“जल - उपयोग एवं मक्का - गेहूँ फसल तंत्र की उत्पादिता पर संरक्षित खेती सम्बन्धी क्रियाओं एवं सिंचाई प्रबंधन का प्रभाव”

“Effect of conservation agriculture practices and irrigation scheduling on water use and productivity of maize – wheat cropping system”

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WATER TECHNOLOGY CENTRE

ICAR- INDIAN AGRICULTURAL RESEARCH INSTITUTE

NEW DELHI 110 012

2016

“Effect of conservation agriculture practices and irrigation scheduling on water use and productivity of maize – wheat cropping system”

By

SUNIL KUMAR

A Thesis
Submitted to the Post-Graduate School,
ICAR- Indian Agricultural Research Institute, New Delhi,
in partial fulfillment of requirements
for the award of degree of

DOCTOR OF PHILOSOPHY
IN
Water Science and Technology
2016

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Date:

Place: New Delhi

Dedicated to

my family

my doctors

my friends

ACKNOWLEDGEMENT

As a prelude to my thanks giving, at first I wish to thank The Almighty God For giving me strength, courage and confidence for all the works and bestowing me with the eternal veil of blessings….. after all He is "The Greatest".

I wish to record my sincere appreciation and gratitude to Dr. S. S. Parihar, Principal Scientist, Water Technology Centre, ICAR-IARI, New Delhi and the Chairman of my advisory committee, for providing me an opportunity to work under his guidance and suggesting a challenging topic for the research work. I am also thankful to him for his valuable guidance, constructive criticism and wholehearted support and encouragement to me throughout the period of this study.

I am highly obliged to Dr. Man Singh, Professor and Co-Chairman Water Science and Technology, P.G. School, ICAR-I.A.R.I., New Delhi for his valuable suggestions and constant encouragement during my course of research. I feel very fortunate to have come across such an affectionate personality whose constant encouragement was a catalyst in my PhD. programme.

I express my sincere thanks and gratefulness to Dr. R. Kaur, Project Director, Water Technology Centre, ICAR-Indian Agricultural Research Institute, New Delhi for encouraging me to undertake this study and providing me with his precious advice, necessary guidance and all the technical help during my course of study.

I would like to extend my gratitude to Dr. K. S. Rana, Principal Scientist, Div. of Agronomy, ICAR-IARI, New Delhi and member of my advisory committee for his valuable help rendered in relation to planning and execution of this work.

I am highly grateful to Dr. V.K. Sehgal, Principal Scientist, Div. of Agri. Physics, ICAR-IARI, and member of my advisory committee for his inspirational help and fruitful discussions. Further, I shall ever remain indebted to Dr. A.K. Singh for providing his valuable suggestions during my course of research as real mentor on motivational aspects.

I owe a debt of gratitude to Dr. S. L. Jat, Scientist, ICAR-IIMR, New Delhi and member of my advisory committee for providing me with the necessary references, unconditional and valuable help, and for his love and affection towards me throughout my PhD. programme.

I will always remain indebted to Dr. Manoj Khanna, Dr. Subedar Singh, Dr. Khajanchi Lal, Dr. D.S. Gurjar, Dr. Rosin, Dr. Neelam Patel and all my teachers for their valuable help and constant inspiration to me during my PhD. programme.

I express my gratefulness to Shri Bishan Devji, Shri Birpal Ji and Shri Ashok Ji for increasing my awareness in the field work rendering his help during the field observations.

I will ever remain indebted for all other facilities and knowledge, ICAR-IARI has provided to me. Also, I must express my sincere thanks and gratitude to the Department of Science and Technology for providing financial assistance in the form of Inspire fellowship during my PhD. Programme.

No words can describe the unending love, moral support and help by my dearest friends during my course of study. I wish to express my heartful thanks to my seniors and all my friends for their moral support and all guidance during my course of study. My dear friends deserve a special mention, for being always there, even before I needed any help from them and for encouraging me at every difficult step towards the completion of my research work. Instead of saying thanks, I put all my good wishes for them. I take this opportunity to express my sincere thanks to one an all for their affection, consistent encouragement and showing their blessings on me.

I shall ever remain indebted and affectionately cherish the blessings and good wishes of my beloved father, mother, brother, wife, bhabhi, Sakshi, Aryan, Kashvi and all my relatives who bestowed on me from miles apart, who were the constant sources of inspiration to me.

I dedicate everything to "Nature" "My Doctor" and "My Family" who are nursing me and my life.

Dated: / / 2016

New Delhi – 110 012 **(Sunil Kumar)**

CONTENTS

S. No.	CHAPTER	PAGE NO.
1.	INTRODUCTION	1-4
2.	REVIEW OF LITERATURE	5-19
3.	MATERIALS AND METHODS	20-41
4.	RESULTS	42-79
5.	DISCUSSION	80-94
6.	SUMMARY AND CONCLUSION	95-100
7.	ABSTRACTS	i
8.	BIBLIOGRAPHY	I-XVIII
9.	APPENDICES	i-x

LIST OF TABLES

Table No.	Particulars	Page No.
3. Materials and methods		
3.1	Methodology used for soil analysis	20
3.2	Physical properties of experimental field soil	21
3.3	Chemical properties of experimental field soil	21
3.4	The details of field operation carried out during experimentation.	26
4. Experimental result		
4.1	Effect of crop establishment methods and irrigation regimes on plant height	43
4.2	Effect of crop establishment methods and irrigation regimes on Dry matter accumulation of maize	43
4.3	Effect of crop establishment methods and irrigation regimes on leaf area index and days to 50 % silking of maize	45
4.4	Effect of crop establishment methods and irrigation scheduling on CGR (g/m2/day) of maize	46
4.5	Effect of crop establishment methods and irrigation scheduling on RGR (mg/g/day) of maize	47
4.6	Effect of crop establishment methods and irrigation regimes on yield attributes of maize	48
4.7	Productivity of maize influenced by different crop establishment methods and irrigation regimes	49
4.8	Effect of crop establishment methods and irrigation regimes on nitrogen uptake of maize	50
4.9	Effect of crop establishment methods and irrigation regimes on phosphorus uptake of maize	51
4.10	Effect of crop establishment methods and irrigation regimes on potassium uptake of maize	52

4.13	The effect of different crop establishment methods and irrigation regimes on economics of maize	53
4.11	Energy relationship influenced by different crop establishment methods and irrigation regimes in maize	54
4.12	Effect of crop establishment methods and irrigation regimes on water use in maize	55
4.14	Effect of crop establishment methods, irrigation regimes and residue management on plant height of wheat	56
4.15	Effect of crop establishment methods, irrigation regimes and residue management on dry matter accumulation of wheat	57
4.16	Effect of crop establishment methods, irrigation regimes and residue management on LAI of wheat	58
4.17	Effect of crop establishment methods, irrigation scheduling and residue management on CGR ($g/m^2/day$) of wheat	59
4.18	Effect of crop establishment methods, irrigation scheduling and residue management on RGR (mg/g/day) of wheat	60
4.19	Effect of crop establishment methods, irrigation regimes and residue management on yield attributes of wheat	62
4.20	Effect of crop establishment methods, irrigation regimes and residue management on yield performance of wheat	63
4.21	Effect of crop establishment methods, irrigation regimes and residue management on Nitrogen uptake of wheat	65
4.22	Effect of crop establishment methods, irrigation regimes and residue management on phosphorus uptake of wheat	66
4.23	Effect of crop establishment methods, irrigation regimes and residue management on potassium uptake of wheat	66
4.24	Wheat economics influenced by different crop establishment methods, irrigation regimes and residue management in 2011-12 and 2012-13	67
4.25	Energy relationship influenced by different crop establishment methods, irrigation regimes and residue management in wheat	68

4.26	Effect of crop establishment methods, irrigation regimes and residue management on IWUE and FWUE of wheat	70
4.27	Effect of crop establishment methods, irrigation regimes and residue management on system productivity of maize-wheat system	71
4.28	Soil physical properties influenced by tillage practices, irrigation regimes and residue management in maize-wheat cropping system (at the end of 2 years crop cycle)	75
4.29	Soil chemical properties influenced by tillage practices, irrigation regimes and residue management in maize-wheat cropping system (at the end of 2 years crop cycle)	76
4.30	Soil biological properties (0-5cm) influenced by tillage practices, irrigation regimes and residue management in maize-wheat cropping system (at the end of 2 years crop cycle)	78

LIST OF FIGURE

Table No.	Particulars	Page No.
3. Materials and methods		
3.1	Mean weekly weather parameters during cropping season of 2011-12 (a) and 2012-13 (b)	23
3.2	Soil moisture characteristic curve	35
4. Results		
4.1	Effect of crop establishment methods and irrigation regimes on Dry matter accumulation of maize (mean of two years)	44
4.2	Effect of crop establishment methods and irrigation regimes on leaf area index of maize (mean of two years)	45
4.3	Productivity of maize influenced by different crop establishment methods and irrigation regimes	50
4.4	Effect of crop establishment methods, irrigation regimes and residue management on dry matter accumulation of wheat (mean of two years)	58
4.5	Effect of crop establishment methods, irrigation regimes and residue management on leaf area index of wheat (mean of two years)	59
4.6	Effect of crop establishment methods, irrigation regimes and residue management on grain yield of wheat	64
4.7	Effect of crop establishment methods, irrigation regimes and residue management on system productivity of maize-wheat system	72

ABBREVIATIONS

S.N.	Legends	Description
1.	₹	Rupees
2.	%	Percentage
3.	&	And
4.	@	At the rate of
5.	^{0}C	Degree Celsius
6.	ANOVA	Analysis of variance
7.	ASMD	Available soil moisture depletion
8.	BBF	Broad bed furrow
9.	C	Cultivars
10.	CD	Critical difference
11.	CGR	Crop growth rate
12.	CGS	Critical growth stage
13.	Cm	Centimetre
14.	CT	Conventional tillage
15.	CWSI	Crop water stress index
16.	DAS	Days after sowing
17.	DF	Degree of freedom
18.	dSm^{-1}	Desi siemen per metre
19.	DW	Dry weight
20.	E	Error means sum of square
21.	EC	Electrical conductivity
22.	*et al.*	Allied (and other)
23.	FIRB	Furrow irrigated raised bed
24.	FS	Flat sowing
25.	FWUE	field water use efficiency
26.	G	Gram
27.	ha^{-1}	Per hectare
28.	HI	Harvest index

29.	i.e.	That is (in reference to)
30.	IWUE	Irrigation water use efficiency
31.	K or K_2O	Potassium
32.	Kg	Kilogram
33.	Km/hr	Kilometer per hour
34.	L	Liter
35.	LAI	Leaf area index
36.	M	Meter
37.	m^2	Meter square
38.	MEY	Maize equivalent yield
39.	Mm	millimeter
40.	Max.	Maximum
41.	Min.	Minimum
42.	Ml	Mililiter
43.	MJ	Milijoule
44.	Mm	Millimeter
45.	MSS	Mean Sum of Square
46.	N	Nitrogen
47.	NS	Non significant
48.	P or P_2O_5	Phosphorus
49.	PB	Permanent bed
50.	Q	Quintal
51.	R	Replication
52.	RB	Raised bed
53.	RGR	Relative growth rate
54.	RH	Relative humidity
55.	S	Sowing dates
56.	S.S.	Sum of Square
57.	SE(m)±	Standard error of mean
58.	SMW	Standard Meteorological Week
59.	SPD	Split plot design

60.	SS	Sum of square
61.	*Viz.*	Vice-versa
62.	ZT	Zero tillage

Chapter 1
INTRODUCTION

Rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) are major cereals in India. These crops mainly contributed to food security and income generation in India. Food security is major concern for growth and development of India. The ever increasing human population is putting a considerable strain on natural resources. In the past, the focus was on increasing food production to attain self-sufficiency. Rice–wheat cropping system (RWCS) has played immense role to make the country self-sufficient in food grains but this cropping system also brought era of scarcity and plenty of problems. Rice is a water guzzling crop and requires about 3000-5000 litres of water for production of 1 kg grain. More than 70% of the country's ground and surface water is being used for agriculture of which two-third is allocated to rice cultivation. Water demand for irrigation is growing to produce more and more food, and therefore, competition for water in different water demanding sectors is increasing. Hence, India is facing challenges to produce many fold more food with minimum use of water. This target can be met only when proper strategies are practiced for water savings and for more efficient use of water in different agricultural practices. Improve the water-use efficiency (WUE) in crop production practices and sustainable water use are of greater need and urgent in clear sense. Thus, the global crisis of water threatens sustainable existing of irrigated rice production system (IWMI, 2000). Consequently, water is expected to be the most scarce ecological factor and costly input in determining agricultural production. The scope for further water exploitation seems to be negligible as indicated by receding water table. For this, solution can be limiting water application to specific stages, minimizing crop yield loss from water stress condition (Zhang *et al*., 1999a). Rice-wheat cropping system provides the food security and livelihood to hundreds of millions of people around the globe but the questions have arisen regarding the sustainability of this system due to various environmental, economic and management problems encountered in areas following this production system (Fujsaka *et al*., 1994). The deteriorating soil health, declining soil organic matter content, increased micronutrient deficiencies and reduced partial factor productivity made a big question

mark on the sustainability of RWCS as high intensity puddling in rice results in poor tilth, increased soil strength in surface and subsurface layers due to illuviation of clay

and iron and manganese compounds, decreased hydraulic conductivity and infiltration, which lead to water stagnation, poor root development and hence causes water stress in wheat crop, and lower recharging of aquifers, all these factors reduce yield of wheat following rice (Bhushan and Sharma, 1999). So, indiscriminate use of resources not only led to reduction in total factor productivity but also resulted in environmental degradation (Yadav, 2003). Under the upcoming limitations of natural resource base, lowering productivity of different crops and ecological imbalances with the existing cropping systems, maize (*Zea mays* L.) based cropping sequences are emerging as a better alternative option for diversification of rice-wheat, rice-rice and other cropping systems. With the development of high yielding varieties and hybrids in maize which are competitive to rice with respect to farm profitability and the resource-use efficiency under diverse soils and climatic conditions, maize-wheat cropping system is gaining importance. Maize production results in remarkable water savings, particularly when irrigated rice replaced in the rice-wheat cropping system.

Maize (*Zea mays* L.), assumes worldwide importance due to its utilization as a food for human and feed for livestock, as well as a source for several hindered industrial products. Its share in the total production of cereals increased from 26.2 per cent in 1991 to 29.2 per cent in 2001 and further to 36.7 percent in 2014. Maize is a one of important crop having worldwide economic importance, together with rice and wheat. It provides approximately more than 30% of food calories to over 4.5 billion people in almost 100 developing countries. Demands for maize in these developing countries are expected to raise double by 2050. The suitability of maize to diverse agro-ecologies is unmatched by any other crop due to its ability to grow in diverse climatic conditions. In Asia, area under maize cultivation is about 57.59 million hectares, yielding about 288.85 million metric tonnes. About 67 per cent of total production of maize in the world is from countries who are having low and lower to middle income. It plays an important role in the livelihoods of millions of poor farmers (FAO, 2015). The greater use of maize in industry sector gives it a prominent place in the economy of agricultural section. Maize is the third most important food crop in India considering all cereal crops. It contributes to nearly 9% of the national

food basket (Dass *et al*., 2012). In India it occupy fourth position in the area and third position in the production among all cereal crops. It is grown in more than 9.3 million hectares with production of 24.2 million tonnes and its productivity is 2.7 tonnes per hectare during 2013-14 (Govt. of India). Now a days, maize is gaining importance in conservation agriculture because of maize is wider spaced crop having slow growth rate in its early stage, which leads to more loss of water through evaporation and heavily infestation of weed, respectively. To overcome this problem, conservation agriculture is mostly adopted, but CA adoption is limited by low fertilizer application.Wheat is the second most important cereal crop after rice in India. It is cultivated in 31.3 million hectares with production of 95.8 million tonnes and productivity of 3.0 tonnes/ha (Govt. of India).

Tillage, manipulating soil for better crop yield, creates favourable soil environment for plant growth. Soil tillage is one of the fundamental agro-technical operations in agriculture because of its influence on soil properties, environment and crop growth. Since regular and repeated soil tillage strongly affects physical, chemical and biological properties of soil. It is important to apply appropriate tillage practices that avoid of soil structure degradation, maintain crop yield as well as ecosystem stability. Intensive tillage systems results to a decrease in soil organic matter and biodiversity (Biamah *et al.*, 2000). This leads to no or very low economic returns to farmers pushing them into perpetual trap of poverty. In conventional systems which involves intensive tillage, there is gradual decline in the soil organic carbon through accelerated oxidation and crop residues burning which cause pollution, emission of greenhouse gases, and loss of valuable nutrients of plant. It is therefore, essential that the soil environment be manipulated suitably for ensuring a good crop stand and improve resource-use efficiency. Some of the agronomic practices like zero tillage, raised bed planting and residue management are found to be the potential resource conservation technologies (RCT's) which can play a big role to save the scarce natural resources like land and water.

Conservation agriculture (CA) practices are recognized as a powerful tool to address the issues related to land and environmental degradation. Thus, CA has great relevance to restore the degraded ecologies where farm income and fatigue in yield have become major concern. Technologies of CA involve reduced soil disturbance

and provides soil cover through crop residues and dynamic crop rotations for achieving higher productivity and sustainability. The key features of these technologies include: (i) minimum soil disturbance, (ii) crop residues management, (iii) adoption of spatial and temporal crop sequences to obtain maximum benefits from inputs and minimize adverse impacts on environment. When the residues are retained on soil surface in combination with minimum soil disturbance, the enhanced biological processes led to improved soil quality. Giller *et al.* (2009) argued that CA appears to offer great potential to address problems related to small holder farming. But region specific CA options need to be identified for implementation by resource-poor farmers.

Adoption of a suitable conservation tillage system and its long term effect on productivity of the system, resource-use efficiency of the system as well soil physical environment are the current research priorities. Strategies under CA systems are highly site specific. Understanding those sites will be of great importance in studying why these CA technologies are much effective in such situation and not much effective in another situations. In future there is every possibility that area under maize-wheat, maize-maize and maize-chickpea cropping systems is going to increase under resource conservation technologies to address the aberrant climatic conditions like cold injury, terminal heat stress, depleting water table, increasing fossil fuel emission and depleting natural resources so these problem require suitable mitigation measures through proper crop establishment methods, optimum irrigation scheduling and residue management. Keeping this background in view, an experiment has been attempted to study "**Effect of conservation agriculture practices and irrigation scheduling on water use and productivity of maize – wheat cropping system"** with the following objectives:

1. To determine the water use and energy use efficiency of maize-wheat cropping system under different conservation practices and irrigation scheduling.
2. To study growth, productivity and economic feasibility of maize-wheat cropping system under different conservation practices and irrigation scheduling.

3. To study the effect of tillage and residue management practices on physical, chemical and biological properties of the soil.

Chapter 2

REVIEW OF LITERATURE

An attempt has been made in this chapter to review the published literature pertaining to this investigation entitled '**Effect of conservation agriculture practices and irrigation scheduling on water use and productivity of maize – wheat cropping system".**The soil-water-plant environment system should be manipulated suitably for ensuring a good crop-stand and to improve resource-use efficiencies, where tillage system has a significant role. Proper tillage can alleviate the soil related constraints while improper tillage may lead to deterioration of soil structure, accelerated erosion, depletion of organic matter and fertility, and disruption in cycles of water, organic carbon and plant nutrients. The intensive conventional tillage operations alter these properties in every cropping cycle, thereby affecting the whole soil-plant system. To combat the soil loss and preserve soil moisture, soil conservation techniques have been developed in USA known as conservation tillage, which involves soil management practices that minimize the disruption of the structure, composition and natural biodiversity of soil, thereby minimizing erosion and degradation, control annual weed and seed bank and also water contamination (Anonymous, 2001).Zero-tillage minimizes time for establishing a crop. Mondal*et al.* (2013) reported that Residue retention as surface mulch along with omission of tillage may significantly and positively improve soil hydrophysical properties under the present soil and climatic condition in pigeon pea-wheat rotation.

2.1 Effect of tillage on maize and Wheat performance

Bachmann and Friedrich (2002) from Bolivia reported that NT with direct seeding of crop significantly increased the crop yield and there was 17% yield increase across of soybean, maize and wheat crops compared to CT. The results of an experiment conducted on maize shows that among the tillage practices, highest plant height (173.1 cm), grain (9.32 t/ha) and straw yield (11.73 t/ha) were recorded in ZT

practices (Patil*et al*., 2014).Torbent*et al.* (2001) suggested that the corn yield in Texas responded positively to planting a corn row either on beds or a conservational tillage system (zero tillage). Similarly, from a field experiment conducted at Ludhiana (India), Kaur and Mahay (2005a) obtained about 25% higher grain yield with raised bed planting of maize than flat sowing. The higher yield in bed planting with bed was due to increased number of cobs per plant and more grains per cob than flat sowing. Planting of two rows per bed proved inferior to row per bed but gave 9.5% higher yield compared with flat sowing. Jat*et al.* (2006) reported that yields of maize were recorded an average 4 and 16% higher with permanent beds compared with CT and ZT, respectively. Similarly, Singh *et al.* (2007) also reported relatively higher maize grain yield (6.9- 14.6%) as compared to CT. In another long-term study on maize-based conservation agriculture (CA) systems in Malawi (Thierfelder*et al*., 2015) noticed that grain yields of various maize based cropping sequences increase significantly (24–40%) over time under NT + legume residues retention on the surface compared with the traditional ridge and furrow system over CT. Incorporation of legume stover (cowpea, groundnut, dry bean and soybean) compared to stover removal increased the total dry matter yield of maize under maize-mustard cropping system (Svubure*et al.*, 2010). The maize grain (5.18 and 4.29 t/ha) and stover yield (5.73 and 4.72 t/ha) with and without incorporation of grain legume stover was consistently higher than those from the maize after maize or after fallow plots. Soil incorporation of food legumes (groundnut, bambaranut, cowpea, pigeon pea 9 and soybean) produced significant effects on 100-grains weight of maize on sandy soil ecologies of Nigeria (Egbe and Ali, 2010).Raimbault and Vyn (1991) reported that maize yields were not significantly affected by different cropping system but were greater with maize in rotations where legumes incorporated than in continuously grown maize due better physico-chemical condition of the soil under maize- legume cropping system.

Jat*et al.* (2005) reported that maize productivity was marginally higher with no tillage than traditional-tillage (TT) practices at Modipuram, Utter Pradesh.Similarly, Ram*et al.* (2010) found that all the growth parameters (plant height, dry matter accumulation and leaf area index), yield attributes (cobs/plant, grains/cob and 1000-grain weight) and yields performance of maize under different conventional and zero tillage practices were observed statistically similar at PAU, Ludhiana. Pedersen and

Lauer (2004) reported that the yields of wheat, maize and soybean obtained under zero tillage were comparable to conventional tillage provided the seeds were properly controlled. Jat*et al.* (2006) also reported marginally lower yields of maize under ZT than CT practices. The yield reduction in no tillage had been explained by more weed infestation. However, water storage was higher in minimum or no tillage treatments than conventionally tilled plots. Reducing the tillage practices resulted in lower grain yield of maize.

Raised beds have potential to reduce water logging stress in water logging sensitive crops like maize, soybean, cotton, chickpea etc. It can be done through improved surface drainage. Raised beds give the opportunity to diversify to water logging sensitive crops. The bed planting has been found to be an effective agronomic practice and mini part of precision agriculture. Behera and Sharma (2009) reported that maize better performance in bed planting than flat planting under heavy rainfall with water logging situation. Ridge planted maize developed denser and deeper root system, which was responsible for lesser crop lodging on ridges than on flat sown crop. Raised bed planting have yield advantage over properly drained soils because of increased aeration in the rooting zone (Debebe, 1999). Ram (2006) reported the higher values of plant height, dry matter accumulation, LAI, CGR and RGR under permanent bed with residue than no-residue under both ZT and CT practices. Raised bed planting has significantly higher yield of maize crop over flat planting in the study conducted at IARI, New Delhi by (Singh *et al*.,2009a).

Similarly, from a field experiment conducted during monsoon season at Ludhiana (India), Kaur and Mahey (2005a) obtained about 25 per cent higher grain yield with one row per raised bed planting of maize than flat sowing. The higher yield in bed planting with one row per bed was due to increased number of cobs per plant and more grains per cob than flat sowing. Planting of two rows per bed proved inferior to row per bed but gave 9.5 per cent higher yield compared with flat sowing. Jat*et al.*, (2006) also reported that yields of the highest yielding varieties were recorded an average 4 and 16 % higher with permanent beds compared with CT and ZT-flat, respectively.

Indo-Gangetic plains (IGP) accounts for 15% of global wheat production and is inhabited by 900 million people. The north western plain zone of IGP is most

productive wheat belt contributing 70-75% of the annual wheat production in India. Even under assured irrigation and other management supports, a large variability in wheat yield has been observed within this region. The average yield variation ranges from 4.2 t ha-1 in Punjab, 3.9 t ha-1 in Haryana to 2.7 t ha-1 in Uttar Pradesh. During 2001-06, the negative trends in the yield growth rate have been found 1.9 and 0.9% in Punjab and Haryana, respectively (Kumar, 2009). The prevalence of high temperature during reproductive stage has become a major concern and source of yield variations in wheat yield in IGP. Chattaraj*et al*. (2011) found that LAI usually increases with the advancement of crop growth up to vegetative stage and then decrease as crop reached to senescence stage. However, LAI of wheat is greatly influenced by water supply, particularly during the vegetative growth period. They further observed that the highest LAI under limited irrigation was obtained at flowering (80-95 DAS) stage compared to milk stage (90-105 DAS) under adequate irrigation availability. Gupta *et al*. (2010) found that significantly improved wheat productivity in eastern-Gangetic plains can be achieved by advancing the sowing time to first week of November. Similarly, delay in sowing from November 21st to December 20th caused an average reduction of 76.7 kg ha-1day-1 mainly due to terminal heat stress.Ortiz-Monasterio*et al*. (1994) described that high temperature around and after wheat heading had significant effect on yield reduction. The optimum sowing 64 dates produced highest wheat yield and there was drastic yield reduction in different cultivars under delayed sowing. Tripathi*et al*. (2001) reported that there was progressive decrease of wheat yield due to shorter duration and high temperature during grain formation stage due to late sowing beyond December 10th (< 17.6 °C). There was an average yield loss of 1.7% per day, when wheat was sown beyond optimum time (Mohammadi, 2002). Zacharias *et al*. (2010) found that the warmer temperature hasten crop development, shortens the crop growth period and thus finally lowers the grain yield in wheat. The impact of high temperature on crop growth and yield is largely determined by the duration and occurrence of it with sensitive crop growth stage. Coincidence of high temperature stress with panicle initiation to flowering stage of crop affect grain yield by reducing dry matter accumulation, effective tillers, number of spikes, grain weight and increased floret sterility. Yield reduction is predominantly caused by floret sterility led to reduced number of grains per spike and grain weight, when crop is exposed to heat stress during flowering to maturity.High temperature is a major determinant of wheat growth and development and affects crop productivity directly

by affecting physiological process such as photosynthesis, respiration, evapo-transpiration and phenology. By virtue of being a biological system, the crop plants are well equipped to modify their own physiological mechanisms to adapt to the environmental stress conditions, but sometimes at the cost of the ultimate economic yield. The economic yield found to be severely affected due to prolonged heat stress through adverse effect on elasticity mechanism (Ellis, 1990).

In Mexico, planting of wheat on beds and irrigation application in furrows had long been introduced. From a survey work it was concluded that by 1996, 90 % of farmers in Mexico had adopted planting of wheat on raised beds. Sayre and Moreno (1997) reported that higher adoption of bed planting in Mexico was due to application of irrigation, less use of herbicides, insecticides and seed besides ease of mechanical cultivation. It was expected that in bed planting availability of nutrients to crop roots increased at optimum supply of water might be helpful in sustaining crop yield with less seed rate, less fertilizer and less water.

Kaur (2003a) obtained higher grain yield and water use efficiency of wheat under raised bed planting when the crop was planted on dry beds and irrigation was applied immediately after sowing than when it was planted on beds prepared after applying pre-sowing irrigation. The dry sowing on beds following by irrigation helped to achieve higher germination count and tiller density. At Faislabad (Pakistan) Khan *et al*. (1987) reported that planting of wheat on raised beds produced more tillers and these increased with nitrogen application. The average grain yield of wheat was 53.0 q/ha with bed planting as compared to 40.0 q/ha with flat planting.

