbury, JM, Direct seeding and reduced tillage options in the rice–wheat systems of the Indo-Gangetic Plains of South Asia, In: Pandey, S, Mortimer, M, Wade, L, Tuong, TP, Lopez, K, Hardy, B (Eds.), Direct Seeding: Research Strategies and Opportunities, Proc. Int. Workshop on Direct Seeding in Asian Rice Systems: Strategic Research Issues and Opportunities, Bangkok, Thailand, International Rice Research Institute, Los Banos, Philippines, pp 201-215, 2000.

Huo, JJ and Shang, SH, Optimization method for crop irrigation scheduling based on simulation technique and genetic algorithms in China, Transactions of the Chinese Society of Agricultural Engineering 23(4), 23-28, 2007.

Ibragimov N, Evett S, Esanbekov Y, Kamilov B and Heng L, Cotton and Winter Wheat Irrigation Scheduling Improvements in Uzbekistan, International Atomic Energy Agency, Soil Science Unit, FAO/IAEA Agriculture & Biotechnology Lab, A-2444 Seibersdorf, Austria, 1-9, 2003.

Idanani, LK and Kumar, A, Relative efficiency of different irrigation schedules for conventional, ridge and raised bed seeding of wheat (*Triticum aestivum*), *Indian Journal of Agronomy*, 57, 148-151, 2012.

Ingle, AU and Shelke, D.K, Effect of irrigation scheduling and nutrients management on WUE and nutrient uptake of wheat on vertisols, *Journal of Soil and crops*, 43, 188-190, 2007.

Jackson, ML, Soil Chemical Analysis, Prentice Hall of India Pvt. Ltd., New Delhi, 1-492, 1973.

Jana, PK, P, Bandopadhyay and D, Ray, Response of wheat to irrigation regimes in new allunial zone of West Begal, *Annals of Agricultural Research*, 22 (4), 498-502, 2001.

Jat, ML, Dagar, JC, Sapkota, TB, Singh, Y, Govaerts, B, Ridaura, SL, Saharawat, YS, Sharma, RK, Tetarwal, JP, Jat, RK, Hobbs, H and Stirling, C, Climate change and agriculture: adaptation strategies and mitigation opportunities for food security in South Asia and Latin America, *Advances in Agronomy*, 137, 127-236, 2016.

Jat, ML, Gathala, M, Sharma, SK, Ladha, JK, Gupta, RK, Saharawat, YS, and Pathak, H, Productivity and profitability of rice–wheat system with double no-till practice, In: Proceedings of the 2nd International Rice Congress, 9–13 October, New Delhi, India, 88, 2006.

Jat, ML, Gathala, MK, Ladha, JK, Saharawat, YS, Jat, AS, Kumar, V, Sharma, SK, Kumar, V and Gupta, RK, Evaluation of precision land leveling and double zero-till systems in the rice–wheat rotation: Water use, productivity, profitability and soil physical properties. *Soil Tillage Research*, 105(1), 112-121, 2009.

Jat, ML, Gathala, MK, Ladha, JK, Saharawat, YS, Jat, AS, Kumar, V and Gupta, R, Evaluation of precision land leveling and double zero-till systems in the rice-wheat rotation: Water use, productivity, profitability and soil physical properties, *Soil and Tillage Research*, 105(1), 112-121, 2009.

Jat, ML, Pal SS, Singh R, Singh, D and Gill, MS, Effect of moisture regimes and nitrogen management options on crop and water productivity and nitrogen-use efficiency in maize (*Zea mays*) and wheat (*Triticum aestivum* L.) cropping system, *Indian Journal of Agricultural Sciences*, 78(10),881-883, 2008.

Jat, ML, Saharawat, YS and Gupta, R, Conservation agriculture in cereal systems of south Asia: nutrient management perspectives, *Karnataka Journal of Agricultural Sciences*, 24(1), 100-105, 2011.

Jat, ML, Singh, Ravi G, Sidhu, HS, Singh, UP, Malik, RK, Kamboj, BR, Jat, RK, Singh, Vicky, Hussain, Israil, Mazid, MA, Sherchan, DP, Khan, Aqil, Singh, VP, Patil, SG, and Gupta Raj, Resource Conserving Technologies in South Asia, Frequently Asked Questions, Technical Bulletin, International Maize and Wheat Improvement Center, New Delhi India. pp 44, 2010.

Jat, RD, Jat, HS, Nanwal, R.K., Yadav, AK, Bana, A, Choudhary, KM, Kakraliya, SK, Sutaliya, JM, Sapkota, TB, Jat, ML, Conservation agriculture and precision nutrient management practices in maize-wheat system: Effects on crop and water productivity and economic profitability, *Field Crops Research*, 222, 111-120, 2018.

