

**सूक्ष्म मौसम विज्ञान का विभिन्न फसलीय वातावरणों के
अंतर्गत विवरण**

**CHARACTERIZATION OF
MICROMETEOROLOGY UNDER DIFFERENT
CROP ENVIRONMENTS**

**REKHA KUMARI MEENA
(Roll No. 10251)**



**DIVISION OF AGRICULTURAL PHYSICS
ICAR-INDIAN AGRICULTURAL RESEARCH INSTITUTE
NEW DELHI - 110012**

2018

**CHARACTERIZATION OF
MICROMETEOROLOGY UNDER DIFFERENT
CROP ENVIRONMENTS**

By
REKHA KUMARI MEENA

A thesis
submitted to the Faculty of Post Graduate School,
Indian Agricultural Research Institute, New Delhi,
in partial fulfilment of the requirements
for the award of degree of

DOCTOR OF PHILOSOPHY
in
AGRICULTURAL PHYSICS
2018

Approved by:

Advisory Committee

Dr. (Mrs.) Ananta Vashisth (Chairperson):

Dr. (Mrs.) Pramila Aggarwal (Co-Chairperson):

Dr. T. K. Das (Member):

Dr. S. D. Singh (Member):

Dr. M. C. Meena (Member):



Division of Agricultural Physics
ICAR-Indian Agricultural Research Institute
New Delhi – 110012, India



Dr. (Mrs.) Ananta Vashisth
Principal Scientist

CERTIFICATE

This is to certify that the thesis entitled “**Characterization of micrometeorology under different crop environments**” submitted to the Faculty of Post Graduate School, Indian Agricultural Research Institute, New Delhi, in partial fulfilment of requirement of degree of **Doctor of Philosophy in Agricultural Physics**, embodies the results of a bona fide research work carried out by **Ms. Rekha Kumari Meena (Roll no. 10251)** under my guidance and supervision. No part of the thesis has been submitted for any other degree or diploma.

It is further certified that any help or source of information, as has been availed of in this work, has been duly acknowledged.

Date:

Place: New Delhi

Dr. (Mrs.) Ananta Vashisth

Chairperson, Advisory Committee

Dedicated To



My

Beloved

Family and Friends



ACKNOWLEDGEMENTS

As a prelude to my thanks giving, at first I wish to thank the almighty for giving me strength, courage and confidence.....after all he is the "greatest".

I wish to express my deepest sense of gratitude and indebtedness to Dr. (Mrs.) Ananta Vashisth, Principal Scientist, Division of Agricultural Physics, as Chairman of my Advisory Committee for her invaluable guidance, constant encouragement, scholarly suggestions, untiring enthusiasm, affectionate behaviour, useful discussion and peerless criticisms during the course of investigation and preparation of manuscript. Her kindness and devotion left an indelible impression in my mind.

It is a great privilege for me to express my esteem and profound gratitude to Dr. (Mrs.) Pramila Aggarwal, Principal Scientist, Division of Agricultural Physics, and co-chairman of my advisory committee, for her cooperative attitude, constructive and valuable suggestions and help throughout the program of this work.

I express my gratitude to Dr. T. K. DAS, Principal Scientist and member of my advisory committee, Division of Agronomy for his guidance, valuable suggestions and careful supervision of this manuscript.

My sincere thanks are to Dr. S. D. Singh, Head of the CESCRA for providing me encouragement and guidance throughout this study. My sincere thanks are also to Dr. M. C. Meena, Senior Scientist, Division of Soil Science and Agricultural chemistry, Indian Agricultural Research Institute, New Delhi.

It is a great privilege for me to express my esteem and profound gratitude to Dr. (Mrs.) Pramila Krishnan, Head of Division of Agricultural Physics, for her cooperative attitude, constructive and valuable suggestions and help throughout the program of this work.

I take this opportunity to express my thankfulness to Dr. V. K. Sehgal, Professor, Division of Agricultural Physics for his useful suggestions and endless help from time to time during the course of my Ph.D. degree.

I express my profuse thanks to Dr. Debashish Chakraborty sir and all other scientists of Division of Agricultural Physics for their help that they extended to me during my research work. I express my gratitude to Dr. S. L. Meena, Principal Scientist, Division of Agronomy for his guidance and valuable suggestions

I am extending my sincere gratitude to technical, administrative and supportive staff members especially to Mrs. Bipin mam, the Division of Agricultural

Physics, IARI for their support which has helped me to complete my study in the division.

The acknowledgement is incomplete if i do not say thanks to Dr. D. K. Joshi, Rajender sir and Mr. Ishwarchand sir for all the help they willingly rendered during the research.

I articulate my appreciation to all my seniors of this division especially Rajkumar sir, Debashis sir, Surajit sir, Amit sir.

I also extend my heartiest thanks to Bharat, Priya, Polson, Amit, Abhishek, Jagriti, Jaya and all of my friends whose constant help and collective efforts have been reflected in the completion of this venture.

I would like express my heartiest thanks to my juniors Goyal, Sushil, Shilpi, Pragya, Alka, Koushik, Brijesh, Vikash, Ram and Madan for their nice companionship and valuable support.

It gives me an immense pleasure to extend my sincere thanks to the entire Scientists community of Agricultural Physics Division & NRL.

I shall be missing if I don't extend my admiration and appreciation to express my humble obligation to my Parents who always raised their hands for my success and gave me confidence and an atmosphere that initiated me to achieve high academic goals. I extend my profound obligations to my brothers for their encouragement, help and moral support throughout the study period.

Finally, I humbly and whole heartedly bow my head before Lord Almighty for blessing me all his grace to successfully complete my two years study and research in IARI. The financial assistance provided by the CSIR in the form of Fellowship during the tenure is duly acknowledged.

Date:

(Rekha Kumari Meena)

Place: New Delhi

1. Introduction

Agriculture is highly susceptible to climate change, more frequent heat waves, warm and humid weather increases the intensity of pests, diseases and impoverishment of crops. Heavy rainfall in some areas leads to soil erosion, water logging and hence reduces the cultivatable area. Frequent drought results crop losses, lower crop yields and sometime total failure of the crops (IPCC WG II, 2007). Fan *et al.* (1998) reported that variation in precipitation patterns causes crop failures and hence reduction in crop production. Atmospheric CO₂ concentration increased by 31% and atmospheric O₃ increased by 1% per year during the past four decades. Therefore climate resilience is necessary in India as the country is experiencing excessive heat stress, increased O₃, high rainfall variability and occurrence of extreme events. In developing countries, due to climate change yield will be lower for paramount crops. To increase crop production without increasing in cultivated area for feeding the burgeoning population is the foremost challenge for agricultural scientists as well as for country.

However, increase in crop production should be achieved by reducing the risk and losses in agricultural production. Today's Indian agriculture scenario, the farmers adopted mechanized cultivation practices in rice-wheat production systems widely resulted serious problems of sub surface compaction. Advancement of mechanization in modern conventional agriculture requires more fossil fuel energy. Now it has been realized that conventional agriculture is not very energy efficient and is detrimental to the air, water and soil environment. In recent years, the rice- wheat system has been suffering from a production fatigue and several economic and ecological problems (Saad *et al.*, 2016). Modifications are required in agriculture practices to pace with the changing climate and it is need of time to measure the impact and vulnerability with augmentation of climate change guidelines (Smith *et al.*, 2009). Different treatments like no tillage, residue effect give effect on crop growth, yield and also help to sustain the crop production in this changing climatic scenario. No tillage with presence of crop residue on the soil surface improved properties of soil like quality and resource utilisation ability (Ghosh *et al.*, 2010). Tractor use is considerably lower when tillage operations are eliminated, thus lowering the emissions of greenhouse gases and other toxicants. In addition, soil moisture is retained and wind and water erosion are further

decreases, under zero tillage as the soil surface, residues, crowns, and roots from previous crops are not disturbed which further protection and improves the soil health. Zero tillage reduces the cost of cultivation since it minimises the uses of tractors and lowers the cost of fuel and labours. Bhattacharya *et al.* (2012) find out the response of changing of seasonal tillage practices on organic carbon retention, soil aggregation, aggregate-associated C and particulate organic matter-carbon in top 15 cm of soil layer and found that soil organic carbon and total soil nitrogen had been improved by inclusion of legume in production systems. There is accelerating trend in past several years, adopting the practice of zero-tillage in north-west India. Sowing of wheat crop by zero seed drill in low laying and alkaline lands followed by rice was found beneficial over conventional tillage in Haryana state of India. The soil does not get dry hence not ready for normal tillage even at the end of November and that delay the wheat harvest and finally the crop faces pre-monsoon temperature stress. Zero-tillage reduces the costs on tractor and implements maintenance and repairing as well. Around 17.4 million liter of diesel can be saved by adopting zero-tillage in half of the rice-wheat area of Haryana. This equals to (conversion factor of 2.6 kg CO₂ /liter of diesel) deduction of more than 25,000 tonne of CO₂ emissions per year (Hobbs and Gupta, 2002). As zero-tillage conserve residual moisture of preceding rice crop, it cuts down the requirement of immediate irrigation hence water requirement is reduced almost 1 million liters per ha (Erenstein *et al.*, 2007).

Maize (*Zea mays* L.)-wheat (*Triticum aestivum* L.) is the third most important cropping system, grown on about 1.83 million ha in India, contributing nearly 3% to the national food production after rice-wheat (32%) and rice-rice (5%) systems (Chaudhary *et al.*, 2009; Sepat *et al.*, 2013). Conventional tillage practice involves multiple passes of tractor for ploughing, harrowing, planking and seeding. Conventional rice-wheat system required higher energy due to intensive field preparations, whereas zero tillage required least energy leading to higher output: input energy ratio. Conventional tillage practice in maize and wheat involves 6-8 tillage operations, consumes 25-30% of the total operational energy. Continuous tillage in both rainy (*kharif*) and winter (*rabi*) season was found to have ill effects on the soil health and high energy requirement. Resource conservation technology like raised-bed planting saves irrigation water and labour consumption without sacrificing productivity. Fresh raised-bed was found beneficial in maize and wheat, saving water

and higher yield and net returns despite higher cost of cultivation. These reports indicate that conservation agriculture system requires the least energy in farm operation compared to other systems but may not be applicable in all cases.

Huge quantities of crop residue are produced in cereal-cereal production systems. Crop residue is a source of renewable energy, generally considered as non-commercial as thought to be freely available. Large portion of unused crop residues are burnt in the fields with intention to clear the left-over straw and stubble for sowing of the succeeding crops. Based on estimates taken from grain production and grain to straw ratios (cereals) indicates of total crop residue production in India is about up to 350 million tonnes of which one-third is available for recycling by soil incorporation or surface retention (Saad *et al.*, 2016). With the aim of conserving resources, improving input-use efficiency and sustaining productivity, conservation agricultural system has emerged. The concept of conservation agriculture was developed in USA during 1970s as a result of primarily steep increase of fuel price therefore, to cut down expenses on tillage machinery. This involves minimum soil disturbance, providing a soil cover through crop residue or other cover crops and following efficient crop rotation (Sharma *et al.*, 2012). Zero tillage (ZT) technique is an ecological approach for soil surface management and seed bed preparation resulting in less energy requirement, less weed problem, better crop residue management and higher or equal yield (Jain *et al.*, 2007). Globally, conservation agriculture is being practised in about 125 million hectare (FAO, 2012). In India, its adoption as ZT is initiated in late 1980s and still conservation agriculture is in initial phases as largely being adopted in wheat of rice-wheat system of IGP (Jat *et al.*, 2011), which is not truly conservation agriculture as the practice is being undertaken in wheat crop, leaving rice with conventional method.

Continuous adoption of cereal based cropping system has led to depletion of inherent soil fertility resulting in a serious threat to its sustainability in the Indo-Gangetic plain region (IGPR) of India. The inclusion of legumes in crop rotation assumes a great significance to restore soil fertility. Pulses, next to cereals in terms of economic and nutritional importance have ability to biological nitrogen fixation, low water requirements, capacity to withstand drought, can contribute significantly to achieve twin objectives of increasing productivity and reduce need of nitrogen application as well cost of cultivation. Sinsinwar *et al.* (2003) observed that higher

yield of cereal crops after legumes in rotation, which is mainly due to remnant effect of biological N fixation along with addition of legumes root biomass to succeeding wheat. Biological nitrogen fixation (BNF) is one of the important sources of nitrogen to the soil (Zapata and Cleemput, 1986). The rotation of animal forage or grain legume with cereal crops acts as fundamental source of N for cereal crops in South-West Australia (Clarke and Russell, 1977). The upper soil structure becomes crusted, which obstruct germination and growth of roots under monoculture practices of cereals. On the other side, incorporation of legume in rotation enhance soil organic matter, stability of aggregates, and spares soil mineral N. Leguminous residue decomposes faster as compared to cereal residue due to its low C: N ratio and enhance the mineral N in soil that helps in improving the crop yield. Nitrogen is the main element in the cereal grown after legumes in contrast with cereals following other non-leguminous crop (Evans *et al.* 1991). After assessing many case studies, Chalk (1998) find out that rotation with legumes benefits the cereal in terms of N supply and finally the yield. Pigeonpea (*Cajanus cajan* L.) is an important grain legume crop of the semi-arid tropics, occupying about 3.55 million ha area with an annual grain production of 2.40 million tonne in India alone (GOI, 2007). India is the major pigeonpea producing country accounting for 91% of the global pigeonpea production. The Indo-Gangetic Plain region (IGP), wherein cereal-based cropping systems predominate, contributes 28% of the total pigeonpea production of India (Ali *et al.*, 2000).

Impact of conservation agriculture (CA) on micrometeorology, like interception of solar radiation (photosynthetically active radiation), mean temperature and relative humidity profile of crop are still unknown. Moreover, conservation agriculture effects on biophysical parameters like biomass accumulation, leaf area index, plant height etc are also studied to a less extent. Generally, it requires accurate observations of crop growth including radiation use efficiency (RUE) under optimal micro environmental conditions for plant dry matter accumulation and grain yield near to its potential values. Adaptive approaches for conservation agriculture systems are very site directed. Studying across the locations will be a potential way to figure out that some of the technologies or practices are adequate in a set of conditions and ineffective in other set of conditions.

Increasing water use efficiency, radiation use efficiency reduces harvesting of natural resources to greater extent which can accelerate the production on sustainable basis. Besides these, reduction in pests and diseases incidences by modifying microclimate instead of completely relying on harmful pesticides can prove beneficial for environment in the long run along with saving cost of plant protection. System and management affecting microclimate of the crop should be understood properly for effective management (Olanya *et al.*, 2006). Micrometeorology of crop can affect the crop production to a great extent. Keeping in view of above points, maize-wheat and pigeonpea-wheat cropping systems under conservation agriculture practices and their impact on modification of microenvironment, crop growth and yield are selected as field of concern in this study.

Therefore, the quantification of microenvironment in maize-wheat and pigeon pea- wheat cropping systems under different conservation agriculture practices and their effects on crop growth and yield are the area of interest. Although some work has been done on radiation use efficiency and different thermal indices accumulation under variable weather conditions in some crops but the studies on the thermal indices, radiation use efficiency, crop growth and yield under different conservation agriculture practices in maize- wheat and pigeonpea-wheat cropping systems are still lacking. Therefore in depth studies should be done on different accumulated thermal indices, radiation use efficiency, water use efficiency and crop productivity for maize-wheat and pigeon pea- wheat cropping systems in different crop environments under conservation agriculture. Keeping view of the above points a study was done with the following objectives:-

1. To study crop microenvironment under different conservation practices along with conventional practice.
2. To study effect due to crop microenvironment under different treatments on biophysical parameters, crop productivity and radiation use efficiency.
3. To calculate crop water requirement and water use efficiency using single crop coefficient, dual crop coefficient and water balance method under different crop micro environments.

2. *Review of Literature*

In the middle of last century, due to increased industrialization, use of power drawn implements and tractors for tillage and various other agricultural operations started replacing animal drawn tillage implements and manual labour. But after few decades, the over use of heavy machinery for soil management and ploughing, along with higher input use such as chemical fertilizers, over irrigation and indiscriminate use of chemical pesticides has led to severe land degradation and unsustainable agricultural production system. Another problem is that the productivity of crop is low in rainfed dry areas because of poor organic matter content (Wang, 2006), inadequate and erratic rainfall (Loss and Siddique, 1994), drought (Rockstrom *et al.*, 2007), nutrients deficiency (Sahrawat *et al.*, 2007), low and unbalanced use of fertilizers (Rashid and Akhtar, 2006) and impoverished physical quality of soils and other inadequate environmental factors.