Similarly Dhillon*et al*. (2000), Dhillon*et al*. (2002) and Singh *et al*. (2002 b) reported that wheat was successfully grown on beds with irrigation application in furrows with higher water use efficiency and savings were recorded in cost of seed and irrigation application time. Yadav*et al*. (2002b) also reported higher number of grains/spike and spike density of wheat planted on raised beds than conventionally sown wheat on flat. The lower tiller and spike density on beds were compensated by more grains/spike and higher grain weight (Sikka*et al*., 2004).However,Singh *et al*. (2001b) recorded less LAI, CGR and RGR in bed planted durum wheat that bidirectional sowing but reported non-significant differences. Three rows per bed gave higher wheat grain yield under raised bed planting that under conventional flat

planting (Hobbs *et al*., 1997; Khatri*et al*., 2001). However, Singh *et al*. (2002b) reported that in timely sown wheat, there was non-significant difference in grain yield between two or three rows per bed. Nonetheless, under late sown conditions (December) three rows per bed resulted in significantly higher wheat yield than two rows per bed.

Experiments conducted in different states of north western India showed that planting of two or three rows of wheat per bed produced grain yield similar to flat sowing. However, wheat sown on raised beds with three rows per bed out yielded than when sown with two rows per bed at Delhi (Aggarwal and Goswami, 2003). Ram *et al.* (2010) reported that grain yield of wheat could not vary significantly among various treatments (different combinations of CT/ZT; flat/bed planting; residue/without residue). However, the effective tillers were less in bed planting treatments but higher grains/ear, and higher test weight compensated the low tiller density.

However, there are some situations where the performance of wheat on beds has been inferior to that on conventional tillage flats due to reduced tillering during vegetative stage due to water deficit stress in sandy loam soil (Sharma *et al*., 2002a). Ram (2006) also reported that more soil temperature under beds than flat planting leads to lower soil moisture and poor growth of the wheat crop.

2.2 Effect of irrigation regime on maize and Wheat performance

Water for agriculture is becoming increasingly scarce and climate change induced higher temperatures will increase water deficits and crop water requirement, so shortages will become more serious in coming decades. The yield reduction due to terminal heat stress will likely to be higher if the compounding impacts of reduced irrigation water availability, declining water tables and increasing cost are considered. Under limited water supply, there is a need to utilize the water judiciously and appropriately enabling minimum yield reduction for a given water deficit level. Irrigation water deficits may lead to economic yield losses while excessive irrigations lead to non beneficial water use.

Dhaka *et al*. (2007) reported that the soil moisture extraction decreased with the soil depth under all treatments. This could be attributed partly because of more

evaporation from exposed soil surface and partly because of more proliferation of roots in the top soil layer. More moisture extraction from deeper layers under stress conditions may be due to greater penetration of roots in search of water under dried surface layers. The roots tend to grow deeper in search of water under stress but it tends to proliferate in surface layers under adequate soil moisture.

Plant response to varying degrees of moisture regime has been a subject of considerable study and review (Kajdi, 1993; Khehr*et al*., 1996). Yet the question of how irrigation regime interacts with other cultural practices such as sowing dates remains one of the important issues for future wheat production. Increased evaporative demand due to temperature rise will have bearing on wheat water requirement in future. In general, soil water content negatively related to temperature. Increase in temperature by 1 -4 °C during growing season of winter wheat led to, increased water requirement by 11.8-153.0 mm (Liu and Lin, 2004). Global warming generally reduces crop yield because of accelerated plant development, reduced grain fill duration and dryness (Mikhail, 2009). Abrupt rise in temperature at the grain filling stage coincided with dry westerly winds that enhance drying processes leading to forced maturity and shrivelled grain. The beneficial effects of early sowing could be realised with proper irrigation. Hence, improved irrigation management can play significant role in light soils, where crops were susceptible to adverse impact of temperature. Modifying crop micro-climate through crop cultivation practices such as frequent irrigation may help in reducing the adverse effect on wheat grain yield in hot environments (Gupta *et al*., 2010; Jin *et al*., 2014).

Performance of the crop depends up on availability of water, especially at various growth stages. It is generally understood that loss in plant growth due to moisture stress in the early stage cannot be recovered by later irrigations. For better wheat yield, different approaches were used to schedule irrigation in various locations. In north western plain zones, 4 irrigations are recommended for wheat crop at different growth stages, which is generally come out to be lower than actual ET of crop. Under limited water supply conditions, four irrigations produce optimum grain yields. There is established fact that crown root initiation (CRI stage *i.e.* 20-25 DAS) is the most sensitive stage in wheat as it results in maximum production per unit of water applied or otherwise (Abo-Shetaia and Abd-El-Gawad,

1995). Increase in level of irrigation in sandy loam soil resulted in significant increase in LAI, dry matter production, CGR, NAR grain yield and harvest index (H.I.) of wheat at different places of Indo-Gangetic plains (Pal *et al*., 1996a; Patil*et al*., 1996).

Luo*et al.* (2009) found that neither changes in N application nor wheat cultivar alone or their synergistic effects could offset the negative impact of climate change in Australia. They suggested that early sowing could be effective adaptation strategy with proper irrigation in future conditions. Irrigation at grain filling stage helped in reducing the adverse effect of terminal heat in wheat and avoided consequent yield penalty of more than 200 kg ha-1 in comparison to last irrigation didn't coincide with grain filling stage of wheat in Haryana (Gupta *et al*., 2010). Chen *et al*. (2014) investigated the responses of wheat production under six irrigation treatments (from rain-fed up to five irrigations) in China. They found that weather conditions and irrigation significantly affected evapo-transpiration (ET), soil water depletion and field drainage. Average yield increase were 1594, 343, 117, 83 and 26 kg ha-1 by adding one more irrigation from rain-fed up to 4 times, respectively. The benefit of increase irrigation numbers was significantly reduced after four irrigations.

Badel*et al.* (2013) conducted experiment in semi-arid region of Ethopia with aim to evaluate the effect of soil moisture levels at different growth stages on growth, ET and biomass yield of bread wheat. Irrigation treatments include three soil moisture depletion (SMD) levels (50, 60 and 75%) and 4 growth stages (vegetative, heading, flowering and grain filling, irrigated at 50% SMD). Irrigation at 50% depletion of ASM produced highest plant height, dry matter, biomass and WUE for biomass. Increasing moisture depletion levels decreased the dry matter, biomass yield and WUE.

Soil moisture extracted by wheat roots decreased with increase in soil depth. Proportionately more moisture was found to be extracted from deeper layers under limited irrigations while adequate irrigation favoured more extraction from upper layer (Mishra *et al*., 1995).

Water use or consumptive use by crop plants is the key factor in crop production and precise information is very essential for proper irrigation provision for optimum yields. The soil, crop and climatic characteristics influence the daily and

seasonal evapo-transpiration loss or consumptive use. by influencing soil-plant-atmosphere continuum in a particular agro-climatic condition. From the irrigation perspective, concept of water use efficiency (WUE) differs from water productivity (WP). Generally, WUE used for gross water applied and WP for actual water consumed (ET). According to this explanation, WP could be a better term than WUE in wheat production. The term WP is represented by the need to maximize the production per unit of available water in times of increasing food requirements and limited available water resources. Higher irrigation availability invariably increases the consumptive water use (CU) but decrease WUE of wheat. Supply of measured irrigation water based on soil moisture deficit approach only up to the crop effective root zone depth increased the grain yield (Gajri*et al*., 1997).

Chaudhary*et al.*(1980)reported that increased irrigation frequency has resulted in increased grain yield of wheat. Wheat crop is sensitive to timing of application of irrigation water rather than total amount of applied water. Stress during vegetative growth has reduced Leaf Area Index thereby decreased the number of reproductive tillers in addition to their contribution to grain yield.Sharma *et al*. (2013) fond that under rainfed condition in maize-wheat sequence, maize field should be ploughed immediately after maize harvesting and covered with maize straw mulch @ 5 t/ha up to wheat sowing to reduce the evaporation losses and soil water storage for the succeeding wheat crop. This practice leads to increase soil moisture conservation efficiency about 3 times higher than control treatments (maize harvesting at 30 cm height and tillage at the time of wheat showing). It has been estimated that an additional 23 kg/ha wheat grain yield can be achieve per mm of conserved moisture. Wang *et al*. (2015) in semi- arid region of China reported that straw incorporation significantly increased water productivity of maize.

Timsina*et al*. (2008)evaluate that options for increasing the yield and water productivity in Punjab. Results reveal that crop water productivity ranges from 1.0 g/kg, for two irrigation at grain filling and flowering, to 1.2 g/kg with three irrigations (at CRI, booting and flowering) to 1.6g/kg with two irrigations at CRI and booting. Zhang and Oweis (2000) reported that water productivity was about 0.96 kg of wheat grain per m3 of water under dry farming conditions and 1.36 kg of wheat grain per m3 under supplemental irrigation. Under rain-fed conditions, supplemental irrigation during the wheat critical growth stage can improve grain yield and water productivity,

even with small amount of water. This may be due to an increase in biomass and nutrient uptake by the plant. Taydon*et al*. (2009) found maximum grain yield and water productivity when supplemental irrigation is applied at jointing stage. Li *et al.*(2008) indicated that irrigation at the jointing and heading or jointing, heading, and milking stages could help increase the PAR capture ratio in the winter wheat growing season. Field experiments were conducted to study the effects of deficit irrigation with saline water on spring wheat yield and growth in arid region of North West China by Jiang *et al.* (2013) during the year of 2008 and 2009. In the first year highest yield was obtained with the highest amount of irrigation (375mm), but in 2009 wheat yield and 1000 grain weight were found to be highest in irrigation with 300mm. The results demonstrated that irrigation with 300mm rainfall with salinity less than 3.2 dS/m is suitable for wheat yields. A field experiment was conducted by

2.3 Effect of Residue Management on maize and Wheat performance

Crop residues are materials left after harvest of a previous crop or when a cover crop is grown and left out to provide mulch. Since it is bulky in nature, its application in field may restricted or limited but availability in huge amount and less cost promote its application. The bulky nature of crop residue may restrict its use to higher-value crops like vegetables. It gives positive effect on control of soil and water erosion. Crop residues and management practices gives positive effect on soil quality, soil nitrogen dynamics and recovery and crop yield (Kumar *et al.*, 2000). Cover crops combined with no till helps in accumulation of organic matter in the surface soil horizon (Madari*et al.*, 2005; Riley *et al.*, 2005). Mulch helps in nutrient recycling in legume cover crops. Cover crops promote biological soil tillage through their rooting. Surface mulch provides food, nutrients and energy for living below ground like micro-organisms, earthworms, arthropods which also till soils biologically. Combination of Cover crops and biological agents (earthworms, etc.) relieve soil compaction under zero-tillage systems. Effects of burning, incorporation and removal of crop residues on soil properties is well established. Unger *et al*. (1988) studied effect of surface residues on water conservation. Result shows the surface residues enhanced water infiltration. Result also shows the positive role of surface residues on soil water conservation and reduction in wind and water erosion. Ram (2006) observed the higher values of plant height, dry matter accumulation, LAI, CGR and RGR of maize under permanent bed with residue than no-residue under both Zero

Tillage and Conservation Tillage practices. Jat*et al.*, (2010) also observed the higher values of yield attributes of maize under residue applications with higher doses of N fertilizers. Ram *et al.* (2010) observed higher yields of wheat under Zero Tillage with residue due to the cumulative effects of higher light interception more dry matter production, low soil and canopy temperature, more soil moisture, tillers, grains/ear and 1000-grain weight than no-residue application under ZT practices, as well as CT practices. Borresen (1999) reported from Norway that chopped show residue on the soil surface increased the grain yield of spring barley, oats and wheat by 2.90 q/ha compared with means of other straw management treatments. Increased yield of spring crops might be due to reduction in evaporation since of a cover by straw mulch.

Limon *et al*. (2000a) reported statistically as per grain yield (36.5 q/ha) of maize in permanent bed system with wheat straw as stable compared to conventional tilled beds plus straw incorporated (32.0 q/ha), permanent beds with straw partially removed (34.7 q/ha) and permanent bed with straw burnt treatment.Talukder*et al*. (2004) from Bangladesh reported that straw retention (50 % or 100 %) or permanent beds produced higher crop yields than straw removal. The retention of 50 % straw significantly increased the grain yield of Maize by 32 % over straw removal. Similar effect was observed in rice and wheat. They suggested that straw retention on permanent bed planting could act as restorative management and would have positive impact on soil health. Based on 12 years experimentation, Govaerts*et al*. (2005) reported that permanent bed planting along with rotation and residue retention had the advantages in yield potential of wheat and maize. Thus residue management under permanent bed planting and zero tillage improved the productivity of crops.

2.4 Soil parameters

Ram *et al.* (2010) reported higher BD values under continuous ZT practices than CT practice, but lower values of soil BD under residue applied treatments than without residue ZT practices in maize – wheat cropping system from Punjab, India. Jat*et al.* (2005) also reported lower BD values under raised beds than flat system due to looseness and lower soil compaction.

Hu *et al.* (2007) in their four years study at Luancheng, reported that NT significantly increased the topsoil (0-5cm) BD, while RT chiseling under NT decrease

the BD. In a long-term experiment at a fixed site in Heinlongjiang province, five different tillage systems were compared for their effects on the BD. The treatment of RT had a lower BD than other treatments (Yu and Zhang, 2007). Czyz and Dexter (2008) found that reduced tillage increases bulk density, especially in the 2-8 and 13-18 cm depth layers in comparison with traditional tillage.

Williams and Weil (2004) reported that hydraulic conductivity was higher on beds than flat system of planting. Residue as mulch on soil surface increase the hydraulic conductivity due to it add the organic matter in the soil which improve the soil macro aggregates that might facilitate easy movement of water in the soil.Verhulst*et al.* (2011) reported that most of the physical soil parameters measured in different maize based sequences was significantly affected while only BD was not affected by tillage-legume residue system. Chen *et al*. (2014) reported that among the different tillage practices RT significantly lowered soil BD in the furrow, at least 0.15 g/cm3 lower than that in NT and CT, thus increasing the initial soil infiltration rate by 30% which is an indicator of higher*Ksat*.Almaraz*et al*. (2009) reported that the NT system had, in most of the cases, slightly more moisture levels than CT but significant differences were not detected. Neugschwandtner*et al*. (2014) reported that SOC, total nitrogen, PMN (potentially mineralizable nitrogen), P and K increased in the uppermost soil layer with reduced tillage intensity. The SOC, total nitrogen, P and K were more evenly distributed in DP (deep ploughing) whereas a generally higher decline downwards the soil profile was observed with lower tillage intensity resulted in a decrease of P and K in 30-40 cm. Gholami*et al*. (2014) reported that NT has 0.12, 12.04 and 360.29 mg/kg of higher nitrogen, phosphorus and potassium respectively compare to CT.

Glubiak and Korzeniowskation (2014) found that ZT did not cause changes in the concentration of macro elements in maize grain in relation to CT which proved that ZT performed better under resource limited condition.In contrast in an another study De Vita *et al*. (2007) reported differences in the concentration of N in wheat grain between ZT and CT where higher content was found in former practice in maize-wheat cropping systems. Chalka and Nepalia (2006) reported during both the years of investigation maize-soybean recorded maximum nitrogen uptake which was statistically superior over rest of the systems. Although all cropping systems were statistically superior over sole maize but they were at par with each other. On mean

basis maize -soybean, maize-cowpea, maize-greengram and maize blackgramregistered 37.5, 22.1, 18.5 and 17.1% increase in nitrogen uptake,respectively over sole maize. P and K uptake were also follow the same trend and their higher uptake were observed under various maize-legume cropping system compared to maize-maize cropping system.Dong *et al.* (2009) reported that the mean annual MBC was highest in the no-tillage with residue, while lowest in conventional tillage.Limon *et al*. (2006) reported from Mexico, that the practice of retaining crop residue as stubble mulch in permanent bed system and straw incorporation in conventional sowing method increased the productivity and soil quality by increasing the soil microbial carbon in maize-wheat cropping sequence.

2. 5 Energy relations

Ram *et al.* (2010) found minimum input energy and energy output/input ratio (13.82) in PB/PB (PB:permanent bed) treatment while energy output (3,92,035 MJ/ha/year) was highest in NT+S/NT (NT: no-till; S: straw) in maize – wheat cropping system.

Pratibha *et al.* (2015) found that the energy input was higher in CT as compared to RT and ZT, however, no difference was observed in different anchored residue height. CT had highest GHG emissions as compared to RT and ZT in both the crops. Furthermore, the contribution of fossil fuel to total energy input and CO2 emissions is the highest. Hence, reduction in tillage operation reduced the energy input and CO2 emission they reported that yields in CT are higher under rainfed conditions but these yields were on par with RT. However, the yield gap between the tillage treatments is narrowing down over years. Hence, it may take time for the ZT to out yield CT and RT. But from the environmental point there is energy saving, higher EUE and lower GHG emissions from ZT followed by RT.

Karunakaran and Behera (2013) reported that the maximum input energy in wheat was recorded with soybean residue involving treatments while the minimum was recorded with no residue and wheat residue. During both the years the maximum energy input was recorded with flat system of crop establishment techniques in soybean-wheat cropping system whereas, the bed system of crop establishment techniques registered less energy input to the system. In the soybean-wheat system

considerably higher energy input was required with wheat + soybean residue treatment. Parihar*et al*. (2012) and Jat*et al*. (2014) reported that among the various maize based cropping system maize-wheat-mungbean result into maximum system productivity over maize-mustard-mungbean and maize-maize-sesbania because this system include legume which not only contributed in yield but also provide better soil 27 health which in turn improve system productivity. At the same time the carbon based sustainability index (CSI) and carbon efficiency (CE) was observed maximum in in maize-maize-sesbania cropping system compared to maize-wheat-mungbean and maize-mustard-mungbean system. This happen due to inclusion of two maize crops in a year resulted into higher CSI and CE which reflect the ability of maize crop to more carbon sequestration than any other crop. Parihar*et al*. (2011a) reported that maize-chickpe-asesbania cropping sequence resulted in maximum energy output, energy productivity and net energy in various maize based cropping system.

2.6 Economics

Wheat could be grown successfully under zero tillage on beds and flats and thus allowing considerable saving in the cost of cultivation ₹412 through zero tillage as compared to conventional planting ₹1238 and with rotavator and conventional tillage ₹1373 in one hectare (Dhillon*et al*., 2002).

Jat*et al.* (2014) found that though during the initial 2–3 years, the benefits of CA based rice production system are not visible but subsequently it is more productive and profitable than CT based system. In case of wheat, yield and economical benefit of CA based production systems were apparent right from beginning. They found that CA based systems became economically profitable than CT based RW production systems. CA based RW system appears to be an important strategy to bridge the management yield gaps and to increase benefits over time in smallholder systems of Eastern IGP; and the potential benefits of CA based management practices in long-term can only be realized with systems' approach.

Parihar*et al*. (2011) reported that highest maize yield were noticed in PB planting compare to ZT and CT similar trend were also observed in wheat when it is sown followed by maize in maize-wheat mungbean cropping system which in turn resulted into highest net return as well as B:C ratio. Khatri*et al*. (2014) from Nepal reported that tillage and residue had no significant effect on B: C ratio (Table 10).

However, higher B:C ratio was obtained from ZT (2.42) as compared to CT (2.20) which indicates that ZT is more profitable . The higher B C ratio from ZT was due to the lower cost of production and higher gross return. Paudel*et al*. (2015) reported that higher net returns obtained in ZT than CT and at the same time intercropping of maize and soybean in 2:2 ratio recorded maximum benefit and maize grain yield equivalent as well as land equivalent ratio than sole and intercropping treatments. Erenstein and Laxmi (2008) reviewed a several studies of the economics of zero tillage in the Indo-Gangetic Plains. They found that due to site specificity and methodological differences the profitability of the various studies is sometimes complicated. Nevertheless, the results consistently showed benefits-both cost savings and increased yields. On average, slightly more than half of the benefits were due to cost savings and slightly less than half were due to yield increases

Chapter 3

MATERIALS AND METHODS

The field experiments were conducted at The Research Farm of Water Technology Center at the ICAR-Indian Agricultural Research Institute, New Delhi during *kharif* and the following *rabi* seasons of 2011-12 and 2012-13 to study the effect of **"Effect of conservation agriculture practices and irrigation scheduling on water use and productivity of maize–wheat cropping system"** This chapter deals in brief the experimental details of materials used, the observations taken and techniques employed during the course of investigation.

3.1 General details

3.1.1 Experimental site, soil and location

The experiments were conducted at The Research Farm of Water Technology Centre, ICAR-Indian Agricultural Research Institute, New Delhi, situated at 28°35'N latitude and 77°12'E longitude and at an altitude of 228.6 meters above mean sea level. Soil samples were taken before the start of the experiment and were analysed for physical, chemical and biological properties of the soil using standard procedures (Table 3.1). The soil at the site was sandy loam in texture (Table 3.2) of alluvial origin with adequate internal drainage and was poor in organic matter, low in nitrogen and medium in both available phosphorus and potassium (Table 3.3).

Table 3.1: Methodology used for soil analysis

Parameters	Methodology/ Instruments	References
Soil texture	Hydrometer	Bouyoucos, 1927
pH	pH meter (1:2, soil: water)	Jackson, 1973
Electrical conductivity	Conductivity bridge	Jackson, 1973
Bulk density	Gravimetric (core)	Jackson, 1973
Hydraulic conductivity	Constant head permeameter	Jackson, 1973
Field capacity	Pressure plate apparatus (1/3 bar)	Richards and Weaver, 1964
Permanent wilting point	Pressure plate apparatus (15 bar)	Richards and Weaver, 1964
Aggregate size analysis	Wet sieving	Yoder, 1936
Organic carbon	Wet digestion and titration	Walkley and Black, 1934
Nitrogen	KEL PLUS semi auto analyzer	KEL PLUS
Phosphorus	Olsen's method and Colorimeter	Olsen *et al*. 1954

Parameters	Methodology/ Instruments	References
Potassium	Flame Photometer	Hanway and Heidal, 1952

Table 3.2: Physical properties of experimental field soil

Depth, (cm)	Mineral content (%)			Textural class	Hydraulic conductivity (cm h^{-1})	Bulk density (g cm^{-3})	FC (% v/v)	PWP (% v/v)
	Clay	Silt	Sand					
0-15	16	12	72	Sandy loam	1.29	1.57	20.91	6.25
15-30	21	10	69	Sandy clay loam	1.32	1.60	26.86	6.22
30-45	24	20	56	Sandy clay loam	0.83	1.56	26.33	9.86
45-60	22	26	52	Sandy clay loam	1.15	1.59	28.33	9.94

Table 3.3: Chemical properties of experimental field soil

Depth (cm)	pH	EC (dSm^{-1})	Organic carbon (%)	Available		
				N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
0-15	7.11	0.30	0.48	76.31	22.86	160.35
15-30	7.44	0.20	0.43	71.85	15.02	100.99
30-45	7.22	0.25	0.41	68.32	10.04	85.68

3.1.2 Climate and weather

New Delhi has a semi-arid and sub-tropical climate with hot dry summers and severe cold winters. The mean maximum temperature in June, which is the hottest month of the year, ranges from 40° to 45°C, while the mean minimum temperature in the coldest month of January is as low as 1.9°C. Sand storms and ground frost are commonly associated with summer and winter seasons, respectively. The mean annual rainfall is about 650 mm, of which nearly 80 per cent is received during the monsoon period from July to September and the rest during the period between October and May. The mean daily U.S. Weather Bureau Class 'A' open pan evaporation value reaches as high as 10.9 mm in the month of June and as low as 1.5 mm in the month of January. The annual pan evaporation is about

850 mm. The mean wind velocity varies from 3.5 km/hr during October to 7.6 km/hr during April. The mean relative humidity attains the maximum value (85 to 90% or even more) during the south-west monsoon season and the minimum (30 to 45%) during the summer months. The daily meteorological data for the cropping season were recorded at meteorological observatory of the ICAR-Indian Agricultural Research Institute, New Delhi situated nearby experimental filed are presented in Fig 3.1. The weekly averages of the same data are presented in Appendices I and II.

3.1.3 Cropping history of the experimental field

The cropping patterns followed at the experimental field during the preceding years of this investigation are given as below:

Year	**Crop Season**	
	Kharif	***Rabi***
2007-08	Maize	Wheat
2008-09	Maize	Wheat
2009-10	Maize	Wheat

3.2 Experimental details

The experiment was conducted in split plot design with three replications on a fixed site during 2011-12 and 2012-13.

Treatments details:

A. Main plot for Maize and wheat: Crop establishment practices (03)

1. Conventional tillage (CT)
2. Zero-tillage (ZT)
3. Raised bed (RB)

B. Sub-plot Irrigation scheduling – 3 (for maize)

1. I_1 (40% Available Soil Moisture Depletion by tensiometer)
2. I_2 (50% Available Soil Moisture Depletion by tensiometer)
3. I_3 (60% Available Soil Moisture Depletion by tensiometer)

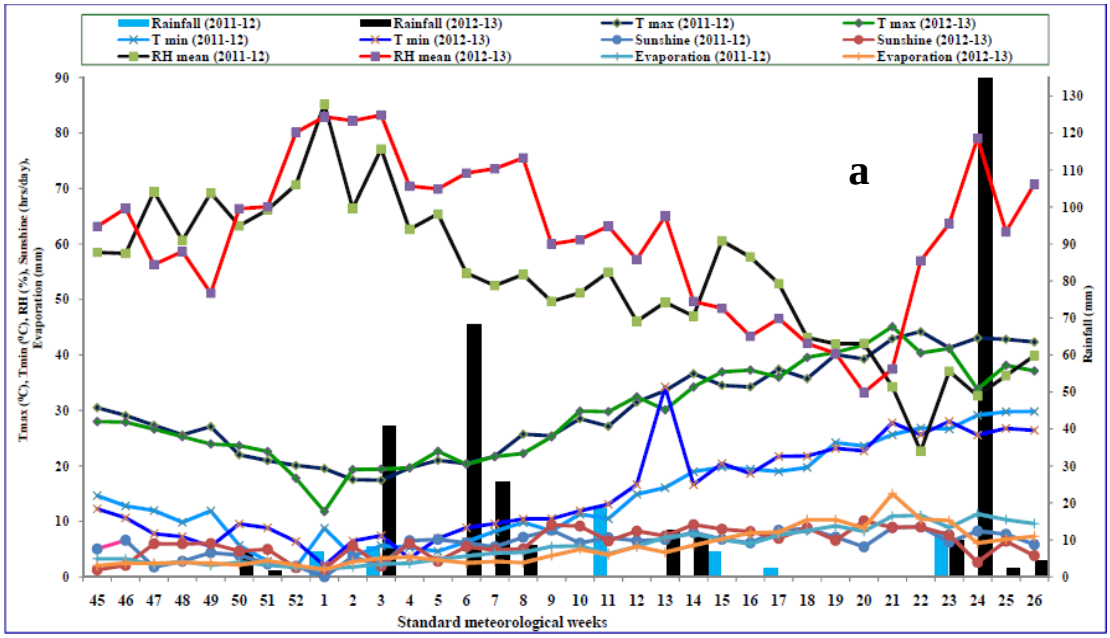
Sub-plot: (Irrigation scheduling) – 3(for wheat)

1. I_1 (based on 5 critical growth stages of irrigation)
2. I_2 (at 60% Available Soil Moisture Depletion by tensiometer)

3. I_3 (calculation of crop wáter stress index by infrared thermometer)

C. Sub-Sub-plot: residue management – 2(for wheat)

1. **With residue**
2. **Without residue**



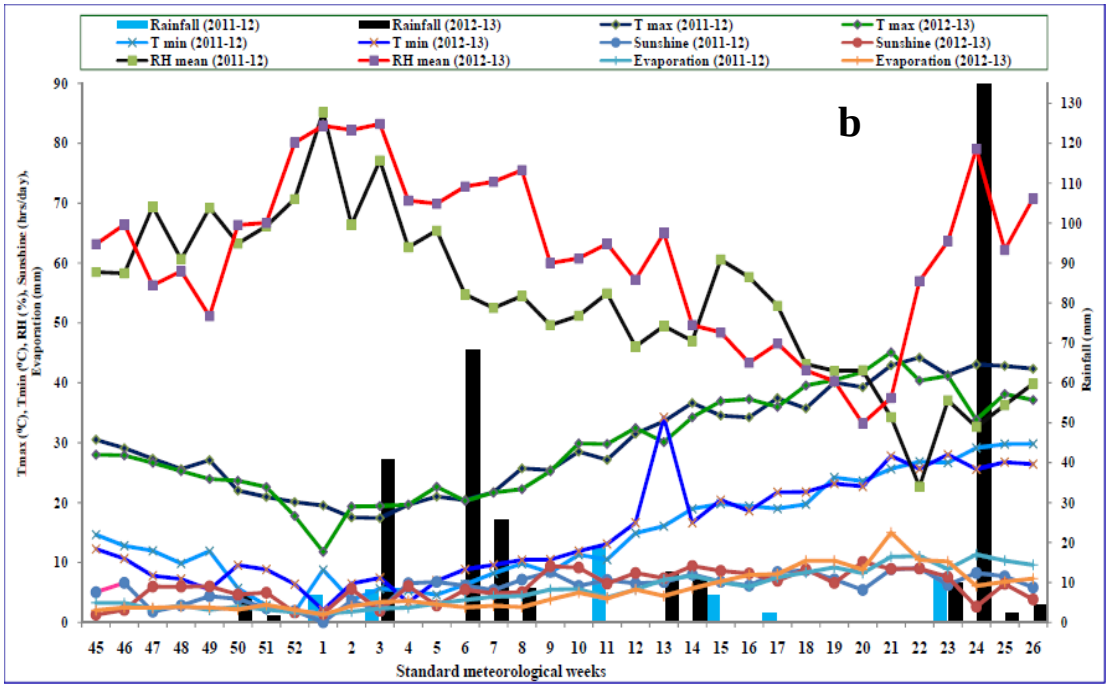


Fig. 3.1: Mean weekly weather parameters during cropping season of 2011-12 (a) and 2012-13 (b)

Total treatments

For maize:

Total number of treatment combinations : 9

Replication : 3

Total number of plots : 27

Experimental design : Split-split plot

Plot size : 18m X 4.6 m = 82.8 m^2

For wheat:

Total number of treatment combinations : 18

Replication : 3

Total number of "plots : 54

Experimental design : Split-split plot

Plot size : 8.5m X 4.6 m = 39.1 m^2

Design : Split-split plot

Spacing between rows (both the experiments)

Maize : 67.5 cm

Wheat : 18.0 cm

3.3 Description of materials used

3.3.1 Crop cultivars

Maize cv HQPM1: This hybrid has been developed by HKI 193-1 crossing with HKI 163). It was released during 2007 by C.C.S.H.A.U., Hisar for maize growing areas J&K, Uttarakhand, NE, HP, Assam, Rajasthan and M.P.. It produces tall slender plant with long, dark green and narrow leaves on stem. It have character like late maturity, yellow, responsive to fertilizers, tolerance to frost/cold, resistance to MLB and common rust and have a potential yield 8 t/ha. The crop matures in 95 to 100 days duration.