Jat, RK, Sapkota, TB, Singh, RG, Jat, ML, Kumar, M and Gupta, RK, Seven years of conservation agriculture in a rice–wheat rotation of Eastern Gangetic Plains of South Asia: Yield trends and economic profitability, *Field Crops Research*, 164,199-210, 2014.

Kang S Z, Zhang Lu Liang, Yin Li Hu, Xiao Tao, Cai Huan Jie and Gu Bin Jie, Effect of limited irrigation on yield and water use efficiency of winter wheat in the loess Plateau of China, *Agricultural Water Management*, 55(3),203-216, 2002.

Karunakaran, V, and Behera, UK, Conservation agriculture in soybean (*Glycine max*) - wheat (*Triticum aestivum*) cropping system, Agricultural Reviews, 36 (3), 169-183, 2015.

Kaur, R, Kumar, S, Singh, G and Kaur, R, Effect of irrigation scheduling and mulches on growth and yield of wheat (*Triticum aestivum* L.) in Central Punjab, *International Journal of Chemical Studies*, 6(5), 723-726, 2018.

Khan, MJ, Sarwar T, Shahzadi A and Malik A, Effect of different irrigation schedules on water use and yield of wheat, *Sarhad Journal of Agriculture*, 23(4), 1061-1066, 2007.

Khan, S, Abbas, SK, Irshad, S, Mazhar, SA, Batool, S, Impact of various irrigation practices on nitrate movement in soil profile and wheat productivity, *Applied Water Science*, 10,151, 2020.

Khang, AS, Mainder, JS and Goyal, KA, Irrigation scheduling in zero-till and bed planted wheat (*Triticum aestivum* L.), *Indian Journal of Soil Conservation*, 38(3),194-198, 2010.

Khatri, RS, AC, Goel and RK, Malik, Water use and application efficiencies in bed and flat sowing ofwheat in rice-wheat system under different irrigation levels, *Crop Research*, Hissar, 21 (1), 20-23, 2001.

Khatri, RS, Goel, AC and Malik, RK, Comparative wheat crop performance in bed sowing and conventional flat sowing in rice-wheat system under different irrigation levels, Haryana Agricultural University, *Journal of Research*, 32,11-18, 2002.

Khokhar, AK and Nepalia,V, Effect of herbicides and nutrient management on weed flora, nutrient uptake and yield of wheat nutrient uptake and yield in wheat (*Triticum aestivum* L), *Indian Journal of Weed Science* , 42(1/2), 14-18, 2010.

Kumar, N, Kamboj, BR, Thakral, SK and Singh, M, Growth parameters and productivity of wheat as influenced by crop establishment methods and different seed rate, *International Journal of Pure & Applied Bioscience*, 5(4), 2134-2140, 2017.

Kumar, R, and Yadav, DS, Effect of zero and minimum tillage in conjunction with nitrogen management in wheat (*Triticum aestivum*) after rice (*Oryza sativa*), *Indian Journal of Agronomy*, 50(1), 54–57, 2005.

Kumar, Rakesh and Singh, UP, Effect of residue and weed management techniques on growth and yield of zero-till wheat (*triticum aestvium* L.) Under rice-wheat cropping system. *The bioscan* 12(3), 1611-1616, 2017.

Kumar, Rakesh, Singh, UP and Mahajan, Gaurav, Performance of Zero-till Wheat (*Triticum aestivum* L.) and Weed Species as Influenced by Residue and Weed Management Techniques in Rice based Cropping System, *International Journal of Current Microbiology and Applied Sciences*, 8(04), 270-277, 2019.

Kumar, Rakesh, Singh, UP and Mahajan, Gaurav, Residue and weed management practices in zero-till wheat (*triticum aestivum* L.) Under Rice- wheat cropping system. *International Journal of Agriculture Sciences*, 9(4), 3708-3712, 2017.

Kumar, Ravi HS, Singh, UP, Singh, SP, Singh,Y and Sravan, Uppu Sai, Impact of Crop Establishment Methods and Weed Management Practices on Productivity and Profitability of Rice-Wheat System in Indo Gangetic Plains, *International Journal of Plant & Soil Science*, 28(3), 1-19, 2019.

Kumar, V, Bellinder, RR, Gupta, RK, Malik, RK and Brainard, DC, Role of herbicide-resistant rice in promoting resource conservation technologies in rice-wheat cropping systems of India: A review, *Crop Protection*, 27, 290-301, 2008.