Thus there is need to improve soil health and need to changes crop microclimate for proper crop growth and development at several levels which, in turn, directly influence crop productivity. One of the solution is use of various practices which includes reduced tillage, crop rotation and residue retention as its main components. For sustainable agricultural system and checking land degradation, in addition to conservation tillage practices, other resource conservation objectives such as conservation of soil moisture, soil structure, soil flora and fauna and nutrients should also be considered (Baker *et al.*, 2002). Thus from 1970 onwards, the farmers have been advised by Scientists and Policy makers to adopt no-tillage that use limited fossil fuels, decreased run-off and soil erosion losses and nourishes the soil with organic matter. This was the kick-off of the conservation tillage evolution and today good amount of area cultivated under conservation tillage. The conservation tillage is the combination of terms generally given to direct drilling, no-tillage, minimum-tillage and ridge-tillage, to keep in mind the conservation of natural resources. It can alter the microenvironment within the crop canopy by changing solar radiation, temperature and humidity profile, controlling evapotranspiration. It helps in environmental conservation in one hand and sustained agricultural production on the other hand. So it can be specified as resource conserving agriculture (FAO).

The literature related to various crop environments like reduced or zero tillage, residue retention or mulching, crop rotation, their impact on soil properties, growth and yield have been found. Still there is dearth of literature on impact of these practices directly on microenvironment of crops. Conservation agriculture has three basic principles; crop rotation, minimal soil disturbance, permanent or semi-permanent organic soil cover. The literature, with direct or indirect relevance, collected for the study is classified broadly into following heads.

Crop rotation

Crop rotation is an important cultural control strategy which is also regarded as an age old practice. It involves the pre-planned series in which same field is sown with particular crops. The series have the crops of different families. Variability in the planned rotation of crops can be between two or three year or longer period. Soils alterations are kept minimum in combination with rotation of divergent crops with diverse rooting patterns in zero-till system which induces a large network of root system and macropores in the soil and further helps in infiltration of water to lower depths. Crop rotations build up the microbial population which helps in checking the pest and diseases (Leake, 2003).

The prime goal of crop rotation is to sustain soil fertility, allowing natural cycles to take place, renovation of soil structure and finally the reduced soil erosion (Eltz and Norton, 1997). Farmers can decide for appropriate crop rotation, depending up interested crops, adequate water and nutrient delivery and appropriate soil and climate (Urbano, 1992).

The crop rotation provides diverse nourishment to micro flora and fauna along with recovering the nutrient elements that have been leached to different deeper layers. Additionally, crop rotation increases the bio-diversity of flora and fauna of the soil. Crop rotation which includes the legumes as one of its components reduces the biotic stresses by life disrupting the life cycles, bio-remediation of pollutants, enhances the biodiversity and biological nitrogen fixation (Dumanski *et. al.*, 2006; Kassam and Friedrich, 2009).

Minimal soil disturbance

Large quantities of fossil fuels is consumed by tractors when used for ploughing which adds more cost as well as greenhouse gases emissions (mostly

CO₂) thus playing major role in global warming (Grace *et al.*, 2003). Conventional animal-based tillage systems used in agriculture are also costly as feed, fodder and maintenance round the year is expensive affair for the farmers. Greenhouse gas emitted by animals mostly the methane is potentially 21 times more dangerous than carbon dioxide (Grace *et al.*, 2003). Zero-tillage is able to suppress these emissions and costs. Farmers in Pakistan and India surveyed and it was found out that zero-till of wheat preceding rice reduces costs of cultivation up to US\$60 ha⁻¹ commonly due to lesser fuel (60–80 L ha⁻¹) and labour (Hobbs & Gupta 2004). Zero-tillage reduces time for establishment of a crop. The practice of zero-tillage (minimum soil disturbance) mean leaving 30% crop residue or stubble on the field even after the harvest of crop (instead of throwing away) or incorporation of residues into the soil from external sources. Reduced tillage practices includes less cultivation than any other conventional system and also provides a better soil environment for crop growth by increasing water along with reducing the quick dissolution of soil structure and slowing the breakdown of organic matter in the soil, hence, making nutrients more available to plants.

CA web of the FAO now involves ‘controlling in-field traffic’ as an element of CA; this is completed by having field traffic follow permanent tracks. This can also be realized using a ridge-till or permanent bed planting system instead of planting on the flat (Sayre & Hobbs 2004). Some farmer’s shares their feelings that sub-soiling or chiselling is required for breaking the sub-surface compaction before adopting a Zero-till strategy, particularly in rainfed areas. The biological processes in soil results in stable soil aggregates also macro and micro pores, permitting air and water circulation. These phenomena may be termed as “biological tillage” and it is not harmonious with mechanical tillage. More is mechanical soil disturbance; less will be biological soil structuring processes. Kassam and Friedrich (2009) reported that if the soil disturbance is less than it helps in allowing adequate amount of respiration gases in the root-zone, reduce organic matter oxidation, moderate soil water retention and release and minimises weed population in crop field. Hobbs & Gupta (2003) reviewed that taking time for tillage could also delay planting of crops on time, with yield potential reduction. By using zero-tillage (ZT) crops can be planted on time, and thus helps to increase yields without greater cost of cultivation. Time consumed in ploughing in rice–wheat cropping system (RWCS) from rice to wheat varies from 22

to 45 days, since farmers used 10–12 passes of a plough to get a good seedbed. Time taking process in tillage practices can be reduced with zero tillage.

Permanent or semi-permanent organic soil cover

When a former crop is left anchored, left after harvest, a cover crop (legume or non-legume) is sown and ploughed leads to accumulation of crop residue in soil. On the other hand composts and manures also can be applied externally, but cost involves in the transportation of these bulky materials may limits their use in large areas.

Crop residue management has impact on crop productivity along with soil fertility, human health and environmental health, thus, it plays a crucial role in the cropping systems sustainability. Residue retention in field after harvest of crops plays important role in nutrient cycling, soil physical properties maintenance and erosion control (Unger *et al.*, 1976). Beneficial effects associated with retaining crop residues in field depends on many factors such as the residue quantity and quality, following crop, soil factors, topography, soil management and climate. Crop residue reduces soil temperature besides minimising diurnal fluctuation of temperature. In temperate region crop residues lower soil temperatures, reduced crop growth and less grain yields in spring-season crops. Standing crop residues causes reduction in wind speed at the surface of soil, trapped snow, thereby increasing infiltration of water which led to more moisture in the soil water content (Bockus and Shroyer, 1998).

A cover crop helps in reducing weed infestation by means of competing and not allowing light to reach to the weed seed which is sometime requires for germination. Some of the cereal residues were found allelopathic on weeds preventing germination of seed (Steinsiek *et al.*, 1982; Jung *et al.*, 2004; Lodhi & Malik, 1987). Practices which increase the microbial activities of bio-agents can also suppress the weed seeds reported by Kennedy (1999). Bissett and O'Leary (1996) verified that water infiltration into long term (8 to 10 years) CA (zero and sub-surface tillage with left crop residue) was superior in comparison to conventional tillage (frequent ploughing plus no residue cover) on a sandy loam soil and a grey cracking clay in south-eastern Australia. Impact of crop residues and management practices on soil nitrogen dynamics, soil quality and crop yield was reviewed by Kumar and Goh (2000).

The soil aggregates are destructed by the high energy raindrops hitting the bare soil, leads to disruption, chocking of soil pores which further results in reduced water infiltration, increased run-off and soil erosion. These negative impacts are reduced by crop residues mulch which increases the infiltration and protect the soil from erosion (Freebairn & Boughtonne, 1985; Dormaar & Carefoot 1996; McGregor *et al.*, 1990). Study in Paraguay recorded topsoil losses of 0.1 tonne ha⁻¹ only under no-tillage whereas 46.5 tonne ha⁻¹ under traditional tillage practice (Derpsch and Moriya, 1999). No-tillage with mulch helps in reducing the surface soil crusting, run-off and enhancing the water infiltration and yield than ploughed soils (Thierfelder *et al.*, 2005; Cassel *et al.*, 1995). Accordingly, the crop residue cover on soil surface reduces the wind erosion equally (Michels *et al.*, 1995). When soils are left bare, the dust bowl is a good reminder of the effects of wind and water erosion.

Combined with no-tillage cover crops helps in deposition of organic matter to soil horizon (Roldan *et al.*, 2003; Madari *et al.*, 2005; Alvear *et al.*, 2005; Riley *et al.*, 2005). Further the legume crops add nutrients and provide food substrate to microbial agents which recycled important nutrients. Organic soil cover is safeguard for the soil in contradiction of the damaging effects of contact to rain and sun; to deliver continuous supply food to soil biota and modify the microenvironment for building up soil biota. Consecutively it enhances soil aggregation, soil biodiversity and carbon sequestration (Ghosh *et al.*, 2010).

2.1. Research Area

The relevant materials for the first objective of the present study (research area I) are given under following heads.

2.1.1 Soil moisture and temperature

A most important goal of soil and water management systems is to assure water infiltration instead of runoff. This can be accomplished by improving soil surface storage and refining the soils physical and hydro-physical assets (Brady and Weil, 1999). The transformation of physical state instantly affects not only water system but also aeration, biological properties and temperature status. CT offers an opportunity to shelter over 30% of the soil surface by plant residues. This biological mulch lessens runoff, escalates infiltration and declines the evaporation of the soils water (Arshad *et al.*, 1999; Rasmussen, 1999). The benefits of tillage decisions may

comprise improved crop establishment, better infiltration and lesser runoff (Cogle *et al.*, 1997). The relationship between moisture and temperature is inversely proportionate (Radke, 1982). Crop rotation can help in enhancing the soil water content and availability especially in rainfed agriculture (Benson, 1985; Roder, 1989). A corn succeeding soybeans displayed better yield benefits, more water retention and lowering the soil temperature over constant corn and particularly when tillage system permits the crop residue of last season crop left on the soil surface (Mannering and Griffith, 1998). Early season soil temperatures were greatly reduced when corn was no-tilled following corn (Roth, 1996)

Surface residue reflects solar radiation to insulates the soil surface and reduce the soil temperature (Van Wijk *et al.*, 1959; Shinnars *et al.*, 1993). In spring, better drainage and greater soil temperatures leads in enhanced seedbed conditions and soil structure because of tillage (Mahboubi and Lal, 1998). Hence, computing the effects of tillage on soil temperature, soil moisture, and compactness may support in elucidating variations in plant growth and development in various tillage systems. Reduction in soil temperature and slowing soil drying by insulating the soil surface by residue cover in the spring season (Fortin, 1993; Kaspar *et al.*, 1990) with declining surface runoff and soil erosion (Cruse *et al.*, 2001). Many scholars have revealed that residue mulch aids to decrease soil water evaporation and enhances soil moisture (Huang *et al.*, 2005; He *et al.*, 2011; Singh *et al.*, 2011).

The tillage depth under CT makes the soil more porous resulting soil has lower thermal conductivity (Sarkar and Singh, 2007). This change leads to greater heat retention under CT. In addition, the higher soil temperature under CT may be due to a surface difference. Under NT, the soil surface is partially covered by remnants of straw from the previous crop, causing the soil to absorb less solar radiation during the day (Wang *et al.*, 2009). Overnight, the cause of the lower temperature in the NT treatment may be due to loose soil (especially in the upper profile) which easily loses the energy stored during the day (Wang *et al.*, 2009).

Conventional agriculture led to soil organic matter reduction, increases water runoff, soil erosion and degradation of soil physical, chemical and biological properties (Thierfelder and Wall, 2009). On the other side, conservation tillage practices like sub-soiling, tied ridging and ripping have the potential to mitigate intra-seasonal dry spells and increase the soil moisture retention (Manyatsi *et al.*, 2011).

Conservation tillage have ability to conserves rainwater which is otherwise lost as surface runoff, evaporation and through deep percolation in the magnitude of 70 to 85 % of rainfall in Sub Saharan Africa, hence makes it beneficial to the crops (Cornelis *et al.*, 2013).

2.1.2 Heat indices

The key climatic factors of crop production are air temperature, light, rainfall and sunshine hours (Ekaputa, 2004; Orkwor *et al.*, 1998). Nevertheless, the most important parameter in all biological processes of yam production is the air temperature (Girijesh *et al.*, 2011). It affects the growth, phenology, development and yield of yam most among the other climatic parameters in the tropical wet and dry climate (Maduakor *et al.*, 1984; Okoh, 2004, Inyang, 2005). Conversion of heat energy to dry matter depends on crop type, sowing time and genetic factors (Sikder, 2009). The most eminent change is inclining in the climatic temperature as a result of augmented levels of greenhouse gases. The global mean annual temperatures towards the end of 20th century were nearly 0.7^oC beyond than those documented towards the end of the 19th century also is probable to surge further by means of 1.8 to 6.4^oC by 2100 AD (Kaur and Rajni, 2010). The vital effect of high temperature is the augmented physiological changes, subsequently hasten maturation and low yield.

Dynamic simulation models of crop growth are extensively utilized for forecasting growth and harvest of crops, but these being very detailed models prerequisite huge input data besides being highly difficult and complex in practical situation (Whisler *et al.*, 1986). Therefore, simplified models, with low input data requirement, will be of great use. Agroclimatic models constructed on thermal indices may possibly fulfil these goals. Therefore efforts have been done to predict phenology (Hundal *et al.*, 1997), leaf area index (Benbi, 1994), growth rate (Singh, 1996), yield (Tripathi *et al.*, 1999), growth and yield (Hundal *et al.*, 2003a, b) using thermal based indices. Thermal time is an independent variable to describe plant development (Dwyer and Stewart, 1986). It can be used as a tool for characterizing thermal responses in different crops. Phenology of crop can be utilised to specify the most appropriate date and time of specific development process. Time period of every phonological stage defines the build-up and segregating of dry matter in various parts (Dalton, 1967). The time interval of a specific growth phase is directly associated to

temperature. The agroclimatic indices, viz., heliothermal units, growing degree days, photothermal units, phenothermal index and heat use efficiency (Wang, 1960).

Occurrence of different phenological events during crop growth period in relation to temperature can be estimated by means of composed growing degree-days or heat units (Gouri *et al.*, 2005). Knowledge of accumulated GDD can provide an estimate of harvest date as well as crop development stage (Ketring and Wheles, 1989; Bonhomme, 2000; Wurr *et al.*, 2002; Roy *et al.*, 2005).

Growing degree-days only explain thermal requirement. However, light which is a source of energy also play a significant role towards crop growth. Though accumulation of growing degree days and photo thermal units are comparatively constant and autonomous of crop variety, sowing date but it can alter significantly (Phadnawis and Saini, 1992) for each developmental stage in crop. Pal *et al.* (1996) reported that the growing degree-days and photothermal unit requirement differ from crop to crop and also from genotype to genotype. The shifting of sowing dates corresponds to fluctuations in temperature causing either lengthening or shortening of the growth periods. Further, it was also found that in general a progressive delay in sowing causes a decrease in GDD and PTU requirement of constituent phenophases as well as for the crop duration.

A photothermal index (PTI) is equals to sum of the ratios of day length per 24 h period and multiplied by the total growing degree days (Masle *et al.*, 1989). Relative Temperature Disparity (RTD) is a linear or direct relationship between temperature and growth of the plants. Heat use efficiency (HUE) depends on crop type, genetic factors and sowing time and has great practical application (Rao *et al.*, 1999). The index helio thermal unit (HTU) helps in calculating effectively and articulating the consequence of variable ambient temperature on the spell between the phenological happenings for relating the crop reactions to the ambient temperature (Rajput *et al.*, 1980).

Slafer and Rawson (1994), Tewari and Singh (1993) observed that the temperature has significant impact on duration of different phonological phases and dynamics of leaf appearance. On the basis of contribution of crop canopy and vegetative growth period to final harvest, it can be assumed that solar radiations and

temperature are the driving force of agriculture production and photothermal quotient (PTQ) use to describe their combined effects on plant growth.

2.1.3 Temperature and Humidity profile within canopy

Winter wheat canopy microenvironment in top, mid and lower layers was dissimilar significantly (Han *et al.*, 2013). In upper layer of crop canopy higher air temperature was recorded under no-tillage. The influences of air temperature in the mid and lower layers were comparatively little with tillage. Lower and higher relative humidity was reported in conventional tillage and no-tillage respectively. To understand the environment surrounding vegetation, it is necessary to consider how sources and sinks of heat, mass and momentum are distributed within a canopy (Elston & Monteith, 1975). In temperate climate, the daily amplitude of temperature and humidity at bottom of dense planted crops is generally lower than that of uncropped land because of shading (Shoubo, 1989). Shuttleworth *et al.* (1985) pointed out that in tropical environments, during day light condition that temperature and humidity in top 2/3rd of the canopy and surrounding atmosphere was same, but these properties in air at canopy base are intensely decoupled. Behaviour is opposite at night and air at lower 2/3rd of the canopy is partially decoupled from that of higher levels. In standing residue the air temperatures are higher at night though air is extra humid over the day in a semi-arid climate utilising standing wheat stubble in cotton crop (Hatfield and Prueger, 1996). Volkmer *et al.* (2004) observed in an experiment that stubble significantly lowers the rate of air movement 25 cm above the soil surface during early crop growth. The effects of stubble on air temperature were most evident closer to the soil surface and decreased with the elevation above the surface. General trend observed that stubble decreased air temperature comparative to the cultivated treatment during night time and increased air temperature compared to the cultivated treatment during the day. This suggested that higher canopy temperatures would accelerate all processes associated with plant growth leading to higher plant emergence rates, and greater mid-season vegetative biomass. It results in increased yield potential through increased seeds per plant and increased seed weight.