Wheat cv DBW17: Average plant height ranges 90-95 cm. Yield can be up to 4.5-5.0 t ha^{-1} under optimum conditions. It can be harvested at 130-135 days after sowing. Optimum sowing time is 3rd week of November to 1st week of December.

3.3.2 Crop residues

The chopped residues of the wheat and maize crops of previous season were applied at 2.5 t/ha to maize and wheat crop, respectively after sowing of crops as surface mulch.

3.4 Field operations

The cultural operations carried out in the maize and wheat during experimentation have been given in **Table 3.4**.

3.4.1 Pre-sowing operations to maize and wheat

Herbicide application

Tank mix solution of paraquat (Gramoxone 24%) and glyphosate (Round up 41%) was applied in the zero tillage treatment plots to control grassy as well as broad leaf weeds before sowing of the crops.

Land preparation

The CT consisted of two pass of a disc harrow, followed by two pass of cultivator with planking in the last pass. Raised beds (fresh bed) were made with a bed planter which made beds at distance of 67.5 cm from bed to bed with a bed height of 8”. The ZT consisted minimum soil disturbance, which accompanied by just opening the furrow, putting the seeds into furrow and covering the seeds in one operation. The permanent beds were reshaped during sowing of succeeding crops with bed planter in both years. The fresh and permanent raised beds were of 67.5 cm width having 37.5 cm top and 30 cm furrow, which was used for irrigation purposes.

3.4.2 Maize

Fertilizer application

Irrespective of the treatment a uniform dose of 150 kg N/ha, 60 kg P_2O_5/ha and 40 kg K_2O/ha in the form of urea, single super phosphate (SSP) and murate of potash (MOP), respectively were applied as basal dose. As per the schedule half of the nitrogen as urea was applied as basal dose, and remaining N was top dressed in two equal splits at knee height and silking stage. In conventional tillage treatments basal dose of fertilizers were broadcasted in the field before the last ploughing, while in zero tillage treatments fertilizers were drilled at sowing of crop.

Table 3.4: The details of field operation carried out during experimentation.

Field operation	**2011-12**	**2012-13**
Maize(*kharif*)		
Pre-sowing irrigation		26.06.2012
Residue incorporation by ploughing(conventional tillage)	28.06.2011	01.07.2012
Glyphosate application(zero tillage)	28.06.2011	02.07.2012
Harrowing and planking(conventional tillage)	01.07.2011	05.07.2012
Bed planter and bed making(conventional and zero tillage)	04.07.2011	09.07.2012
Fertiliser application and sowing	05.07.2011	10.07.2012
Application of pendimethalin and atrazinre	07.07.2011	12.07.2012
Residue application in zero tillage plots	08.07.2011	13.07.2012
Thinning and gap filling	20.7.2014	26.07.2012
Sampling for plant height, DMA and LA(30DAS)	06.08.2011	10.08.2012
Weeding and intra culturing(conventional tillage)	07.08.2011	11.08.2012
Top dressing of urea(50%N)	11.08.2011	15.08.2012
Sampling for plant height, DMA and LA(60 DAS)	05.09.2011	9.09.2012
Sampling for plant height, DMA and LA(90DAS)	06.10.2011	10.10.2012
Harvesting	24.10.2011	29.10.2012
Shelling	18.11.2011	23.11.2012
Irrigation	01.09.2011	10.09.2012
Irrigation	27.09.2011	30.09.2012
Wheat (*rabi*)		
Pre-sowing irrigation	24.10.2011	27.10.2012
Residue incorporation by ploughing (conventional tillage)	1.11.2011	05.11.2012
Glyphosate application (zero tillage)	03.11.2011	07.11.2012
Harrowing and planking	04.11.2011	08.11.2012
Bed planter and bund making (conventional and zero tillage)	05.11.2011	09.11.2012
Fertiliser application and sowing	06.11.2011	10.11.2012
Residues application in zero tillage plots	09.11.2011	13.11.2012
Sampling for plant height, DMA and LA(30 DAS)	07.12.2011	11.12.2012
Application of post emergence herbicide	08.12.2011	12.12.2012
Irrigation	28, 30 Nov. 2011	2,4 Dec. 2012
1st top dressing of urea (25%)	10.12.2011	15.12.2012
Inter- culturing	19.12.2011	25.12.2010
Sampling for plant height , DMA and LA(60DAS)	06.01.2013	10.01.2013
Irrigation	19, 23 Dec.2012	24, 28 Dec.2010
2nd top dressing of urea	11.01.2012	16.01.2013
Irrigation	10,12,15 Jan. 2012	14,16,23 Jan. 2014
Sampling for plant height, DMA and LA (90DAS)	06.02.2012	09.02.2013
Irrigation	1,4 Feb. 2012	5, 9 Feb. 2013
Irrigation	26 .02.2012	02.03. 2013
Sampling for plant height, DMA and LA(120DAS)	06.03.2012	10.03.2013
Harvesting	03.04.2012	08.04.2013
Threshing	14.04.2012	18.04.2013

Seed sowing

The maize variety HQPM1 was dibbled at a spacing of 70 cm X 20 cm in conventional tillage flat and zero tillage flat treatments. While one row of maize crop was established on top of the raised beds by keeping plant spacing of 20 cm and irrigation was given in 30 cm furrow. The seed rate of maize was 20 kg /ha.

Gap filling

The gap filling was accomplished immediately after the germination in order to maintain optimum uniform plant population.

Weeding and inter-cultivation

In conventional tillage treatments weed were controlled by manual weeding twice at 3 and 5 weeks after sowing. It was done by hoeing the soil which besides checking weed growth provides good aeration to plant roots. In zero tillage treatments, Atrazine (Atrataf 50 WP) as pre-emergence at 1.0 kg *a.i.*/ha in 500 liters of water was applied after 2 days of sowing for controlling the weed.

Irrigation

Irrigations were given according to the predetermined irrigation schedule treatments.

Harvesting and shelling

The crop was harvested when cob sheath turns brownish and grains become hard. Net plot was considered by leaving two border rows on one side and one on the other side of the plot. The cobs were harvested by plucking method and grains were separated from cob by hand shelling.

3.4.3 Wheat

Fertilizer application

Irrespective of the treatment a uniform dose of 150kg N/ha,60 kg P_2O_5/ha and 40 kg K_2O/ha in the form of single super phosphate (SSP) and murate of potash (MOP), respectively. Half of the nitrogen and full dose of P and K were applied as

basal and remaining half of N was applied at first irrigation at 21 days coinciding with crown root initiation (CRI) and other at maximum tillering stages. In conventional tillage treatments basal dose of fertilizers were broadcasted in the field before the last ploughing, while in zero tillage treatments fertilizers were drilled at sowing of wheat.

Seed treatment

Seed treatment was done with chlorpyriphose (20 EC at 90 ml/100 kg seed + 5 liter water) before sowing of crop.

Seed sowing

The wheat (DBW17) crop was sown at a spacing of 18 cm X 5 cm in conventional tillage flat and zero tillage flat treatments by multi-crop planter. While bed-planter was used for sowing on the raised bed. The seed rate @ 100 Kg/hq was common for both flat bed & raised bed sowing.

Gap filling

The gap filling was accomplished in wheat immediately after the germination in order to maintain optimum uniform plant population.

Weeding and inter-cultivation

In conventional tillage treatments weeds were controlled by manual weeding twice at 3 and 6 weeks after sowing. It was followed by shallow hoeing to provide aeration, facilitate root growth and make soil receptive to moisture and nutrients. In zero tillage treatments the weeds were managed by the application of herbicides. Tank mix solution of isoproturon (75 WP at 1 kg *a.i.*/ha) and 2,4-D sodium salt (80 WP at 0.5 kg *a.i.*/ha) was applied in the zero tillage treatment plots to control grassy as well as broad leaf weeds after 35 days of sowing of crop.

Irrigation

A measured amount of water was delivered to the crop by star flow meter as per the treatments.

Plant protection measures

Tank mix solution of chlorpyriphose (20 EC) and endosulfan (Thiodone @ 0.03%) was sprayed before sowing of the crop in order to control termite infestation. chlorpyriphose was also applied once in the standing crop with irrigation water.

Harvesting and threshing

At maturity plants from border rows were harvested and material was removed from the field, thereafter, net plots were harvested separately in first week of April during first year and last week of March and produce was left in the field for some days to get dried. Threshing was done by using ALMACO Pullman thresher.

3.5 Biometric observations

Five plants in each plot from 2nd and 3rd row were randomly selected and marked for recording plant height, tillers per hill, dry matter accumulation and leaf area index at 30, 60, days after sowing (DAS) and at harvest. In wheat, 0.25 m^2 areas was selected after leaving the first row of the each plot for the measurement of dry matter accumulation and leaf area index.

3.5.1 Maize

Plant height

It was measured from the base of the plant (first nodal mark) to the tip of tassel at 30, 60 DAS and at harvest. The height of five plants was measured in centimeters (cm) and average values are reported.

Dry matter accumulation

Plants used for leaf area measurement were chopped into piece and sun dried. The sample then oven dried at 65^oC for 24 hours and dry matter accumulation per plant was worked out at different crop growth stages. The sampled plants were dried in hot air oven at 65^oC for 48 hours. Dry weight was expressed in g $plant^{-1}$.

Days to 50% silking

The date on which 50% plants in net plots produced silks was recorded and used for calculating days taken to silking stage.

Number of cobs /ha

The total number of cobs obtained from plants present in net plot area was counted and calculated for one hectare area.

Cob length

Five cobs were randomly selected from each plot during harvest and their length from base to tip of the cob was measured and the mean value was recorded in cm.

Cob girth

The girth of five cobs was measured at the middle portion of the cob and the mean value was recorded in cm.

Number of grains/ row

The total numbers of grains in a row were counted from the same cobs previously selected for recording the number of grain rows and averaged out.

Cobs weight/ha

The total cobs obtained from plants present in net plot area was weighted and calculated for one hectare area.

1000-grain weight

From the representative samples of each plot yield, the weight of 200 grains was recorded and the 1000-grain weight was calculated by multiplying 200-grain weight with 5 and expressed in gram.

Grain yield

After separating from stalk and peeling of husk and silk, all the cobs from each plot were dried in the sun and threshed by a hand thresher. The grain yield was adjusted to 14% moisture content and expressed as t/ha.

Stover yield

The maize stalks were cut from ground level from the net plot and weighed after sun drying. Final yield was expressed in t/ha.

Harvest index

Harvest index was computed by dividing the grain yield by the total biological yield and was expressed as percentage.

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

3.5.2 Wheat

Plant height

Five plants from sampling rows were randomly selected and tagged for all the periodic height observations and height was measured from the ground level to the tip of flag leaf at 30, 60 and 90 days after sowing and up to tip of ear at harvest.

Dry matter accumulation

In flat sown wheat, 0.25 m^2 areas was selected after leaving the first row from either side of the plot and the same area was selected from second bed of plot from the bed sown plots for the measurement of dry matter accumulation. The samples were sun dried first and then in an oven at 65°C till the constant weight arrived. The dry weight was expressed as g/m^2.

Leaf area index (LAI)

The crop leaves were stripped off from their base from the collected samples for dry matter accumulation. LAI was expressed as the ratio of leaf area to the land area occupied by the plant.

$$\text{LAI} = \frac{\text{Total leaf area (cm}^2\text{)}}{\text{Total ground area (cm}^2\text{)}}$$

Crop growth rate (g day^{-1} m^{-2}):

The average daily increment in plant growth is an important characteristic. It may be calculated as per rate of dry matter production (Blackman, 1968) or as crop growth rate (Watson 1952) or as productivity. The crop growth rate was calculated as an increase in dry matter production per unit ground area per unit time. In this investigation the crop growth rate was worked out with the help of following formula; as proposed by Watson (1952):

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

where,

P is ground area ($1m^2$);

CGR is Crop growth rate and

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

Relative growth rate ($g\ g^{-1} day^{-1}$):

It is an index of the amount of growing material per unit dry weight of plant per time. The RGR at any stage is ratio of the increase in biomass on per unit of biomass previously present. It is also called efficiency index. The mean relative growth rate over a time interval from t_1 and t_2 was calculated with the help of following algebraic expressions as proposed by Fisher, 1921.

$$RGR = \frac{Log_e\ W_2 - Log_e\ W_1}{t_2 - t_1}$$

where,

RGR is Relative growth rate;

W_1 and W_2 are the dry weight (g) at time t_1 and t_2, respectively and

Log_e is natural Log.

Effective tillers/m^2

Effective tillers (ear bearing tillers) were counted from 0.25 m^2 area randomly from four spots in the net plot, averaged and expressed as number of effective tillers per square meter area.

Number of grains/spike

Ten ear heads from sampled plants were randomly selected, threshed and numbers of grains were counted. The average was worked out to obtain the number of grains per ear.

1000-grain weight

A representative sample of grains was taken from each plot after drying and cleaning and weight of 1000-grains recorded.

Grain yield

Total biomass of each net plot harvested was weighed and threshed after drying. The grains were cleaned and sun dried for 3 to 4 days and weight was recorded. Final yield was expressed in q /ha.

Straw yield

The weight of straw was computed by subtracting the weight of grain from total dry matter yield of each net plot. Final straw yield was expressed in q /ha.

3.5.3 Productivity

Productivity of maize–wheat cropping system was calculated in terms of maize equivalent (ME) by using following expression:

$$\text{ME of wheat} = \frac{\text{Wheat yield x Wheat price}}{\text{Maize price}}$$

Total productivity = Maize yield + ME of wheat

3.6 Plant chemical analysis

3.6.1 Nitrogen content

N content (%) in grain and straw was determined by modified Kjeldahl method (Jackson, 1973).

3.6.2 Phosphorus content

Phosphorus content in grain and straw was determined by Vanadomolybdophosphoric acid yellow colour method.

3.6.3 Potassium content

Potassium content in grain and straw was determined by Flame photometer method.

3.7 Soil properties

3.7.1 Physical properties

Soil physical properties were analyzed at the end of the two cropping cycle as follows:

Bulk density

The core sampler was used to collect the soil from the center of the given depth (e.g. 0-15 and 15-30 cm). Core with soil samples were dried in oven at 105^0C for 48 hrs. Bulk density (g cm^{-3}) was calculated by dividing weight of dried soil by using the formula (Veihmeyer and Hendrickson, 1948):

$$BD = \frac{(X-Y)}{V}$$

Where, *BD* is the bulk density in g cm^{-3}, *X* is the weight of core with oven dry soil (g), *Y* is the weight of empty core (g) and *V* is the volume of core (cm^3).

Hydraulic conductivity

The hydraulic conductivity was determined using constant head method (Mishra and Ahamed, 1987) and it was calculated using the formula:

$$K = AB / CDE$$

Where

K = Hydraulic conductivity (cm/hr)

A = Quantity of water collected (cc)

B = Flow length/length of sample (cm)

C = Loss in head (cm)

D = Cross sectional area of sample (cm^2)

E = Time interval (minute)

Infiltration rate

Infiltration rate was measured using double ring infiltrometer (Bouwer, 1986). Soil moisture (0-15 cm) before and after infiltration measurement was determined for the interpretation of infiltration data.

Soil moisture studies

Soil Moisture

Soil moisture at 15 cm (0-15 cm) and 30 cm (15-30 cm) depths was estimated by gravimetric method. In gravimetric method, soil sample collected by

screw-auger in aluminum cans were weighed and kept in hot air oven and allowed to dry at 105°C for at least 24 hrs. Dried sample was weighed and the moisture content on mass basis was calculated using the following formula:

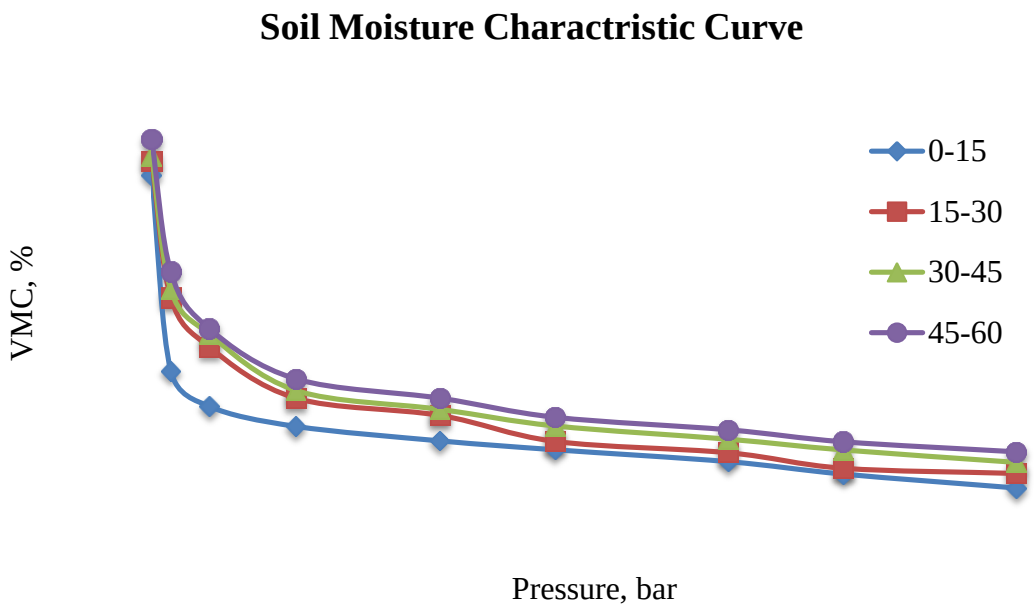
$$SM(\%) = \frac{(M_w - M_d)}{M_d} * 100$$

Where, *SM* is soil moisture in percent, *Mw* is soil sample weight of before drying *Md* is the sample weight after drying. From the soil moisture content and available meteorological data, used for computation of consumptive use of water, rate of water use, water use efficiency and moisture extraction pattern were done.

Soil Moisture Constants

Soil moisture at field capacity and permanent wilting point were determined by pressure plate apparatus (Soil Moisture Equipment Corporation, USA) for each soil horizon of 0-15, 15-30, 30-60, 60-90 and 90-120 cm depths. The pressure chamber containing ceramic plates of 1/3 and 15 bars were used for determining field capacity and permanent wilting point, respectively. The pressure plates were saturated for overnight and undisturbed soil samples were placed on plate in separate rubber rings. Then water was added to saturate the sample and kept for 24 h for complete saturation. Saturated plates containing soil samples were placed in pressure chambers and desired pressures were applied. For attaining equilibrium it was kept for 48 h at the specified pressure. Then, samples were taken out from the chambers after they reached to equilibrium and the weight of each soil samples was recorded. Following oven-drying at 105-110°C till constant weight, the moisture content retained by each sample at the specified potential was determined from the moist and dry soil weights. Respective bulk density value was multiplied to get volumetric moisture content (θ).Total available water in each horizon was determined by taking the difference between field capacity and permanent wilting point for that horizon. Average value for field capacity (FC) and permanent wilting point (PWP) for each depth from three samples is listed in the table.

Soil moisture retentions at various levels of suctions were estimated using Pressure Plate Apparatus to draw the soil moisture characteristic curve. These curves for various layers of soils are presented in Fig. 3.2.



Soil aggregation stability

Aggregate stability was measured using wet sieving techniques (Haynes, 1993). The mean weight diameter (MWD) of aggregates were determined using the procedure given by (Kemper and Roseneau, 1986) MWD = ∑ Xi. Wi where, Wi, is the proportion of aggregates returned and the sieves in relation to the whole, Xi is the mean diameter of the class (mm).

3.7.2 Soil Chemical properties

Organic carbon

The soil samples (0-15 cm depth) were collected in small polythene bags from each plot of the experimental field before the initiation and at the end of experimentation period. The air dried samples were used to determine organic carbon content in soil (Walkley and Black, 1934).

Available N, P and K

The available N was estimated by alkaline $KMnO_4$ method (Subbiah and Asija, 1956) and available P content in soil was estimated by Olsen's method (Olsen *et al*., 1954). Whereas available K was determined using neutral normal ammonium acetate extraction method and flame photometry as described by Jackson (1973) and expressed in kg/ha. A balance sheet of N, P and K used of the crop sequence was

prepared by comparing the net change in nutrient status of soil after maize-wheat system.

3.7.3 Soil Biological properties

Microbial Biomass Carbon (MBC)

Microbial biomass carbon in soil samples was estimated by the method described by Nunan *et al*. (1998).

Reagent

1. Chloroform
2. 0.5M K_2SO_4: Prepared by adding 87.135 g of K_2SO_4 in one litre distilled water.

$$\text{MBC } (\mu g/g \text{ of soil}) = \frac{(\text{O.D. of fumigated soil} - \text{O.D. of non-fumigated soil}) \times 100}{\text{Amount of soil used}}$$

Basal soil respiration rate

Basal soil respiration was determined by 100 g of soil from each sample into wide- neck screw- top glass jars (1000ml) together with 10 mL 0.1N NaOH in 20 mL glass vials. The soil was remoistened to 70 % of field capacity in order to offset the drying effect of the alkali. The glass jars were screwed down with the original cap and sealed tightly. Blank incubations, in which the jar contained NaOH but no soil, were incubated in the observation. All samples were incubated for 10 days (2 days interval) at 25°C, and the CO_2 evolved and trapped during the period was determined by titration of the NaOH with 0.1 N HCl. But before titration the reaction between atmospheric CO_2 amd NaOH solution was stopped by adding 2-3 drops of saturated $BaCl_2$ and then adding indicator, phenophthalin. End point was known by changing the red/pinkish solution of the vials into whitish colour.

3.8 Crop water requirement and irrigation

The estimation of water requirement of a crop is one of the basic need for crop planning on the farm. Total water used from the field preparation to harvesting of the crop was considered in computing water requirement. Water requirement is calculated

by sum of irrigation requirement, effective rainfall and soil profile contribution. Effective Rainfall was calculated with the help of USDA Soil Conservation Service formula in CROPWAT 8. The Evapotranspiration (ETo) were also calculated with the help of CROPWAT 8. The amount of irrigation water applied to each plot was measured using a starflow meter. The quantity of water applied and the duration of irrigation were computed using the following equations:

Irrigation water-use efficiency

Irrigation water-use efficiency (kg/ha-cm) was calculated as the grain yield (kg) divided by the irrigation water applied (ha-cm) (Ibragimov *et al*., 2011).

$$\text{Irrigation water-use efficiency} = \frac{\text{Grain (kg/ha)}}{\text{Irrigation water applied (ha-cm)}}$$

Field water-use efficiency (kg grain/m^3 water used)

Field water-use efficiency (FWUE) was calculated by the following formula and expressed as kg/m^3 water.

$$\text{FWUE} = \frac{\text{Economic yield of rice (kg)}}{\text{Water requirement (m}^3\text{)}}$$

3.9.1 Soil Moisture Depletion (SMD)

It is the amount of water required to raise the soil-water content of the crop root zone to field capacity. The SMD was determined by estimating soil moisture content. For this purpose soil samples were taken from the effective root-zone (0 – 90 cm) of the wheat plant. Soil moisture contents were then calculated as under:

$$\text{Soil moisture content (\%)} = \frac{\text{(Fresh weight- dry weight)}}{\text{Dry weight}} \text{ X } 100$$

The following irrigations were applied according to the specified treatments. The amount of water applied to each treatment was calculated on the basis of the soil moisture contents at the time of irrigation by using the following expression.

$d = M.C. \times B.D. \times D$

Where,

d = depth of water to be applied

M.C. = moisture content (%)

B.D. = bulk density of the soil

D = depth of root-zone to be irrigated

3.9.2 Critical Growth Stage

The critical stage defines the stage of growth when the plants are most sensitive to shortage of water. In wheat CRI, late tillering, jointing, flowering and dough stage are most critical stage in relation to irrigation application.

3.9.3 CWSI Calculation

The calculation of CWSI based on two baselines: the non-water-stressed baseline, which represents a fully saturated crop, and the maximum stressed baseline, which corresponds to a non-transpiring crop. There are two non-water stressed baselines for determining the CWSI. One is according to Idso definition (Idso *et al*., 1981), according to which it is empirical relationship between the canopy–air temperature differences (Tc − Ta) and the air vapor pressure deficit (VPD) for a well watered crop. Another definition of CWSI is that of Jackson *et al*. (1981, 1988), which is the theoretical explanation for the empirical relationship between Tc − Ta and VPD based on the one-layer canopy energy balance model. The CWSI was computed following the method of Idso *et al*. (1981) as follows:

$$CWSI = \frac{dT - dT_{min}}{dT_{max} - dT_{min}}$$

Where dT, dT_{max} and dT_{min} are actual, maximum, and minimum canopy-air temperature differences, respectively. The value of dT_{max} was empirically set as 4^0C for winter wheat based on the observations for canopy-air temperature difference in the current research although previously reported research generally used 2^0C (Idso *et al*., 1981; Howell *et al*., 1986; Alderfasi and Nielsen, 2001). The air temperature

and RH measurements were used to calculate the VPD of the air as follows as described by Allen *et al*. 1998:

$$e_s=0.6108X \exp(17.27T/(T+237.3)$$

$$e_a=e_s X (RH/100)$$

$$VPD= e_{s-} e_a$$

Where, e_s is the saturation vapor pressure (kPa), T, the mean air temperature (^oC), RH, the relative humidity of the air (%), and, VPD, the vapor pressure deficit (kPa). For the calculation of the non-water-stressed baseline, for this we used Idso formula

$$D2 = A + B \text{ VPD}$$

Where VPD is the air vapor pressure deficit (Pa), *A* (intercept) and *B* (slope) are the linear regression coefficients of the lower limit canopy and air temperature difference on VPD. Infrared thermometers were used to measure canopy temperature. The IRT was used with the canopy viewed at an angle of 35–45° from the horizontal.