Kumar, V, Gathala, MK, Saharawat, YS, Parihar, CM, Kumar, R, Kumar, R, Jat, ML, Jat AS, Mahala, DM, Kumar, L, Nayak, HS, Parihar, MD, Rai, V, Jewlia, H, Kuri, BR, Impact of tillage and crop establishment methods on crop yields, profitability and soil physical properties in rice–wheat system of Indo-Gangetic Plains of India, 2018.

Kumar, V, Saharawat, YS, Gathala, MK Jat, AS, Singh, SK, Chaudhary, N, Jat, ML, Effect of different tillage and seeding methods on energy use efficiency and productivity of wheat in the Indo-gangetic plains, *Field Crops Research*, 142, 1-8, 2013.

Kumar,V and Ladha, JK, Direct seeding of rice- recent developments and future research needs, *Advances in Agronomy*,111, 297-413, 2011.

Lal, R, Axle load and tillage effects on crop yields on a mollic ochraaqualf in northwest Ohio, *Soil and Tillage Research*, 37, 143-160, 1996.

Mahbod M, Sepaskhah AR and Monfared M, Development of an irrigation scheduling model for winter wheat based on soil water and precipitation, *Journal of Science and Technology of Agriculture and Natural Resources*, 13(4-B),1-12, 2009.

Mahmood, N, Akhtar, B and Saleem, M, Scheduling irrigation in wheat at different seed rates, *Asian Journal of Plant Sciences,* 2, 136-137, 2002.

Malhi, SS and Lemke, R, Tillage crop residue and N fertilizer effects on yield, nutrient uptake, soil quality and greenhouse gas emissions in the second 4-year rotation cycle, *Soil and Tillage Research*, 96, 269-283, 2007.

Malik, RK, Balyan, RS, Yadav, A, Pahwa, SK (Eds.), Herbicide resistance management and zero tillage in rice–wheat cropping system, Proceedings of International Workshop at Chaudhary Charan Singh Haryana Agricultural University (CCSHAU), Hisar, India, 4-6 March 2002.

Malik, RK, Yadav, A and Singh, S, Resource conservation technologies for maintaining health of natural resources in rice-wheat cropping system, Proc. Workshop on Sustaining Agriculture: Problems and Prospects, Punjab Agricultural University Ludhiana, India, 2004.

Maliwal GL, Patel JK, Kaswala RR, Patel ML, Bhatnagar R and Patel JC, Scheduling of irrigation for wheat (*Triticum aestivum* L.), *Indian Journal of Agricultural Sciences*, 70(2), 90-92, 2000.

Maqsood, M, Ali, A, Aslam, Z, Saeed, M and Ahmad, S, Effect of irrigation and nitrogen levels on grain yield and quality of wheat, *International Journal of Agriculture and Biology*, 4, 164-165, 2002.

Masanta, S and Mallik, S, Effect of mulch and irrigation on yield and water use efficiency of wheat unser Patloi Nala micrp-watershed in Pirulia district of West Bengal, *Journal of Crop and Weed,* 5(2), 22-24, 2009.

Maurya RK and Singh GR, Effect of crop establishment methods and irrigation schedules on economics of wheat (*Triticum aestivum* L.) production, moisture depletion pattern, consumptive use and crop water use efficiency, *Indian Journal of Agricultural Sciences* ,78(10), 830-833, 2008.

McMaster, GS, Palic, DB and Dunn, GH, Soil management alters seedling emergence and subsequent autumn growth and yield in dry land winter wheat-fallow systems in the Central Great Plains on a clay loam soil, *Soil and Tillage Research*, 65, 193-206, 2002.

Meena, RM, Effect of weed control measures under varying irrigation schedules on productivity of wheat (*Triticum aestivum* L.) Ph.D. Thesis, Department of Agronomy, MPUAT, Udaipur, 2015.

Molden D, Accounting for water use and productivity. SWIM Paper 1. International Irrigation management Institute, Colombo, Sri Lanka, 1997.

Moursi, E, Khalifa, RM, Meleha, AM and Aiad, MA, Effect of irrigation scheduling at different management allowable deficit using pan evaporation on wheat yield and water efficiencies at North Delta, *Journal of Sustainable Agricultural Sciences*, 45 (1), 11-25, 2019.

Muhammad Aslam, and Manzoor Hussain, Effect of irrigation at different growth stages on the grain yield of wheat, Annual wheat Newsletter, 49, 87-89, 2003.

Mukharjee, S and Ghosh, AS, Water relations, New central book agency Ltd., 8/1 Chintamoni Das Lane, Kolkatta, India, 2006.

Nadeem, MA, Ali, ATA, Ayub, M and Tahir, M, Effect of weed-control practice and irrigation levels on weeds and yield of wheat (*Triticum aestivum*), *Indian Journal of Agronomy*, 52, 60-63, 2007.