2.1.4 Stomatal Conductance

The parameters such as the net stomatal conductance and CO₂ assimilation rate associated with water use efficiency (WUE) can be measured by gas exchange

methods. It has been observed in pearl millet (Kholova *et al.*, 2010b), soybean (Liu *et al.*, 2003) and wheat (Zhang *et al.*, 2005) that stomatal regulation rather than stomatal density effect transpiration rate in different genotype. Stomatal conductance controls water efflux and CO₂ influx leads to regulation of photosynthetic rate and water loss due to transpiration. Hence increase in biomass and yield potential are highly correlated with water use. Bota *et al.* (2001) found that in well irrigated situations the higher stomatal conductance support higher biomass/yield content. In rainfed conditions Boogaard *et al.* (1997) found 20% higher WUE in different varieties which had higher stomatal conductance compared to other varieties with the lower stomatal conductance.

2.1.5 Transpiration rate

With help of appropriate crop and soil management practices (Huang *et al.*, 2005) especially straw mulching (Albright *et al.*, 1989) improves the microenvironment and crop growth by enhancing the plant transpiration at the expense of soil evaporation (Raeni-Sarjaz and Barthakur, 1997; Wang *et al.*, 2009). The crop residue and film mulch prevents evaporation of water and also helps in maintaining the topsoil-water content reasonably constant by means of drawing the water from deeper soil through vapour transfer and capillary forces (Wang *et al.*, 1998; Tian *et al.*, 2003; Li *et al.*, 1999). Therefore, in crop residue plots stomata being more open than in the rainfed plots which help to increase the transpiration rate with minute soil evaporation. This might have nurtured biomass build-up throughout initial growth stages and enhanced plant development from seedling appearance to physiological maturity.

2.1.6 Photosynthesis rate

Light regulates the life and provide energy for life. Fundamentally the quality and quantity of light effect all physiological processes like emergence of seedlings to fruit production. The photosynthetically active radiation (PAR) reflected from the crop canopy was higher in short and tall stubble as compared to cultivated stubble during crop establishment in initial 20 days after emergence (Volkmer *et al.*, 2004). Hortonne *et al.* (1995) observed in wheat crop that fallow increased fractional IPAR (fIPAR) in both growing seasons and drought conditions but PAR interception in pea was not affected by crop sequence. Ghanbari *et al.* (2010) found that intercropping

had improved the quantity of absorbed PAR in comparison to sole maize crop. Soil moisture storage under crop residue enriched together the IPAR and RUE, thus considerably enhancing the grain yield because it encourages physiological processes subsequently the soil dehydration episodes, resulting to enhance the plant growth and grain yield (Deng *et al.*, 2006). Li *et al.* (2006) showed that chlorophyll contents and net photosynthetic rates increased with conservation practices such as zero tillage and sub-soiling tillage as compared to conventional tillage. In contrast, Jiang *et al.* (2006) found that the net photosynthetic rate of conventional tillage is higher than those of the other two types of the minimum tillage. Evans *et al.* (1994) observed that some plants are able to change their leaf anatomical characteristics and CO₂ conductance to maintain photosynthetic rates at low leaf water status.

2.2. Research Area II

The relevant literatures to the second objective of the present study are given under following heads.

2.2.1 Leaf water potential

Leaf water potential (energetic status of water inside the leaves cells) measure water deficit or water stress to crop plants (Slatyer & Taylor, 1960). Kramer & Boyer (1995) found that leaf is correlated to numerous physiological variables for instance leaf growth, turgor pressure, stomatal conductance, transpiration, photosynthesis and respiration. Water movement occurs from higher to lower water potential gradient. This movement along the potential gradient got the free energy so that such a flow has the potential to do work. The responses of plants are dissimilar toward the moisture stress both in their leaf water potentials and in photosynthetic performance in relation to reduced leaf water potentials (Kumar and Tieszen, 1980). Kumar and Tieszen (1980) found that stomata are affected by low leaf water potential hence suppresses the productivity nevertheless low water potential due to rise in temperature may subordinate photosynthetic rate by dropping both mesophyll and stomatal conductance. Plant water stress response are measured based on dependable parameter like leaf water potential. Wheat genotypes in drought stress showed variations in leaf water potential substantially (Singh *et al.*, 1990). Change in osmotic pressure, the osmotic component of water potential leads to changes in plant water potential.

Increases on the water availability in no-till soils may allow to several plant responses. Bianchi *et al.* (2003) observed higher values of leaf water potential in no-tillage than conventional tillage in maize crop, irrespective of the irrigation levels. Dalmago *et al.* (2003b) recorded the higher amount of available water into the no-till soil. In many crop species, including snap bean, even small diurnal fluctuations in leaf waterstatus at anthesis can adversely affect the activity of reproduction structures (Tsukaguchi *et al.*, 2003; Weaver and Timm, 1988; Kuo *et al.*, 1988; Saini and Aspinall, 1982). Coyne *et al.* (1982) found that a steeper leaf water potential gradient from soil to plant enhance capacity of the plants to extract soil water at low soil water content.

2.2.2 Relative water content (RWC)

The leaf relative water content (RWC) is a superior indicator of water status than water potential (Sinclair and Ludlow, 1985). Leaf water content plays the role of indicator of plant water equilibrium since it articulates the relative amount of water existing in the plant tissues. The relative water content controls the turgor pressure inside leaf tissues which helps to maintain the leaf activities leads to higher photosynthesis. Water content measurements expressed on the basis of dry or fresh tissue masson the maximum amount of water a tissue can grasp which is termed as relative water content (Barrs, 1968). Numerous studies have concentrated on developing suitable techniques to measure the RWC (Weatherley, 1950; Catsky, 1967; Barrs and Weatherley, 1962). Photosynthesis, NO₃ reduction, protein synthesis and leaf senescence are better correlated with tissue relative water content (Sinclair and Ludlow, 1985). Decrease in relative water content was strongly and linearly correlated with the reduction in the yield attributes and seed yield, indicating that cultivars with a less reduction in relative water content showed a less reduction in yield attributes and seed yield due to drought stress (Omae *et al.*, 2007).

2.2.3 Leaf area index (LAI)

The leaf area index (LAI) is a key biophysical parameter of crop canopies. It is the over-all area of leaves/unit ground area. It is a unit less quantity which is very vital for biogeochemical cycles since many crop growth functions such as radiation attenuation are determined and controlled by it along with canopy water interception for gas exchange and interception and absorption of IPAR and RUE. Alteration in leaf

area of a crop canopy may modify crop productivity and photosynthesis rate to a larger extent therefore it has a large impact on crop yield. Maize grain yield was found strongly correlated with LAI by signifying the prominence of green leaf area for the upkeep of higher crop yields (Bavec and Bavec, 2002; Kamara *et al.*, 2003). Leaf area index (LAI) measurements are required for critical to various features of crop growth and development (Williams *et al.*, 2000). As a result, LAI is a crucial variable in modelling of agricultural quantitative measurements (Baez-Gonzalez *et al.*, 2005) and investigation of water utilization, foliage density and crop growth (Tewolde *et al.*, 2005). For best light interception the early reproductive stage of soybean requires at least 3.5 of LAI (Board and Harville, 1993; Board and Tan, 1995). Verma and Acharya (1996) reported the LAI was better in CT and minimum tillage with *Lantana camera* mulch. Aikins *et al.* (2012) found no noteworthy influence of tillage practices on maize leaf area index except for the one and four weeks after planting respectively. The treatment of disc harrowing after 10 weeks of planting produced superior leaf area index over disc ploughing treatment. Board and Harville (1993) observed positive correlation between LAI and grain yield of soybean. There is close association between total dry-matter and grain production in plant. Relations and functions are established to permit the comparisons of crop growth rates above diverse environments and these collectively known as growth analysis. Hunt (1978) observed that dry-matter accumulation rate (crop growth rate, CGR) is the combinations of leaf area index (LAI) and dry-matter assimilation rate (net assimilation rate, NAR). LAI is a good indicator of differences in growth conditions and may be used to determine yield potential during the different vegetative growth stages (Agenbag and Maree, 1991). LAI is important to understand different phases of crop growth, development and management (Williams *et al.*, 2000). Legume leaf mulch caused significant increase in leaf area indices by 21% in cassava and 10% in sweet potato than plants which are grown without mulching (Sangakkara *et al.*, 2004). Dalirie *et al.* (2010) found that the decline in LAI following the flag leaf stage might be ascribed by aging and yellowing of leaves, leaf senescence and thermal stress at later growth stages.

2.2.4 Plant height

The tillage practices affect the plant height and stem diameter during the growing period. Lampurlanes *et al.* (2001) reported that no-tillage is potentially found

superior for semi-arid regions since it maintained larger water content and greater growth of root especially in years of low rainfall. Varsa *et al.* (1997) observed that tillage systems affects the soil physical properties which further have direct or indirect impact on the shoot and root systems of the crops. Van Beem *et al.* (1998) found the effect of tillage on root capacitance in dry season that signifying superior root biomass. When the top soil remains untilled the root and shoot mass increases (Ball-Coelho *et al.*, 1998). Robertson *et al.* (1993) found the root growth is very important for crops, consumptive use of water and subsequent crop growth and yield under limited water conditions. Soil management practices such as tillage are very critical which are having greater impact on growth of root and shoot (Mosaddeghi *et al.*, 2009). The positive impact of conservation practices like ridges and furrows for enhancing the plant height and yield attributes of sorghum, cowpea, Bengal gram and sunflower (Somasundaram *et al.*, 2000). Earlier researchers specified that tillage systems affects the temporal and spatial modifications in soil structure affecting the wheat root characteristics underneath numerous irrigation, soil and climatic circumstances (Munoz-Romero *et al.*, 2010; Martinez *et al.*, 2008; Huang *et al.*, 2012). No-tillage improved the soil bulk density and penetration resistance paralleled to conventional plough tillage and rotary tillage in upper layer of the soil and considerably affected the spatial and temporal pattern of root weight density through the 0–110 cm soil profile. The conventional plough tillage and rotary tillage considerably enriched the root weight density in comparison to no-tillage in the initial growth stages (before grain filling stage); no-tillage indicated healthier root weight density in advanced growth stages. Underneath standard water supply state these outcomes are constant (Pearson *et al.*, 1991; Munkholm *et al.*, 2008). Conservation tillage along with organic matter/crop residue improved root spread and root length diameter (Ishaq *et al.*, 2001; Aggarwal and Goswami, 2003 and Kadzinene *et al.*, 2011). Root length density of wheat was higher in bed plantation up to 30 cm as compared conventional system (Aggarwal *et al.*, 2006). Around 70% of root length density and 76–82% of root surface area was confined upto 30 cm of soil in both systems.

2.2.5 Chlorophyll content

Spaner *et al.* (2005) observed that chlorophyll meter readings were influenced by tillage practices and soil moisture availability. There are various factors

responsible for variations in chlorophyll content other than water stress that could be nutrient deficiency, atmospheric pollution, nutrient toxicity, phenological status of the plant, radiation stress and plant diseases (Ceccato *et al.*, 2001 and Larcher, 2003). The coupled soil moisture deficit and deprived soil fertility directly affects the biophysical parameters like chlorophyll, relative water content, chlorophyll stability index, proline and ultimately the harvest of rainfed crops. Moderately harsh conditions prevent chlorophyll synthesis in wheat further uninterrupted deficiency of water leads to destruction of leaf chlorophyll (Singh *et al.*, 1985). The altered activities of enzymes like nitrate reductase and drop in the flux of nitrogen leads to loss of chlorophyll content in the leaves (Begaum and Paul, 1993). Similarly Thomas *et al.* (2005) found that high chlorophyll content might also contribute to higher photosynthetic rate. Positive correlation between chlorophyll content and photosynthesis rate was reported in previous findings. Chlorophyll colouration is directly related to the amount of nutrients absorbed by the plant from the soil (Follet *et al.*, 1981).

2.2.6 Radiation use efficiency

In plant growth determination solar radiation is the key factor. According to Monteith (1994) relation among the solar radiation captured by the crop and its biomass production rate is called radiation use efficiency. Radiation use efficiency (RUE) defined as the amount of dry biomass above ground or total dry matter produced per unit intercepted photosynthetically active solar radiation. Further it is defined as the efficiency by which the captured radiation produces new material (Black and Ong, 2000) and this parameter have been used in simulating the growth of various microbial cultures (Albrizio and Steduto, 2005). RUE has been considered to be constant for a given crop species (Yang *et al.*, 2004; Sinclair, 1986), but it vary during plant growing seasons (Werker and Jaggard, 1998; Lecoeur and Ney, 2003) and is mostly dependent on climatic parameters like abiotic stresses can significantly reduce both the interception of photosynthetically active solar radiation and RUE.

Yield is determined by the intensity and the quality of solar radiation intercepted by the canopy. According to Kahle *et al.* (2003), approximately 50% of the solar radiation lies in the infrared region, about 40% in the visible region and about 10% in the UV region. Solar radiation provides energy for carbon assimilation of plant canopies and for evaporation. Capability of interception of incoming radiation and conversion of it into biomass determines the crop growth in the field conditions

(Gifford *et al.*, 1984). Long *et al.* (2006) suggested that photosynthesis and yield potential could be improved up to 50% through changes in the efficiency of light interception as well as light utilization. The important impression of double cropping on the resources capture specifies the variance between storable (water) and non-storable resources (radiation) and water use efficiency was thoroughly linked with radiation use efficiency (Carriglia *et al.*, 2004). However, differences in biomass accumulation were observed due to differences in radiation interception, which varied primarily due to differences in LAI (Lindquist *et al.*, 2005). Solar radiation interception and efficiency of conversion of intercepted light in to dry matter by plant's leaf, affects the crop biomass production. Leaf area index and cropping geometry determines the absorption of incoming photosynthetically active radiation (Plenet *et al.*, 2000). Scopel *et al.* (1998) observed the effect of the mulch on radiation in their experiment and found that interception was significant and varied with residue quality and with the percentage of soil cover. Muchow *et al.* (1993) found that underneath optimum circumstances of water availability, the radiation use efficiency (RUE) rests almost persistent during most of the plant growth cycle and demonstrates no effects due to local atmospheric conditions. Factors such as air temperature, vapour pressure deficit and water stress are the most common elements which affect the RUE. However, crop productivity is not entirely dependent on resource capture during the growing season but also on resource use efficiency (Azam-Ali *et al.*, 1994; Yang *et al.*, 2004). Maize is C₄ crop having high WUE and RUE and in the study the RUE_{DM} varied from 2.7 to 3.4 g /MJ (depends on the water management treatments), within the range (2–4.3 g/ MJ) reported in earlier studies (Yang *et al.*, 2004; Andrade *et al.*, 1993).

2.2.7 Biomass and yield

Moreno *et al.* (1997) recorded that there were marginally higher yields in wheat and sunflower in the conventional treatment (CT) than in the traditional tillage. Further they summarised that when the precipitation is far below the normal, CT appears highly effective in improving soil water recharge and water conservation. No-tillage + crop residue management practices were potentially better than tillage for dry land crop production (Baumhardt and Jones, 2002). Zhang *et al.* (2006) observed that improved soil tilth, particularly in the seeding depth has a tendency to encourage root growth and seedling development. Weed control, soil improvement, optimum use of

water resources and greater crop yields may be enhanced by using correct tillage methods (Hanna *et al.*, 2009). Corn grain yield and root length index can be considerably enhanced by deep ploughing up to the depth of 30 cm (Arora *et al.*, 1991). Diaz-Zorita (2000) observed higher crop growth and grain yield because of deep tillage over no-tillage plots. Overall reduced grain yield was obtained due to severe weed population pressure under conservation tillage system (Nakamoto *et al.*, 2006; Blaise and Ravindran, 2003; Keeling and Abernathy 1989). Appropriate tillage practices and weed management improved spatial dispersal of plant roots, water availability and nutrients uptake, therefore finally enhanced productivity (Nakamoto *et al.*, 2006; Singh and Malhi, 2006). Tolk *et al.*, (1999) found that the diverse dry land crops like sorghum, maize, mungbean and soybean sown with zero-tillage with suitable mulch produced higher grain yield analogous with or higher than (especially in drier period) those obtained from conventional tillage practice. Aslam *et al.* (1993) established that zero-tillage produced 10% higher wheat grain in comparison to farmers' practices of minimum three ploughings with planking in rice based crop rotation in Pakistan. Zero-tillage and crop residues retention on surface of soil increased the organic matter content in cultivated soil (Lal *et al.*, 2002; Dalal and Chan, 2001; Heen and Chan, 1992) and was more beneficial for dry land crop production (Baumhardt and Jones, 2002) due to soil moisture conservation (Lampurlanes *et al.*, 2001).

Domua *et al.* (2009) observed the lowest yield of wheat in monocrop and higher yield in wheat-maize-soybean crop rotation after using the irrigation along with improved microenvironment conditions. Moreover, grain yield and quality are usually higher in diverse crop rotations. Crop rotation enhanced soybean yields by 16% in comparison to monoculture soybean (Kelley *et al.*, 2003). Soybean seed weight was considerably higher when grown in rotation in most of the years as compared to monoculture of soybean. Fischer *et al.* (2002) reported persistent higher grain yield of wheat under vetch wheat system as compared wheat after maize and equally greater yield was obtained in the wetter years over drier ones because plant water stress. Besides, the high transpiration in crop plants leads high stomatal conductance and intense photosynthesis resulted greater production of carbohydrates for the grain filling under no-tillage system (Dalmago *et al.*, 2003c).