3.10 Energy-use efficiencies

3.10.1 Estimation of energy requirement

The energy inputs referred to the both renewable and non-renewable energy. Total physical, output referred to both grain and by-product yield. The energy output from the economic and by-product yield was also estimated. For estimation of energy inputs and outputs (expressed in MJ/ha) for each items of inputs and agronomic practices equivalents (Annexure III) were computed as suggested by Mittal and Dhawan (1988), Baishaya and Sharma (1990), Panesar and Bhatnagar (1994) and Singh et al. (1997). Energy-use efficiency was calculated using the following formula as suggested by Mittal and Dhawan (1998).

$$\text{Energy-use efficiency} = \frac{\text{Energy Output (MJ/ha)}}{\text{Energy input (MJ/ha)}}$$

Net energy (MJ/ha) = Energy output (MJ/ha) – Energy input (MJ/ha)

$$\text{Energy productivity} = \frac{\text{Grain output (kg ha}^{-1})}{}$$

Energy input (MJ ha^{-1})

3.11 Economic analysis

The economic analysis in terms of gross and net returns and benefit: cost ratio (returns per rupee invested) was worked out on the basis of existing rate of inputs and output (Annexure-IV). Total variable cost included in the cost of input such as seeds, fertilizers, irrigation and various cultural operations such as ploughing, sowing, weeding, harvesting, threshing etc. The rental value of land was also considered in the cost of cultivation. Returns were calculated by using the following formula expression:

Gross returns = Value of the grain/seed + Value of straw/stover

Net returns = Gross returns – Total variable costs

Benefit cost ratio (BC ratio) = Net returns/Total variable cost

3.12 Statistical analysis

The data recorded for different parameters were analysed with the help of analysis of various (ANOVA) technique for a split-plot design using MSTAT-C software. Source of variation and corresponding degrees of freedom used in the ANOVA for deciphering main and interaction effects. The results presented at 5% level of significance (P=0.05). Pooled mean of the two years data were given wherever felt necessary.

Chapter 4

RESULTS

The results of the field experiment entitled **"Effect of conservation agriculture practices and irrigation scheduling on water use and productivity of maize – wheat cropping system**"conducted during *kharif* and *rabi* seasons of 2011-12 and 2012 -13 at the research farm of Indian Agricultural Research Institute, New Delhi are being presented in this chapter. The observations pertaining to growth parameters, yield attributes, yield, nutrient content and uptake, resource use efficiency, economics and soil fertility status of wheat and maize recorded in experimentation were statistically analyzed and significance of results verified.

Performance of Maize

Growth attribute

Data pertaining to growth parameters *viz.*, plant height, leaf area index and dry matter accumulation as influenced by crop establishment techniquesand irrigation regimes are presented in this section.

Plant height (cm)

Plant height is an indicator of crop growthwhich can be easily deciphered by observing at different growth stages of maize. Data on plant height recorded at various growth stages (30, 60 and at maturity) of maize as influenced by crop establishment techniquesand irrigation regimes have been presented in (Table 4.1). Plant height of the maize was better during 2012 in comparison to 2011due to favorable weather conditions during the season. In general, maize grown on raised beds performed better than zero tillage and conventional tillage. However, no significant variation in plant height at allstages except 30 DAS in 2011was observed among the different crop establishment techniques. With regards to different irrigation scheduling at 30 DAS and 90 DAS there was no significant difference in plant height of maize. However, at 60 DAS significantly highest plant height was recorded with 40% ASMD (available soil moisture depletion) over all other irrigation schedules.

Dry matter accumulation (g/plant)

The dry matter accumulation (DMA) at various growth stages of maize was significantly influenced by crop establishment techniques and irrigation scheduling during both the years (Table 1.2 and Fig. 4.1).Maize recorded significantly maximum DMA/plant at 90 DAS during both the years. In general, crop grown on beds performed better than other crop establishment techniques in both the years. With regards to different irrigation scheduling it was found that there was significant difference at all the stages of crop growths. The significantly highest dry matter accumulation was recorded under 40% ASMD compared to other irrigation scheduling.

Table 4.1: Effect of crop establishment methods and irrigation regimes on plant height

Treatment	Plant height (cm)					
	30 DAS		60 DAS		90 DAS	
	2011	2012	2011	2012	2011	2012
Crop establishment method						
RB	51.66	52.41	153.64	152.40	166.24	168.18
ZT	49.46	51.00	152.81	159.63	164.69	166.86
CT	48.27	49.51	152.16	154.84	161.16	163.73
SEm±	0.63	1.06	1.22	0.85	1.62	2.16
CD (P = 0.05)	2.47	NS	NS	NS	NS	NS
Irrigation scheduling						
40%ASMD	50.82	51.31	156.40	158.39	166.84	169.17
50%ASMD	49.44	51.23	152.37	156.78	163.07	165.67
60%ASMD	49.12	50.38	149.85	151.71	162.18	163.93
SEm±	1.00	1.36	1.10	1.15	2.54	3.37
CD (P = 0.05)	NS	NS	3.39	3.53	NS	NS

RB - Raised bed, CT- Conventional tillage, ZT - Zero tillage, ASMD- Available soil moisture depletion

Table4.2: Effect of crop establishment methods and irrigation regimes on Dry matter accumulation of maize

Treatment	Dry matter accumulation (g/plant)					
	30 DAS		60 DAS		90 DAS	
	2011	2012	2011	2012	2011	2012
Crop establishment method						
RB	36.24	36.72	78.4	80.4	270.71	274.57
ZB	33.71	35.74	76.1	75.6	265.98	267.42
CT	31.97	32.90	72.5	73.0	259.47	260.89
SEm±	2.31	2.97	1.07	1.30	2.04	1.91
CD (P = 0.05)	NS	NS	4.20	5.12	8.02	7.51
Irrigation scheduling						
40%ASMD	35.78	36.58	79.7	81.7	267.92	270.81

50%ASMD	34.95	37.21	75.7	75.4	266.49	268.47
60%ASMD	31.19	31.58	71.7	71.9	261.74	263.61
SEm±	0.90	1.20	1.49	1.60	1.33	1.78
CD (P = 0.05)	2.78	3.70	4.59	4.92	4.09	5.49

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

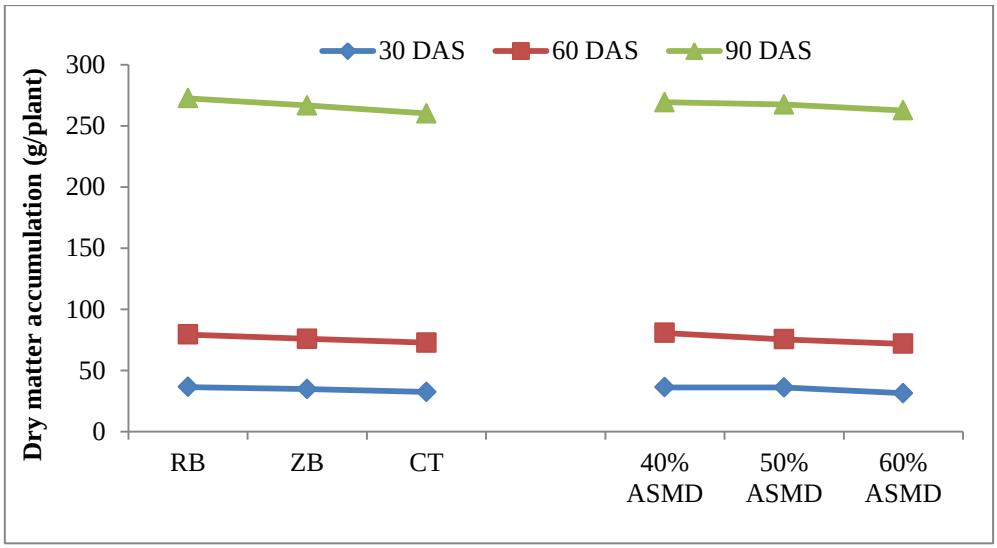


Fig. 4.1:Effect of crop establishment methods and irrigation regimes on Dry matter accumulation of maize (mean of two years)

Leaf area index (LAI)

The LAI increased up to60 DAS and thereafter there was reduction in LAI of maize (Table 4.3 and Fig. 4.2).The leaf area index at various stages of crop growth was significantly influenced by crop establishment techniquesand irrigation scheduling. Similar to dry matter accumulation, significantly highest leaf area index was also recorded under raised bed followed by zero tillage and lowest in CT during both the years of study.Among different irrigation scheduling, significantly highest leaf area index was recorded at 40% ASMD at all the stages except at 30 DAS during both the years of experimentation.

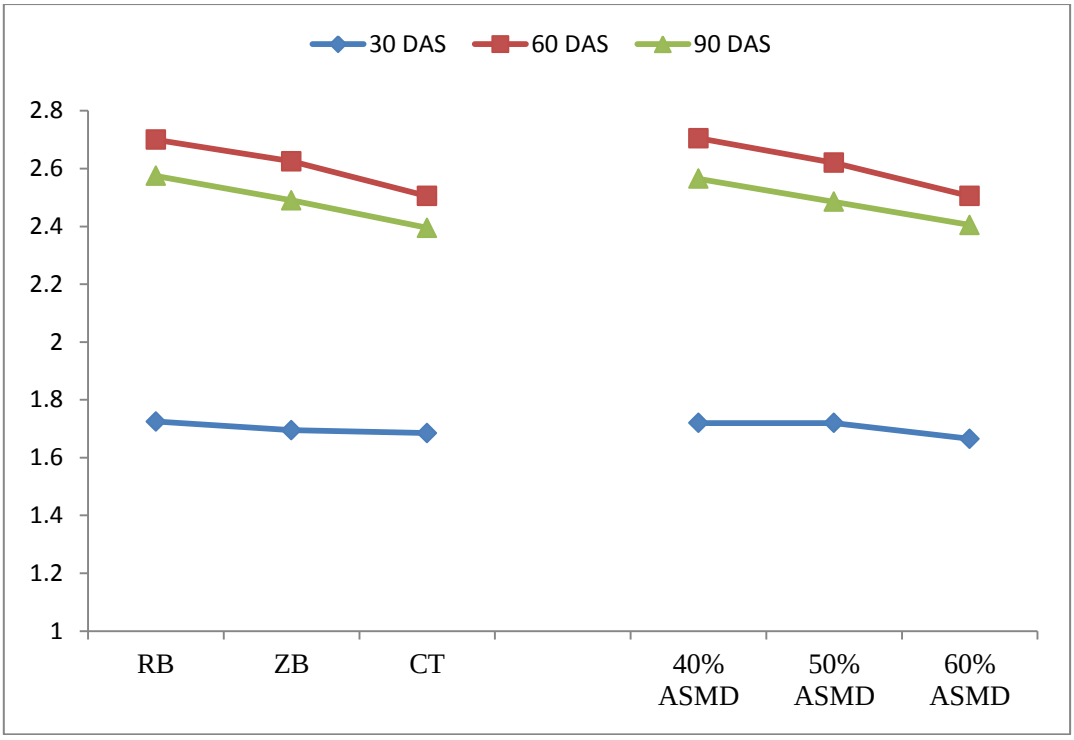


Fig. 4.2:Effect of crop establishment methods and irrigation regimes on leaf area index of maize (mean of two years)

Table 4.3: Effect of crop establishment methods and irrigation regimes on leaf area index and days to 50 % silking of maize

Treatments	LAI						Days to 50%Silking	
	30 DAS		60 DAS		90 DAS			
	2011	2012	2011	2012	2011	2012	2011	2012
Crop establishment method								
RB	1.72	1.73	2.68	2.72	2.55	2.60	53.1	54.6
ZB	1.69	1.70	2.61	2.64	2.48	2.50	52.9	55.1
CT	1.68	1.69	2.50	2.51	2.35	2.44	52.4	54.3
SEm±	0.01	0.01	0.03	0.04	0.03	0.02	0.20	0.23
CD (P = 0.05)	NS	NS	0.12	0.16	0.13	0.09	NS	0.92
Irrigation scheduling								
40%ASMD	1.71	1.73	2.69	2.72	2.54	2.59	52.7	54.5
50%ASMD	1.71	1.73	2.59	2.65	2.47	2.50	52.0	53.8
60%ASMD	1.67	1.66	2.50	2.51	2.37	2.44	53.8	55.6
SEm±	0.01	0.02	0.03	0.03	0.03	0.03	0.44	0.46
CD (P = 0.05)	NS	NS	0.09	0.08	0.11	0.11	1.35	1.43

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

Growth indices in maize

The maize crop has taken more days for silking by ZT and 60%ASMD (Table 4.3). The crop growth rate (CGR) and relative growth rate (RGR) were not influenced significantly by crop establishment techniques at all three intervals during both the years (Table 4.4 and 4.5).

Table 4.4: Effect of crop establishment methodand irrigation scheduling onCGR(g/m^2/day) of maize

Treatments	0-30 DAS		30-60 DAS		60-90 DAS	
	2011	2012	2011	2012	2011	2012
Crop establishment method						
RB	8.63	8.74	10.05	10.39	45.8	46.23
ZT	8.02	8.51	10.10	9.50	45.2	45.66
CT	7.61	7.83	9.64	9.55	44.5	44.73
SEm±	0.55	0.71	0.77	0.89	0.56	0.43
CD (0.05)	NS	NS	NS	NS	NS	1.68
Irrigation scheduling						
40%ASMD	8.52	8.71	10.45	10.75	44.8	45.01
50%ASMD	8.32	8.86	9.70	9.09	45.4	45.97
60%ASMD	7.43	7.52	9.65	9.61	45.2	45.63
SEm±	0.21	0.29	0.33	0.45	0.49	0.51
CD (0.05)	0.66	0.88	NS	NS	NS	NS

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

However, CGR was significantly higher under different tillage practices during 2012. CGR recorded gradual increase with enhancement of growth stages with maximum values at 60-90 DAS while the RGR recorded a reverse trend in comparison to CGR.The growth indices were not significantly influenced due to various irrigation schedules during both the years, except CGR at 0-30 DAS intervals on the other hand, RGR was influenced significantly due to different irrigation schedules at 60-90 DAS.

Table 4.5: Effect of crop establishment methodand irrigation schedulingon RGR(mg/g/day) of maize

Treatments	30-60DAS		60-90 DAS	
	2011	2012	2011	2012
Crop establishment method				
RB	26.2	27.1	41.4	41.1
ZT	27.2	25.1	41.7	42.1
CT	27.7	27.1	42.6	42.5
SEm±	2.88	3.34	0.60	0.51
CD (P = 0.05)	NS	NS	NS	NS
Irrigation scheduling				
40%ASMD	26.9	27.3	40.5	40.0
50%ASMD	26.0	23.8	42.0	42.4
60%ASMD	28.3	28.1	43.3	43.3
SEm±	1.06	1.37	0.72	0.68
CD (P = 0.05)	3.27	4.22	2.21	2.10

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

Yield attributes in maize

Yield attributes *viz.*,cobs/plant, grains/cob, grain rows/cob, and test weight at harvest were influenced by crop establishment techniquesand irrigation regimes and the datahave been presented in (Table 4.6).The grain rows/cob and grains/row were significantly influenced due to crop establishment techniques. However, cob length, cob/plant and cob girth were statistically similar in both the years in all crop establishment methods.

Table 4.6:Effect of crop establishment methods and irrigation regimes on yield attributes of maize

Treatments	Cob/plant		Cob length (cm)		Cob girth (cm)		Grain rows/cob		Grains/row		Shelling (%)		Test weight(g)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Crop establishment method														
RB	1.07	1.11	17.67	17.86	13.93	13.97	13.41	13.46	31.07	31.39	74.00	75.1	258.6	259.9
ZT	1.04	1.11	17.34	17.50	13.75	13.77	13.12	13.08	30.21	30.46	71.44	72.5	254.4	254.2
CT	0.99	1.03	16.79	16.63	13.39	13.52	12.68	12.74	29.63	29.82	69.33	70.4	250.9	251.9
SEm±	0.02	0.03	0.35	0.39	0.24	0.30	0.11	0.27	0.29	0.29	1.18	0.86	1.6	1.4
CD (P = 0.05)	NS	0.08	1.39	1.21	NS	NS	0.42	1.07	NS	1.12	4.62	3.39	6.5	5.4
Irrigation scheduling														
40%ASMD	1.03	1.14	17.60	17.68	13.78	13.93	13.25	13.30	30.62	31.00	72.67	73.9	259.0	259.1
50%ASMD	1.06	1.10	17.44	17.76	13.77	13.74	13.24	13.45	30.21	30.39	71.67	72.8	253.7	254.7
60%ASMD	1.01	1.01	16.76	16.56	13.53	13.58	12.71	12.51	30.08	30.26	70.44	71.4	251.2	252.2
SEm±	0.02	0.02	0.20	0.25	0.14	0.14	0.31	0.35	0.47	0.50	1.45	1.60	2.4	2.9
CD (P = 0.05)	NS	0.07	0.63	0.77	NS	NS	NS	1.07	NS	NS	NS	NS	7.5	8.9

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

The maximum values of yield attributing traits were recorded under raised bed (RB)while minimum under conventional tillage (CT). The yield attributes like cob length, grains/row were also significantly influenced due to different irrigation regimes during both the years and the value of yield attributes were significantly higher under 40% ASMD as compare to 50 and 60% ASMD.

Yield

Data pertaining to grain, stover and biological yields as affected by crop establishment techniquesand irrigation regimeshave been presented in Table 4.7. In both the years' grain, stover and biological yields were significantly higher underRB than other crop establishment methods. The grain yield was significantly higher under RB planting to the tune of 13.3% over CTduring both the years (Fig. 4.3).

The grain and biological yields were also influenced significantly due to different irrigation scheduling during both the years. Significantly lowest grain, stover and biological yields were obtained under 60% ASMD as compare to other irrigation schedules.The interaction effects between crop establishment techniques, and irrigation scheduling on yield of maize were found non-significant in both the years.There wasnon-significant difference was found in the harvest index (HI) of maize under different crop establishment practices and irrigation regimes in both the years.

Table 4.7: Productivity of maize influenced by different crop establishment methods and irrigation regimes

Treatments	Grain yield(t/ha)		Stoveryield (t/ha)		Biological yield (t/ha)		Harvest index (%)	
	2011	2012	2011	2012	2011	2012	2011	2012
Crop establishment method								
RB	4.41	4.53	8.36	8.54	12.77	13.07	34.58	35.22
ZT	3.95	4.00	7.89	7.99	11.84	11.99	33.27	32.90
CT	3.82	3.92	7.44	7.58	11.27	11.50	33.90	33.62
SEm±	0.10	0.12	0.17	0.18	0.20	0.26	0.01	0.79
CD (P = 0.05)	0.41	0.46	0.66	0.71	0.79	1.03	NS	NS
Irrigation scheduling								
40%ASMD	4.38	4.60	8.13	8.26	12.51	12.86	34.92	34.53
50%ASMD	3.98	4.01	7.98	8.12	11.96	12.14	33.28	33.91
60%ASMD	3.83	3.83	7.58	7.72	11.41	11.56	33.56	33.30
SEm±	0.16	0.13	0.15	0.20	0.19	0.20	1.31	1.23
CD (P = 0.05)	0.48	0.41	NS	NS	0.60	0.60	NS	NS

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

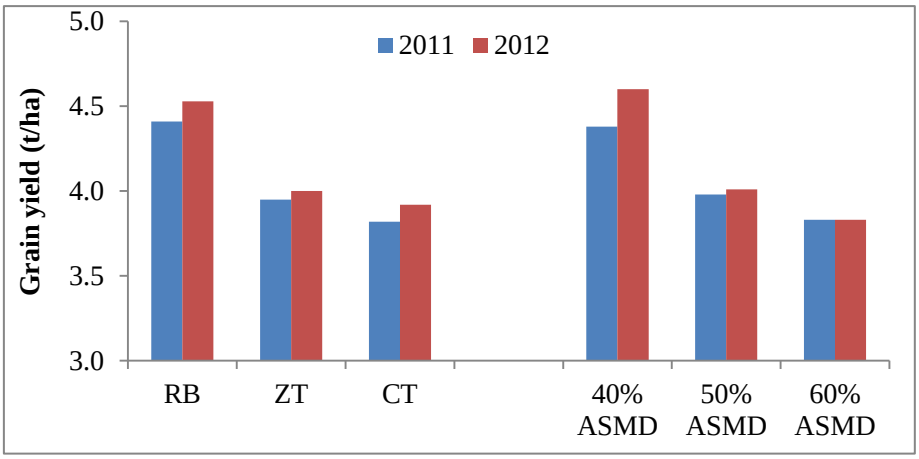


Fig. 4.3:Productivity of maize influenced by different crop establishment methods and irrigation regimes

Nutrient content and uptake

Nitrogen

Nitrogen content and uptake by grain and straw of maize were influenced significantly due to crop establishment techniquesand irrigation regimes(Table 4.8). Nitrogen content and uptake in grain and straw were significantly higher with RB over CT practices but it was on par with ZT. Amongst irrigation regimes significantly higher nitrogen uptake by grain and straw were obtained under 40% ASMD as compared to 60% ASMD it remained at par with 50% ASMD.Bed planting system of crop establishment significantly improved the nutrient uptake in grain as well as instover over conventional tillage.

Table 4.8: Effect of crop establishment methods and irrigation regimes on nitrogen uptake of maize

Treatments	Nitrogen content (%)				Nitrogen uptake (kg/ha)				Total uptake(kg/ha)	
	Grain		Straw		Grain		Straw			
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Crop establishment method										
RB	1.34	1.36	0.39	0.40	59.34	61.46	32.21	33.92	91.55	95.38
ZT	1.29	1.30	0.37	0.38	51.18	52.15	29.21	30.05	80.39	82.20
CT	1.28	1.29	0.35	0.36	49.02	50.56	26.26	27.20	75.28	77.76
SEm±	0.01	0.01	0.01	0.01	1.34	1.40	0.63	0.78	1.20	1.72
CD (P = 0.05)	0.04	0.04	0.03	0.03	5.27	5.50	2.46	3.06	4.73	6.77
Irrigation scheduling										
40%ASMD	1.33	1.35	0.38	0.40	58.35	62.11	30.90	32.87	89.24	94.98
50%ASMD	1.30	1.30	0.37	0.38	51.67	52.40	29.87	30.64	81.53	83.04
60%ASMD	1.29	1.29	0.35	0.36	49.53	49.66	26.92	27.66	76.45	77.32
SEm±	0.02	0.02	0.01	0.01	2.01	1.86	0.64	0.82	2.28	1.87
CD (P= 0.05)	NS	NS	NS	0.02	6.20	5.74	1.97	2.53	7.01	5.77

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

Phosphorus

The data pertaining to Phosphorus content and uptake in straw as well total uptake was significantly influenced by crop establishment techniquesand irrigation regimes(Table 4.9).However,non-significant response was observed on phosphorus content in grain during both the year of study.

Table 4.9: Effectof crop establishment methods and irrigation regimes on phosphorus uptake of maize

Treatments	Phosphorus content (%)				Phosphorus uptake(kg/ha)				Total P uptake(kg/ha)	
	Grain		Straw		Grain		Straw			
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Crop establishment method										
RB	0.191	0.197	0.223	0.225	8.45	8.90	18.66	19.26	27.11	28.15
ZT	0.182	0.190	0.221	0.222	7.20	7.57	17.46	17.77	24.65	25.33
CT	0.174	0.184	0.205	0.207	6.70	7.23	15.30	15.71	22.00	22.95
SEm±	0.011	0.012	0.003	0.003	0.63	0.60	0.31	0.36	0.85	0.93
CD (P = 0.05)	NS	NS	0.010	0.013	NS	NS	1.22	1.43	3.32	3.66
Irrigation scheduling										
40%ASMD	0.186	0.186	0.223	0.225	8.15	8.57	18.16	18.62	26.32	27.19
50%ASMD	0.179	0.193	0.214	0.217	7.14	7.77	17.14	17.66	24.28	25.44
60%ASMD	0.183	0.192	0.212	0.212	7.05	7.35	16.11	16.45	23.16	23.80
SEm±	0.006	0.003	0.002	0.003	0.37	0.28	0.39	0.49	0.51	0.53
CD (P = 0.05)	NS	NS	0.008	0.010	NS	0.85	1.21	1.50	1.58	1.63

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

Potassium

Potassium content and uptake in grain and straw of maize was influenced significantly due to various crop establishment techniquesand irrigation regimes(Table 4.10). Significantly higher potassium content in grain and straw was obtained underRB however there was no difference between ZT and CT during both the years.There was no significant difference in potassium content of both grain and straw due to different irrigation schedules. Similar trend was also observed with total potassium uptake. Among irrigation regimes significantly higher total potassium uptake was observed with irrigations given at 40% ASMD in both the years.

Table4.10:Effect of crop establishment methods and irrigation regimes on potassiumuptake of maize

Treatments	Potassium content (%)				Potassium uptake(kg/ha)				Total K uptake(Kg/ha)	
	Grain		Straw		Grain		Straw			
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Crop establishment method										
RB	0.626	0.629	1.67	1.70	27.63	28.46	139.14	144.91	166.77	173.37
ZT	0.623	0.625	1.66	1.72	24.61	25.00	130.85	137.19	155.46	162.19
CT	0.617	0.619	1.60	1.61	23.61	24.31	119.22	122.36	142.83	146.67
SEm±	0.002	0.002	0.01	0.02	0.78	0.74	2.99	4.08	3.03	4.66
CD (P = 0.05)	0.007	0.007	0.03	0.07	3.07	2.91	11.73	16.03	11.90	18.29
Irrigation scheduling										
40%ASMD	0.626	0.628	1.67	1.70	27.37	28.87	135.40	140.41	162.76	169.28
50%ASMD	0.621	0.624	1.62	1.68	24.72	25.04	129.52	136.56	154.24	161.60
60%ASMD	0.619	0.622	1.64	1.65	23.76	23.86	124.30	127.49	148.06	151.35
SEm±	0.001	0.002	0.02	0.03	0.98	0.85	3.15	2.88	3.30	2.79
CD (P = 0.05)	NS	NS	NS	NS	3.02	2.60	NS	8.88	10.17	8.59

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

Economics

The economic considerations are the deciding factor for any technology to be adopted by farmers. The cost of cultivation, gross return, net return and beneit:cost ratio of maize as affected by crop establishment techniquesand irrigation regimes have been presented in Table 4.13.The total cost of cultivation varied among different treatments due to variation in operations under different method of crop establishment techniques and irrigation scheduling .Highest cost of cultivation was observed in CT practices and lowest with RB. Significantly highest net return and benefit:costratio(33830 ₹/ha and 1.28) during 2011 and 2012 (35321 ₹/ha and 1.34) were obtained with RBpractices. Amongst irrigation regimes 40% ASMD produced significantly highest gross return, net return and B C ratio over other irrigation regimes.TheBed planting gave 31% and 30% while ZT gave 14% and 12% more net returns over CT during 2011 and 2012, respectively. In general, bed planting gave 36.77% and 36.00% higher benefit: costratio over CT during 2011 and 2012, respectively.

Table 4.13:The effect of different crop establishment methods and irrigation regimes on economics of maize

Treatments	Cost of cultivation (□/ha)		Gross returns (□/ha)		Net returns (□/ha)		Benefit :Cost ratio	
	2011	2012	2011	2012	2011	2012	2011	2012
RB	25993	26395	60225	61716	33830	35321	1.28	1.34
ZT	26386	26785	54328	54950	27542	28164	1.03	1.05
CT	28433	28925	52369	53677	23443	24752	0.81	0.86
SEm±	-	-	1243	1491	1243	1491	0.05	0.06
CD (P = 0.05)	-	-	4880	5855	4880	5855	0.18	0.22
Irrigation scheduling								
40%ASMD	27080	27515	59559	62300	32044	34785	1.17	1.27
50%ASMD	27080	27515	54743	55279	27227	27764	1.00	1.02
60%ASMD	26653	27075	52619	52764	25544	25689	0.95	0.96
SEm±	-	-	1818	1510	1818	1510	0.07	0.05
CD (P = 0.05)	-	-	NS	4653	NS	4653	NS	0.17

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

Energy parametersin maize

Input Energy

Input energy consumption under various tillage practices was different during both the years(Table 4.12). The input energy requirement under CT practices was higher than ZT and RB practices during both years. Results indicate that input energy consumption decreased with increasein depletion of available soil moistureregimes and it was highest with 40% ASMD and lowest in 60% ASMD during both the years.

Output energy

Output energy production by maize was significantly influencedin both the yearsdue to different tillage practices(Table 4.12). During 2011, the highest gross output energy was produced under RB (171.10 x 10^3MJ/ha) followed by ZT (158.29 x 10^3 MJ/ha) and the lowest in CT (150.79 x 10^3 MJ/ha). Moreover, output energy production was more in 2012 than 2011.Similarly different irrigation schedules have significant effect on gross output energy production during both the years. The highest output energy was estimated in 40% ASMD while, the lowest observed with 60% ASMD (152.61 x $10^3$to 154.41 x 10^3 MJ/ha) for both the year, respectively.