Nagargade, M, Sen, A and Tyagi, V, Influence of various crop establishment methods on yield and nutrient uptake of wheat (*Triticum aestivum* L.) in rice-wheat cropping system, *Bangladesh Journal of Botany*, 45(3), 713-716, 2016.

Nandan, R., Singh, V, Singh, SS, Kumar, V, Hazra, KK, Nath, CP, Poonia, SP, Malik, RK, Bhattacharyya, R and McDonald, A, Impact of conservation tillage in rice–based cropping systems on soil aggregation, carbon pools and nutrients, *Geoderma*, 340, 104-114, 2019.

Narolia, RS, Harphool, M, Pratap, S, Meena BS, Baldev, R, Effect of irrigation scheduling and nutrient management on productivity, profitability and nutrient uptake of wheat (*Triticum aestivum*) grown under zero-tilled condition in south-eastern Rajasthan, *Indian Journal of Agronomy*, 61, (1), 53-58, 2016.

Olsen, SRCV, Watanabe, FS and Dean, LA, Estimation of available phosphorus in soil by extraction with sodium bicarbonate, USDA Circular 939, Fine Method of Soil Analysis, Agronomy No. 9, Black, CA (Ed.), American Society of Agronomy, 19-23, 1954.

Orta, A H, Baser I, Sehirali S, Erdem T. and Erdem Y, Use of infrared thermometry for developing baseline equations and scheduling irrigation in wheat,*Cereal Research Communications*, 32(3), 363-370, 2004.

Pal, SK, Verma, UN, Singh, MK and R Thakur, Growth and yield of late sown wheat (*Triticum aestivum*) under different irrigation schedules, *Indian journal of Agricultural Sciences*, 71 (10), 664-667, 2001.

Paramjit, V, Singh, P and Anureet, K, Effect of different levels of nitrogen and irrigation on growth and yield of malt barley var. Alfa-93, *Crop Research*, 21, 261-264, 2001.

Parashar, A and Thaman, S, Studies on irrigation requirements of late sown wheat (*Triticum aestivum*), *Progressive Agriculture*, 5, 10-12, 2005.

Parihar, MD Parihar, CM, Nanwal, RK, Singh, AK, Jat, SL, Nayak, HS, Ghasal, PC, Jewlia, HR, Choudhary, M and Jat, ML, Effect of different tillage and residue management practices on crop and water productivity and economics in maize (*Zea mays*) based rotations, *Indian Journal of Agricultural Sciences*, 89 (2), 360-6, 2019.

Parihar, SS and Tiwari, RB, Effect of irrigation and nitrogen levels on yield, nutrients uptake and water use of late-sown wheat, *Indian Journal of Agronomy*, 48, 103-107, 2003.

Parihar, SS, Khera, KL, Sandhu, KS and Sandhu, BS, Comparision of irrigation schedule based on pan evaporation and growth stages in wheat, *Agronomy Journal* , 68, 650–653, 1976.

Patel, MR, Sadhu, AC, and Patel, JC, Effect of irrigation, nitrogen and biofertilizer inoculation on N, P and K content and uptake of forage oat (*Avena sativa* L.), *Research on Crops*, 9, 544-546, 2008.

Pathak H, YS, Saharawat, M, Gathala, JK, Ladha, Impact of resource-conserving technologies on productivity and greenhouse gas emission in rice-wheat system, *Greenhouse Gases: Science and Technology*, 1(3), 261-277, 2011.

Patra, AK, Chhonkar, PK and Khan, MA, Nitrogen loss and wheat (*Triticum aestivum*) yields in response to zero-tillage and sowing time in a semi-arid tropical environment, *Journal of Agronomy and Crop Science*, 190, 324-331, 2004.

Piper, CS, Soil and Plant Analysis, Hans Publisher, Bombay, 1966.

Punia, SS, Singh, S, Yadav, A, Yadav, DB. and Malik, RK, Long-term impact of crop establishment methods on weed dynamics, water use and productivity in rice-wheat cropping system, *Indian Journal of Weed Science*, 48(2), 158-163, 2016.

Rahim Ranjha, Rahamtullah MA and Waraich AE, Effect of phosphorus application and irrigation scheduling on wheat yield and phosphorus use efficiency, *Soil & Environment* 29(1), 15-22, 2010.

Rahman, MA, Chikushi, J, Saifizzarman M and Lauren, JG, Rice straw mulching and nitrogen response of no-till wheat following rice in Bangladesh. *Field Crops Research*, 91, 71-81, 2005.