2.3. Research Area III

The relevant materials to the third objective of the present study (research area III) are given under following heads.

2.3.1 Crop Evapotranspiration

The straw on the surface of soil may reduce the evaporation by 30% in zero-tillage in comparison to conventional tillage (Morote *et al.*, 1990; Bragnolo *et al.*, 1990; Salton *et al.*, 1995). The reduction in evaporation would be the main cause of higher water availability to plants in no-tillage. According to Kjaersgaard *et al.* (2008) awareness about crop water requirement is necessary for irrigation scheduling and agricultural water management in hydrological research and field management. Crop water requirement directly related to an accurate estimation of crop evapotranspiration (ET_c) which depends on crop characteristics and its developmental stages, environmental conditions, weather parameters and management practices.

ET_0 can be estimated by many methods (Jensen, 1971). According to Hargreaves and Samani (1985) ET_0 measurement methods ranged from simple equation that requires limited meteorological data to the complex energy balance equations (Allen *et al.*, 1998). Determination of crop evapotranspiration (ET_c) includes various measurement (direct) and modelling (indirect) techniques. Tyagi *et al.* (2000) said that an accurate estimation of crop ET is an important factor for efficient water management. Field water balance equation is commonly used to measure total water use or actual crop water requirement when lysimeter is not available (Prihar and Sandhu, 1987; Bandyopadhyay and Mallick, 2003; Kar *et al.*, 2007). Direct measurement methods of ET_c are costly and involve hard work and results apply only to the some exact or in similar conditions or place where they are measured.

The indirect estimation using the FAO-56 model (Penman-Monteith approach, Allen *et al.*, 1998) has often been used because it requires only crop phenological data and standard weather parameters which can be easily obtained. According to Allen *et al.* (1998) the FAO Penman-Monteith method was developed by defining as hypothetical crop with an assumed height of 0.12 m, surface resistance of 70 s m^{-1} and an albedo of 0.23, closely resembling the evaporation from an extensive green grass surface of uniform height, actively growing and no shortage of moisture. This method provides values that are more consistent with actual crop water use data and

overcomes the shortcomings of the FAO-24 Penman method (Doorenbos and Pruitt, 1977). The FAO-56 Penman-Monteith model is the most precise one for its good results when compared with other models in various parts of the world (Gavilan *et al.*, 2006; Garcia *et al.*, 2004; Chiew *et al.*, 1995).

The semi-empirical FAO-56 model used to calculate plant transpiration and soil evaporation based on specific crop coefficients and water balance method. The crop coefficient method has been used to calculate crop water use and irrigation requirements of a various agricultural crops under different climatic conditions (Abdelhadi *et al.*, 2000; Poulouvassilis *et al.*, 2001; Zhang *et al.*, 2004; Howell *et al.*, 2004; Kar *et al.*, 2005; Bodner *et al.*, 2007). Doorenbos and Kassam (1979) said that crop coefficient (K_c) established relation between evapotranspiration and climate for most agricultural crops which is the ratio of crop evapotranspiration (ET_c) to reference evapotranspiration (ET_0).

Modified FAO-56 method prefer to calculate actual crop evapotranspiration (Allen *et al.*, 1998) due to its accuracy compared to other previous methods (Jensen *et al.*, 1990) and the single and dual crop coefficients (Allen *et al.*, 1998) are used to assess its magnitude. This method provide ET_c more accurately and overcomes the shortcomings of the previous FAO-24 Penman method.

2.3.1.1 Crop coefficients

Jensen (1968) introduced crop coefficient (K_c) concept and further improved by the other scientists (Doorenbos and Pruitt, 1977; Burman *et al.*, 1980; Allen *et al.*, 1998).

The crop coefficient K_c is needed to estimate ET_c which give crop- specific water use and also used for accurate estimation of irrigation water requirements. The crop coefficient used to describe the physiological and morphological characteristics of the crop and the cultural practices used in field. Each crop has specific crop coefficient, crop evapotranspiration varies due to the season because morphological and bio-physiological characteristics of the crop change with time. Tarantino and Spano (2001) said that the FAO and WMO (World Meteorological Organization) experts have summarised the crop characteristics in the “crop coefficient curve” to identify the values of K_c corresponding to the different crop development and growth stages.

K_c values for most agricultural crops increase from seed germination and reach at maximum at mid-season stage full canopy cover and then declines in late season stage. Crop growth characteristics are primarily responsible for this declination (Jensen *et al.*, 1990). The FAO-56 paper give a method to calculate E_t with help of three K_c values that are appropriate for four crop growth stages for a large number of crops. Single crop coefficient combined the effect of crop transpiration and soil evaporation in a single crop coefficient while in dual crop coefficient method E_{Tc} is determined by splitting K_c into two different coefficients i.e. the basal crop coefficient (K_{cb}) for crop transpiration and soil water evaporation coefficient (K_e) for soil evaporation. Where soil evaporation is not a large component of crop evapotranspiration, use of single crop coefficient approach will provide good results (Allen *et al.*, 1998). Majority of the studies considers single crop coefficient approach due to its simplicity. Dual crop coefficient used less frequently where the crop transpiration and soil evaporation are determined separately (Lopez-Urrea *et al.*, 2009; Casa *et al.*, 2000).

2.3.1.1.1 Single crop coefficient approach

According to Grattan *et al.* (1998) various experiments and research have been carried out to make K_c use operational worldwide and to determine the average value of K_c which may take in the course of the season over the years. The K_c values are affected by various factors that affect soil water status like the irrigation method and frequency (Doorenbos and Pruitt, 1977; Wright, 1982), the soil characteristics, the weather factors and the agronomic techniques that affect crop growth (Stanghellini *et al.*, 1990; Tarantino and Onofrii, 1991). The crop coefficient values are different at various growth stages of mustard. Kar *et al.* (2007) found K_c values of 0.39, 0.92, 1.31 and 0.42 were achieved at initial, development, mid season and late season, respectively at Bhubaneswar for mustard crop. K_c values have increasing trend from initial to mid season stage than after decreasing trend due to crop toward physiological maturity. According to Kumar *et al.* (2012) initially slow increase in the K_c values from 0.3 to 0.6 can be attributed to slow increase in LAI from below 0.2 to near 0.8 during initial period than peak K_c values around 1.12 during mid season stage because LAI also reached peak value around 1.5 during this period (41st-70th DAS) and in the late season stage starting from 71 to 90 DAS crop coefficient rapidly decreased to 0.35 with fast decline in LAI value (0.8).

Miranda *et al.* (2006) found a 3–14 % higher average K_c value for tabasco pepper during the mid-season stage than that reported in the FAO-56 publication. Other evapotranspiration studies carried out for melon and watermelon also showed that the average crop coefficients during the mid-season stage was close to 1.2 and 15 % higher than the K_c values recommended in the FAO-56 paper (Miranda *et al.*, 1999, 2004; Bezerra and Oliveira, 1998). Kar *et al.* (2007) revealed that during the crop development and maturity stages of oilseed, the estimated K_c values were 11–23 % higher than the values reported by the FAO-56 paper. According to Bandyopadhyay and Mallic (2003), during the wheat crop development and end growth stages, the estimated K_c values were 15 and 23 % higher, respectively, than the values reported by the FAO-56, although the values of the initial and mid-season stages were identical.

2.3.1.1.2. Dual crop coefficient approach

An evaluation of water lost by direct soil evaporation from crop plants needs separation of total crop evapotranspiration into plant transpiration and soil evaporation components. Williams *et al.*, (2004) said that direct and separate measurements of soil evaporation and crop transpiration have been successfully obtained, but difficult to employ. Dual crop coefficient method can be successfully used for detailed soil and water balance studies (Allen *et al.*, 1998). Lopez-Urrea *et al.*,(2009) reported that the evapo-transpiration measured with dual crop coefficient approach is more rational than the single crop coefficient in onion grown under semi-arid climatic conditions during the whole crop cycle. For FAO-56 dual crop coefficient application required proper evaluation of K_{cb} value during entire crop growing period. Raki *et al.*, (2007) reported that the calculated K_{cb} values for winter wheat at mid season stage was considerably lower than the value suggested by FAO-56.

FAO-56 dual crop coefficient method determination requires a number of parameters that may not be accessible in field measurements (Hay and Irmak, 2009). Hay and Irmak (2009) said that dual crop coefficient method resulted in good estimates of seasonal ET_c for wheat and maize, while the performance was less reliable on a everyday basis. When dual crop coefficient was used to calculate evaporation and transpiration the addition of values of evaporation and transpiration for onion was substantially lower than ET values obtained with help of lysimeter

(López-Urrea *et al.*, 2009) because of an underestimation of the transpiration from crop and evaporation from soil which were corrected when the lysimetric measured values of K_{cb} and K_e were used.

2.3.2. Water use efficiency

Crop yield response to irrigation water input can be helpful for various water management practices in the crops. Water production functions for various agronomic crops are used for optimal water use. Hexem and Heady (1978) observed that water production functions relates yield to applied water for the calculation of crop water requirements by irrigation water in addition to available soil moisture and rainfall. Vaux and Pruitt (1983) combined the yield of a given crop to cumulative ET as a linear function. Doorenbos and Kassam (1979) introduced the yield response factor to describe the relationship between ET deficit and yield reduction. Water use efficiency (WUE), where $WUE = Y/ET$, described the water used by the crop for grain yield production, and has been often taken as a useful comprehensive index (Hunsaker *et al.*, 1996; Wang, 1987; Turner, 1987; Eck, 1986). For sorghum a linear relationship was observed between grain yield and ET by Garrity *et al.* (1982) and found that the intercept of the ET governs whether WUE decreases or increases with ET deficit.

Singh and Bhushan (1980) observed that the addition of nutrient like P to chickpea (*Cicer arietinum* L.) increased WUE. The WUE was increased from 8.5 to 12.2 kg/ ha/mm at 0 and 100 kg P/ha respectively. This gain was due to a greater consumption of soil water with fertilizer and a yield increase. Zhang *et al.*, (2000) observed that the average water use efficiency and potential transpiration efficiency for lentil and chickpea were lower than those for cereals. Lower seed yield was associated with low water use efficiency in the study. Brown *et al.*, (1989) observed that Chickpea survived under drought stress by maximizing its root water uptake through continuous root growth from seed germination to grain-filling and by continues substantial water uptake until the fraction of extractable moisture in the root profile falls to 0.4.

Semiarid region have the potential to improve WUE because water vapor gradient between plants and the atmosphere is small and evaporation rates may be reduced (Tanner and Sinclair, 1983). The different forms of relationships that have been used to characterize water use efficiency summarized by Tanner and Sinclair (1983). Similarly earlier summaries developed by Unger and Stewart (1983) and

Power (1983) provided a strong base for describing the role of soil management on WUE.

According to Hatfield *et al.* (2001) most of the research that forms the foundation for understanding the relationships among precipitation, soil moisture, crop water use, and crop response has been carried in semiarid regions and it was said that semi-arid region may have the most potential for improvement in WUE, which was due to less vapour gradient between plants and the atmosphere and evaporation rates may be deducted (Tanner and Sinclair, 1983).

Increasing the soil moisture availability in the absence of other crop growth and yield-limiting factor can lead to increased WUE (Hatfield *et al.*, 2001). Wheat yield enhanced from 1000 to 3000 kg ha⁻¹ as available soil moisture increased from 220 to 400 mm (Good and Smika, 1978). Farahani *et al.* (1998) observed that the improvement in efficiency was possibly due to less use of fallow seasons and using water for crop growth that otherwise would have lost by runoff, evaporation or deep percolation during fallow field. Application of phosphorous also improved the yield, water use and WUE of chickpea (Singh and Bhushan, 1980), possibly because of greater utilization of soil water with fertilizer and corresponding yield increase associated with low seed. Water use efficiency of field crops can increased through proper irrigation scheduling by providing only water that matches the crop evapotranspiration and providing irrigation at critical growth stages (Eck, 1984; Wang, 1987; Turner, 1987; Wang *et al.*, 2001; Hunsaker *et al.*, 1996; Kipkorir *et al.*, 2002; Norwood and Dumler, 2002; Kar *et al.*, 2005)

A study was conducted during 1998 to 2000, to evaluating crop water use and soil-water extraction by Kabuli chickpea by Anwar *et al.*, 2003. The response of three cultivars to eight irrigation treatment in 1998-99 and four irrigation in 1999-2000 at different crop growth stages were studied on Wakanui silt loam soil moisture in Canterbury, New Zealand. Crop evapotranspiration was computed from soil moisture data monitored though a neutron moisture meter and water use efficiency (WUE) was calculated at crop physiological maturity. There were highly significant interacting effect of sowing date, cultivar and sowing date on WUE and the trend was similar to that for grain yield. The calculated WUE varies from 22-29 kg dry matter/ ha/ mm and 10-13 kg seed yield /ha/mm water use. Zhang *et al.* (2000) said that despite the importance of water use by legumes, little attention has been given to the pattern of water use and the water-seed yield relationship of legumes.

High water use efficiency (WUE), capacity of the plant to produce dry matter/unit of water is a genetic character, dependent on transpiration rate (T) and photosynthetic rate (Pn) and, is very crucial for crop productivity under water stress condition. Since low photosynthetic efficiency is believed to be one of the major constraints in achieving high yield (Thurling,1992) because enhancing photosynthetic efficiency resulting higher yield.

Seed yield is also limited by the relatively shorter duration of crop growing season and the soil water deficits during the productive phase. The contribution of photosynthesis of pods to the seed yield in Brassicas is about 70%, therefore, genotypes with high WUE during this phase would be highly desirable. Generally water use efficiency and evapotranspiration are the measurement of Water consumption in crops (Cantero-Martínez *et al.*, 2007; Zhang *et al.*, 2008; Katerji *et al.*, 2008), meanwhile 99% of the water utilized by the crops is freed to the air as the water vapor (Katerji *et al.*, 2008). In water scared regions, the efficient utilization of the available water for the agricultural production is need as the limited resources of water are shirking (Zhang *et al.*, 2008; Cantero-Martínez *et al.*, 2007). In dryland systems rain is only source of water hence judicious use of rainfall is measured in terms of WUE which is having great impact on crop management, (Hatfield *et al.*, 2001). Capitalization of WUE is a vital concern for semi-arid land tropics (Gregory, 1989). WUE of crops and availability of water depends on soil management practices (Hatfield *et al.*, 2001). In the great plains of the USA in the fallow period 75% precipitation was lost, with improved 16-25% effectiveness of zero tillage for soil water storage (Farahani *et al.*, 1998). As compared to conventional tillage, in conservation tillage, the WUE was 13% higher for the winter wheat (Du *et al.*, 2000). Bouzza (1990) recorded that water storing improved by 50 to 85 mm due to surface application of straw in comparison to deeply incorporated straw. The zero-tillage + crop residue management is potentially found better than tillage for dryland crop production (Baumhardt and Jones, 2002). As it maintained more root growth and higher water content in the soil especially in years of low rainfall (Lampurlanes *et al.*, 2001). Additionally, standing residue reported to trap snow, improve water infiltration, and intensify soil water storage (Aase and Siddoway, 1990). Soil water storage found to increase by surface residues forming mulch as it enhances water infiltration and decreases evaporation (Greb, 1966; Ramig *et al.*, 1983; Schillinger and Boltonne, 1993; Bonfil *et al.*, 1999; Halvorson *et al.*, 1999; Hatfield *et al.*, 2001; Lafond *et al.*, 2006).

3. Materials & Method

In order to achieve the objectives of the present investigation, field experiments were conducted during the *kharif* and *rabi* seasons of 2014-15 and 2015-16 under maize-wheat and pigeon pea-wheat cropping systems respectively at the research farm of ICAR-Indian Agricultural research Institute (IARI), New Delhi. The details of the materials and methods adopted during the course of investigation have been presented in this chapter.

3.1 Field experiments

3.1.1 Location of the experimental farm

The present study was carried out in the experimental field of ICAR-Indian Agricultural research Institute (IARI), New Delhi, India which is stretching from 28°35' N latitude to 77°12' E longitude at an altitude of 228.16 m above mean sea level. The field had fairly levelled topography.