Energy-use efficiency

Energy use efficiency (output / input ratio) was influenced significantly due to different tillage practices during both the years (Table4.12).In general, energyefficiency was more in the year 2012 than 2011. The maximum energy use efficiency (3.91 and 4.01) was recordedunder RB while the lowest energy efficiency was estimated (3.28 and 3.35) under CT during 2011 and 2012, respectively. Similarly, Energyuse efficiency was significantly influenced due to different irrigation schedulesduring both the years.Energy use efficiency increased with decrease in available soil moisture depletion and it was highest with 40% ASMD and the lowest with 60% ASMD irrigation schedules during both the years.

Table 4.11:Energy relationship influenced by different crop establishment methods and irrigation regimes in maize

Treatments	Input energy (10^3MJ/ha)		Output energy (10^3MJ/ha)		Energy balance (10^3MJ/ha)		Energy use efficiency		Energy productivity	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
RB	43.71	43.71	171.10	175.10	127.39	131.39	3.91	4.01	0.10	4.01
ZT	43.77	43.77	158.29	160.21	114.52	116.44	3.62	3.66	0.09	3.66
CT	45.96	45.96	150.79	153.96	104.82	108.00	3.28	3.35	0.08	3.35
SEm±	-	-	2.67	3.54	2.67	3.54	0.06	0.08	0.00	0.08
CD (P = 0.05)	-	-	10.48	13.91	10.48	13.91	0.24	0.31	0.01	0.31
Irrigation scheduling										
40%ASMD	44.87	44.87	167.75	172.73	122.88	127.86	3.74	3.86	0.10	3.86
50%ASMD	44.38	44.38	159.82	162.13	115.44	117.75	3.61	3.66	0.09	3.66
60%ASMD	44.19	44.19	152.61	154.41	108.42	110.22	3.46	3.50	0.09	3.50
SEm±	-	-	2.71	2.58	2.71	2.58	0.06	0.06	0.00	0.06
CD (P = 0.05)	-	-	8.34	7.95	8.34	7.95	0.19	0.18	NS	0.18

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

Moisture use by maize

Irrigation requirement

The data pertaining to irrigation requirement (mm) of maize as influenced by crop establishment techniques and irrigation regimesare given in Table 4.12. It shows that irrigation requirement in RB was lower (81 and 44 mm) in comparison to CT (117 and 71 mm) .The saving in irrigation water to the tune of 30% and 38% in RB and 14% and 9% in ZTwas found during 2011 and 2012, respectively.Amongst irrigation regimes in 2011 both 40% and 50% ASMD received 2irrigationson the other hand at 60% ASMD only one irrigation was required.However, in 2012 there was more

rainfallthis resulted in nil irrigation required at 60%ASMD however,one irrigationwas givenunder 40% and 50% ASMD irrigation schedules.

Water requirement

The data pertaining to water requirement (mm)of maize as influenced by crop establishment techniques and irrigation regimes (Table 4.12). In general,water requirement in RB (320mm and 324mm) was lower than CT (356mm and 351 mm)during both the years respectively.In terms of percentage saving ofwater under RBwas 10% and 7.6% while in ZT it was 4% and 1.7% over CT during 2011 and 2012,respectively. Amongst irrigation regimes the water requirement at 40% and 50% ASMD was more compared to 60% ASMD during both the years.

Irrigation water use efficiency(IWUE) and field water use efficiency(FWUE)

Irrigation and field water use efficiency of maize as influenced by crop establishment techniques and irrigation regimes(Table 1.12). Remarkably higher IWUE/water productivity (kg grain m^{-3} water) of maize was recorded in RB planting (545 and 1049) followed by ZT (391and 615) and the lowest in CT (327 and 553) systemduring both the years respectively.

Amongst irrigation regimes highest IWUE was observed under 40% ASMD irrigation schedule during 2012. The percentage increase in IWUEwas found higher in bed planting (40% and 46%) over conventional tillage while in ZT it was only 16% and 10% over CTduring 2011 and 2012, respectively. Similarly, there was higher FWUE under RB and it was to the tune of 22% and 20% over CT during 2011 and 2012,respectively.

Table4.12:Effect of crop establishment methods and irrigation regimes on water use in maize

Treatments	Irrigation requirement (mm)		Effective rainfall (mm)		Water requirement (mm)		IWUE (kg/ha-cm)		FWUE (kg/ha-cm)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Crop establishment method										
RB	81	44.00	239.00	280.00	320.00	324.00	545	1029	138	140
ZT	101	65.00	239.0	280.00	340.00	345.0	391	615	116	116

			0			0				
CT	117	71.00	239.00	280.00	356.00	351.00	327	553	107	112
Irrigation scheduling										
40%ASMD	112	55.00	239.00	280.00	351.00	335.00	391	836	125	137
50%ASMD	123	65.00	239.00	280.00	362.00	345.00	324	617	110	116
60%ASMD	65	0.00	239.00	280.00	304.00	280.00	590	0	126	137

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

IWUE – Irrigation water use efficiency, FWUE - Field water use efficiency

Performance of Wheat

Data pertaining to growth parameters *viz.*, plant height, leaf area index and dry matter accumulation as influenced by crop establishment techniques, irrigation scheduling and residue management are presented in this section

Plant height

Plant height recorded at various growth stages (30, 60 and at maturity) of wheat as influenced by crop establishment techniques, irrigation scheduling and residue managementhave been presented in Table 4.14. Results indicated that plant heightof the wheat was better during 2012-13 in comparison to 2011-12 due to favorable weather conditions during the season. In general, crop grown on RB performed better than ZT and CT. The tallest plant height (52.62 cm) was recorded at 90 DAS under RB during both the year of experiments.The tallest plant (55.71) was recorded at 90 DAS when irrigations were scheduled at critical growth stages of wheat. Among different irrigation schedules,plant height at 30 and 60 DAS was significantly higher with irrigations applied at critical growth stages compare to CWSI and 60% ASMD. Similarly, residue management resulted in higher plant height at 60 and 90 DAS over noresidue in wheat during first year of study.

Table4.14: Effect of crop establishment methods, irrigation regimes and residue management on plant height of wheat

Treatments	**Plant Height(cm) wheat**					
	30DAS		**60 DAS**		**90DAS**	
	2011-12	**2012-13**	**2011-12**	**2012-13**	**2011-12**	**2012-13**

Crop establishment method						
RB	14.74	15.97	30.26	31.42	52.62	56.12
ZT	13.67	14.83	29.52	30.86	49.57	55.29
CT	12.96	14.34	28.86	29.97	47.02	52.58
SEm±	0.30	0.14	0.58	0.65	0.53	0.93
CD (P = 0.05)	1.17	0.57	NS	NS	2.08	3.65
Irrigation scheduling						
CGS	13.47	15.69	30.83	31.72	49.60	55.71
CWSI	14.07	15.29	29.37	30.81	49.29	54.62
60%ASMD	13.82	14.16	28.44	29.72	50.33	53.66
SEm±	0.22	0.15	0.48	0.45	0.40	0.75
CD (P = 0.05)	NS	0.47	1.48	1.38	1.25	NS
Residue management						
With mulch	13.93	15.19	30.44	31.26	50.45	55.11
Without mulch	13.65	14.91	28.65	30.24	49.03	54.21
SEm±	0.26	0.05	0.38	0.44	0.71	0.37
CD (0.05)	NS	0.16	1.13	NS	2.10	NS

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

CGS – Critical growth stage, CWSI –Crop water stress index

Dry matter accumulation (DMA)

Dry matter accumulation attained maximum accumulation at 90 DAS (Table 4.15 and Fig. 4.4). Tillage management practices failed to bring out any significant response on dry matter accumulation at 30 and 60 DAS during first year. However, the highest dry matter (6.81t/ha and 6.40) was recorded at 90 DAS under RB. DMA was less during early growth stages as compare to later stages during both the year of study. With regards to irrigation scheduling there was significant difference DMA at all the stages.However, the highest dry matter accumulation (6.82 t/ha) was recorded at 90 DAS under irrigation given at critical growth stage.

Table 4. 15: Effect of crop establishment methods, irrigation regimes and residue management on dry matter accumulation of wheat

Treatments	**Dry matter accumulation (t/ha)**					
	30DAS		**60 DAS**		**90DAS**	
	2011-12	**2012-13**	**2011-12**	**2012-13**	**2011-12**	**2012-13**
Crop establishment method						
RB	0.85	0.89	3.48	3.64	6.40	6.81
ZT	0.84	0.88	3.16	3.57	6.08	6.64
CT	0.83	0.87	2.95	3.50	5.82	6.60
SEm±	0.01	0.01	0.10	0.05	0.06	0.05
CD (P = 0.05)	NS	0.02	NS	0.19	0.23	0.18
Irrigation scheduling						

CGS	0.81	0.89	3.53	3.62	6.10	6.82
CWSI	0.86	0.89	3.29	3.60	5.97	6.71
60%ASMD	0.84	0.87	2.76	3.48	6.25	6.53
SEm±	0.01	0.01	0.07	0.03	0.16	0.04
CD (0.05)	0.04	0.02	0.22	0.11	NS	0.14
Residue management						
With mulch	0.86	0.89	3.24	3.61	6.03	6.78
Without mulch	0.82	0.88	3.15	3.53	6.18	6.59
SEm±	0.01	0.01	0.06	0.02	0.11	0.05
CD (P = 0.05)	0.02	0.02	NS	0.07	NS	0.16

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

CGS – Critical growth stage, CWSI – Crop water stress index

Leaf area index (LAI)

The LAI increased with the advancement of age and attained maximum at 90 DAS of wheat (Table 4.16 and Fig. 4.4). Data pertaining to leaf area index at various stages of crop growth were significantly influenced by crop establishment techniques. Similar to DMA, significantly highest LAI was also recorded under RB and lowest under CT. Among different irrigation scheduling significantly highest leaf area index was recorded under CGS based irrigation schedules while lowest at 60% ASMD except 30 DAS during both the year of study. Similarly,the LAI were maximum under with residue treatments during both the years.

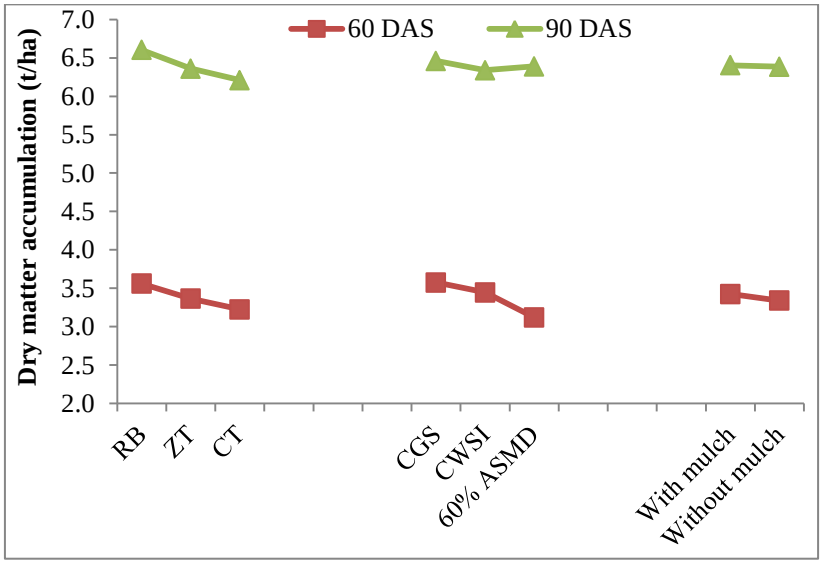


Fig. 4.4: Effect of crop establishment methods, irrigation regimes and residue management on dry matter accumulation of wheat (mean of two years)

Table 4.16: Effect of crop establishment methods, irrigation regimes and residue management on LAI ofwheat

Treatments	30 DAS		60 DAS		90 DAS	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Crop Establishment Method						
RB	0.353	0.364	1.330	1.406	3.733	3.777
ZT	0.344	0.357	1.303	1.391	3.534	3.697
CT	0.336	0.348	1.281	1.358	3.467	3.544
SEm±	0.005	0.005	0.011	0.009	0.063	0.052
CD (P = 0.05)	NS	NS	0.045	0.027	NS	0.204
Irrigation Scheduling						
CGS	0.351	0.365	1.313	1.392	3.623	3.708
CWSI	0.343	0.353	1.315	1.387	3.554	3.637
60%ASMD	0.338	0.350	1.286	1.377	3.558	3.673
SEm±	0.006	0.005	0.027	0.007	0.071	0.051
CD (P = 0.05)	NS	NS	0.084	0.020	NS	0.157
Residue Management						
With mulch	0.353	0.366	1.314	1.397	3.638	3.722
Without mulch	0.335	0.346	1.295	1.373	3.519	3.623
SEm±	0.004	0.003	0.026	0.005	0.036	0.033
CD (P = 0.05)	0.012	0.010	0.077	0.016	0.107	0.097

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion
CGS – Critical growth stage, CWSI – Crop water stress index

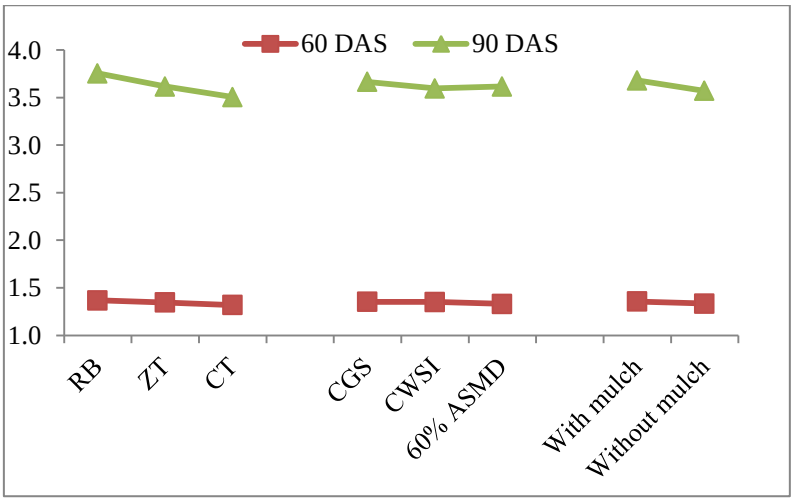


Fig. 4.5: Effect of crop establishment methods, irrigation regimes and residue management on leaf area index of wheat (mean of two years)

Growth indices in wheat

Data pertaining to CGR and relative growth rate (RGR) were not influenced significantly by crop establishment techniques(Table 4.17 and 4.18). CGR recorded a gradual increase with increase in crop duration with maximum values at 60-90 DAS, while the RGR recorded a reverse trend in comparison to CGR.The CGR were

significantly influenced due to various irrigation scheduling during both the years, except CGR at 60-90 DAS during 2012-13.

Table 4.17: Effect of crop establishment method, irrigation scheduling and residue management on CGR (g/m^2/day) of wheat

Treatments	0-30 DAS		30-60 DAS		60-90 DAS	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Crop establishment method						
RB	2.82	2.970	8.76	9.152	9.76	10.58
ZT	2.79	2.935	7.74	8.957	9.45	10.24
CT	2.76	2.906	7.07	8.752	9.59	10.35
SEm±	0.03	0.017	0.35	0.145	0.55	0.18
CD (P = 0.05)	NS	NS	NS	NS	NS	NS
Irrigation scheduling						
40%ASMD	2.70	2.972	9.06	9.102	8.56	10.66
50%ASMD	2.87	2.954	8.11	9.044	8.91	10.36
60%ASMD	2.79	2.885	6.40	8.715	11.33	10.15
SEm±	0.04	0.026	0.24	0.111	0.50	0.21
CD(P = 0.05)	0.12	0.079	0.74	0.341	1.53	NS
Residue management						
With mulch	2.85	2.953	7.94	9.073	9.09	10.57
Without mulch	2.72	2.921	7.77	8.835	10.10	10.20
SEm±	0.02	0.019	0.19	0.087	0.42	0.23
CD (P = 0.05)	0.07	NS	0.58	0.259	NS	NS

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

The RGR were significantly not influenced due to various irrigation scheduling during both the years, except RGR at 30-60 DAS intervals during 2011-12 and 60-90 DAS during 2012-13. Moreover, RGR at various stages of crop growth were significantly not influenced by residue application.

Table 4.18: Effect of crop establishment method, irrigation scheduling and residue management on RGR (mg/g/day) of wheat

Treatments	30-60DAS		60-90 DAS	
	2011-12	2012-13	2011-12	2012-13
Crop establishment method				
RB	47.05	46.87	20.32	20.90
ZT	43.87	46.63	22.22	20.71
CT	41.51	46.29	23.42	21.19
SEm±	1.44	0.31	1.60	0.44
CD (P = 0.05)	NS	NS	NS	NS
Irrigation scheduling				

40%ASMD	49.06	46.71	18.01	21.09
50%ASMD	44.47	46.72	19.95	20.75
60%ASMD	38.90	46.36	27.99	20.96
SEm±	0.96	0.38	1.00	0.43
CD (P = 0.05)	2.95	NS	3.09	NS
Residue management				
With mulch	43.87	46.80	21.08	21.03
Without mulch	44.42	46.39	22.89	20.84
SEm±	0.71	0.36	0.93	0.42
CD (P = 0.05)	NS	NS	NS	NS

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

Yield attributes

Yield attributes *viz.*,number of effective tillers/m^2, grains/spike, grain weight/spike and 1000 grain wt. (test weight) at harvest were influenced by crop establishment techniques, irrigation scheduling and residue management (Table 4.19). Number of effective tillers/m^2 and 1000 grain weight were recorded significantly higher underraised bed followed by ZT and CT. Relatively higher Shelling percentage of maize was recorded under RB than CT. The yield attributes like number of effective tillers/m^2 and test weight wassignificantly influenced due to different irrigation regimes during both the years of study. The highest values of effective tillers/m^2 were recorded under irrigation given on critical growth stage. The yield attributes like grain/ spike and test weight were not significantly influenced due to different residue management practices during both the years. However, significantly highereffective tillers/m^{2}was recorded with residue as compare to without residue treatment.

Table 4.19:Effect of crop establishment methods, irrigation regimes and residue management on yield attributes of wheat

Treatments	Grain weight/spike		Grains/spike		Grain diameter (mm)		Test weight (g)		Effective tillers/m^2	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Crop establishment method										
RB	2.05	2.08	52.61	53.56	2.70	2.80	36.66	36.72	359.17	364.17
ZT	1.99	2.00	50.67	51.94	2.54	2.77	36.17	36.17	349.89	352.67
CT	1.91	1.91	49.89	51.94	2.50	2.77	35.36	35.58	340.67	344.94
SEm±	0.03	0.03	0.81	1.07	0.13	0.01	0.15	0.24	1.98	2.05
CD (P = 0.05)	0.11	0.11	3.16	NS	NS	0.04	0.61	0.93	7.77	8.03
Irrigation scheduling										
CGS	2.03	2.05	51.22	52.56	2.59	2.79	36.23	36.39	357.56	362.00
CWSI	1.95	1.96	51.22	52.83	2.53	2.78	36.45	36.45	350.33	354.06
60%ASMD	1.96	1.98	50.72	52.06	2.62	2.77	35.51	35.63	341.83	345.72
SEm±	0.02	0.02	0.38	0.75	0.05	0.02	0.32	0.30	2.46	1.50
CD (P = 0.05)	0.05	0.06	1.17	NS	NS	0.05	NS	0.93	7.59	4.61
Residue management										
With mulch	2.01	2.02	51.63	52.74	2.53	2.78	36.18	36.29	353.26	358.33
Without mulch	1.95	1.95	50.48	52.22	2.63	2.77	35.95	36.03	346.56	349.52
SEm±	0.02	0.02	0.51	0.50	0.04	0.01	0.14	0.12	1.82	1.28
CD (P = 0.05)	0.06	0.06	NS	NS	NS	0.04	NS	0.36	5.40	3.82

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion,CGS – Critical growth stage, CWSI – Crop water stress index

Yield

The grain, straw and biological yields were significantly influenced by the crop establishment technique. It was found that RB planting resulted in significant higher grain yield in comparison to ZT and CT (Table 4.20). Similar trend was also observed in case of straw and biological yield.The grain yield was higher under RB planting to the tune of 6-13%, while in ZT 2-6 % in comparison to CT during both the years, respectively. The results also revealed that the grain yield significantly influenced by irrigation scheduling. Thegrain and straw yieldwere significantly higher under irrigation given at CGS. With regards to different Residue management there was no significant difference in grain yield during 2011-12 whereas, significantly higher grain yield (4.74) was recorded during 2012-13.Similarly the straw and biological yields were maximum under with residue than without residue treatments during both the year of study.

Table 4.20:Effect of crop establishment methods, irrigation regimes and residue management on yield performance of wheat

Treatments	Grain yield (t/ha)		Straw yield(t/ha)		Biological yield(t/ha)		Harvest index (%)	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Crop establishment method								
RB	4.61	4.82	7.02	8.28	11.63	13.10	39.63	36.77
ZT	4.29	4.63	6.52	7.98	10.82	12.61	39.61	36.72
CT	4.02	4.54	6.48	7.51	10.50	12.04	38.30	37.67
SEm±	0.08	0.05	0.11	0.04	0.16	0.06	0.74	0.26
CD (P = 0.05)	0.31	0.17	0.42	0.14	0.62	0.24	NS	NS
Irrigation scheduling								
CGS	4.50	4.77	6.68	8.07	11.18	12.84	40.22	37.13
CWSI	4.26	4.68	6.81	7.95	11.07	12.63	38.39	37.08
60%ASMD	4.17	4.54	6.53	7.75	10.69	12.29	38.92	36.94
SEm±	0.10	0.06	0.10	0.05	0.14	0.07	0.70	0.35
CD (P = 0.05)	0.31	NS	NS	0.14	0.42	0.21	NS	NS
Residue management								
With mulch	4.35	4.74	6.84	7.98	11.19	12.72	38.75	37.26
Without mulch	4.27	4.59	6.51	7.87	10.78	12.46	39.61	36.85
SEm±	0.07	0.05	0.11	0.02	0.13	0.05	0.55	0.23
CD (P = 0.05)	0.20	0.13	0.32	0.07	0.39	0.16	NS	NS

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion
CGS – Critical growth stage, CWSI – Crop water stress index

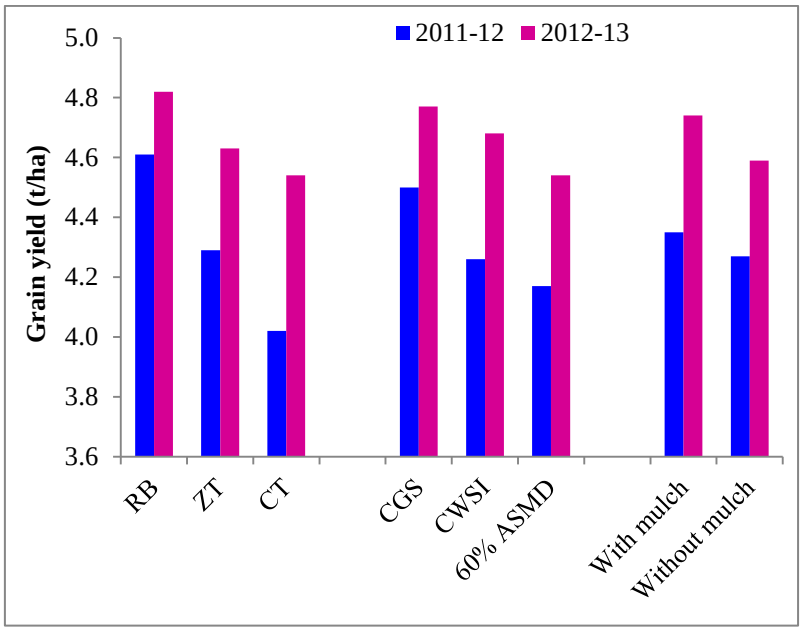


Fig. 4.6:Effect of crop establishment methods, irrigation regimes and residue management on grain yield of wheat

Nutrient content and uptake

Nitrogen

Nitrogen content and uptake in grain of wheat were not significantly influenced due to crop establishment techniques, irrigation scheduling and residue management(Table 4.21).However, significantly highertotal N uptake was recorded under RB as compare to other crop establishment techniques in both the years of study.Similarly the total N uptake was significant higher under irrigation based oncritical growth stage over 60% ASMD.Similarly residue management also had significantly highertotal N uptake.

Phosphorus

Phosphorus content in grain and straw of wheat was not significantly influenced due to crop establishment techniques (Table 4.22). However, the total P uptake was significant higher under RB as compare to ZT and CT during both the years.Irrigation scheduling did not show significant influence on P content in grain and straw in both years. However, significantly increase in total uptake of P was observed under the irrigation scheduled at CGS over 60% ASMD. Moreover, total P uptake was also not significantly influenced by residue management practices during first year of study.

Table 4.21: Effect of crop establishment methods, irrigation regimes and residue management on Nitrogen uptake of wheat

Treatments	N conc. In grain(%)		N conc. in straw(%)		N uptake in grain(kg/ha)		N uptake in straw(kg/ha)		Total uptake(kg/ha)	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Crop establishment method										
RB	1.41	1.47	0.40	0.41	66.50	71.06	32.34	33.89	100.73	100.73
ZT	1.35	1.51	0.39	0.42	65.22	70.05	31.82	33.21	97.09	97.09
CT	1.24	1.46	0.37	0.41	64.07	66.46	29.76	30.43	93.16	93.16
SEm±	0.04	0.02	0.01	0.02	0.97	1.07	0.07	0.23	0.70	0.70
CD (P= =0.05)	NS	NS	NS	NS	NS	NS	0.29	0.90	2.76	2.76
Irrigation scheduling										
CGS	1.33	1.50	0.38	0.42	69.13	71.41	31.87	33.59	97.95	97.95
CWSI	1.36	1.49	0.40	0.41	65.48	69.87	31.62	32.45	97.94	97.94
60%ASMD	1.32	1.46	0.39	0.41	61.17	66.29	30.43	31.48	95.10	95.10
SEm±	0.03	0.01	0.01	0.002	0.82	1.01	0.15	0.22	0.71	0.71
CD (P = 0.05)	NS	NS	NS	0.01	2.52	3.11	0.45	0.69	2.20	2.20
Residue management										
With mulch	1.34	1.49	0.39	0.41	65.92	70.47	31.68	32.87	98.89	98.89
Without mulch	1.33	1.48	0.39	0.41	64.61	67.91	30.93	32.15	95.09	95.09
SEm±	0.02	0.01	0.01	0.001	0.65	0.80	0.22	0.16	0.49	0.49
CD (P= =0.05)	NS	NS	NS	NS	NS	2.39	0.65	0.49	1.45	1.45

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

CGS – Critical growth stage, CWSI – Crop water stress index

Potassium

Potassium uptake in grain and straw of wheat was influenced significantly due to various crop establishment techniques and irrigation regimes (Table 4.23). Significantly higher potassium uptake in straw was obtained under RB over CT during both the years. In general, significant increase in total K uptake was observed under irrigation based on CGS than other irrigation schedules. The total K uptake was significantly influenced due to residue management during both years of study. The significantly higher total P uptake was found under with residue than without residue treatment due to higher biomass.