Ram, H, Kler, DS, Singh, Y and Kumar, K, Productivity of maize (*Zea mays*)–wheat (*Triticum aestivum*) system under different tillage and crop establishment practices, *Indian Journal of Agronomy*, 55(3), 185-190, 2010.

Rathod, JR and Vadodaria, PK, Response of irrigation and weed management on productivity of wheat (*Triticum aestivum*) under middle Gujarat condition, *Pakistan Journal of Biological science*,7 (3), 346-349, 2004.

Rhoton, FE, Influence of time in soil response to no-till practices, *Soil Science Society of America Journal*, 64, 700-709, 2000.

Saharawat YS, Ladha JK, Pathak H, Gathala MK, Chaudhary N, Jat ML, Simulation of resource conserving technologies on productivity, income and greenhouse gas GHG emission in rice–wheat system, *Journal of Soil Science & Environmental Management*, 3, 9-22, 2011.

Saharawat, YS, Singh, B, Malik, RK, Ladhaa, JK, Gathalaa, M, Jat, ML, Kumar,V, Evaluation of alternative tillage and crop establishment methods in a rice–wheat rotation in North Western IGP, *Field Crops Research*, 116 (3), 260-267, 2010.

Saini, S, Singh, SK and Mahapatra, BS, Improving wheat productivity in rice (*Oryza sativa*) wheat (*Triticum aestivum* L.) cropping system through crop establishment methods, *Indian journal of Agricultural Sciences*, 81(2), 174-176, 2011.

Sarel, KL, Effect of Irrigation and Nitrogen Levels on productivity of Wheat (*Triticum aestivum* L.) M. Sc. Thesis, Department of Agronomy, MPUAT, Udaipur, 2015.

Saren BK, Dey S and Mandal D, Effect of irrigation and sulphur on yield attributes, productivity, consumptive use, consumptive use efficiency of wheat (*Triticum aestivum*), *Indian Journal of Agriculture Sciences,* 74(5), 257-261, 2004.

Saren BK. and Jana PK, Growth and productivity of wheat (*Triticum aestivum L.*) as influenced by depths of irrigation, nitrogen and its time of application, *Journal of Inter academician,* 5(1), 39-44, 2001.

Sayre, KD, Limon-Ortega, A, and Govaerts, B, Experiences with permanent bed planting systems CIMMYT/Mexico. In: Roth CH, Fischer RA, Meisner CA, Eds. Evaluation and performance of permanent raised bed cropping systems in Asia, Australia and Mexico. Proceedings of a workshop held in Griffith, Australia. ACIAR Proceedings 121, ACIAR, Griffith, pp 12-25, 2005.

Scheer, C, Wassmann, R, Butterbach-Bahl, K, Lamers, JPA and Martius, C, The relationship between N_2O, NO, and N_2 fluxes from fertilized and irrigated dryland soils of the Aral Sea basin, Uzbekistan, *Plant and Soil*, 324, 273-283, 2009.

Shahane, AA, Shivay, YS, Prasanna, R, and Kumar, D, Nutrient removal by rice–wheat cropping system as influenced by crop establishment techniques and fertilization options in conjunction with microbial inoculation, *Scientific Reports*, 10, 1-20, 2020.

Shamsi K. and Kobraee S, Effect of different irrigation regimes on yield and water use efficiency of winter wheat, *Annals of Biological Research*, 4(5), 222-227, 2013.

Sharma, PC, Datta, A, Yadav, AK, Choudhary, M, Jat, HS and McDonald, A, Effect of Crop Management Practices on Crop Growth, Productivity and Profitability of Rice–Wheat System in Western Indo-Gangetic Plains, Proceedings of the National Academy of Sciences, India Section B: *Biological Sciences*, 89(2), 715-727, 2019.

Sharma, PK, Bhushan, L, Ladha, JK, Naresh, RK, Gupta, RK, Balasubramnian, V and Bouman, BAM, Crop-water relations in rice–wheat cropping and water management practices in a marginally sodium medium-textured soil. In, Water-Wise Rice Production, Bouman, BAM (Eds.), IRRI, Los Banos, Philippines, 22-36, 2002.

Sharma, V, Bali, AS and Kachroo, D, Effect of different establishment methods and sowing schedules on growth and yield of hybrid rice (*Oryza sativa*) and their after effects on succeeding wheat (*Triticum aestivum*) in rice-wheat cropping system, *Economic Affairs*, 61(3), 487-493, 2016.

Sidhu, HS, Singh, M, Humphreys, E, Singh, Y, Singh, B, Dhillon, SS, Blackwell, J, Bector, V, Singh, M and Singh, S, The happy seeder enables direct drilling of wheat into rice stubble, *Australian Journal of Experimental Agriculture*, 47, 844-854, 2007.