3.1.1.1 Climate

Climate of New Delhi is sub-tropical and semi-arid with warm and dry summer and cold winters, comes under 'Trans-Gangetic Plains' agro-climatic zone. The hottest months (May and June) during summer have daily mean maximum temperature remains in the range of 40°C- 46 °C most of the days while temperature decreases from September onwards. The all time record of highest daily maximum temperature (46.8 °C) was recorded on 29th May, 1998. In January daily mean minimum temperature ranges around 5 °C to 7.5 °C, it is the coldest month in winter season. The all time lowest daily minimum temperature (-1.4°C) was recorded on 9th January, 2006. Annual mean rainfall is around 710 mm and the wettest months are July and August. Maximum rainfall around 80 per cent of the annual rainfall is received from July to September during south-west monsoon period (normal date of arrival of monsoon at Delhi is 29th June). The rest amount is received through "Western Disturbances" during winter months (December to February) and some local convections during pre-monsoon months (March-June). However, air remains dry during most part of the year. The monthly mean relative humidity ranged between 35% (June) and 94% (December). Monthly mean wind velocity varies from 3.5 km hr⁻¹ in October to 4.4 km hr⁻¹ in April. Air remains dry during most part of a year. Pan

evaporation varied between 3.5 to 13.5 mm day⁻¹ and reference evapotranspiration varies from 9-15 mm day⁻¹.

3.1.1.2 Soil

The soil of the experimental site belongs to Indo-Gangetic alluvium soil group. The soil belongs to order Inceptisols having sandy clay loam (fine loamy, illitic, Typic Haplustept) in upper 30 cm layer and loam below with weak to medium angular blocky structure. The soil was neutral in reaction, non-calcareous and poor in available N, and medium in available P and organic carbon.

3.1.1.3 Detail of field experiment

Long term conservation agriculture (CA) experiments were initiated in May 2010 at the research farm of the IARI, New Delhi on an alluvial sandy clay loam soil (fine loamy, illitic, Typic Haplustept) with maize-wheat and pigeonpea-wheat cropping system. The surface (0-15 cm) soil of the experimental site had pH 7.7, Walkley-Black organic C 5.2 g kg⁻¹, KMnO₄ oxidizable N 182.3 kg ha⁻¹, 0.5 M NaHCO₃ extractable P 23.3 kg ha⁻¹ and 1 N NH₄OAc extractable K 250.5 kg ha⁻¹.

3.1.2 Cropping systems

Two long term conservation agriculture (CA) experiments were initiated at the research farm of the ICAR-IARI, New Delhi, India on an alluvial sandy clay loam soil (fine loamy, illitic, Typic Haplustept) with maize-wheat and pigeon pea-wheat cropping systems. Maize (*Zea mays* L.) variety BIO 9637 was sown on 5th July during *kharif* 2014 and wheat (*Triticum aestivum* L.) variety CSW 18 was sown on 10th November during *rabi* (2014-15) in maize-wheat cropping system. In *kharif* 2015, Pigeonpea (*Cajanus cajan* L.) variety Pusa 992 was sown on 30th May and wheat (*Triticum aestivum* L.) variety HD 3117 was sown on 11th December during *rabi*, 2015-16 in the pigeon pea-wheat cropping system.

3.1.3 Treatment details

The field experiment was carried out with seven treatments i.e. conventional tillage (CT), permanent narrow-bed without residue (PNB), permanent narrow-bed with residue (PNB+R), permanent broad-bed without residue (PBB), permanent broad-bed with residue (PBB+R), zero tilled flat bed without residue (ZT), zero tilled

flat bed with residue (ZT+R). Layout of field experiment was randomized block design (RBD) with three replications.

Table 1: Treatment description in maize-wheat and pigeonpea-wheat cropping systems.

Treatment	Tillage	Type of bed	Residue retention
CT	Conventional tillage	Flat beds	No
PNB	Zero tillage	Permanent narrow bed (PNB; 40 cm bed and 30 cm furrow)	No
PNB+R	Zero tillage	Permanent narrow bed (PNB; 40 cm bed and 30 cm furrow)	Yes, wheat residue in pigeonpea/maize and pigeonpea/maize residue in wheat
PBB	Zero tillage	Permanent broad bed (PBB; 110 cm bed and 30 cm furrow)	No
PBB+R	Zero tillage	Permanent broad bed (PBB; 110 cm bed and 30 cm furrow)	Yes, wheat residue in pigeon pea/maize and pigeonpea/maize residue in wheat
ZT	Zero tillage	Flat beds	No
ZT +R	Zero tillage	Flat beds	Yes, wheat residue in pigeonpea/maize and pigeonpea/maize residue in wheat

3.2 Intercultural operations

3.2.1 Irrigation and fertilizers

In the CT and ZT plots, irrigation was applied using flooding method (water applied during the first irrigation, measured with a water meter, was in the range of 0.065 m and 0.056 m in CT and ZT) always resulted more water application than that in the plots under PNB and PBB (where irrigation water was applied in furrows). The irrigation water amount applied in both bed planting schemes were slightly different. The maximum amount of applied water in a furrow was equal to half of the area of an ellipse (with semi axes a and b) * the length of a furrow (L), where, a was depth of furrow and b was $\frac{1}{2}$ of the width of a furrow. In the plots under PNB, the maximum amount of applied irrigation water per ha during first irrigation was $0.5 * \pi * 0.15 * 0.15 * 143 * 100$ m = 0.05 m, whereas in the PBB, the amount was = $0.5 * \pi * 0.20 * 0.20 * 72 * 100$ = 0.045 m. So the ratio of amount of water applied per ha in PNB

to PBB plots was 1:0.9. In subsequent irrigations due to settling of soils by wetting and displacement and deposition of bed soil into furrow, the depth of furrow reduced hence, the volume of irrigation water in both systems were decreased. For wheat, a common fertilizer dose of 120 kg N + 60 kg P₂O₅ + 40 kg K₂O ha⁻¹ was applied, of which P and K were applied as basal along with 50% N through a seed-cum-fertilizer drill or a bed planter, while the remaining N was top-dressed in two equal splits after the first and second irrigations. Recommended doses of fertilizer 120 kg N + 60 kg P₂O₅ + 40 kg K₂O ha⁻¹ was applied in maize crop and 20 kg N + 60 kg P₂O₅ + 40 kg K₂O ha⁻¹ was applied in pigeonpea crop.

3.2.2 Tillage

In the maize-wheat and pigeonpea-wheat system, after harvest maize, pigeonpea and wheat residues were taken away from the plots under ZT, PNB, PBB and CT. However, tender pigeonpea and maize twigs and leaves (about one third of total residues) and the entire wheat residues retained in the plots under ZT+R, PNB+R, PBB+R. In both ZT and ZT+R plots, very little pigeonpea, maize stalk and wheat stubble (~10-15 cm) remained anchored during ploughing of the next crop. The experiment design was randomized block design with three replications for each treatment. Conventional tillage involved one deep (~30 cm) ploughing with a disc plough followed by two ploughing each with a disc harrow and cultivator, while ZT treatment had no ploughing. A zero-till seed-cum-fertilizer drill was used for sowing of the crops on the flat surface (ZT and CT), while a bed planter was used for sowing under raised-bed systems (PNB and PBB).

3.2.3 Pest control

To control the pests, seed treatment was done with fungicides and insecticides at the rate of 2g/kg seed and 20 ml/ kg seed, respectively. However, two spray of imidachloprid @ 200 ml/ha and chloropyrphos @ 400 ml/ha were done to control the insect-pests during cropping season. Different kind of weeds was observed in the field during cropping period. The herbicide namely pendimethalin was applied after planting and before crop emergence for controlling most of weeds in the crop. After 30 days of crop the spray of herbicide quizalofop was done for controlling weeds in standing crop. In addition, two hand weeding was also done in pigeonpea under pigeonpea-wheat cropping system.



A



B



C

Plate: 1. Tillage implements used during field study
[A. Zero seed drill B. Bed planter C. Cultivator]



Plate: 2. Field view under different treatments at early stage of the pigeon pea crop, (A) Zero tillage (ZT), (B) Permanent narrow bed (PNB), (C) Permanent narrow bed + Residue (PNB+R) (D) Permanent broad bed + Residue (PBB+R)

3.3 Schedule of observations

The observations were recorded and measured on different parameters of weather, microenvironment under different treatments like air temperature and relative humidity, soil temperature etc, biophysical parameters of crop plants are given below.

3.3.1 Weather parameters

Data on daily rainfall, minimum and maximum temperatures, wind speed, relative humidity, sunshine hours, pan evaporation were collected from the agrometeorological observatory of the Division of Agricultural Physics, ICAR-IARI, New Delhi situated near the experimental plots.

3.3.2 Soil temperature

Soil temperature at different depth (5, 10, 15 and 20 cm) was measured with the help of soil thermometer under different treatments.

3.3.3 Heat indices

Different thermal indices were calculated at physiological maturity under different conservation practices along with conventional practice as given by the equations in table 2.

Table 2: Methods for calculation of different heat indices

S.No.	Indices	Computation	Reference
1	Growing degree days (GDD)	$=\sum \{(T_{\max}+T_{\min})/2\} - T_b$	(Iwata,1984)
2	Helio thermal units (HTU)	$=\sum \text{GDD} \times \text{SSH}$	(Rajput,1980)
3	Photo thermal units (PTU)	$=\sum \text{GDD} \times \text{Day length}$	(Major et al.,1975)
4	Relative temperature disparity (RTD)	$=\sum \{(T_{\max}-T_{\min})/T_{\max}\} \times 100$	(Rajput,1980)
5	Heat use efficiency (HUE)	$=\text{Yield}/\text{GDD}$	(Haider et al., 2003)
6	Photo thermal index (PTI)	GDD/Growing day	(Haider et al., 2003)

3.3.4 Photosynthesis, transpiration rate and stomatal conductance measured by Infra red gas analyser

Photosynthesis rate, transpiration rate and stomatal conductance were measured by infrared gas analyser (model LI-6400XT). The technique was based on the principle that hetero-atomic gas molecules (like H₂O, CO₂, N₂O etc) have a characteristic spectrum and absorb radiation at specific sub millimetre infrared wavebands. The absorption bands are made from a series of absorption lines which correspond to the rotational states of the molecules. Absorption of radiation by CO₂ at any one wavelength follow Beer Lambert Law and depends on radiation path length through measuring gas and molar concentration of CO₂.

$$\alpha_{\lambda} = 1 - \exp(-M \cdot I \cdot K_{\lambda}) \text{ -----(1)}$$

Where, K_{λ} = extinction coefficient at wavelength λ , I = radiation pathlength, M = molar concentration of CO₂ in air. The main absorption band of CO₂ is 4.25 μm with secondary peaks at 2.66, 2.77 and 14.99 μm . The only hetero-atomic gas is water-vapour which normally present in air with an absorption spectrum overlapping with that of CO₂ (both molecules absorb IR in the 2.7 μm region). Since water vapour is present at much higher concentration than CO₂ in air, so its interference is significant. This is overcome either by drying the air that is to be examined or by filtering out all radiation at wavelength where absorption of two gases coincides.

3.3.5 Air temperature and relative humidity profile within crop canopy

Air temperature and relative humidity within crop canopy were measured at mid-height of canopy with the help of a pocket weather tracker (Model: Kestrel 4000) around 14:00 hours (i.e., time of occurrence of daily maximum temperature).

3.3.6 Plant bio-physical parameters

Observations of biomass accumulation, leaf area index (LAI), plant height etc were recorded at 30 days intervals.

3.3.6.1 Accumulation of biomass

Three plants were selected randomly in each plot and cut at ground level for this study. Those plants were oven dried at 65⁰C for 48 hours and weighed by using electrical digital balance until a constant weight was achieved. The dry matter production was expressed in t/ha.



Plate 3: Digital Soil Thermometer



Plate 4: Infrared gas analyser



Plate 5: Pocket Weather Tracker (Model: Kestrel 4000)



Plate 6: LAI-2000 Plant Canopy Analyzer (LI-COR, USA)

3.3.6.2 Leaf Area Index (LAI)

Measurements of LAI were carried out in a field at 30 days intervals using LAI-2000 Plant Canopy Analyzer (LI-COR, USA), whose principle is based on “fish-eye” measurement of diffuse radiation interception by measurement of gap fraction at five zenith angles (0–13, 16–28, 32–43, 47–58, 61–74°) simultaneously. The measured gap-fractions are then inverted to get the effective LAI and the instrument was set to take four below and one above canopy measurements to estimate the LAI. Three LAI readings were recorded in each plot and then averaged out to represent each plot LAI. At later stages in case of pigeonpea the LAI values also included pod surface area after pod formation.

3.3.6.3 Plant height

Plant heights of three plants were measured by digital scale from each treatment in the interval of 30 days during cropping season. The average plant heights of three plants from each treatment are shown in the result.

3.3.6.4 Leaf water potential

Leaf water potential was measured with the help of pressure bomb (PMS Instruments Co, USA) using the method of Scholander *et al.*, (1964). Leaves were plucked from field and brought in packed humid polythene bags to minimize the evaporation losses. These leaves were kept inside the pressure bomb apparatus and pressure was applied till the first droplet of water oozed out at the out end. The pressure applied was read from the meter. This was repeated for all the samples.

3.3.6.5 Relative water content

For estimating relative water content discs of 1cm diameter were taken from middle portion of fully developed leaf from chosen plants of each replicate under different treatments. Fresh weight was measured immediately and these leaves dices were floated on distilled water for around 5 h then turgid weights of leaves discs were measured after drying excess surface water with paper towels. Dry weights (DW) of discs were obtained after drying at 75 °C for 48 h. Following formula was used to calculate Relative water content (RWC).

$$\text{RWC (Relative water content): } \frac{\text{Fresh wt-Dry wt}}{\text{Turgid wt-Dry wt}} \dots\dots (2)$$

3.3.6.6 Leaf Chlorophyll Content

Fresh leaf samples from different tillage treatments were taken, than 100 mg of it was weighed accurately in an analytical balance and chlorophyll from leaves was extracted by a non-macerated method equilibrating it with 10 ml Dimethyl Sulfoxide (DMSO) in a capped vial and keeping in an oven at 45°C for the overnight (Hiscox and Israelstam, 1979). The decanted solution was used to estimate the absorbance at 645 nm and 663 nm wavelength using Spectrophotometer Spectronic-20. Formula given by Arnon (1949) is used for calculating the total chlorophyll content.

$$\text{Total Chlorophyll content (mg/g of fresh weight)} = \frac{[20.2 \times A_{645} + 8.02 A_{663}] V}{1000 W} \dots (3)$$

Where, A_{645} = Absorbance at 645 nm,

A_{663} = Absorbance at 663 nm,

V = Final volume of chlorophyll extract in DMSO,

W = Weight of plant sample

3.3.7 Radiation use efficiency (RUE)

RUE of the crop was calculated using the following formula:

$$\text{Radiation use efficiency (RUE): } \frac{\text{Amount of dry matter produced (g/m}^2\text{)}}{\text{Amount of Cumulative light absorbed (MJm}^{-2}\text{)}} \dots (4)$$

3.3.8 Radiation Characteristics

Both incoming and outgoing photosynthetically active radiation (PAR) values were measured using line quantum sensor (LICOR-3000) at top of crop canopy, middle of crop height and bottom of crop throughout the crop growing season. To get reflected radiation from top and bottom ground, the sensor was held in inverse position. The above measurements were taken in different growth stages between 11:30 and 12:00 hours IST on clear days when disturbances due to leaf curling, leaf shading and solar angle were minimum. These data were further used to calculate radiation use efficiency.



Plate 7: Spectrophotometer Spectronic-20



Plate 8: Line Quantum Sensor (LI-COR, USA)

3.3.8.1 Absorbed Photosynthetically Active Radiation (APAR)

APAR by the whole canopy = {Incident radiation on the top of the canopy – reflected radiation by the top of the canopy– incident radiation at the bottom (transmitted radiation) + reflected from the ground}.

3.3.8.2 Intercepted Photosynthetically Active Radiation (IPAR)

Radiation interception (percent) by the whole canopy = {(Incoming PAR at top –reflected from the canopy –incoming PAR at bottom)*100}/ (Incoming PAR at the top)

3.3.8.3 Accumulated PAR and incoming short wave solar radiation

The mean daily values of incoming shortwave solar radiation were estimated using Angstroms equation and the PAR was calculated by multiplying it with 0.48 (Monteith, 1972). The extra terrestrial radiation for daily periods (Ra) was calculated following Allen *et al.* (1998) with the following equation:

$$Ra = [(24 \times 60) / \pi \times Gsc \times dr \times \{Ws \times \sin(\Phi) \times \sin(\sigma) + \cos(\Phi) \times \cos(\sigma) \times \sin(Ws)\}]$$

Where, Ra = Extra terrestrial radiation (MJ/m²/day)

Gsc = Solar Constant (0.082 Mj/m²/min)

dr = Inverse relative distance earth –sun

Ws = Sunset hour angle

Φ = Latitude (radian)

σ = Solar declination

dr was estimated by the following equation:

$$dr = \{1 + 0.033 \times \cos(2\pi/365 \times J)\}$$

Where, J is the Julian day

The incoming shortwave solar radiation (Rs) is calculated by the Angstrom formula:

$$Rs = Ra \times (0.32 + 0.46 \times n/N) \text{ for Delhi condition}$$

Where, n= actual bright sunshine hours for a day

N= maximum possible sunshine hours for the same day.