Table 4.22: Effect of crop establishment methods, irrigation regimes and residue management on phosphorus uptake of wheat

Treatments	P conc. in grain(%)		P conc. in straw(%)		P uptake in grain(kg/ha)		P uptake in straw(kg/ha)		Total P uptake(kg/ha)	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Crop establishment method										
RB	0.33	0.35	0.12	0.12	16.45	16.86	10.03	10.31	26.87	27.17
ZT	0.31	0.36	0.11	0.13	16.17	16.87	9.83	10.01	26.05	26.88
CT	0.30	0.35	0.11	0.12	15.33	15.94	9.09	9.15	25.01	25.09
SEm±	0.01	0.002	0.00	0.00	0.19	0.18	0.04	0.06	0.20	0.17
CD (P = 0.05)	NS	NS	NS	0.00	0.75	0.72	0.16	0.22	0.80	0.67
Irrigation scheduling										
CGS	0.34	0.36	0.11	0.13	16.36	16.97	9.91	10.11	26.39	27.08
CWSI	0.32	0.36	0.11	0.12	16.07	16.68	9.71	9.86	26.38	26.54
60%ASMD	0.28	0.35	0.11	0.12	15.52	16.02	9.33	9.50	25.17	25.52
SEm±	0.01	0.001	0.01	0.001	0.33	0.26	0.13	0.08	0.22	0.25
CD (P = 0.05)	0.03	NS	NS	NS	NS	NS	0.39	0.25	0.68	0.77
Residue management										
With mulch	0.31	0.36	0.11	0.12	16.36	16.84	9.75	9.96	26.11	26.80
Without mulch	0.32	0.35	0.11	0.12	15.61	16.27	9.55	9.69	25.84	25.96
SEm±	0.01	0.001	0.01	0.0002	0.22	0.17	0.09	0.04	0.16	0.17
CD (P= 0.05)	NS	NS	NS	0.001	0.65	0.49	NS	0.11	NS	0.51

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

CGS – Critical growth stage, CWSI – Crop water stress index

Table 4.23: Effect of crop establishment methods, irrigation regimes and residue management on potassium uptake of wheat

Treatments	K conc. in grain (%)		K conc. in straw (%)		K uptake in grain(kg/ha)		K uptake in straw(kg/ha)		Total K uptake(kg/ha)	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Crop establishment method										
RB	0.41	0.43	1.32	1.41	20.26	20.82	115.04	116.93	131.86	137.74
ZT	0.39	0.44	1.30	1.45	19.96	20.55	112.64	115.42	128.03	135.97
CT	0.34	0.43	1.26	1.37	19.24	19.62	101.50	103.22	119.51	122.84
SEm±	0.01	0.00	0.01	0.01	0.26	0.19	0.91	1.12	0.82	1.22
CD (P= 0.05)	NS	0.01	0.03	0.05	NS	0.74	3.59	4.40	3.21	4.81
Irrigation scheduling										
CGS	0.38	0.44	1.29	1.44	20.42	20.81	112.03	116.58	126.83	137.39
CWSI	0.39	0.44	1.30	1.42	19.84	20.45	111.24	112.57	129.19	133.02
60%ASMD	0.36	0.44	1.28	1.37	19.21	19.74	105.91	106.41	123.37	126.15
SEm±	0.02	0.00	0.02	0.02	0.35	0.25	1.51	1.53	1.24	1.45
CD (P = 0.05)	NS	0.01	0.07	NS	NS	0.77	4.66	4.71	3.82	4.48

Residue management										
With mulch	0.39	0.44	1.28	1.42	20.19	20.68	110.55	113.25	128.90	133.93
Without mulch	0.37	0.44	1.30	1.40	19.45	19.99	108.90	110.46	124.03	130.44
SEm±	0.02	0.00	0.01	0.01	0.24	0.16	0.79	0.90	1.09	0.95
CD (P = 0.05)	NS	NS	NS	NS	0.71	0.49	NS	2.68	3.23	2.82

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

CGS – Critical growth stage, CWSI – Crop water stress index

Economics

Data pertaining to cost of cultivation, gross and net return and benefit: cost ratio as affected by crop establishment techniques, irrigation regimes and residue management have been presented in Table 4.24. Highest cost of cultivation was observed in CT practices while lowest was under RB. The maximum net returns and benefit:cost ratio were recorded under raised bed (44633 and 48580 ₹/ha, 2.08 and 2.26) during both the year, respectively. While minimum net returns and benefit:cost ratio were obtained under CT (33711 ₹/ha and 41,348 ₹/ha,1.39 and 1.70) in 2011 and 2012 respectively. Amongst irrigation regimes irrigation applied atcritical growth stage produced significantly highest net return and benefit: cost ratio over other irrigation schedules. The economic analysis exhibited that the highest gross and net returns were found with crop residue treatmentthan without residue. The crop residues have economic value, and their prevailing market prices were added to the production cost due to which cost of cultivation was higherwith residue treatment and therefore the B: C ratio was higher in without residue treatment in 2012-13. Ingeneral,RB planting gave 24.9% and 14.9% while ZT gave 14.4% and 8.5% higher net returns over CT during both the year, respectively.RB also resulted inhigher benefit: cost ratio (32.1% and 24.8%) over CT during both the year, respectively.

Table 4.24:Wheat economics influenced by different crop establishment methods, irrigation regimes and residue management in 2011-12 and 2012-13

Treatments	Cost of cultivation(□/ha)		Gross returns (□/ha)		Net returns (□/ha)		Benefit :Cost ratio	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Crop establishment method								
RB	20889	21625	66258	70206	44633	48580	2.08	2.26
ZT	21589	22335	61707	67517	39372	45182	1.77	2.04
CT	23449	24475	58186	65823	33711	41348	1.39	1.70
SEm±	-	-	1425	624	1425	624	0.06	0.03
CD (P= 0.05)	-	-	5593	2449	5593	2449	0.24	0.11

Irrigation scheduling								
CGS	22259	23109	64502	69360	41394	46251	1.82	2.02
CWSI	22259	23109	61581	68127	38473	45018	1.69	1.97
60%ASMD	21409	22219	60068	66059	37849	43840	1.73	2.00
SEm±	-	-	1290	743	1290	743	0.06	0.03
CD (P= 0.05)	-	-	3973	2290	3973	2290	0.18	NS
Residue management								
With mulch	23625	24502	62698	68868	38196	44366	1.57	1.82
Without mulch	20325	21122	61403	66829	40281	45707	1.92	2.18
SEm±	-	-	881	583	881	583	0.04	0.03
CD (P= 0.05)	-	-	NS	1733	NS	1733	0.12	0.08

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

CGS – Critical growth stage, CWSI – Crop water stress index

Energy relations

Input andOutput Energy

Input energy consumption under various tillage practices, irrigation scheduling and residue management practices are presented in Table 4.25. The input energy analysis showed that the highest consumption of energy was observed in CT practices. The input energy requirement under residue treatments was much higher than the non residue treatments.The highest input energy consumption was estimated under irrigation based on CGS while lowest under 60% ASMD in both the years of study.

Higher gross output energy was recorded under RB (179.19 x 10^3 MJ $ha^{-1}$and 160.12 10^3 MJ ha^{-1}) while lowest under CT (165.07x 10^3 and 144.17x 10^3MJ ha-1) during both the years.In general, RB gave 10% and 7.9% higher output energy than CT during 2011-12 and 2012 -13, respectively.output energy production was also significantly influenced due to different irrigation scheduling during both the years.The highest gross output energy was obtained under irrigation scheduled at CGS and the lowest was observed with 60% ASMD in both the years.Similarly the highest output energy (174.12) was observed under residue treatment during the year 2011-12 as compare to other residue management practices.

Table 4.25:Energy relationship influenced by different crop establishment methods, irrigation regimes and residue management in wheat

Treatments	Input energy (10^3MJ/ha)		Output energy (10^3MJ/ha)		Energy balance (10^3MJ/ha)		Energy use efficiency		Energy productivity	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13

Crop establishment method										
RB	28.03	28.03	160.12	179.19	132.09	151.16	8.20	9.23	0.237	0.248
ZT	28.09	28.09	148.96	172.48	120.88	144.39	7.60	8.86	0.219	0.237
CT	30.68	30.68	144.17	165.07	113.49	134.39	6.32	7.22	0.178	0.198
SEm±	--	--	2.25	0.89	2.25	0.89	0.10	0.06	0.008	0.003
CD (P= 0.05)	--	--	8.84	3.49	8.84	3.49	0.39	0.24	0.030	0.012
Irrigation scheduling										
CGS	28.93	28.93	154.20	175.79	125.27	146.86	7.51	8.59	0.220	0.232
CWSI	29.05	29.05	152.06	172.85	123.01	143.81	7.40	8.43	0.210	0.228
60%ASMD	28.82	28.82	146.99	168.10	118.17	139.28	7.21	8.30	0.205	0.223
SEm±	--	--	1.95	0.99	1.95	0.99	0.14	0.05	0.006	0.003
CD (P= 0.05)	--	--	6.02	3.04	6.02	3.04	0.44	0.14	NS	NS
Residue management										
With mulch	44.58	44.58	153.78	174.12	109.20	129.54	3.46	3.91	0.098	0.106
Without mulch	13.28	13.28	148.39	170.37	135.10	157.09	11.29	12.96	0.325	0.349
SEm±	--	--	1.76	0.81	1.76	0.81	0.11	0.04	0.004	0.002
CD (P= 0.05)	--	--	5.22	2.40	5.22	2.40	0.31	0.13	0.013	0.007

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion
CGS – Critical growth stage, CWSI – Crop water stress index

Energy-use efficiency

Maximum energy use efficiency (9.23% and 8.20%) was recorded under RB minimum (7.22and 6.33%) with CTduring both the years of investigation (Table 4.25). In general, bed planting gave 22.6% and 21.7% and ZT it was found 16.6% and 18.5% higher energy use efficiency over CT during both the years of study. Energy use efficiency was also significantly influenced due to different irrigation schedules in both the years. The highest energy use efficiency(8.59) was observed under irrigations given at CGS whereas minimum was estimated with 60% ASMD (7.21) during both the years of study. The energy use efficiency under residue treatments was much lower than the non residue treatments and the highest (12.96) was observed at without residue treatment during the year 2012-13.

Moisture use in wheat

Irrigation requirement

The data pertaining to irrigation requirement (mm) in wheat as influenced by crop establishment techniques, irrigation regimes and residue managementare given in Table 4.26.It shows that maximum irrigation water requirement (314 mm and 181 mm) was recorded under CT while minimum under RB (244 and 115 mm). There was saving in irrigation water under RB to the tune of 22.3% and 36.5% as compared to CT during 2011-12 and 2012-13 respectively. Amongst irrigation regimes maximum

irrigation requirement (330mm and 191 mm) was recorded under irrigation schedule based on CGS while minimum (242 and 131mm) was under 60% ASMD.In our study there was saving of 36.4% and 45.2% in irrigation water under 60% ASMD as compare to CGS based irrigation schedule during 2011-12 and 2012-13respectively. Similarly residue management also favourably influenced the saving of water as compare to without residue treatments.

Water requirement and saving of water

The data pertaining to water requirement (mm) ofwheat as influenced by crop establishment techniques, irrigation regimes and residue management are given in Table 4.26. It shows that water requirement in RB (312 mm and 321 mm) was lower than CT (382 mm and387 mm) during both the year.The saving in water underRB was to the tune of 18.3% and 17.1% over CT during both the year, respectively. Itwas found that there was water saving in tune of 18-30% under 60% ASMD over CGS during 2011-12 and 2012-13, respectively .Similarly irrigation given on CWSI schedule also saved irrigation requirement as compare to CGS during both the years, respectively.Residueapplication also helps in saving in irrigation water in comparison to without residue treatments during 2011 and 2012, respectively.

Table4.26:Effect of crop establishment methods, irrigation regimes and residue management on IWUE and FWUE of wheat

Treatments	Irrigation requirement(mm)		IWUE(Kg/ha-cm)		Effective rainfall (mm)		Water Requirement including pre-sowing irrigation at 60 mm (mm)		FWUE (Kg/ha-cm)	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Crop establishment method										
RB	244.00	115.00	188.93	419.03	8.2	146	312.20	321.00	147.66	150.12
ZT	294.00	169.00	146.07	274.16	8.2	146	362.20	375.00	118.57	123.56
CT	314.00	181.00	128.15	250.74	8.2	146	382.20	387.00	105.28	117.27
Irrigation scheduling										
CGS	330.00	191.00	136.35	249.71	8.2	146	398.20	397.00	112.99	120.14
CWSI	280.00	143	152.22	327.51	8.2	146	348.20	349.00	122.41	134.19
60%ASMD	242.00	131.00	172.18	346.40	8.2	146	310.20	337.00	134.32	134.65
Residue management										
With mulch	269.00	146.00	161.59	324.56	8.2	146	337.20	352.00	128.90	134.62

Without mulch	301.00	164.00	141.93	279.79	8.2	146	369.20	370.00	115.72	124.01

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

CGS – Critical growth stage, CWSI – Crop water stress index

Irrigation water use efficiency and field water use efficiency

Irrigation and field water use efficiency of wheat as influenced by crop establishment techniques, irrigation regimes and residue management are given in Table4.26.In our study remarkably higher IWUE (kg grain m^{-3} water) of wheat was recorded in RB planting (419 and 189) followed by zero tillage (274 and 146) and lowest in CT (250and 128) for both the years. The percentage increase in IWUE was found higher in bed planting (32.1% and 40.1%) while in ZT it was 12.2% and 8.5% over CT during 2011-12 and 2012-13 respectively. Different irrigation schedules also resulted in increasing IWUE of water and was found that there was 20.8% and 27.9%higher IWUE under 60% ASMD over CGS during 2011-12 and 2012-13, respectively.. In general, there was higher IWUE with residue application (12.2% and 13.8%) over without residue treatments during both the year of study.Similarly higher FWUE of Wheat was recorded in RB planting (150 and 147) followed by no-till (123 and 118) and lowest in conventional-till system (117and 105)during both the years, respectively. The percentage increase in FWUE was found higher in RB (28.7% and 21.8%) over CT. Different irrigation schedules also resulted in increased FWUE and there was 15.8% and 10.8% higher FWUE under 60% ASMD over CGS during both the years, respectively.

System productivity

Crop establishment techniques, irrigation regimes and residue management practices brought considerable improvement in system productivity of maize -wheat cropping system during both the years of investigation (Table 4.27 and Fig. 4.7).Maize equivalent yield (MEY) of wheat was significantly influenced due to different tillage practices during both the year of experiment. The highest MEY of was recorded under RB followed by ZT and minimum under CT during both the years.The results also revealed that system productivity of maize -wheat cropping system were significantly influenced due to different irrigation scheduling during both the years.

Table 4.27: Effect of crop establishment methods, irrigation regimes and residue management on system productivity of maize-wheat system

Treatment	System productivity (t/ha)	
	2011-12	2012-13
Crop establishment method		
RB	9.92	9.80
ZT	9.08	9.04
CT	8.63	8.84
SEm±	0.22	0.14
CD (P = 0.05)	0.87	0.56
Irrigation scheduling		
CGS	9.75	9.76
CWSI	9.07	9.12
60%ASMD	8.81	8.80
SEm±	0.23	0.18
CD (P= 0.05)	0.70	0.56
Residue management		
With mulch	9.25	9.33
Without mulch	9.16	9.12
SEm±	0.08	0.05
CD (P = 0.05)	NS	0.15

Significantly higher system productivity were obtained underirrigation based on CGS as compare to other irrigation schedules. However, system productivity by residue management not significantly influenced during both the years.

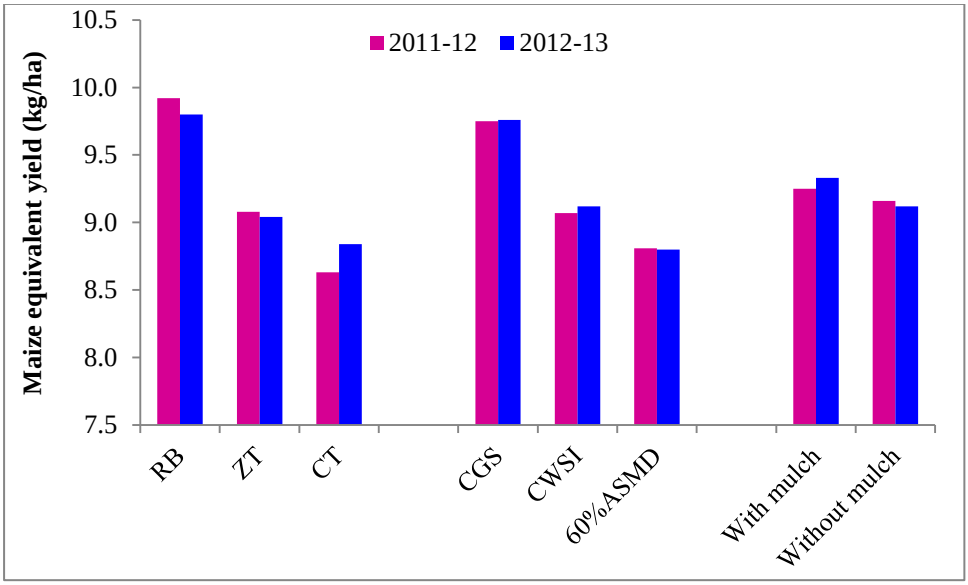


Fig. 4.7: Effect of crop establishment methods, irrigation regimes and residue management on system productivity of maize-wheat system

Soil Physical property

Bulk Density: The soil bulk density (BD) of different soil layers was not significantly influenced due to tillage practices, irrigation scheduling and residue management except 0-15 cm where it was significantly higher in ZT (Table 4.28). Irrespective of the various treatments the B.D in the deeper soil layer was higher as compare to upper soil layer. In general, the soil B.D of 0-15,15-30 and 30-45 cm layers was in the order of ZT(1.54,1.65 and 1.73) < CT(1.43,1.58 and 1.66 Mgm^{-3}) < RB(1.38,1.54 and 1.69 MgM^{-3}).

Hydraulic conductivity

The average saturated hydraulic conductivity (HC) in different soil layers was significantly influenced due to different tillage practicesand residue management (Table 4.28). Moreover, hydraulic conductivity was recorded lower at 15-30 cm soil depth compare to 0-15 cm soil depth.Bed planting resulted significantly higher HC of different soil layers than other tillage practices. Similarly,Residue application also resulted in higher HC than no-residue application.However, difference was not significant under residue management practices during first years of study.On the other hand H.C of different soil layers was not influenced significantly due to different irrigation schedules.

Infiltration rate:

The maximum infiltration rate was recorded under RB (1.92 Cm/hr), which was significantly higher than rest of the treatments, whereas, minimum infiltration rate was observed under CT (1.32 Cm/hr).RB gave 16.9% higher Infiltration over conventional tillage while under ZT it was 17.2%.Moreover, residue application also resulted in significantly higher infiltration rate over no-residue applied treatments.Residue application gave 13.3% higher Infiltration rateover without residue.However different irrigation scheduling did not significantly influence the IR at the end of cropping cycle.

Soil aggregation

Soil aggregation was analyzed in terms of mean weight diameter (MWD), Percentage of micro (<0.25mm) and macro aggregates (>0.25 mm), in relation to crop establishment techniques, irrigation scheduling and residue management (Table 4.28). The soil MWD at all depths was found in the following order of ZT(0.76)> RB(.72 mm) > CT(.61 mm). In general, ZT system of crop establishment was registered

higher values of MWD and gave 18.8%whileRB gave14.4% higher MWD over CT. Similarly, with residue application MWD was 8.4% higher over without residue. On the other hand, MWD of soil was not influenced significantly due to different irrigation schedules.

The significantly higher value of percentage of micro aggregate was found under CT while the minimum under RB. Moreover, residue application also produced lower values of micro aggregate than no-residue. In general, CT planting gave 9.3% higher percentage of micro aggregateover RB while ZT get 7.4% lowerpercentage of micro aggregate over CT. On the other hand, micro aggregate and macro aggregate did not get influenced significantly due to different irrigation scheduling. In general, RB planting gave 31.3% higher PMA (Percentage of Macro Aggregates) over CT while ZT give 25.9% higher PMA (Percentage of Macro Aggregates) over CT at the end of cropping system.Moreover,residue application also resulted significantly higher values of macro aggregate over no-residue.

Table 4.28:Soil physical properties influenced by tillage practices, irrigation regimes and residue management in maize-wheat cropping system(at the end of 2 years crop cycle)

Treatments	Bulk density			Hydraulic conductivity(cm/day)		Infiltration rate(cm/hr)	MWD(mm)	Micro aggregate%	Macro aggregate%	Soil moisture(%)
	0-15 cm	15-30 cm	30-45	0-15 cm	15-30 cm					
Crop establishment method										
RB	1.38	1.54	1.69	16.67	12.41	1.92	0.72	75.04	25.37	17.02
ZT	1.54	1.65	1.73	8.87	7.24	1.59	0.76	76.65	23.39	20.07
CT	1.43	1.58	1.66	11.48	9.91	1.32	0.61	82.80	17.32	15.96
SEm±	0.05	0.03	0.02	0.29	0.98	0.08	0.03	1.15	0.41	0.41
CD (P =0.05)	0.19	0.13	NS	1.13	3.85	0.31	0.11	4.52	1.61	1.62
Irrigation scheduling										
CGS	1.46	1.58	1.70	12.93	10.53	1.62	0.70	77.99	22.03	18.87
CWSI	1.45	1.60	1.69	11.25	9.36	1.62	0.67	78.46	21.98	17.59
60%ASMD	1.44	1.58	1.69	12.83	9.66	1.59	0.72	78.04	22.06	16.58
SEm±	0.04	0.04	0.04	1.89	1.64	0.07	0.02	1.10	0.41	0.39
CD (P = 0.05)	NS	NS	NS	NS	NS	NS	0.07	3.39	1.26	1.20
Residue management										
With mulch	1.43	1.56	1.67	12.79	10.65	1.72	0.73	77.32	20.94	18.47
Without mulch	1.46	1.62	1.72	11.89	9.05	1.49	0.67	79.00	23.11	16.89
SEm±	0.03	0.03	0.03	0.71	0.72	0.08	0.02	0.74	0.55	0.52
CD (P = 0.05)	NS	0.08	NS	NS	2.14	0.25	0.06	2.20	1.62	1.55

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion, CGS – Critical growth stage, CWSI – Crop water stress index

Soil Moisture

The soil moisture status of soil was significantly influenced by the crop establishment practices, irrigation scheduling and residue management. The maximum soil moisture was recorded under ZT (20.07%), which was significantly higher than rest of the treatments, whereas, minimum soil moisture was observed under CT (15.96%).Similarly, significantly increase in total soil moisture was observed under the irrigation scheduled at CGS over 60% ASMD. Moreover, residue application also resulted in significantly higher soil moisture over no-residue applied treatments.

Soil chemical properties

All soil chemical parameters (pH, EC organic carbon, and available, N, P and K) in 0-15 cm soil depth were determined at end of the research experiments and data have been presented in Table 4.29

Table4.29: Soil chemical properties influenced by tillage practices, irrigation regimes and residue management in maize-wheat cropping system(at the end of 2 years crop cycle)

Treatment	Organic C (%)	Available N(Kg/ha)	Available P(Kg/ha)	Available K(Kg/ha)	Soil pH	EC(dS/m)
Crop establishment method						
RB	0.40	162.92	23.04	178.03	7.77	0.343
ZT	0.42	168.26	24.07	180.70	7.82	0.358
CT	0.36	159.99	22.04	172.86	7.68	0.335
SEm±	0.01	1.57	0.39	1.68	0.05	0.007
CD (P= 0.05)	0.02	6.17	NS	6.59	NS	NS
Irrigation scheduling						
CGS	0.40	164.65	23.39	177.04	7.77	0.341
CWSI	0.40	163.33	22.85	178.12	7.77	0.349
60%ASMD	0.39	163.20	22.91	176.43	7.74	0.346
SEm±	0.01	1.98	0.27	1.08	0.04	0.008
CD P= (0.05)	NS	NS	0.82	NS	NS	NS
Residue management						
With mulch	0.40	164.98	22.78	177.86	7.74	0.337
Without mulch	0.38	162.47	23.32	176.54	7.78	0.354
SEm±	0.01	1.53	0.21	1.03	0.03	0.007
CD (P= 0.05)	0.02	4.54	0.61	3.06	NS	0.022

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

CGS – Critical growth stage, CWSI – Crop water stress index

Electrical conductivity and pH

Electrical conductivity (EC) and pH of the soil were not significantly influenced due to different crop establishment techniques. However, the maximum value of EC was recorded under ZT (0.358 dS/m) followed by RB (0.343 dS/m) and lowest in CT (0.335 dS/m). Whereas, maximum value of pHwas recorded under ZT (7.82) followed by RB (7.77) while least was recorded under CT (7.68). In general, Zero tillage system of crop establishment resulted slightly higher values of both EC and pH than corresponding RB and CT. Similarly, EC values were also found slightly higher under residue applied treatments than corresponding no-residue applied treatments.

Organic Carbon

Soil organic carbon determined in 0–15 cm depth was significantly influenced by crop establishment techniqueand residue management practices (Table). The maximum value of Organic Carbon was recorded under ZT (0.42%) followed by RB (0.40%), while minimum value recorded under CT(0.36%). In general, zero tillage gave 13.2% higher organic Carbon over conventional tillage practices. Similarly the data also revealed that crop residues application significantly influenced the SOC. On the other hand, Soil organic carbon was not influenced significantly due to different irrigation schedules.

Available NPK

Statistically analysis of the data indicated that available N and K status in soil (after completion of 2 years research study in maize – wheat cropping system) was significantly influenced due to different crop establishment techniques, however P is not significantly influences due to different crop establishment techniques . However, maximum available N and K was recorded under ZT while minimum under CT. However different irrigation scheduling and residue application did not significantly influence the available N and K status in soil at the end of cropping cycle.

Soil Biological properties

Microbial Biomass Carbon

Microbial Biomass Carbonwere determined at end of the research experiments and data have been presented in Table 4.30 .The highest microbial biomass carbon was recorded with RB, which was significantly higher than rest of treatments while the significantly least MBC recorded with CT. The maximum MBC were recorded under

with residue plot while minimum were obtained under without residue treatment. Moreover residue application also enhanced soil MBC, which was significantly higher than non residue.Soil biological property like MBC was significantly influenced due to different irrigation regimes at the end of 2 year cropping cycle. The highest values of MBC were recorded at irrigation given at 60% ASMD as compare to CWSI and critical growth stage.

Basal Soil Respiration

Basal Soil Respirationwere determined at end of the research experiments and data have been presented in Table 4.30 .The highest Basal Soil Respirationwas recorded with RB, which was significantly higher than rest of treatments while the least with CT. Similarly significant higher BSR were recorded under with residue treatment while minimum under without residue treatment. Soil BSR was significantly not influenced due to different irrigation regimes at the end of 2 year cropping cycle.

Table4.30: Soil biological properties(0-5cm) influenced by tillage practices, irrigation regimes and residue management in maize-wheat cropping system(at the end of 2 years crop cycle)

Treatments	MBC(µ g C/g soil)	SBR(µg CO_2/g/day)
Crop establishment method		
RB	308.13	23.10
ZT	287.70	22.89
CT	239.60	24.74
SEm±	1.97	0.14
CD (P = 0.05)	7.75	0.56
Irrigation scheduling		
CGS	271.61	23.92
CWSI	272.15	23.04
60%ASMD	291.66	23.77
SEm±	4.07	0.94
CD (P = 0.05)	12.55	NS
Residue management		
With mulch	288.96	25.01
without mulch	267.99	22.15
SEm±	4.56	0.91
CD (P = 0.05)	13.55	2.71

RB - Raised bed, ZT - Zero tillage, CT- Conventional tillage, ASMD- Available soil moisture depletion

CGS – Critical growth stage, CWSI – Crop water stress index

Chapter 5

DISCUSSION

Water availability is becoming lesser in agriculture sector for irrigation due to the competition between industrial and domestic sectors. It seems that food production per unit area has attained saturation. So, the concept is slowly changing from increasing food production per unit area to per unit of water. Improved land and water management practices over the last two decades have improved water productivity globally. Conservation agriculture practices have gained importance to make farming more profitable by cutting down the variable cost, and enhancing resource-use efficiency and soil health. This methodology is now being used on over 124 million hectares of land worldwide (Lal, 2004). There is thus, a need for working out the effects of various irrigation scheduling methods and conservation agriculture practices in Maize–Wheat cropping systems for improving productivity, resource-use efficiency and soil health.

In view of these considerations, a field study on entitled **"Effect of conservation agriculture practices and irrigation scheduling on water use and productivity of maize – wheat cropping system"** was conducted during 2011-12 and 2012-13 at Indian Agricultural Research Institute, New Delhi. The important findings of this study have been discussed under the following headings with possible scientific bases, providing a logical analysis of cause and effect relationship. The findings of earlier workers on the subject have also been taken into account while discussing the results of the present experimentation.

5.1 Crop growth, yield and nutrient uptake
5.2 System productivity and profitability
5.3 Resource-use efficiency
5.4 Soil physico-chemical and biological properties

5.1 Crop growth, yield and nutrient uptake

5.1.1 Maize

Growth parameters *viz.*,plant height, dry matter accumulation(DMA), leaf area index(LAI) and growth indices of maize responded differentially due to different crop establishment techniques and irrigation scheduling.