Singh B, Humphreys E, Eberbach P L, Katupitiya A, Singh Y and Kukal SS, Growth, yield and water productivity of zero-till wheat as affected by rice straw mulch and irrigation schedule, *Field Crops Research*, 121(2), 209-225, 2011.

Singh SS, Prasad LK and Upadhya A, Root growth, yield and economic of wheat (*Triticum aestivum*) as affected by irrigation and tillage practices in South Bihar, *Indian Journal of Agronomy*, 51(2),131-134, 2006.

Singh, J, Mahal, SS and Manhas, SS, Effect of sowing methods, nitrogen levels and irrigation scheduling on yield and quality of malt barley (*Hordeum vulgare* L.), *Indian Journal of Agronomy*, 57, 259-264, 2012.

Singh, Lakhapati, Singh, CM and Singh, GR, Response of bed planted wheat (*Tritcum aestivum* L.) under the different moisture regime on water use and it's efficiency, *Journal of Chemical and Pharmaceutical Research*, 4, 4941-4945, 2012.

Singh, M, Kumar, P, Kumar, V, Solanki, IS, McDonald, AJ, Kumar, A, Poonia SP, Kumar, V, Ajay, A, Kumar, A, Singh, DK, Singh, B, Singh, S, Malika, RK, Intercomparison of crop establishment methods for improving yield and profitability in the rice-wheat system of Eastern India, *Field Crops Research*, 250, 1-12, 2020.

Singh, M, Mishra, DJS and Bhatt, BP, Effect of crop establishment methods on crop yield, weed dynamics, profitability and nutrient uptake under rice-wheat cropping system of Indo-gangetic plains of Eastern India, *Ecology, Environment and Conservation*, 23, 207-215, 2017.

Singh, M, Studies on seed rate requirement and time of first irrigation in no-till wheat following rice, M.Sc. Thesis, Punjab Agricultural University, Ludhiana, India, 2000.

Singh, PN, BP, Joshi and G, Singh , Water use and yield response of wheat to irrigation and nitrogen on an alluvial soil in North India, *Agricultural water management*; 12 (4), 311-321, 2003.

Singh, Prabhat Kumar ,Singh UP, Singh, Lakhapati, Singh, Himanshu, Das, M, Pooja and Kumar, Virender, Zero-tillage combined with residue mulch suppressed weeds and increased yield in wheat in the Eastern India, *In: 25th Asian-Pacific Weed Science Society Conference on "Weed Science for Sustainable Agriculture, Environment and Biodiversity*, Hyderabad, India pp 361, 2015.

Singh, RK, Naresh, Kumar, V, Chaudhary, M., Mahajan, NC, Sachan, DK, Pandey, A, Yadav, A and Jat, L, Effect of Irrigation Schedules and Crop establishment methods on physiological processes, light interception, water and crop productivity of wheat under a semiarid agro-ecosystem, *International Journal of Current Microbiology & Applied Sciences* , 7(12), 3427-3451, 2018.

Singh, S and Sheoran, P, Growth, yield and nutrient uptake of late sowed wheat under different irrigation regimes, *Journal of Soils and Crops*, 16, 48-51, 2006.

Singh, S, Dhindwal, AS, Sheoran, P and Bhattoo, MS, Dry matter accumulation, partitioning and translocation in late-sown wheat (*Triticum aestivum*) under different irrigation levels, *Annals of Agri-Bio Research*, 10, 151-154, 2005.

Singh, S, Mahal, SS, Singh, A and Uppal, HS, Yield and yield attributes of bed planted wheat as affected by irrigation and fertilizer levels, *Research on Crops*, 8, 58-61, 2007.

Singh, S, yadav, A, Malik, RK and Singh, H, Long term effect of zero tillage sowing technique on weed flora and productivity of wheat in rice-wheat cropping zones of Indo-gangetic plains. In proceedings of International workshop on herbicide resistance management and zero tillage in rice-wheat cropping system held at Hissar, March 4-6, pp 155-157, 2002.

Singh, SN, Sah, AK, Om Prakash Singh, RK, Singh, VK, Assessing the impact of zero tilled wheat growing in rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping systems the case of central Uttar Pradesh in the Indo-Gangetic Plain, *Outlook on Agriculture*, 39 (3), 197-202, 2010.

Singh, Udai P, Singh,Y, Kumar Virender and Ladha JK, Evaluation and promotion of resource conserving tillage and crop establishment techniques in the rice-wheat system of eastern India, *In:* Ladha JK, Singh Yadvinder, Erenstein O, Hardy B, edited books on Integrated crop and resource management in rice-wheat system of South Asia. International Rice Research Institute, Los Banos (Philippines), p 151-176, 2009.