Where $N = (24/\pi) \times W_s$

W_s is the sunset hour angle (Radian) = Arc Cosine [$-\text{ten}(\Phi) \times \tan(\sigma)$]

Φ = Latitude in radian,

For IARI, Delhi $\Phi = (28.12 \times \pi)/180$

σ = solar declination in radiation, calculated as follows:

$$\sigma = 0.409 \times \text{Sine} [(2 \times \pi \times J)/d - 1.39]$$

Where, J = Julian days (1 to 365/366) and d = no. of days in the year

Finally, PAR was calculated by $\text{PAR} = 0.48 \times R_s$

The cumulated APAR was calculated by

$$= R_s \times f\text{APAR} \times 0.48$$

$f\text{APAR}$ = Fraction of Absorbed PAR

Radiation use efficiency (RUE) was calculated at thirty days interval in both cropping systems.

3.3.9 Soil water monitoring

Soil moisture at different depth (0-15, 15-30, 30-45, 45-60 cm) measured prior to irrigation under conservation treatment along with conventional treatment. In case of pigeonpea the soil moisture measured upto 75 cm depth due to its deep root system.

In the absence of lysimeter measurement, soil water balance equation is a sound alternative for calculating ET_c . The soil water balance method (Hanks and Ashcroft, 1980) determined the components (all expressed in mm) of the water balance equation for total volume defined by the soil profile of a given root zone depth and is written as:

$$ET_c = (P + I + U) - (R + D) - (\Delta S + \Delta V) \dots \dots \dots (5)$$

Where, ET_c denotes estimated crop evapotranspiration (mm), P is precipitation (mm), I is irrigation (mm), D is deep percolation below the root zone (mm), R is runoff (mm) and ΔS is the change in profile soil moisture (mm), and ΔV is increment of water content in plants.

Runoff (R) was assumed to be negligible as the field plots were banded upto 30 cm height and no over flow over bands occurred. ΔV is considered to be insignificant and was, therefore, ignored. The water table was below 15 m and therefore, capillary rise (U) was assumed to be zero. Change in soil moisture content (ΔS) was calculated for each period of crop growth from the initial and final soil moisture. Soil moisture was calculated using gravimetric method. For gravimetric method, soil sample was collected by screw-auger in aluminium cans, weighed and kept in hot air oven to dry at 105°C for at least 24 hours. Dried sample was weighed and the moisture content on mass basis was calculated using the following formula:

$$\text{Mass wetness} = \frac{(\text{Wet weight}) - (\text{Dry weight})}{\text{Dry weight}} \quad \dots \dots \dots (6)$$

3.3.10 Reference evapotranspiration

The FAO Penman-Montieth equation (Allen *et al.*, 1998) was used to calculate reference evapotranspiration, ET_0 .

$$ET_0 = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 U_2)} \quad \dots \dots \dots (7)$$

Where ET_0 expressed in (mm day⁻¹); R_n net radiation at crop surface (MJ m⁻²hr⁻¹); G soil heat flux density (MJ m⁻² day⁻¹); T air temperature at 2 m height (°C); u_2 wind speed at 2m height (m s⁻¹); e_s saturation vapour pressure (kPa); e_a actual vapour pressure (kPa); Δ the slope of the vapour pressure curve (kPa°C⁻¹) and γ is the psychrometric constant in (kPa °C⁻¹).

3.3.11 Net radiation calculation

$$R_n = (1 - r) (0.25 + 0.5 n/N) R_o - (0.9n/N + 0.1)(0.34 - 0.14 \sqrt{e_a}) \sigma T^4 \quad \dots \dots \dots (8)$$

Where, R_o = extraterrestrial radiation (MJ m⁻² day⁻¹),

e_a = actual vapor pressure (kPa),

σ = Stefan-Boltzmann constant (4.903 × 10⁻⁹ MJ m⁻² K⁻⁴ day⁻¹),

T = air temperature (K),

r = reflection coefficient (observed mean value, 0.24),

n = number of hours of bright sunshine per day (h),

N = total day length

3.3.12 Crop coefficient K_c

Single crop coefficient approach

$$ET_c = K_c \times ET_0 \dots \dots \dots (9)$$

Calculation- Adjustment was done according to experiment.

$$K_{c \text{ ini}} = f_w \times K_{c \text{ ini}} (\text{Tab}) \dots \dots \dots (10)$$

Where, f_w the fraction of surface wetted by irrigation or rain (0-1), for flood irrigation in CT and ZT treatments, f_w was 1, for PBB treatment, f_w was 0.5 and for PNB treatment, f_w was 0.7 taken.

$K_{c \text{ ini}} (\text{Tab}) = 0.3$ for wheat and maize crop, 0.4 for pigeonpea crop

Crop coefficient for the mid-stage season ($K_{c \text{ mid}}$)

$$K_{c \text{ mid}} = K_{c \text{ mid}} (\text{Tab}) + [0.04(u_2 - 2) - 0.004(RH_{\text{min}} - 45)](h/3)^{0.3} \dots \dots \dots (11)$$

Where, $K_{c \text{ mid}} (\text{Tab})$ value for $K_{c \text{ mid}}$ was 1.15 for wheat and pigeonpea and for maize 1.20 taken.

Crop coefficient for the end of the late season stage ($K_{c \text{ end}}$)

$$K_{c \text{ end}} = K_{c \text{ end}} (\text{Tab}) + [0.04(u_2 - 2) - 0.004(RH_{\text{min}} - 45)](h/3)^{0.3} \dots \dots \dots (12)$$

Where, $K_{c \text{ end}} (\text{Tab})$ value for $K_{c \text{ end}}$ was 0.25 for wheat, 0.35 for maize and pigeonpea crop.

u_2 = mean value for daily wind speed at 2m height over grass during the late season growth stage [m s^{-1}], for $1 \text{ m s}^{-1} \leq u_2 \leq 6 \text{ m s}^{-1}$,

RH_{min} = mean value for daily minimum relative humidity during the late season growth stage [%], for $20\% \leq RH_{\text{min}} \leq 80\%$,

h = mean plant height during the late season stage [m] for $0.1 \text{ m} \leq h \leq 10 \text{ m}$.

Dual Crop Coefficient approach

$$ET_c = (K_{cb} + K_e) ET_0 \dots \dots \dots (13)$$

Basal crop coefficient (K_{cb})

The basal crop coefficient (K_{cb}) is the ratio of the crop evapotranspiration over the reference evapotranspiration (ET_c/ET_0) when the soil surface is dry but transpiration is occurring at a potential rate, i.e., water is not limiting transpiration. Adjustment were done according to prevalent conditions-

$$K_{cb} = K_{cb(Tab)} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)](h/3)^{0.3} \dots \dots \dots (14)$$

Where, $K_{cb(Tab)}$ the value for $K_{cb \text{ mid}}$ or $K_{c \text{ end}}$ (if ≥ 0.45) given by FAO-56,
 u_2 = mean value for daily wind speed at 2m height over grass during the mid or late season growth stage [$m \text{ s}^{-1}$], for $1 \text{ m s}^{-1} \leq u_2 \leq 6 \text{ m s}^{-1}$,
 RH_{min} = mean value for daily minimum relative humidity during the mid or late season growth stage [%], for $20\% \leq RH_{min} \leq 80\%$, h = mean plant height during the mid or late season stage [m], $K_{cb(iini)}$ was 0.15 used for wheat, pigeonpea and maize crop, it was < 0.45 so no adjustment needed, $K_{cb \text{ mid}}$ was 1.10 used for wheat and pigeonpea, 1.15 for maize, it was > 0.45 so no adjustment needed, $K_{c \text{ end}}$ was 0.30 used for wheat, it < 0.45 no adjustment, for maize and pigeonpea it was 0.50 which > 0.45 so adjustment according to climatic conditions.

Evaporation component ($K_e ET_0$)

$$K_e = K_r \times (K_{c \text{ max}} - K_{cb}) \leq f_{ew} \times K_{c \text{ max}} \dots \dots \dots (15)$$

Where, K_e soil evaporation coefficient
 K_{cb} = basal crop coefficient,
 $K_{c \text{ max}}$ = maximum value of K_c following rain or irrigation,
 K_r = dimensionless evaporation reduction coefficient dependent on the cumulative depth of water depleted (evaporated) from the topsoil,
 f_{ew} = fraction of the soil that is both exposed and wetted, i.e., the fraction of soils surface from which most evaporation occurs.

Upper limit $K_{c \max}$, $K_{c \max}$ ranges from about 1.05 to 1.30 when using the grass reference ET_0 :

$$K_{c \max} = \max(\{1.2 + [0.04(u_2 - 2) - 0.0004(RH_{\min} - 45)] (h/3)^{0.3}\} \{K_{cb} + 0.05\}) \dots \dots \dots (16)$$

h = mean maximum plant height during the period of calculation (initial, development, mid-season, or late season) [m],

K_{cb} = basal crop coefficient, maximum value of the parameters in braces {} that are separated by commas.

Soil evaporation reduction coefficient (K_r)

When the soil surface is sufficient wet ($REW > D_{e,i-1}$), K_r value is 1. When the water content in the upper soil becomes limiting, K_r reduced and becomes zero when the available water that can be evaporated from the topsoil is depleted.

$$K_r = TEW - D_{e,i-1} / TEW - REW \quad \text{for } D_{e,i-1} > REW \dots \dots \dots (17)$$

Where, K_r is dimensionless equation reduction coefficient dependent on the soil water depletion (cumulative depth of evaporation) from the topsoil layer ($K_r = 1$ when $D_{e,i-1} \leq REW$),

$D_{e,i-1}$ is cumulative depth of evaporation (depletion) from the soil surface layer at the end of the day $i-1$ (the previous day) [mm],

TEW is maximum cumulative depth of evaporation (depletion) from the soil surface layer when $K_r = 0$ ($TEW = \text{total evaporable water}$) [mm]

REW is cumulative depth of evaporation (depletion) at the end of stage 1 ($REW = \text{readily evaporable water}$) [mm].

Water stress coefficient, K_s

$$K_s = \frac{TAW - D_r}{TAW - RAW} = \frac{TAW - D_r}{(1-p) TAW} \dots \dots \dots (18)$$

$$ET_a = K_s K_c ET_0 \dots \dots \dots (19)$$

$$ET_a = (K_s K_{cb} + K_c) ET_0 \dots \dots \dots (20)$$

K_s is dimensionless transpiration reduction factor dependent on available soil water (0-1), D_r is root zone depletion (mm), TAW is total available soil water in the root zone (mm),

RAW is the readily available water.

$$TAW = 1000 (\Theta_{FC} - \Theta_{WP}) Z_r \dots \dots \dots (21)$$

Where, TAW is total available soil water in the root zone (mm), Θ_{FC} is the water content at field capacity (m^3/m^3), Θ_{WP} is the water content at wilting point (m^3/m^3), Z_r is the rooting depth (m).

$$RAW = p.TAW \dots \dots \dots (22)$$

Where, RAW is the readily available water, p is average fraction of TAW that can be depleted from root zone before moisture stress occurs (0-1).

$$p = p(\text{FAO value}) + 0.04(5 - \text{Etc}) \dots \dots \dots (23)$$

Where, p (FAO value) is 0.55 for wheat and maize and 0.45 for pigeonpea when ET is 5mm/day. D_r is root zone depletion which was calculated by water balance equation.

3.3.13 Water use Efficiency (WUE)

Root water uptake was computed from the depletion of soil moisture during the same period, assuming no drainage occurred as the soil moisture was very less during this period. Water use efficiency of the crop was calculated as:

$$\text{Water use efficiency (WUE)} = \frac{\text{Biomass or yield produced (g m}^{-2}\text{)}}{\text{Amount of water used (cm)}} \dots \dots \dots (24)$$

3.3.14 Yield attributes and yield

The yield attributes of different crops were recorded during cropping period and after harvest of the crops. Biological yield of the treatment plot was measured

with hand balance after drying the crop for 3 days under bright sunshine. The weight of grains was measured after threshing. Finally average seed yield and stover yield (i.e., difference between final above ground biomass and seed yield) in g m^{-2} was calculated and converted in to tonne/ha. The overall system productivity was calculated by converting the price value of maize and pigeonpea in to wheat equivalent yield. The prices of crops were kept as per the minimum support price of the crops declared by government of India time to time.

3.3.15 Statistical Analysis

The data were analyzed using SPSS (version 10.0), Excel package (version 7.0). Analysis of variance as applicable for randomized block design was used to test least significant differences among the various treatment means and their interactions using statistical analysis. MS Excel software package was used to drawn required graphs. The means of all the treatments were separated by DMRT at 5% level of significance and as per standard ANOVA. Pearson's correlation matrix was also computed.

4.1 Objective 1: To study crop microenvironment under different conservation practices along with conventional practice.

4.1.1 Weather during crop growing period

The daily weather data recorded at Agromet observatory near the experiment area during the crop growing season were taken for analysis. Weather data were compared with the normal weather data during crop growing period. Crop growth period of maize was from 5th July to 20th October, 2014. For wheat crop growing period was from 10th November, 2014 to 13th April 2015 in maize-wheat cropping system. In pigeonpea-wheat cropping system the crop growing period of pigeonpea was 30th May to 25th November 2015 and for wheat crop growing period was from 11th December 2015 to 20th April 2016.

***Kharif* season 2014**

The maximum temperature during *kharif* season in 2014 was 0.3-5.6 °C lower than the normal during forty eight days, rest of days the maximum temperature was more than normal by 0.1-7.5 °C. The minimum temperature was lower than normal by 0.1-4.5 °C in eighty five days, other days the minimum temperature was 0.1-5.4 °C more than normal. Total rainfall received during this period was 512.8 mm (607.4 mm normal rainfall) and total rainy days were twenty seven. Maximum rainfall was 120.6 mm on 18th July and second highest was 55.6 mm on 3rd July. Bright sunshine hours were found to be 1.0-7.1 hours lower than normal in sixty nine days and in rest of days, observed value is 1.2-4.5 hours higher than normal. Evaporation during different days of *kharif* season was 0.1-3.6 mm lower than normal in forty four days of growing season, in other days evaporation was 0.1-6 mm higher than normal value. Wind speed was found to be 0.1-12.7 km/hr more than normal during different days of growing season, except forty days it was 0.1-2.7 km/hr lower than normal. Percentage value of maximum relative humidity measured at 7.21 AM was found lower than normal throughout the crop growing period except sixty nine days it was 2 to 23% higher than the normal. Percentage value of minimum relative humidity measured at 2.21 PM was found 1-2.7% lower than the normal during forty days, rest of the crop growing period it was 0.1-12.7% more than normal (Fig. 1a).

Rabi season 2014-15

The maximum temperature was 0.1-8.3 °C lower than normal during ninety six days and rest of days the temperature was more than normal by 0.1-4.6 °C during *rabi* 2014-15. The minimum temperature remained lower than normal by 0.1-6.9 °C in eighty four days while other days minimum temperature was 0.2-8.8 °C more than normal. Total rainfall received during this period was 316 mm and total rainy days were eighteen. Maximum rainfall was 79.4 mm on 1st March and second highest was 45 mm on 7th March 2015. Bright sunshine hours were 0.1-8.4 hours lower than normal in ninety days and on rest of the days was 0.2-3.4 hours higher than normal. Evaporation during different days of *rabi* season was 0.1-3.9 mm lower than normal in eighty five days while it was 0.1-2.4 mm higher than normal value on the rest of days. Wind speed was observed 0.1 -7.2 km/hr more than normal during different days of growing season except fifty nine days was 0.1-2.5 km/hr lower than normal. Percentage value of maximum relative humidity measured at 7.21 AM was found lower than normal throughout the crop growing period except twenty nine days it was 1 to 28 % higher than normal. Percentage value of minimum relative humidity measured at 2.21 PM was lower than normal throughout the crop growing period except thirty eight days it was 1-22 % more humidity than normal (Fig.1b).

Kharif season 2015

Maximum temperature was 0.2-7.6 °C lower than normal for thirty two days of growing period and rest of days the temperature was more than normal by 0.2-4.1 °C. The minimum temperature remained lower than normal by 0.1-4 °C in sixty eight days of growing period and on other days it was 0.2-3.4 °C more than normal. Total rainfall received during this period was 709.5 mm (512.1 mm normal rainfall) and total rainy days were thirty one. Maximum rainfall was 161.9 mm on 12th July and second highest was 65.2 mm on 11th July. Bright sunshine hours were observed 0.1-5.7 hours lower than normal in forty days and 0.1-4.5 hours higher than normal for rest of the days. Evaporation was 0.6-5.8 mm lower than the normal in fifty eight days during *kharif* season and on other days it was 0.1-3.2 mm higher than normal. Wind speed was recorded 0.5-5.8 km/hr more than normal during the growing period except forty two days that was 0.3-4.2 km/hr lower than normal. Percentage value of maximum relative humidity measured at 7.21 AM was found higher than the normal throughout the crop growing period except thirty six days that was 18-23 % lower

than normal. Percentage value of minimum relative humidity was found 1-37 % higher than the normal during thirty days and for rests of the period it was 2-29.71% more humidity than normal (Fig. 2a).