The plant height, DMA and LAI were higher under permanent raised bed (RB) in both 2011 and 2012. Maize is a waterlogging sensitive crop so within the genetic limits higher yield of crop can be realized under favourable crop environment condition. Growing maize on beds avoids the adverse effect of short-term waterlogging during heavy rains and results in more efficient use of irrigation water and nutrients as well bed offer better drainage condition and reduced possibility of aeration stress, consequently resulting better root growth of maize. Crop growth indices *viz.* crop growth rate and relative growth rate are governed by DMA and LAI achieved by crop since value of these two parameter higher with RB so better crop growth indices were also indicated in these treatments. Similarly, residue application improves the physical condition in the soil. It provides plant nutrient and source of energy for soil microbes. In conservation tillage crop residue left on soil surface protect the soil against crusting and surface sealing, reduce soil compaction and temperature, conserve soil moisture as well increase macro porosity and root growth. Ram (2006) also reported the higher values of plant height, DMA, LAI, CGR and RGR under residue than no-residue under both ZT and CT practices.

The improved growth parameters led to increased cob length, grain rows/cob grains/row, and cob yield/ha. The maximum cob length and grain rows/cob was observed in RB during both the years. This might be due to better early vigour and growth of maize seedling under bed planting during continuous rainfall. Further, LAI might helped in better photosynthesis and assimilation rate resulting in more dry matter and better growth indices, which ultimately showed effect on cob length and grain rows/cob. Better performance of maize under RB was probably because of no adverse effect on germination, good crop establishment and better anchorage of roots. The highest grain, stover and biomass yields of maize were observed in RB. The grain yield was significantly increased under RB planting to the tune of 13.3% over CT during 2011 and 2012, respectively. Raised bed might have offered more effective control of irrigation, moisture conservation and drainage, reducing short term

temporary aeration stress under high rainfall condition. The significant improvement in maize yield under RB also reported by

Different irrigation scheduling also significant effect on growth parameters, yield attributes and yield performance of maize. The higher growth parameters under 40% ASMD was might be due to better growth of roots and shoots because of optimum soil moisture availability under this irrigation regime. In later part of the crop maize performed better under 40% ASMD than 60% ASMD practice. The lower growth parameters of maize under 60% ASMD was might be due to more competition for water and nutrients, poor root growth, and thus reduced the growth of maize. Higher soil moisture depletion was observed at 60% ASMD. This was due to more extraction of water by crop roots from deeper layers under drier regime due to limited availability of moisture in upper layers. The total water depletion from soil profile varied significantly with number of irrigations applied. The deficit treatment extracted more water from deeper layer than in non-deficit treatment. In general, moisture extraction was maximum from upper soil irrespective of irrigation treatment and year and decreased with soil depth.

Ram *et al.* (2010) reported higher yields under ZT with residue due to the cumulative effects of higher light interception more dry matter production, low soil and canopy temperature, more soil moisture, tillers, grains/ear and 1000-grain weight than no-residue application under ZT as well as CT practices. Improved grain yield due to straw mulch in maize under no-tillage and permanent bed planting was also reported in earlier studies by Tolk *et al*., (1999) and Govaerts *et al*., (2005).

5.1.2 Wheat performance

Wheat crop performance varied due to weather condition particularly rainfall and temperature during growth period. More favorable weather condition in 2012-13 including good rainfall as well no terminal heat stress and congenial weather conditions at the time of sowing led to better performance of crop. Growth of wheat plant in terms of plant height, dry matter production and leaf area varied due to crop establishment techniques, irrigation scheduling practices and residue management at all the growth stages of wheat during both years. The plant height was marginally higher with RB compared to ZT and CT. However, at middle stages no significant

variation in plant height was observed with crop establishment practice. The DMA and LAI were also higher on the beds because wheat accumulated high dry matter in RB compared to ZT treatments, which can be ascribed to good light interception, optimum soil moisture content in the top of the bed which consequently led to higher dry matter accumulation on RB. Raised bed sowing might have provided comparatively higher nutrient and water supply and thereby triggered better vegetative growth.

Among yield attributes, grain weight/spike, effective tillers/$m^2$and test weight showed improvement due to crop establishment practices in both 2011-12 and 2012-13. The number of spikes/m^2 was significantly greater in raised bed. These results indicate that crop sown under raised bed at uniform row spacing led to increased number of effective tillers/m^2.In general, the values of these yield attributes increase with residue application compared to no residue application. All the productivity parameters wheat (grain, straw and total biomass yield) were higher on RB, than ZT and CT. The percentage increase in grain yield under RB was 12.7 and 6.3%, while in ZT it was 5.8 and 2.1% over CT in 2011-12 and 2012-13, respectively. It indicates that these CA based tillage practices (ZT and PB) leads to efficient utilization of source for higher sink (grain yield) advantage. It shows that CA practices improve the source-sink relationship. The narrow raised-bed (40 cm top width and 30 cm furrow width) accommodating 3 rows/raised-bed might have produced enough productive tillers to compensate the number of plant rows (20 cm apart) on the same land area as compared to ZT and CT. Optimum spacing of wheat crop on these raised-beds probably create optimum resources utilization among plants, subsequently produced higher productive tillers. Moreover, bed-planting system decreased the humidity in the crop canopy, which is helpful to reduce disease incidences as well as crop lodging. Adoption of permanent raised beds led to controlled traffic, thereby providing a healthy root environment than other crop establishment techniques. Ram *et al*. (2012) reported higher wheat yield on narrow raised-bed possibly due to better canopy photosynthesis in wider spacing producing longer spikes which compensated lower tiller and spike density compared to CT.

Similar to crop establishment technique, significant effect of residue management was observed on growth parameter and yield attributes like grain

weight/spike, effective tillers/$m^2$and test weight. In general, the values of these yield attributes increases with residue application. All the productivity parameters of wheat (grain, straw and total biomass yield) were higher on residue applied plot than non residue applied conditions because application of residue on soil surface reduce water losses from the soil by evaporation, moderate soil temperature, promote biological activity and enhances nitrogen mineralization, especially in the surface layers, which will helpful to increase these yield parameter. Cover crop and previous crop residue reduces weed infestation and suppress the germination of weed seeds. Govaerts *et al*. (2005) reported that permanent bed planting along with rotation and residue retention had the advantages in yield potential of wheat and maize. Thus residue management under RB planting and ZT improved the productivity of crops. Sayre and Moreno (1997) reported that higher adoption of bed planting in Mexico was due to application of irrigation, less use of herbicides, insecticides and seed besides ease of mechanical cultivation. It was expected that in bed planting availability of nutrients to crop roots increased at optimum supply of water might be helpful in sustaining crop yield with less seed rate, less fertilizer and less water. Yadav *et al*. (2002b) also reported higher number of grains/spike and spike density of wheat planted on raised beds than conventionally sown wheat on flat. The lower tiller and spike density on beds were compensated by more grains/spike and higher grain weight. The physical, chemical and biological properties of soil were improved with residue application. Mulching favoured conditions for growth of earthworms as it moderated hydro-thermal regimes and provided organic food to the earthworms (Acharya *et al.*, 1998). The earthworms create better aeration in soil and favour for *Rhizobium* bacteria for nodulation. However earthworm population was not studied in this experiment, but had been seen more in residue plots prior to sowing of next maize crop after wheat.

Similarly, wheat performance also influenced due to different irrigation scheduling practices. However, marginally higher values of growth, yield attributes and yields were recorded under critical growth stage (CGS) than other irrigation scheduling, this was might be due to optimum soil moisture provide uniformity in plant population, which results equal competition amongst plants for resources like nutrients, moisture, light and space which were almost equally available for every treatment. General, the soil moisture extraction decreased with the soil depth under all treatments. This could be attributed partly because of more evaporation from exposed

soil surface and partly because of more proliferation of roots in the top soil layer. More moisture extraction from deeper layers under stress conditions may be due to greater penetration of roots in search of water under dried surface layers. The roots tend to grow deeper in search of water under stress but it tends to proliferate in surface layer adequate soil moisture. Such shift in water extraction under irrigated and non irrigated environment has also been reported by Solomon *et al*., (2003) and Pal *et al*., (2001).

5.2 System productivity

The ultimate effect of experimental variables is reflected on the final yield of crop and, thus, it is a major criterion to identify the efficiency of various treatments under a given situation.The highest system productivity in term of maize equivalent yield (MEY) was recorded under RB (9.92 t ha^{-1}) followed by ZT while minimum observed under CT (8.63 t ha^{-1}) during both the years. This was due to good crop growth, resulted in higher values of yield attributes and ultimately yields under these treatments. Both Maize and wheat crop performed significantly better under RB thus contribution of both crops resulted in higher productivity of the system under these treatments. Similar to crop establishment technique, higher system productivity were also recorded under residue management treatments. Moreover, residue application improved the soil physio-chemical and biological environment in the soil through addition of nutrients, enhanced microbial activity (Singh *et al.,* 2009a). Jat *et al.* (2005) reported that productivity of maize-wheat system was maximum (10.84 t/ha) under furrow irrigated raised bed (FIRB) system of planting followed by ZT and CT systems, respectively. The system productivity of maize- wheat cropping system was higher under CGS irrigation scheduling practices which was due to good crop growth, lower crop ETs, higher values of yield attributes and yields under these treatments. Similar finding were also reported by (Jat *et al*., 2010).

5.3 Crop and system economics

The total cost of cultivation varied due to crop establishment technique, irrigation regimes and residue application across crop as well as at the system level. This was mainly due to differences in land preparation and weed control/herbicidal application across the crop establishment practices and residue application. Labour, implements and fuel were required lower under RB. In maize and wheat, highest cost

of cultivation was observed in CT practices .The benefit to cost was much higher in RB practices due to twin reasons *viz*; lower production cost and enhancement in yields, which lead to increase in net returns of wheat by 14-24% and B:C by 24-32% over CT during both the year. The lowest cost of cultivation, highest net returns and benefit: cost ratio recorded under RB was due to comparatively better yields performance, saving of cost of seeds and irrigation water and its application cost, lower weed infestation and lower labour cost involved in harvesting of crops under these treatments. In maize RB gave 30-31% higher net returns while ZT gave 12-14 % more net return over CT similarly, for wheat the maximum net returns and benefit: cost ratio were recorded under RB (44633 and 48580 ₹/ha, 2.08 and 2.26) but minimum net returns and benefit: cost ratio were obtained under CT (33711 ₹/ha and 41,348 ₹/ha, 1.39 and 1.70) in 2011and 2012, respectively. The similar results were also reported by Singh *et al.* (2014) at Udaipur. In contrast, Pal and Bhatnagar (2014) reported higher net returns in CT at Pantnagar due to lower yield of maize in heavy soil with ZT practices. The positive effects of sowing on bed and residue retention witnessed on productivity were translated into more favorable economics. Raised Bed planting is reported by several researchers to be economical as well as ecologically-viable as compared to CT due to savings in labour, fuel, repair and machinery overhead charges and less emission of greenhouse gases (Singh *et al*., 2001; Zentner *et al*., 2002). The highest net returns and benefit: cost ratios were also reported in maize–wheat–greengram system practiced under zero tillage and crop residue retention (Gathala-Mahesh *et al.*, 2013). Cost of irrigation and its associated cost for labour made variation in the total cost for irrigation treatment applied in maize-wheat cropping system. The highest net return was affected due to irrigation scheduling but gain from higher yield is greater than the associated irrigation cost in our study.

The higher net returns with RB and ZT were also reported by Parihar *et al.* (2011), Khatri *et al.* (2014) and Paudel *et al.* (2015).

5.4 Nutrient uptake

The crop establishment techniques brought significant differences in the nutrient uptake particularly N and P by the maize – wheat cropping system. The higher average total N, P and K uptake under bed planting by the maize-wheat cropping might be due to better root growth leads to more extraction of nutrient from

soil, lower weed infestation and better performance of crops particularly by maize under water logging condition, thus all these reasons might contributed to higher uptakes of nutrients under bed planting than flat sowing. The higher concentration of these nutrients along with higher yield ultimately leads to higher uptake (as uptake is derived by multiplication of nutrient concentration in grain and stover with respective yields). Moreover, these nutrients (NPK) are synergistic to each other in nature and uptake of one enhances the uptake of other as well. The higher concentration of N in grain caused enhancement in protein content of maize as this is one of the essential part of amino acid and basic unit for protein synthesis. The similar finding of higher NPK uptake under conservation agriculture were also reported by Alam *et al.* (2014) and Naresh *et al.* (2014). Singh *et al.* (2007a) reported that total N uptake by maize was highest (67.46 kg/ha) under bed planting than flat sowing of maize. On RB higher root length density and root surface were mainly due to fact that beds were formed after normally tilling the soil in fresh tillage (surface of beds ware higher by 20 cm than flat sowing) which results in more loose soil on beds. Because of this reason, the mechanical impedance offered was relatively less in upper 0-40 cm of soil under fresh beds hence root growth was significantly higher there. The higher nutrient uptake in wide raised beds is mainly due to less leaching loss of nutrients and availability of sufficient moisture for mineralization of native as well as applied nutrients. The higher uptake efficiency of nutrients depends on a myriad of factors including nutrient availability due to favorable soil biota under crop establishment techniques compared to CT. The maximum N, P and K uptake were recorded under residue applications treatment, this was might be due to addition of nutrients through residue, improved physical environment favorable for better microbial activity that might helps in mineralization of native nutrient resulted in better availability of nutrients (macro and micro) to crops and thus increased the uptake under these plots.

5.5 Resource-use efficiency

5.5.1 Energy use efficiency

Like crop productivity and profitability, resource-use efficiency (e.g. irrigation water-use, nutrient-use and energy-use efficiencies) responded differently to different tillage and crop establishment and residue management practices. The total input

energy in CT was higher than ZT and RB and the lowest energy was consumed with RB (28,030 MJ/ha), compared to CT (30, 6809 MJ/ha) wheat crop. The wheat planting under RB practices resulted in higher energy use efficiency by 21-23% and output energy by 8-10% over CT. The higher energy efficiencies might be due to two reasons; either due to less energy consumption by RB compared to CT and higher production (which leads to more energy output per unit of energy used) or both for production of wheat. The energy accumulation capacity was higher in RB due to better crop growth environment in terms of higher nutrient availability, better root growth and modulation of climatic conditions with better water retention.The output energy was higher with residue application but the net energy balance and energy-use efficiency of the system were higher with no residue treatment. Higher energy consumption through residue application lowered the energy return, energy-use efficiency and energy productivity. The similar findings of higher energy output under RB were also reported by Chaudhary *et al.* (2006) and Parihar *et al.* (2011). The enhanced energy efficiency in CA practices compared to CT was also reported by Ram et al (2010) and Parihar *et al.* (2011). Zero tillage practices reduce the energy requirement due to saving of energy in land preparation and weeding operations (Jain *et al.,* 2007). Among the irrigation regimes CGS based irrigation schedule recorded the highest output energy and highest energy use efficiency for the wheat crop. It was due to the good yields of the wheat.

5.5.2 Irrigation water-use efficiency

The maximum Irrigation water-use efficiency **(**IWUE) was recorded under RB during both the year, this was might be due to reduction in wastage of water than the flat system, more grain yields and less application of irrigation water in RB during the year 2011-112 and 2012-13, respectively. The percentage increase in IWUE in wheat was found higher in RB (32.1% and 40.1%) over CT while in ZT it was 12.2% and 8.5% during 2011-12 and 2012-13 respectively. In maize irrigation requirement in RB was lower (81mm) than CT (117mm) and the saving in irrigation water to the tune of 30% and 38% during 2011 and 2012 while in ZT it was 14% and 9% respectively while for wheat there was saving in irrigation requirement in RB to the tune of 22.3% and 36.5% as compared to CT during 2011-12 and 2012-13, respectively.

The crops were planted on the raised bed and irrigation was applied through the furrows. The bed surface remains almost dry and the lateral water movement fulfills the crop water requirement. The infiltration rate of the furrow bottom remains almost zero due to compaction developed by tractor and machinery movement and irrigation which facilitates the lateral water movement of irrigated water into the bed area. The use of furrows/beds hastens the speed with which irrigation water reaches the other end of the field and thus reduces irrigation amount, as the furrows occupy less than half the area of the field**.** Hence, the grain yield (output) was more with per unit of water applied in maize-wheat production system under Raised bed (RB). Similarly, higher WUE was also reported in bed planting (Ram *et al*., 2010). The better root growth (Aggarwal *et al*., 2006) and lower infestation of weeds on the beds was might be other possible reasons of higher IWUE under RB. In wheat IWUE was higher during 2012-13 than 2011-12 due to higher grain yield as well as less numbers of irrigations was applied due to good distribution of rainfall in the year 2012-13. The higher infiltration rate (Ferrreras *et al.*, 2000) as well as hydraulic conductivity (Chen *et al.*, 2014) also maintains better water dynamics under Permanent bed (PB) and ZT practices compared to CT, which leads to better water availability to crop. The enhancement in water productivity by adoption of ZT and PB practice over CT was also reported by Jat *et al.* (2005) and Parihar *et al.* (2011).

There was saving 36.4% and 45.2% of irrigation water under 60% ASMD as compare to CGS based irrigation schedule during 2011-12 and 2012-13, respectively. The main reason for the higher IWUE in 60%ASMD method could be due to the uniform distribution of irrigation water, lower evaporation from the soil surface and easy availability of water and nutrients within the root zone. Also since evaporation from this is minimal, transpiration is increased and increasing transpiration improves stomata opening, and photosynthesis. Generally, efficient irrigation systems and efficient irrigation scheduling methods not only led to a considerable reduction in applied water but also led to a significant increase in yield compared to conventional irrigation methods.

5.6 Soil properties

5.6.1 Soil Physical properties

Soil physical properties, viz. bulk density (BD), hydraulic conductivity, infiltration rate, moisture content and soil aggregation were significantly influenced due to different crop establishment techniques. Bulk density (BD) is used to quantify soil compactness affecting germination and crop growth, varies with management as well as with inherent soil qualities.

In general, BD of the surface soil layer (0 – 15 cm) was less as compared to sub-surface soil layer (15-30 cm), and slightly less on raised beds compared to flat beds. The more organic matter content and lesser trafficking of machinery and tractors in farm operations might lead to lower down the BD of RB compared to CT plots. This variation was presumably due to favourable role of soil organic matter present on surface layer and continuous tillage making soil more porous. The highest value of soil BD under ZT in surface and sub-surface layer may be due to non-disturbance of the soil matrix, which resulted in less total porosity compared to CT and bed systems (Bhattacharyya *et al*., 2008). However, crop residue decrease the soil BD under ZT practices by improving soil aggregation, organic matters content in soil that might helps in improving the porosity of soil. The similar findings of lower BD values were also reported by Salem *et al.* (2015). Contrary to this, Ram *et al*. (2010) also reported that soil BD in continuous-tillage was significantly higher than sequential fresh-bed and permanent-bed treatments.

In our study, hydraulic conductivity was higher under beds than CT and residue applied treatments than no-residue applied treatments. The lower hydraulic conductivity of CT practices was might be due to higher BD and compaction in surface as well as sub surface layers which restrict the water flow in the soil. The hydraulic conductivity (*K*) was lower in deeper soil layers as compare compare to top soil layer of 0–15 cm depth in all the treatments. The maximum value of *K* was measured under RB (16.67 cm/day) in 0–15 cm soil profile. The highest *K* in all the three irrigation schedules was recorded in CGS at 0-15 cm depth. The higher value of *K* under ZT and Permanant bed (PB) were found due to greater number of macrospores and higher biological activity helps in formation of soil organic matter which resulted in increased soil *K*. The hydraulic conductivity of soil is more related with soil macro-pores (Rasse *et al.*, 2000) and disruption of macro-pores continuity by tilling of soil can reduce hydraulic conductivity. Similarly, lowered infiltration rate was observed with CT, while the highest was observed with RB. The infiltration rate

was also highest with residue application. In general, the rate of infiltration increased with residue retention/ incorporation in all the tillage treatment. But surface residue retention in RB and ZT showed higher rate of infiltration compare to non residue incorporation treatment. In general, infiltration was greater under RB than in tilled soils due to the larger number of macro-pores (McGarry *et al*., 2000) as a result of increased fauna activity and accumulated organic matter forming a litter of residues (Arshad *et al*., 1999). In contrary, Disruption of macro-pore continuity by tillage can reduce infiltration. In contrast to this, beds having loose soil on the top as well as near the soil surface which permits, the easy water flow in surface as well as sub surface layers of soil profile. The increase of hydraulic conductivity and infiltration rate by RB system was also probably due to better root growth and continuous channels formed by decaying roots serve as routes linking the soil surface to deeper layers and this corroborate with the findings of Williams and Weil (2004). Residue increase the hydraulic conductivity and infiltration rate as it add the organic matter in the soil which improves the soil macro aggregates that might facilitate easy movement of water in the soil. The effect of different irrigation scheduling practices on soil physical properties was found non-significant. However, in CGS treatment higher mean weight diameters were recorded than other irrigation scheduling treatment.

In our study, soil moisture content in RB was slightly lower than ZT, whereas in CT it was found the lowest among all the crop establishment practices. The management of soil through tillage have ability to changes the water storage and evaporation losses dynamics of soil profile.

The aggregate size distribution and stability are important indicators of soil physical health. The stability of soil aggregates was evaluated in terms of mean weight diameter (MWD), % distribution of micro-aggregate (<0.25mm) and macro-aggregate (>0.25 mm). The proportion of macro-aggregates was lower in the CT compare to ZT and there was a corresponding increase in the proportion of micro-aggregates in the CT. In comparison to ZT and RB lower MWD was also observed with CT but, MWD was higher with ZT in both tillage practices. The macro-aggregates are less stable than micro-aggregates, and therefore, more susceptible to the disruptive forces of tillage. The reduction in macro-aggregates and MWD with CT could be mainly due to mechanical disruption of macro-aggregates from frequent

tillage, resulting reduced aggregate stability. Tillage increases the effect of drying–rewetting and freezing–thawing, which increase macro-aggregate susceptibility to disruption (Mikha and Rice, 2004). In general residue application increased the MWD and macro-aggregates over no-residue treatments in both the tillage systems. Fresh residues contain Carbon source for microbial activity induces the binding of residue and soil particles in to macro-aggregates. Soil organic carbon and labile C fractions play important roles in aggregate stabilization. Labile C fractions act as cementing agent that form micro-aggregates into macro-aggregates. Besides disruption of macro-aggregates by tillage, reduction in labile C fraction was also responsible for macro-aggregate disruption as suggested by Bronick and Lal (2005). Many investigators have also found more macro-aggregates in ZT compared with CT soils (Six *et al*., 2000; Mikha and Rice, 2004).

5.6.2 Soil chemical properties

Most of the soil chemical properties, viz. pH, EC, soil available P were not influenced due to different crop establishment practices, except soil organic carbon, available N and K. Generally, soil pH decreased under residue applied practice may be attributed to the formation of organic acids from mineralization of crop residues in the surface layer of ZT soil (Ismail *et al*., 1994), and by surface application of chemical fertilizers. The amount of salt reduced in ZT with crop residue might be due to enhanced soil structure and water infiltration, decreased evaporation and increased soil moisture content, and leaching of salts out of top surface layer (Patino-Zúñiga *et al*., 2009). Thus, decrease trend in EC and pH were associated with residue application.

In our study soil organic carbon (SOC) was also changed significantly due crop establishment and residue management practice. ZT recorded higher organic carbon in comparison to CT and ZT and residue application increased the SOC in the surface soil. The carbon build up in soil was due to application of the more residues in ZT and RB than CT .Intensive tillage hastens SOM decomposition and reduces the carbon content by increasing the access of microorganisms to SOM upon aggregate destruction. Moreover, the roots of the crops were also remained indicted in the root zone due to non-disturbance of the soil, which might facilitates movement of organic carbon in deeper root zones through capillaries formed due to the their decay. In

addition to this, the more tillage increases the oxidation of SOM while ZT reduces it due to less mixing with soil. Availability of NPK was more in ZT over CT as well more in surface residue than without residue application. All soil chemical parameters were not influenced due to different irrigation scheduling practices. However, marginally improved soil health was observed under CGS (critical growth stage) criteria of irrigation scheduling. Most comparative field studies have shown that ZT results in greater accumulation of SOM in surface layers (0–20 cm) than CT (Govaerts, *et al.,* 2007).

5.6.3 Soil biological properties

Generally microbial biomass carbon (MBC) and basal soil respiration (BSR) showed higher values with RB and crop residue application. MBC represents the living component of the organic matter, acts as a substrate for soil micro-organisms, not only improves soil structure and water retention but also serves as a nutrient reservoir for plant growth. The higher MBC under RB with residue were might be due to better aeration and more organic matter content under these practices and addition of crop residue as well as decomposed roots. The greater seasonal variation in the MBC in the frequent till than long term ZT treatment could be due to the greater variations in the micro environments of the soils (water content of soil and soil temperature). Basal soil respiration (BSR) is one of the oldest and still the most frequently used parameter for quantifying microbial activities in soils. The highest BSR was observed with CT, The BSR was significantly higher with Residue application. The BSR is related to carbon availability in biomass, and is generally higher at the soil surface because of greater biological activity. Variability of soil respiration in this study might have been resulted from the micro-climate created by tillage and crop establishment treatment, availability of substrate provided by crop residues and micro-organism density. Many investigators have also earlier reported the same results by Valpassos *et al*. (2001).

Chapter 6

SUMMARY AND CONCLUSION

A field experiment was carried out at ICAR- Indian Agricultural Research Institute, New Delhi, India during *Kharif* and *rabi* season of 2011-12 and 2012-13 on sandy loam soiltostudy "**Effect of conservation agriculture practices and irrigation scheduling on water use and productivity of maize – wheat cropping system"**. The salient findings of the experiments are summarized as below.

- Plant height of the maize was better during 2012 in comparison to 2011due to treatment effect on height favorable weather conditions during the season.Maize recorded significantly maximum dry matter accumulation (DMA) at 90 DAS during both the years. The significantly highest DMA was recorded under 40% ASMD compared to other irrigation scheduling.

- Similar to DMA, significantly highest leaf area index of maize was also recorded under raised bed (RB) followed by zero tillage (ZT) and lowest inconventional tillage (CT) during both the years of study.CGR recorded gradual increase with enhancement of growth stages with maximum values at 60-90 DAS while the RGR recorded a reverse trend in comparison to CGR.

- The grain rows/cob and grains/row of maize were significantly influenced due to crop establishment techniques. However, cob length, cob/plant and cob girth were statistically similar in both the years in all crop establishment methods. The maximum values of yield attributing traits were recorded under RB while minimum under CT.

- The grain yield was significantly higher under RB planting to the tune of 13.3% over CT during both the years. Significantly lowest grain, stover and biological yields were obtained under 60% ASMD as compare to other irrigation schedules.

- Highest cost of cultivation was observed in CT practices and lowest with RB. Significantly highest net return and benefit:cost ratio during 2011 (33830 ₹ /ha and 1.28) and 2012 (35321 ₹/ha and 1.34) were obtained with RB

practices. Amongst irrigation regimes 40% ASMD produced significantly highest gross return, net return and B C ratio over other irrigation regimes.TheRB planting gave 31% and 30% while ZT gave 14% and 12% more net returns in maize over CT during 2011 and 2012, respectively. In general, RB planting gave 36.77% and 36.00% higher benefit: cost ratio over CT during 2011 and 2012, respectively.

- During 2011, the highest gross output energy was produced under RB (171.10 x 10^3 MJ/ha) followed by ZT (158.29 x 10^3 MJ/ha) and the lowest in CT (150.79 x 10^3 MJ/ha). The maximum energy use efficiency (3.91 and 4.01) was recorded under RB while the lowest energy efficiency was estimated (3.28 and 3.35) under CT during 2011 and 2012, respectively.

- The irrigation requirement in RB was lower (81 and 44 mm) in comparison to CT (117 and 71 mm) .The saving in irrigation water to the tune of 30% and 38% in RB and 14% and 9% in ZTwas found during 2011 and 2012, respectively.In general,water requirement in RB (320mm and 324mm) was lower than CT (356mm and 351 mm) during both the years, respectively. In terms of percentage saving of water under RB was 10% and 7.6% while in ZT it was 4% and 1.7% over CT during 2011 and 2012, respectively.

- Remarkably higher IWUE/water productivity (kg grain m^{-3} water) of maize was recorded in RB planting (545 and 1049) followed by ZT (391and 615) and the lowest in CT (327 and 553) system during both the years, respectively. The percentage increase in IWUE was higher in RB planting (40% and 46%) over CTin comparison to ZT(16% and 10%) over CT during 2011 and 2012, respectively. Similarly, there was higher field-WUE (FWUE) under RB and it was 22% and 20% higher over CT during 2011 and 2012, respectively.