Singh, UP, Kumar, HS Ravi, Singh, Himanshu, Kashyap, Sanjeev Kumar, Upadhyay, Anurag, Dahiphale A V, Sutaliya J M, Singh Nikhil Kumar, Kumar Rakesh, Singh M K, Singh Y, Enhancing productivity through climate smart agriculture in rice-based cropping system of Eastern Uttar Pradesh, India. *In: 5th International Rice Research Conference*, at Singapore, October 15-17, 2018.

Singh, UP**,** Singh Yashwant, Sutaliya, JM, Kumar HS Ravi, Jat ML and Gupta RK, Performance of double no-till in rice-wheat system of Easten Indo-Gangetic plains, *In: 3rd International Agronomy Congress- Agriculture Diversification, Climate Change Management and Livelihoods*, New Delhi, India, pp 838-839, 2012.

Singh, V, Bhunia, SR and Chauhan, RPS, Response of late sowed wheat to row spacing-cum population densities and level of nitrogen and irrigation in north western Rajasthan, *Indian Journal of Agronomy*, 48, 178-181, 2003.

Singh,UP, Singh, Yashwant, Sutalia, JM Singh, Kumar, Nikhil, Singh, MK, Jat ML, Gupta, RK, and Malik, RK, Conservation Agriculture Practices for Higher Resource Use Efficiency, Productivity and Profitability, *In: 4th International Agronomy Congress on Agronomy for Sustainable Management of Natural Resources, Energy livelihood Security to Achieve Zero Hunger Challenge*, New Delhi, India November 22-26, 2016.

Subbiah, BW and Asija, GL, A rapid procedure for estimation of available nitrogen in soil, *Current Science*, 25(8), 259-260, 1956.

Takate PS, Jadhav AS and Takate AS, Irrigation scheduling on the basis of CPE and corroboration with canopy temperature in wheat, *Journal of Maharashtra Agricultural Universities,* 27(1), 91-94, 2002.

Thakur, R, Singh,MK, Pal, SK, and Verma, UN, Tillering pattern and productivity of wheat under different irrigation, seed rate and fertilizer, *Indian Journal of Agricultural Sciences,* 70 (10), 686-688, 2000.

Tomar, SK, Singh, SN, Rao, AP, Naresh, RK, Sharma, VK, Singh, S, Bargaha, SK., Singh, SK, Pandey, A, Singh, JP and Singh, RV, Influence of crop establishment methods on crop water productivity and profitability in rice-wheat systems under Eastern Indo Gangetic Plains, *International Journal of Current Microbiology & Applied Sciences*, 8(6), 259-268, 2019.

Tripathi, SC and Chauhan, DS, Effect of tillage and fertilizer on productivity of wheat (*Triticum aestivum* L.) under dry seeded and transplanted rice condition, *Indian Journal of Agronomy*, 46 (1), 107-111, 2001.

Tripathi, SC and Chauhan, DS, Evaluation of fertilizer and seed rate in wheat under different tillage conditions after transplanted rice, *Indian Journal of Agricultural Sciences*, 70, 574-576, 2000.

USDA, World Agriculture Production, June, pp 15, 2019.

Ussiri, DAN and Lal, R, Long-term tillage effects on soil carbon storage and carbon dioxide emissions in continuous corn cropping system from an alfisol in Ohio, *Soil & Tillage Research*, 104, 39-47, 2009.

Vaughan, DA, Morishima, H and Kadowaki, K, Diversity in the *Triticum* genus, *Current Opinion in Plant Biology*, 6, 139-146, 2003.

Walkley, AJ and Black, TA, Estimation of soil organic carbon by the chromic and titration method, *Soil Science*, 37, 29-38, 1934.

Yadav, DS, Shukla, RP, Sushant and Kumar, B, Effect of zero tillage and nitrogen level on wheat (*Triticum aestivum*) after rice (*Oryza sativa*), *Indian Journal of Agronomy*, 50(1), 52-53, 2005.

Yaghobi, GA, Effect of Irrigation Levels and Weed Management on Productivity of Wheat (*Triticum aestivum*, L.) Under Zero Tillage, M.Sc. Thesis, Department of Agronomy, MPUAT, Udaipur, 2008.

Zhang, Xi Ying , Linking water balance to irrigation scheduling- a case study in the piedmont of Mount Taihang (ACIAR Monograph No. 84), Regional water and soil assessment for managing sustainable agriculture in China and Australia, 57-69, 2002.