Rabi season 2015-16

During crop growing period the maximum temperature was 0.1-6.2 °C lower than normal for fifty two days and rest of days the temperature was more than normal by 0.1-6.9 °C. The minimum temperature remained lower than normal by 0.1-5.5 °C for sixty seven days of the growing period and for rest other days was 0.6-5.4 °C more than normal. Total rainfall received during this period was 19.8 mm and total rainy days were five. Bright sunshine hours were 1.2-3.8 hours higher than normal in fifteen days and for rest of days was 0.1-6.4 hours higher than normal. Evaporation during different days of crop growing period was 0.1-3.1 mm lower than the normal in fifty five days and 0.2-1.9 mm higher than normal in rest of the days. Wind speed was 0.5-4.9 km/hr more than normal during different days of growing season except fifty six days where it was 0.1-2.5 km/hr lower than normal. Percentage value of maximum relative humidity was higher than the normal throughout the crop growth period except thirty three days where it was 1-22% higher than normal. Percentage value of minimum relative humidity was observed higher than normal throughout the crop growth period except thirty five days where it was 3-42% more than normal (Fig.2b).

4.1.2 Soil details of the experimental site

A composite representative soil sample was collected from the experimental field prior to start of experimentation and analysed for physico-chemical properties (Table 3).

Table 3: Soil properties of the experimental site

S. N.	Particulars	Content
A	Physical characteristics	
	Sand (%)	52.1
	Silt (%)	22.6
	Clay (%)	25.3
	Textural class	Sandy clay loam
	Moisture at 1/3 atmospheric tension (%) (Pressure plate apparatus, Richards and Weaver, 1943)	25.4
	Moisture at 15 atmospheric tension (%) (Pressure plate apparatus, Richards and Weaver, 1943)	12.2
	Bulk density (0-15 cm layer) (g cc ⁻¹)	1.48
B	Chemical characteristics	
	Organic carbon (%) (Walkley and Black, 1934)	0.54
	Available nitrogen (N kg ha ⁻¹) (Subbiah and Asija, 1956)	170.6
	Available phosphorus (P ₂ O ₅ kg ha ⁻¹) (Olsen <i>et al.</i> , 1954)	18.6
	Available potassium (K ₂ O kg ha ⁻¹) (Flame photometer method, Hanway and Heidel, 1952)	275.0
	pH (1:2.5 soil: water) (Cyber scam 500 pH meter)	8.0

4.1.3. Soil Moisture content at different depth under different conservation practices along with convention practice in different cropping system

4.1.3.1. Soil moisture at different depth in maize crop under different conservation practices along with conventional practice in maize-wheat cropping system

In maize crop soil moisture measured two-three days before irrigation at 25, 45, 70 and 90 days after sowing (DAS) during crop season. The data on soil moisture as affected by the date of sampling, soil depth, and tillage treatment. Soil moisture gradually decreased from sowing to harvesting of crop. The crop microenvironment was affected by soil moisture profile in upper layer (0-15 cm) of the soil. At 25 DAS maximum soil moisture found in 0-15 cm layer under ZT+R (10.8%) treatment followed by ZT (10.2%), PBB+R (9.5%), PNB+R (8.9%) and CT (8.5%) treatment at weight basis. Lower soil moisture was obtained under PBB (8.0%) and PNB (7.6%)

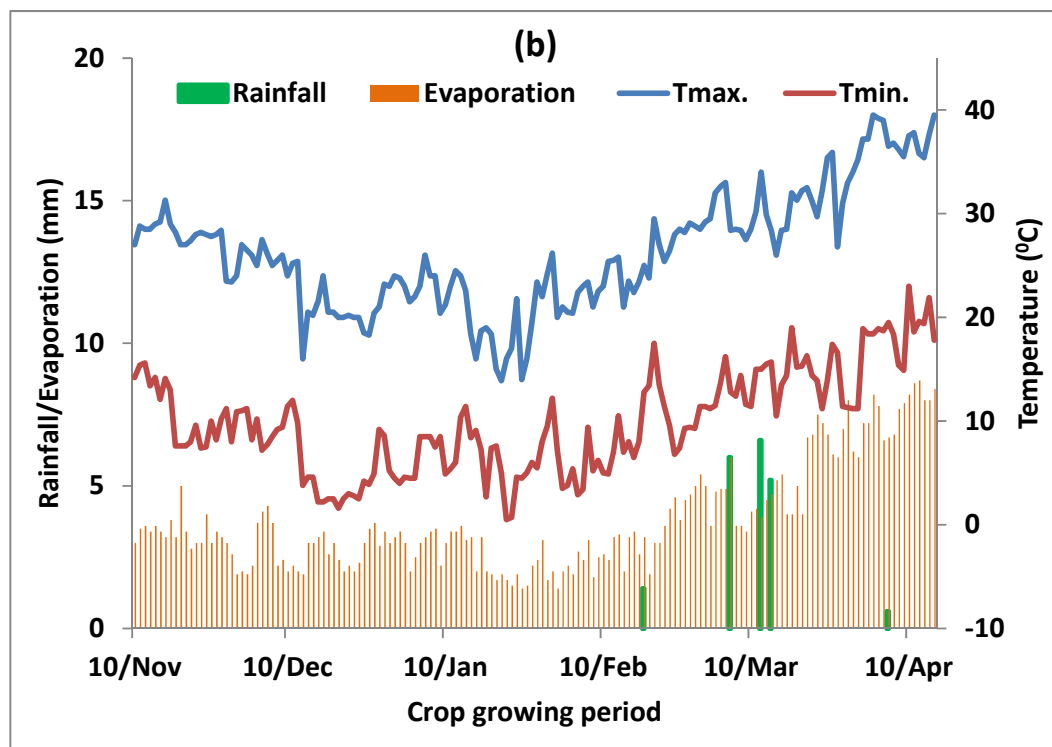
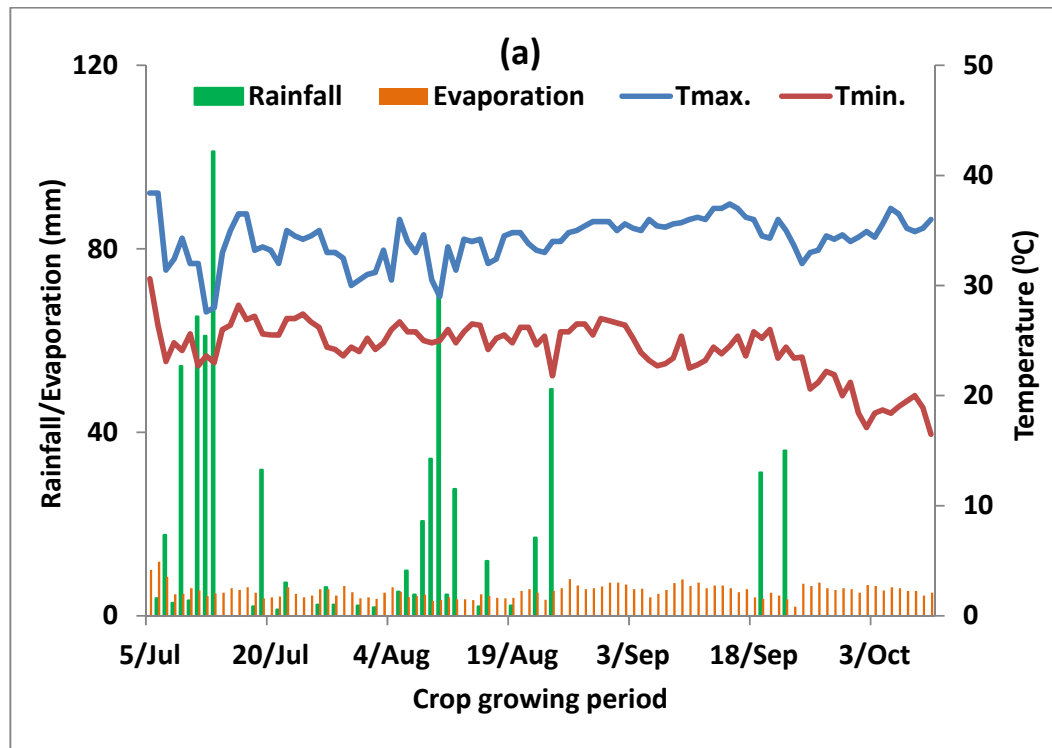


Fig.1. Daily weather data during crop growing period (a) *Kharif* 2014 (b) *Rabi* 2014-15

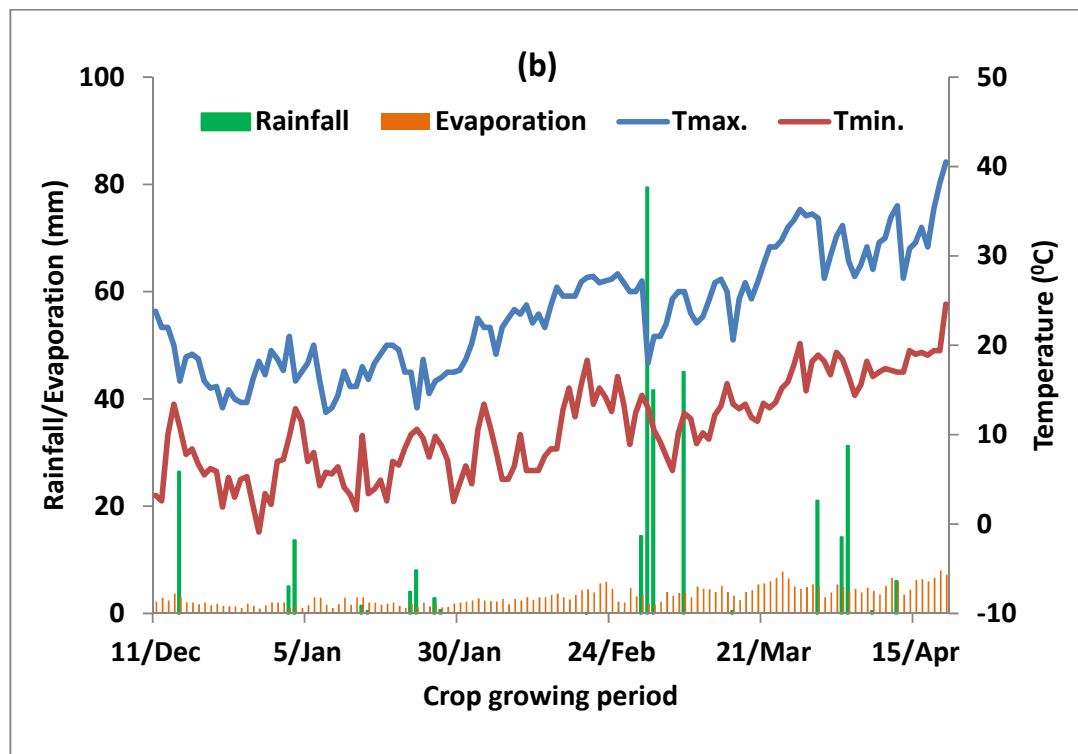
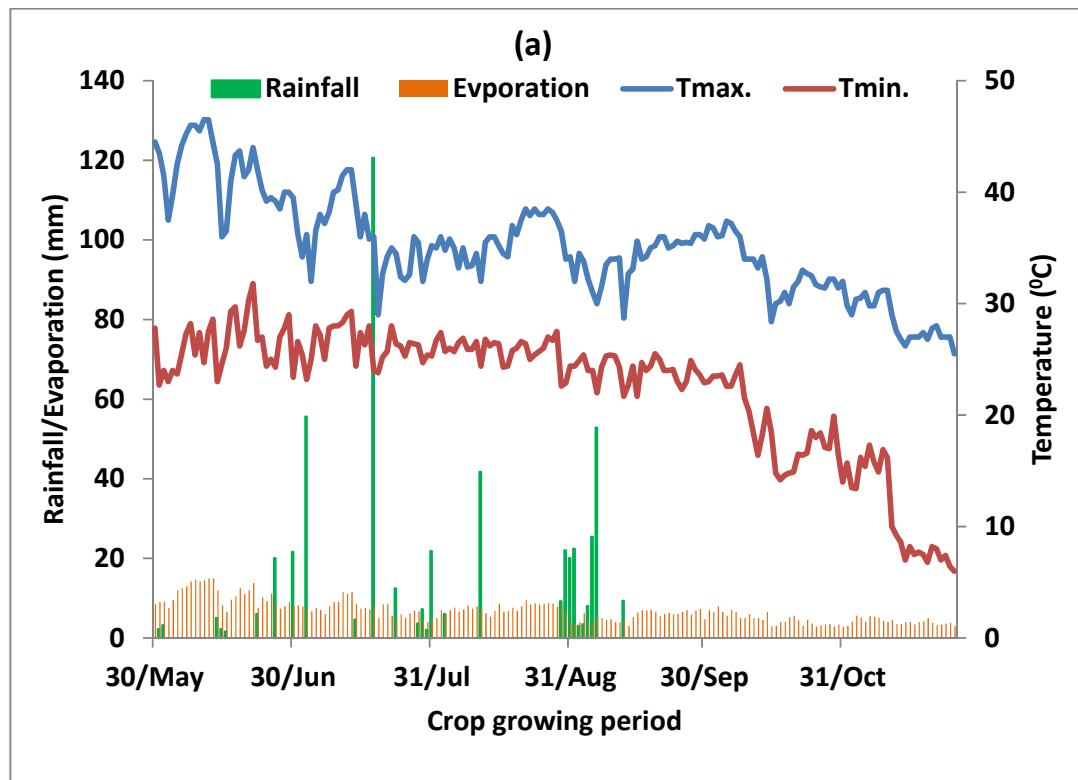


Fig.2. Daily weather data during crop growing period (a) *Kharif* 2015 (b) *Rabi* 2015-16

treatments. PNB and PBB treatments had significantly lower moisture content than the other treatments but it was sufficient to fulfil crop water requirement. ZT+R and ZT treatments had non-significant difference in soil moisture content, similarly PNB+R and PBB+R treatments also had non-significant difference. ZT+R, ZT, PBB+R and PNB+R treatments had higher moisture content than CT treatment. Soil moisture content increased with increased of soil depth and the difference in soil moisture between treatments decreased with increase of soil depth. At 60 cm depth most of treatments found at par. Similar trend was found throughout the growing period. At 45 DAS the soil moisture uptake increased as crop plant grow rapidly and at 70 and 90 DAS maximum uptake of soil moisture as root depth increased at flowering stage more water required, similarly at grain filling stage more soil moisture removed. ZT treatment had 8.6% soil moisture content followed by ZT (8.1%), PBB+R (7.6%), PNB+R (7.4%), CT (7.1%), PBB (6.2%) and PNB (5.9%) in 15 cm of soil layer at 90 DAS. ZT+R had 21-30%, ZT had 15-20%, PBB+R had 8-10% and PNB+R had 3-5% higher soil moisture content than CT treatment. PBB treatment had 10-13% and PNB treatment had 16-20% lower soil moisture content than CT treatment. Although PNB+R treatment had slightly higher soil moisture content than CT treatment but both treatments were statistically at par. PNB and PBB treatment had sufficient moisture for fulfil crop water demand this means these treatments saved nearly 10-20% soil moisture content (Fig.3).

4.1.3.2 Soil moisture at different depth in wheat crop under different conservation practices along with conventional practices in maize-wheat cropping system

Maximum moisture content under different treatments was found at 20 DAS. ZT+R had maximum soil moisture content (9.9%) at weight basis followed by ZT (9.3%), PBB+R (9.0%), PNB+R (8.6%), CT (8.0%), PBB (7.5%) and PNB (6.7%) in 15 cm upper soil layer at 20 DAS. Among PNB and PBB treatment had no significant difference but they had lower moisture content than other treatments. Similarly ZT+R and ZT treatments had non-significant difference. PNB+R and PBB+R treatments were at par. CT treatment performed similar to PNB+R treatment. The similar trends were also found at 50 and 75 DAS. The soil moisture content gradually decreased from sowing to physiological maturity of crop. Among all treatments soil moisture variation decreased with increased of soil depth. At 95 DAS soil moisture content in

0-15 cm depth was 8.4% under ZT+R treatment followed by ZT (7.6%), PBB+R (7.3%), PNB+R (6.9 %), CT (6.4%), PBB (5.7%) and PNB (5.3%). At 75 and 95 DAS ZT+R and ZT treatments had significant difference in soil moisture content at 15 cm depth. PBB+R and PNB+R treatments had non-significant difference and PNB and PBB were found at par. The soil profile moisture content decreased from 20 DAS to 95 DAS. In ZT+R treatment it decreased from 10.7 to 9.2%, under ZT decreased from 10.5 to 8.7%, under PBB+R varied from 10.1 to 8.3%, under PBB varied from 8.7 to 7.1%, under PNB+R decreased moisture profile from 9.8 to 8.0%, under PNB varies from 8.2 to 6.7% and under CT treatment varied from 9.2 to 7.7%. Soil moisture content in soil profile under ZT+R treatment had 17-20%, ZT had 13-14%, PBB+R had 8-10% and PBB had 4-7% higher soil moisture content than CT treatment. PBB had 5-8% and PNB had 10-12% lower soil moisture content than CT treatment. PBB and PNB had lower soil moisture content but they had sufficient moisture to fulfil crop water requirement. They saved around 5-12% soil moisture content than CT treatment (Fig.4).