- In wheat, the tallest plant height (52.62) was recorded at 90 DAS under RBamong different irrigation schedules, plant height at 30 and 60 DAS was significant by higher with irrigations applied at critical growth stages (CGS) compared to CWSI and 60% ASMD.The highest dry matter (6.81t/ha and 6.40) was recorded at 90DAS under RB planting during first and second year,

respectively.Similar to DMA, significantly highest LAI was also recorded under RB and lowest under CT.

- Number of effective tillers/m^2 and 1000-grain weight were recorded significantly higher under RB planting of wheat followed by ZT and CT.However, different tillage practices did not influence the grain/ spike of wheat during both the years.The highest values of effective tillers/m^2 were recorded under irrigation based on critical growth stage. Similarly, higher effective tillers/m^2were recorded with residue application.

- In comparison to CT, the grain yield of wheat was higher under RB (6-13%), and ZT(2-6 %) during both the years, respectively. The results also revealed that the grain and straw yield were significantly higher under irrigation given at CGS.

- The maximum net returns and benefit: cost ratio were recorded under raised bed planting (44633 and 48580 ₹/ha, 2.08 and 2.26) of wheat during both the year, respectively. While minimum net returns and benefit: cost ratio were obtained under CT (33711 ₹/ha and 41,348 ₹/ha,1.39 and 1.70) in 2011 and 2012, respectively. In general, RB planting gave 15-25% while ZT gave 9-15% higher net returns over CT during both the year, respectively. RB also resulted in higher benefit: cost ratio (32.1% and 24.8%) over CT during both the year, respectively.

- The N, P and K uptake in wheat and maize was more in RB than CT. The maximum nutrient uptake by wheat and maize noticed when residue in both the crops was applied.

- In our study, RB gave 8-10% higher wheat output energy than CT during both the years, respectively. The highest output energy was obtained when the irrigations were scheduled at CGS and the lowest was observed with 60% ASMD in both the years. Maximum energy-use efficiency (9.23% and 8.20%) was recorded under RB while minimum under CT (7.22and 6.33%) during both the years of investigation.TheRB and ZT gave20-23% and 16-19% higher energy-use efficiency over CT, respectively during both the years of

study. The highest energy-use efficiency (8.59) in wheatwas observed under irrigations scheduled at CGS whereas minimum was estimated with 60% ASMD (7.21) during both the years of study.

- The maximum irrigation water requirement (314mm and 181 mm) was recorded under CT while minimum under RB (244 and 115mm) in wheat. There was saving in irrigation water under RB to the tune of 22.3% and 36.5% as compared to CT during 2011-12 and 2012-13, respectively. Amongst irrigation schedules , there was saving of 36.4% and 45.2% in irrigation water under 60% ASMD as compare to CGS based irrigation schedule during both the years, respectively.

- The water requirement of wheat in RB (312mm and 321mm) was lower than CT (382mm and387 mm) during both the years. The saving in water under RB was to the tune of 18.3% and 17.1% over CT during both the year, respectively. It was found that there was water saving to the tune of 18-30% under 60% ASMD over CGS during 2011-12 and 2012-13, respectively.

- The percentage increase in IWUE of wheat over CT was found higher in RB (32.1% and 40.1%)compared to ZT (12.2% and 8.5%) during 2011-12 and 2012-13, respectively. Different irrigation schedules also resulted in increasing IWUE of water and it was found that there was 20-28% higher IWUE under 60% ASMD compared to CGS during 2011-12 and 2012-13, respectively. In general, there was higher IWUE with residue application (12.2% and 13.8%) over without residue application during both the year of study.

- The percentage increase in FWUE was found higher in RB (28.7% and 21.8%)over CT. Different irrigation schedules also resulted in increased FWUE and there was 15.8% and 10.8% higher FWUE under 60% ASMD over CGS during both the years of study, respectively.

- The highest maize equivalent yield (MEY) of the maize-wheat system was recorded under RB followed by ZT and minimum under CT during both the years.The results also revealed that productivity of maize -wheat cropping

system were significantly influenced due to different irrigation schedules during both the years.

- At the end of two year study on fixed plots, the RB planting resulted significantly higher hydraulic conductivity(*k*) of different soil layers than other tillage practices. Similarly, residue application also resulted in higher *k* than no-residue application.The maximum infiltration rate (IR) was recorded under RB (1.92 Cm/hr), which was significantly higher than rest of the treatments, whereas, minimum IR was observed under CT (1.32 Cm/hr).The RB and ZT gave 16.9% and 17.2% higher IRover CT, respectively.

- In our study, ZT registered higher values of mean weight diameter (MWD)by 18.8% while RB gave14.4% higher MWD over CT. Similarly, with residue application gave 8.4% higher MWD over without residue. In general, RB planting gave 31.3% and ZT give 25.9% higher macro aggregatesover CT at theend of two years study in maize-wheat cropping system. In general, CT planting gave 9.3% higher micro aggregate over RB while ZT resulted in 7.4% lower percentage of micro aggregate over CT.

- The maximum value of soil organic carbon was recorded under ZT (0.42%) followed by RB (0.40%), while minimum value recorded under CT(0.36%) at the end of two years study. In general, zero tillage gave 13.2% higher organic carbon over conventional tillage practices. The maximum microbial biomass carbon (MBC) wasalso recorded with residue application while minimum were obtained under without residue application.

Conclusion

Study indicates that conservation agriculture system of RB was superior to CT inmaize-wheat systems for enhancing productivity and profitability.Tillage and different irrigation scheduling practices could bring out significant difference in maize and wheat productivity during both the years.Resource-use efficiency (e.g. irrigation water-use, nutrient-use and energy-use efficiencies) was also found superior in RB compare to CT.There was an improvement in organic C and available nutrients status with adoption of RB and ZT in maize-wheat system at the end of two cropping cycle at fixed plot. Similarly, the beneficial effect of residue management practices on

physicochemical properties of soil was also evident in RB.Therefore, conservation agriculture practice of RB may be recommended for higher productivity, profitability and resource-use efficiency in the maize-wheat cropping system.

FUTURE LINE OF WORK

On the basis of the findings of the present study, the following future line of work is suggested:

- Research on conservation agriculture needs to be carried forward on long-term basis in a fixed layout.
- This study needs to be continued further with exploring suitable replacement of crops so as to satisfy the basic principle of crop rotation of conservation agriculture.
- Water management and soil moisture dynamics aspects need to be critically studied on long-term basis.
- Carbon sequestration, soil quality index and climate change mitigation potentialunder conservation agriculture practices need to be quantified on long-term basis.

Effect of conservation agriculture practices and irrigation scheduling on water use and productivity of maize – wheat cropping system

ABSTRACT

A field experiment entitled 'Effect of conservation agriculture practices and irrigation scheduling on water use and productivity of maize – wheat cropping system' was carried out for two consecutive years at the research farm of ICAR-Indian Agricultural Research Institute, New Delhi, India, during 2011-12 and 2012-13 insandy loam soil.The water and energy use efficiency, growth, productivity and economic feasibility as well as soil properties of maize-wheat cropping systemwere studied under different conservation practices and irrigation scheduling. The treatments comprised of 3 crop establishment practices of raised bed (RB), zero-tillage (ZT), conventional tillage (CT) and 3 irrigation regimes viz. 40%,50%and 60% available soil moisture depletion (ASMD) for maize and crop growth stages (CGS),crop water stress index (CWSI) and 60%ASMD for wheat with this two residue application treatment. Weather condition varied over the years,which resulted in variable crop performance,resulted in better yield in the second year irrespective of treatments.The grain yield of maize was significantly higher under RB planting to the tune of 13.3% over CT during both the years. The RB planting in maize gave 31% while ZT gave 14% more net returns over CT. The maximum energy-use efficiency of maize was recorded under RB while the lowest under CT. The percentage increase in irrigation water-use efficiency (IWUE) of maize was 40-46% and 10-16% higher with RB and ZT over CT, respectively.Residue retention was more beneficial under RB than residue incorporation in CT.In wheat,6-13% higher grain yield under RB was found in comparison to CT. In general, RB planting gave 15-25% while ZT gave 9-15% higher net returns over CT in wheat during both the year. The percentage increase in IWUE of wheat was found higher in RB (32-40%) compared to ZT (8-12%)over CT as the grain yield was more with per unit of water applied under RB. The highest system productivity was recorded under RB followed by ZT and minimum under CT during both the years of study. The yield crops and system productivity improved due to application of crop residue.The results also revealed that system productivity of maize -wheat cropping system were significantly influenced due to different irrigation scheduling during both the years.The soil physical properties, viz. hydraulic conductivity, infiltration rate, soil aggregation, organic carbon as well as biological properties were improved with RB and ZT treatments compared to CT. It was

concluded that adoption of RB with crop residue along with 40% ASMD was essential for improving productivity and sustainability of maize – wheat cropping system.

“जल –उपयोग एवंमक्का –गेहूँफसल तंत्र की उत्पादिता पर संरक्षित खेती सम्बन्धी क्रियाओं एवं सिंचाई प्रबंधन का प्रभाव”

सारांश

बलुई - दोमट मृदामें सन२०११-१२ एवं २०१२-१३ के दौरान लगातार दो वर्षों तक भा.कृ.अनु.प.- भारतीय कृषि अनुसन्धान संस्थान, नई दिल्ली, भारत के अनुसन्धान प्रक्षेत्र पर, “जल-उपयोग एवंमक्का- गेंहूँफसल तंत्र की उत्पादिता पर संरक्षित खेती सम्बन्धी क्रियाओं एवं सिंचाई प्रबंधन का प्रभाव”, नामक शीर्षक से एक प्रक्षेत्र प्रयोग किया गया | विभिन्न संरक्षण एवं सिंचाई प्रबंधन क्रियाओं के अंतर्गत जल एवं ऊर्जा उपयोग क्षमता, वृद्धि, उत्पादिता और आर्थिक अनुकूलता तथा साथ ही मक्का- गेहूँ फसल तंत्र के मृदा - गुणों का अध्ययन किया गया | इस प्रयोग में दो फसलावशेष अनुप्रयोग उपचार सहित, मक्का हेतु ३फसल स्थापना क्रियाओं, उत्थित क्यारी (आर बी), शून्य जुताई (जेड टी), पारंपरिक जुताई (सी टी) एवं ३ सिंचाईप्रणालियोंअर्थात ४०%, ५०% एवं ६०% उपलब्ध मृदा नमी अवक्षय (ए एस एम् डी) तथागेहूँहेतु, फसलवृद्धिअवस्थाओं (सी जी एस), फसल जल प्रतिबल घातांक (सी डब्ल्यू एस आई) एवं ६०%ए एस एम् डी, उपचारों का समावेश था | इनवर्षोंके दौरान मौसम संबंधीपरिस्थितियाँपरिवर्तनशील रहीं जिसके परिणाम स्वरुप फसल का प्रदर्शन भी भिन्न भिन्न रहा और द्वितीय वर्ष में बिना किसी उपचार –प्रभाव के उपज बेहतर थी | दोनों ही वर्षोंमें, आर बी बुवाई के अंतर्गत,मक्का की दाना उपज महत्वपूर्ण रूप से सी टी की अपेक्षा १३.३% अथिक थी | मक्का में सी टी की तुलना में, आर बी बुवाई में ३१% अधिक जबकि जेड टी से १४% अधिकशुद्धलाभ प्राप्त हुआ | मक्का में आर बी के अंतर्गत उर्जा –उपयोग क्षमता अधिकतम जबकि सी टीके अंतर्गत न्यूनतम रेकार्ड की गई | मक्का में सी टी की तुलना में, आर बी एवं जेड टी के अंतर्गत सिंचाईजल-उपयोग क्षमता(आई डब्ल्यू यूई) में प्रतिशत बढ़ोत्तरी क्रमशः ४०-४६% एवं १०-१६% अधिक थी | आर बी के अंतर्गत फसल-अवशेष का बने रहना, सी टी में अवशेष मिलाने से अधिकलाभकारी पाया गया |गेंहूँ में,सी टी की तुलना में, आर बी केअंतर्गत दाना उपज ६-१३% अधिक पाई गई | दोनों वर्षों के दौरान गेंहूँकी फसल में, सीटी तुलना में, आर बी बुवाई द्वारा १५-२५% जबकि जेड टी द्वारा ९-१५% अधिकशुद्ध लाभ प्राप्त हुआ | गेंहू में,सी टी की तुलना में, आर बी (३२-४०%) एवं जेड टी (८-१२%) में आई डब्ल्यू यू ई में प्रतिशत बढ़ोत्तरीअधिक पायीगईक्योंकिआर बी के अंतर्गत,प्रति इकाई अनुप्रयुक्त जल के साथ दाना उपज अधिक देखीगई| इसअध्ययनके दोनों वर्षोंके दौरान, आर बी के अंतर्गत अधिकतमतंत्र उत्पादिता रेकार्ड की गई जिसके पश्चातजेड टी का स्थान रहा और सीटी के अंतर्गत न्यूनतम तंत्र उत्पादिता पायी गई| फसल अवशेष का अनुप्रयोग करने पर इन दोनों फसलों की उपज एवं तंत्र उत्पादिता में सुधार देखा गया | परिणामों ने यह भी दर्शाया की दोनों वर्षो के दौरान विभिन्नसिंचाईप्रबंधनोंका मक्का-गेहूँफसल तंत्र की तंत्र-उत्पादिता पर महत्वपूर्ण प्रभावपड़ा | सीटी की तुलना में आर बी एवं जेड टी उपचारों के साथ मृदा के भौतिक गुणों यथा, जलीय चालकता, निस्पंदन दर, मृदासमुच्चयन, जैविककार्बन अंश तथा साथ ही जीव विज्ञानसम्बन्धीगुणों में भी सुधार हुआ | यह निष्कर्ष निकला गयाकिमक्का गेंहू फसला तंत्र में अधिक उपज प्राप्ति हेतु फसल-अवशेष अनुप्रयोग एवं ४०% एएस एम्डी के साथ आर बी को अपनाया जाना चाहिए |

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ANNEXURE-I

Mean weekly meteorological data during 2011-12

Month	Std. Week	Rainfall (mm)	Temperature (°C) Tmax.	Tmin.	Sunshine (hrs/day)	RH (%)	Evaporation (mm)
July	27	0.0	36.3	26.8	3.0	71	4.2
	28	10.2	33.5	25.9	3.1	84	3.0
	29	18.2	33.5	25.6	2.5	77	3.8
	30	15.4	33.8	25.8	1.9	80	3.4
August	31	21.0	35.7	26.9	3.6	73	4.7
	32	52.2	33.0	25.9	3.3	87	3.2
	33	54.5	31.5	24.5	4.1	87	3.4
	34	96.7	33.1	25.3	4.0	83	3.0
Sept.	35	2.4	34.1	26.5	6.6	76	4.5
	36	113.8	32.5	24.4	3.0	90	2.4
	37	38.2	33.0	25.5	5.2	84	3.2
	38	11.6	32.9	24.0	7.8	81	3.3
Oct.	39	0.0	34.3	22.7	9.2	68	4.9
	40	0.0	34.3	21.6	9.0	65	5.0
	41	0.0	34.0	19.8	7.7	62	5.0
	42	0.0	33.1	15.8	7.8	55	4.2
	43	0.0	31.3	14.7	4.1	57	3.5
Nov.	44	0.0	30.9	13.4	5.3	57	3.3
	45	0.0	30.5	14.7	5.0	59	3.3
	46	0.0	29.1	12.8	6.6	58	3.2
	47	0.0	27.3	12.0	1.8	69	2.2
Dec.	48	0.0	25.6	9.8	2.8	61	2.8
	49	0.0	27.1	11.9	4.4	69	2.1
	50	0.0	22.0	5.7	3.9	63	2.6
	51	0.0	21.0	2.8	2.4	66	2.1
	52	0.0	20.1	1.7	1.9	71	1.7
Jan	1	6.6	19.5	8.8	0.0	85	1.5
	2	0.0	17.5	3.7	3.6	66	1.8
	3	8.2	17.4	5.6	2.0	77	2.3
	4	0.0	19.6	5.3	6.5	63	2.4
Feb.	5	0.0	21.0	4.6	6.8	65	3.1
	6	0.0	20.4	6.3	6.1	55	3.7
	7	0.0	21.7	8.2	5.4	53	4.3
	8	0.0	25.7	9.8	7.1	55	4.4
March	9	0.0	25.4	8.3	8.4	50	5.5
	10	0.0	28.5	11.3	6.1	51	5.6
	11	19.2	27.1	10.5	7.1	55	4.2
	12	0.0	31.5	14.9	6.5	46	5.5
	13	0.0	33.6	16.1	6.7	50	7.1
April	14	0.0	36.6	19.0	8.0	47	7.8
	15	6.8	34.5	19.8	6.8	61	6.7
	16	0.0	34.2	19.4	6.1	58	6.0
	17	0	37.5	19.0	8.4	53	7.5
May	18	0	35.7	19.7	8.7	43	8.3
	19	0	40.1	24.2	7.2	42	9.2
	20	0	39.3	23.6	5.4	42	8.2
	21	0	42.9	25.6	8.9	34	11.0
June	22	12.4	44.2	26.8	9.0	23	11.1
	23	0	41.3	26.7	6.3	37	8.9
	24	0	43.1	29.1	8.2	33	11.3
	25	0	42.8	29.8	7.7	36	10.3
	26	0	42.3	29.8	5.8	40	9.6

ANNEXURE-II

Mean weekly meteorological data during 2012-13

Month	Std. Week	Rainfall (mm)	Temperature (°C) Tmax.	Tmin.	Sunshine (hrs/day)	RH (%)	Evaporation (mm)
July	27	46.0	41.1	27.7	6.0	62	9.2
	28	63.4	33.0	27.8	3.4	79	4.7
	29	0.0	37.4	28.2	7.0	62	5.6
	30	0.0	35.5	27.5	3.2	69	6.0
August	31	54.0	33.4	26.3	1.4	80	3.7
	32	22.4	33.2	26.2	1.5	83	3.2
	33	33.8	33.1	25.5	5.1	78	4.5
	34	80.6	31.8	26.0	1.4	85	3.7
Sept.	35	113.6	31.8	24.6	1.3	84	4.6
	36	6.4	33.4	25.6	4.9	76	4.8
	37	32.0	33.8	26.0	4.2	75	4.1
	38	18.6	32.1	23.4	5.3	74	3.6
	39	0.0	34.0	21.3	9.5	66	5.2
Oct.	40	0.0	34.8	19.4	9.2	77	5.5
	41	0.0	34.4	17.2	8.4	63	4.8
	42	0.0	33.3	16.5	8.2	57	4.5
	43	11.0	30.1	13.9	5.8	64	3.1
Nov.	44	0.0	28.5	12.8	2.1	67	2.4
	45	0.0	28.0	12.3	1.3	63	2.0
	46	0.0	27.9	10.6	2.1	66	2.5
	47	0.0	26.6	7.8	6.0	56	2.4
Dec.	48	0.0	25.3	7.2	6.0	59	2.6
	49	0.0	23.9	5.5	6.0	51	2.5
	50	7.0	23.7	9.6	4.6	66	2.1
	51	1.6	22.6	8.8	5.0	67	2.9
	52	0.0	17.8	6.4	1.6	80	2.1
Jan.	1	0.0	11.8	2.0	1.4	83	1.3
	2	0.0	19.3	6.5	5.6	82	2.7
	3	40.8	19.4	7.4	1.9	83	3.4
	4	0.0	19.7	3.3	6.1	70	3.6
Feb.	5	0.0	22.6	6.9	2.8	70	3.0
	6	68.2	20.3	8.9	5.5	73	2.5
	7	25.8	21.7	9.6	4.8	74	2.8
	8	8.4	22.2	10.4	5.0	76	2.5
March	9	0.0	25.2	10.5	8.4	60	3.8
	10	0.0	29.9	11.9	6.1	61	5.0
	11	0.0	29.8	13.1	7.1	63.2	4.0
	12	0.0	32.5	16.6	6.5	57.2	5.5
	13	12.6	30.1	34.2	6.7	65.0	4.4
April	14	11.2	34.2	16.6	8.0	49.6	5.7
	15	0.4	36.9	20.4	6.8	48.4	6.8
	16	0.0	37.3	18.6	6.1	43.4	7.9
	17	0.0	36.0	21.7	8.4	46.6	8.1
May	18	0.0	39.6	21.8	8.7	42.1	10.3
	19	0.0	40.5	23.2	7.2	40.3	10.3
	20	0.0	41.8	22.7	5.4	33.2	8.8
	21	0.0	45.1	27.8	8.9	37.5	15.0
June	22	0.0	40.4	25.6	9.0	57.0	10.4
	23	9.8	41.2	28.0	6.3	63.6	10.2
	24	134.8	33.8	25.6	8.2	79.1	6.1
	25	2.2	38.1	26.8	7.7	62.2	6.8
	26	4.2	37.1	26.4	5.8	70.8	7.3

ANNEXURE-III

Prices of output used in economic analysis of different crops (`/t)

S. No.	Crops	Product	2011-12	2012-13	S. No.	Crops	Product	2011-12	2012-13
1	Soybean				4	Potato			
	i	Seed	16900	22400		i	Tubers*	4500	4500
	ii	Stover	1500	1500	5	Mungbean			
2	Wheat					i	Grain	35000	44000
	i	Grain	12850	13500		ii	Stover	2000	2000
	ii	Straw	3500	3500	6	Fodder sorghum			
3	Chickpea					i	Green* fodder	1000	1000
	i	Grain	28000	30000					
	ii	Stover	2000	2000					

Note: Prices of seed/grain are based on MSP of respective crops in experimental years
* Based on market prices

Price of inputs used in economic analysis

S. No.	Particulars	2011-12	2012-13	S. No.	Particulars	
1	FYM (`/t)	500	500	**1**	**Herbicides**	
2	**Fertilizers**				Pendimethalin	550/litre
	Urea (`/50 kg)	298	298		Metribuzin	235/100 g
	DAP (`/50 kg)	598	1260			
	MOP (`/50 kg)	380	892	**2**	**Insecticides**	
3	**Biofertilizers (`/200g)**	20	20		Rogor	340/litre
4	**Seed (`/ kg)**				Chlorphyriphos	260/litre
	Soybean	25	30		Carbofuran	80/ kg
	Wheat	30	35	**3**	**Fungicides**	
	Chickpea	85	90		Ridomil	1600/kg
	Potato	15	20		Dithane-M45	380/kg
	Mungbean	80	100		Bavistin	750/kg
	Fodder sorghum	25	30		Thiram	300/kg

ANNEXURE-IV

Estimation of common cost of cultivation of soybean (`/ha)

S. No.	Particulars	2011	2012
1.	Disking	1000	1000
2.	Ploughing by cultivator and planking	800	800
3.	Seed @ 80 kg/ha	2000	2400
4.	Sowing	1000	1000
5.	Weed control		
	ii. Chemical	1650	1650
	iii. Application	300	400
6.	Irrigation (` 500/irrigation)	2000	1500
7.	Plant protection		
	i. Insecticide/fungicide	340	720
	ii. Chlorpyriphos	1040	1040
	iii. Application	450	600
8.	Harvesting /8 man days	1200	1600
9.	Threshing/6 man days	900	1200
10.	Rental value of land (4 months @ ` 1000/ha/annum)	350	350
11.	Interest on capital (6%)	266	292
	Grand total	13296	14552

Note: Labour wage 2011 @ ` 150/man-day, 2012 @ ` 200/man-day

ANNEXURE-V

Estimation of common cost of cultivation of winter-season crops (`/ha)

S. No.	Particulars	Wheat		Chickpea		Potato	
		2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
1	Disking	1000	1000	1000	1000	1000	1000
2	Ploughing by cultivator and planking	800	800	800	800	800	800
3	Seed	3000	3500	6800	7200	37500	50000
4.	Sowing/planting	1000	1000	1000	1000	2100	2100
5.	Weed control						
	ii. Chemical	350	-	1650	-	705	-
	iii. Application	400	-	400	-	400	-
	iv. Hand weeding/earthing	1600	1600	1600	1600	1600	1600
6.	Irrigation@ `500/irrigation	3000	2500	1000	500	2500	2500
7.	Plant protection						
	i. Insecticide/fungicide	340	340	340	340	1600	1600
	ii. Chlorpyriphos	1040	-	-	-	-	-
	iii. Application	400	400	400	400	400	400
8.	Harvesting	2000	2000	1600	1600	4000	4000
9.	Threshing	1600	1600	1200	1200	-	-
10.	Rental value of land @ ` 1000/ha/annum)	420	420	420	420	250	270
11.	Interest on capital (6%)	417	371	448	420	789	960
	Grand total	17367	15531	18658	16454	53644	65230

Note: Labour wage @ ` 200/man-day

ANNEXURE-VI

Estimation of common cost of cultivation of summer-season crops (`/ha)

S. No.	Particulars	Mungbean		Fodder sorghum	
		2012	2013	2012	2013
1	Disking	1000	1000	1000	1000
2	Ploughing by cultivator and planking	800	800	800	800
3	Seed	800	840	750	900
4.	Sowing	1000	1000	1000	1000
5.	Weed control				
	ii. Chemical	-	-	-	-
	iii. Application	-	-	-	-
	iv. Hand weeding/hoeing	1600	1600	1600	1600
6.	Irrigation	2000	2000	3000	3000
7.	Plant protection				
	i. Insecticide/fungicide	720	720	1200	1200
	ii. Application	400	400	400	400
8.	Harvesting	1600	1600	1600	1600

9.	Threshing	1200	1200	-	-
10.	Rental value of land @ ` 2000/ha/annum)	200	200	200	200
11.	Interest on capital (6%)	133	134	176	179
	Grand total	1145 3	11494	12126	12279

Note: Labour wage @ ` 200/man-day

ANNEXURE- VII

Analysis of data of soybean:
Treatments compared
A. Cropping systems:

1. Soybean–wheat–fallow
2. Soybean–wheat–mungbean
3. Soybean–chickpea–fodder sorghum
4. Soybean–potato–mungbean

B. Nutrient sources:

1. Control
2. 100% RDF through fertilizers
3. 50% RDF through fertilizers + 50% RDN through FYM
4. 50% RDF through fertilizers + 25% RDN through FYM + biofertilizers
5. 25% RDF through fertilizers + 50% RDN through FYM + biofertilizers

Analysis of variance

Source of variance	Degree of freedom
Replication	2
Cropping systems	3
Error (a)	6
Nutrient source	4
Error (b)	8
Cropping system x nutrient source	12
Error (c)	24
Total	**59**

Note: Data have been analyzed in strip plot design

Analysis of data of wheat:
Treatments compared

A. Cropping systems:

1. Soybean–wheat–fallow

2. Soybean–wheat–-mungbean

B. Nutrient sources:

Analysis of variance

1. Control
2. 100% RDF through fertilizers
3. 50% RDF through fertilizers + 50% RDN through FYM
4. 50% RDF through fertilizers + 25% RDN through FYM + biofertilizers
5. 25% RDF through fertilizers + 50% RDN through FYM + biofertilizers

Analysis of variance

Source of variance	Degree of freedom
Replication	2
Cropping systems 1	1
Error (a)	2
Nutrient source	4
Error (b)	8
Cropping system x nutrient source	4
Error (c)	8
Total	**29**

Note: Data have been analyzed in strip plot design

ANNEXURE-VIII

Analysis of data of mungbean:

Treatments compared

A. Cropping systems:

1. Soybean–wheat–mungbean

2. Soybean–potato–mungbean

B. Nutrient sources:

1. Control
2. 100% RDF through fertilizers
3. 50% RDF through fertilizers + 50% RDN through FYM
4. 50% RDF through fertilizers + 25% RDN through FYM + biofertilizers
5. 25% RDF through fertilizers + 50% RDN through FYM + biofertilizers

Analysis of variance

Source of variance	Degree of freedom
Replication	2
Cropping systems	1
Error (a)	2
Nutrient source	4
Error (b)	8
Cropping system x nutrient source	4
Error (c)	8
Total	**29**

Note: Data have been analyzed in strip plot design

Analysis of data of chickpea, fodder sorghum and potato:
Treatments compared
Nutrient sources

1. Control
2. 100% RDF through fertilizers
3. 50% RDF through fertilizers + 50% RDN through FYM
4. 50% RDF through fertilizers + 25% RDN through FYM + biofertilizers
5. 25% RDF through fertilizers + 50% RDN through FYM + biofertilizers

Analysis of variance

Source of variance	Degree of freedom
Replication	2
Nutrient source	4
Error	8
Total	**14**

Note: Data have been analyzed in randomized block design