APPENDICES

Appendix I: General cost of cultivation of wheat

S.No.	Operations Materials	Input	Rate (₹)	Cost (₹)
1	Pre sowing irrigation			
	Water charges	1	300/Irrigation	300
	Labour charges	2 mandays	300/manday	600
2	Field preparation			
	Layout(reshaping)	6 mandays	300/manday	1800
3	Sowing by seed drill	1 tractor (35 HP) for two hrs	700/hrs	1400
4	Seed	100 kg	40/kg	4000
5	Fertilizer			
	120 kg nitrogen	209.93 kg	7.5/kg	1575
	60 kg phosphorus	130.43 kg	26/kg	3391
	60 kg potassium	100kg	18/kg	1800
	Labour charges	2 time 2 mandays	300	1200
6	Weed management			
	Sulfosulfuron + Metsulfuron (PoE)	40 g	450/16 g	1125
	Spraying (Labour charges)	2 mandays	300/manday	600
7	Harvesting	25 mandays	300/manday	7500
8	Threshing with tractor and thresher	6 hr	700/hr	4200
9	Land revenue	For ½ year	120/annum	60
			Total	**29551**

Appendix II: Treatment wise cost of cultivation

Treatments	Tillage		Irrigation		Labor required (No.)	Labour charge (₹ 300 labor^{-1})	Total	General cost	Working capital	Interest @12%/ annum	Total cost
	Disc ploughing (₹ ha^{-1})	Harrowing (₹ ha^{-1})	No. of Irrigation	Water charges (₹ 300 irrigation^{-1})							
CE1I1	3200	2400	4	1200	4	1200	8000	29551	37551	2253	39804
CE1I2	3200	2400	5	1500	5	1500	8600	29551	38151	2289	40440
CE1I3	3200	2400	6	1800	6	1800	9200	29551	38751	2325	41076
CE1I4	3200	2400	4	1200	4	1200	8000	29551	37551	2253	39804
CE2I1	3200	2400	4	1200	4	1200	8000	29551	37551	2253	39804
CE2I2	3200	2400	5	1500	5	1500	8600	29551	38151	2289	40440
CE2I3	3200	2400	6	1800	6	1800	9200	29551	38751	2325	41076
CE2I4	3200	2400	4	1200	4	1200	8000	29551	37551	2253	39804
CE3I1	0	0	4	1200	4	1200	2400	29551	31951	1917	33868
CE3I2	0	0	5	1500	5	1500	3000	29551	32551	1953	34504
CE3I3	0	0	6	1800	6	1800	3600	29551	33151	1989	35140
CE3I4	0	0	4	1200	4	1200	2400	29551	31951	1917	33868
CE4I1	0	0	4	1200	4	1200	2400	29551	31951	1917	33868
CE4I2	0	0	5	1500	5	1500	3000	29551	32551	1953	34504
CE4I3	0	0	6	1800	6	1800	3600	29551	33151	1989	35140
CE4I4	0	0	4	1200	4	1200	2400	29551	31951	1917	33868

Appendix III: Date frequency and total water applied in different irrigation scheduling treatment for water productivity

Treatment	Evapo-ration amount (mm)	Date of irrigation		Days interval		No. of irrigation		Total depth of irrigation(mm)		Rainfall During crop period		Total water applied to crop	
		2016-17	**2017-18**	**2016-17**	**2017-18**	**2016-17**	**2017-18**	**2016-17**	**2017-18**	**2016-17**	**2017-18**	**2016-17**	**2017-18**
I_1-IW/CPE = 0.75	80	15.12.2016	22.12.2017			4	4	240	240	0	0	240	240
		06.02.2017	12.02.2018	53	52								
		06.03.2017	11.03.2018	28	28								
		26.03.2017	28.03.2018	20	17								
I_2-IW/CPE = 1.0	60	15.12.2016	22.12.2017			5	5	300	300	0	0	300	300
		25.01.2017	03.02.2018	41	43								
		22.02.2017	28.02.2018	27	25								
		11.03.2017	15.03.2018	17	15								
		26.03.2017	30.03.2018	15	15								
I_3-IW/CPE = 1.25	48	15.12.2016	22.12.2017			6	6	360	360	0	0	360	360
		20.01.2017	29.01.2018	36	38								
		12.02.2017	19.02.2018	23	21								
		28.02.2017	07.03.2018	16	17								
		14.03.2017	18.03.2018	14	11								
		26.03.2017	28.03.2018	12	10								
I_4-Farmer's practice	Need based	15.12.2016	22.12.2017			4	4	240	240	0	0	240	240
		23.01.2017	31.01.2018	39	38								
		25.02.2017	02.03.2018	33	30								
		20.03.2017	24.03.2018	23	22								