4.1.3.3 Soil moisture at different depth in pigeonpea crop under different conservation practices along with conventional practices in pigeonpea-wheat cropping system

Pigeonpea is a deep rooted crop; therefore the soil moisture was measured up to 75 cm depth. At 30 DAS in month of June soil moisture measurement in upper 0-15 cm soil depth showed maximum soil moisture content under ZT+R treatment (8.1%), followed by ZT (7.6%), PBB+R (7.1%), PNB+R (6.3%), CT (6.1%), PBB (5.6%) and PNB (5.3%) treatment, which affects the crop microenvironment. ZT+R and ZT treatments had non-significant difference but they had higher soil moisture content than other treatments. CT treatment performs similar to PNB+R, PBB+R and ZT treatments. With increase of soil depth the soil moisture content also increased and the difference among treatments was narrow down. PBB+R and PNB+R treatments had significantly difference at 30 DAS in 15 cm soil profile but at later period these treatments were found at par. The average soil moisture content at 30 DAS in 0-75 cm soil profile was maximum under ZT+R (8.8%) followed by ZT (8.5%), PBB+R (8.0%), PNB+R (7.6%), CT (7.3%), PBB (6.9%) and PNB (6.5%). At 60 DAS in July month less evapotranspiration losses and more rainfall as compared to 30 DAS, the average soil moisture content in 0-75 cm profile was 9.8% under ZT+R followed by

9.5% under ZT, 9.3% under PBB+R, 8.9% under PNB+R, 8.5% under CT, 8.1% under PBB and 7.8% under PNB treatment. As crop plant grows it needed more water to fulfil demand for evapotranspiration losses and metabolic activities. So soil moisture gradually decreased and at 140 DAS the soil moisture content in 0-15 cm depth was less than 60 & 90 DAS. Soil moisture in 0-75 cm profile also decreased up to 8.9% in ZT+R followed by 8.6% in ZT, 8.2% in PBB+R, 7.9% in PNB+R, 7.5% in CT, 6.9% in PBB and 6.5% in PNB treatment. The increase in soil moisture throughout growing period was 15-22% under ZT+R, 12-17% under ZT, 9-13% under PBB+R, 5-8% under PNB+R over CT treatment. PNB and PBB treatments had lower soil moisture content than CT, PNB treatment had 9-14% and PBB treatment had 4-7% lower soil moisture content as compared to CT treatment (Fig.5).

4.1.3.4 Soil moisture at different depth in wheat crop under different conservation practices along with conventional practices in pigeonpea-wheat cropping system

Soil moisture measured at 25, 45, 65 and 90 DAS. At 25 DAS soil moisture in 0-15 cm depth was maximum under ZT+R treatment (10.8%) followed by ZT (10.2%), PBB+R (9.4%), PNB+R (8.9%), CT (8.5%), PBB (8.0%) and PNB (7.6%). CT and PNB+R treatments had non-significant difference. Similarly PNB+R and PBB+R treatments were found at par. ZT+R and ZT treatments also performed similar trend. The average soil moisture in 0- 60 cm soil profile was 11.4 % under ZT+R treatment followed by ZT (11.1%), PBB+R (10.5%), PNB+R (10.0%), CT (9.6%), PBB (9.2%) and PNB (9.0%). At 45 DAS the soil moisture content under 0- 60 cm profile was 11.1% under ZT+R, 10.4% under ZT, 10% under PBB+R, 9.5% under PNB+R, 9% under CT, 8.5% under PBB and 7.8% under PNB treatment. At 65 DAS soil moisture in profile was found similar trend. At 90 DAS soil moisture at flowering stage was found minimum. At 0-15 cm depth it was 9.3% under ZT+R, 8.7% under ZT, 8% under PBB+R, 7.7% under PNB+R, 7.3% under CT, 7.2% under PBB and 6.9% under PNB treatment. Soil moisture in 0-60 cm profile at 90 DAS in ZT+R treatment had 10.1%, ZT had 9.7%, PBB+R had 9.3%, PNB+R had 9.1%, CT had 8.6%, PBB had 8.4% and minimum soil moisture 7.9% was under PNB treatment. ZT+R and ZT had non-significant difference at 90 DAS. Similar results were found under PBB+R and PNB+R, PNB and PBB, CT and PBB treatments. ZT+R had 17-22%, ZT had 12-15%, PBB+R had 8-11% and PNB+R had 4-6% higher moisture

content over CT treatment. PBB had 3-6% and PNB had 7-13% lower soil moisture content than CT treatment (Fig.6).

4.1.4 Thermal indices under different conservation practices along with convention practice in different cropping system

4.1.4.1 Thermal indices in maize crop under different conservation practices along with conventional practice in maize-wheat cropping system

The total heat units consumed by the maize crop to reach physiological maturity under different conservation treatments and conventional treatment (CT) were analysed. Growing degree days (GDD) required to reach physiological maturity was lower under CT treatment (3098 °C days). Conservation treatments required higher growing degree days than CT treatment because the residue retained treatment had longer days to maturity than without residue treatment. The PBB+R and PBB treatments required higher amount of growing degree days to reach the maturity followed by ZT+R, ZT, PNB+R and PNB treatments. However there was non-significant difference among different treatments for growing degree days required to reach the maturity. Similar trends were also found for heliothermal unit (HTU), photothermal index (PTI), relative temperature disparity (RTD) and photothermal unit (PTU). All thermal indices had higher values under PBB+R and PBB treatments because there was slightly delay in physiological maturity under these treatments (Table. 4).

4.1.4.2 Thermal indices in wheat crop under different conservation practices along with conventional practice in maize-wheat cropping system

Wheat crop required GDD around 1499 °C days to reach physiological maturity under PBB+R, PBB and ZT+R treatments followed by ZT (1458 °C days). PNB and PNB+R required same GDD (1438 °C days) to reach physiological maturity. HTU requirement under PBB+R, ZT+R and PBB treatments was 8011 °C day hour followed by ZT (7759 °C day hour) and PNB, PNB+R had 7558 °C day hour. PTI varies between 10.2 -10.4 °C day/day. RTD value under PBB+R, PBB and ZT+R was 7222 and lowest was 7064 in CT. PTU was found 17190 °C day hour in PBB+R, PBB and ZT+R treatments followed by ZT (16667 °C day hour). Different thermal indices had non-significant difference for different tillage practices (Table. 5).

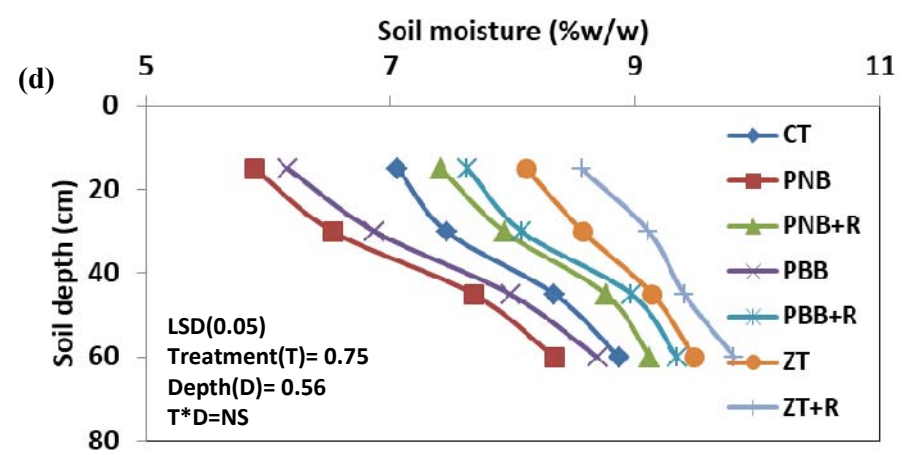
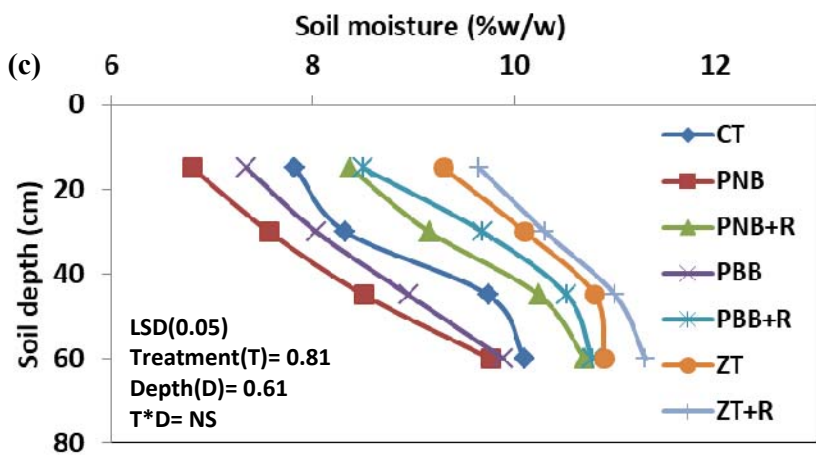
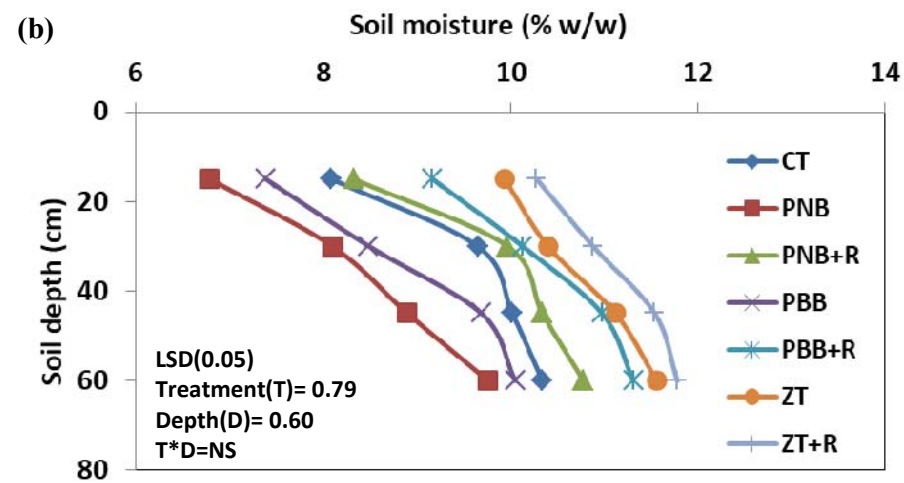
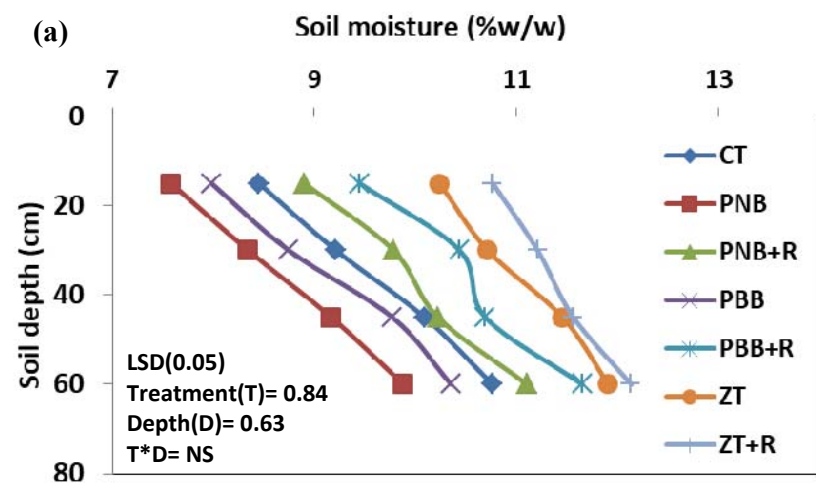


Fig.3. Soil moisture under different conservation practices along with conventional practice in maize during crop growing season in maize -wheat cropping system at (a) 25 DAS (b) 45 DAS (c) 70 DAS and (d) 90 DAS

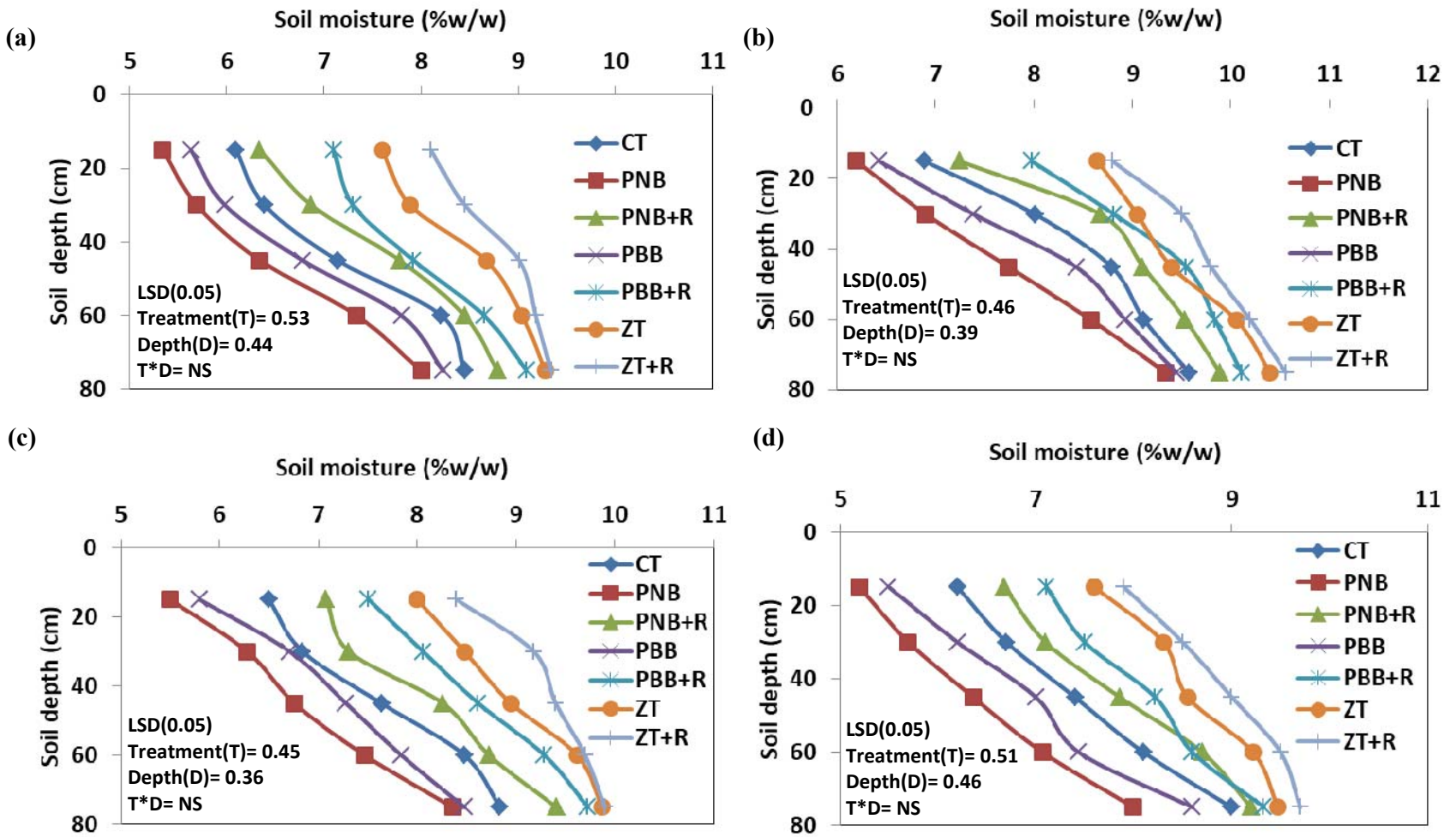


Fig.5. Soil moisture under different conservation practices along with conventional practice in pigeonpea during crop growing season in pigeonpea -wheat cropping system at (a) 30 DAS (b) 60 DAS (c) 90 DAS and (d) 140 DAS

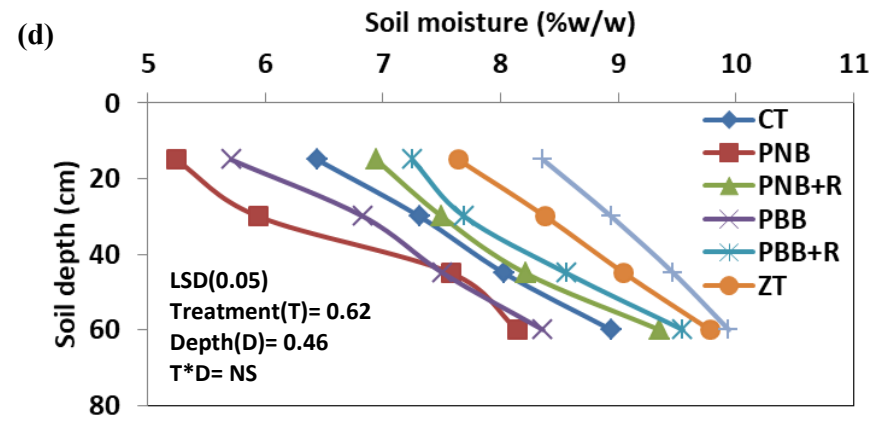
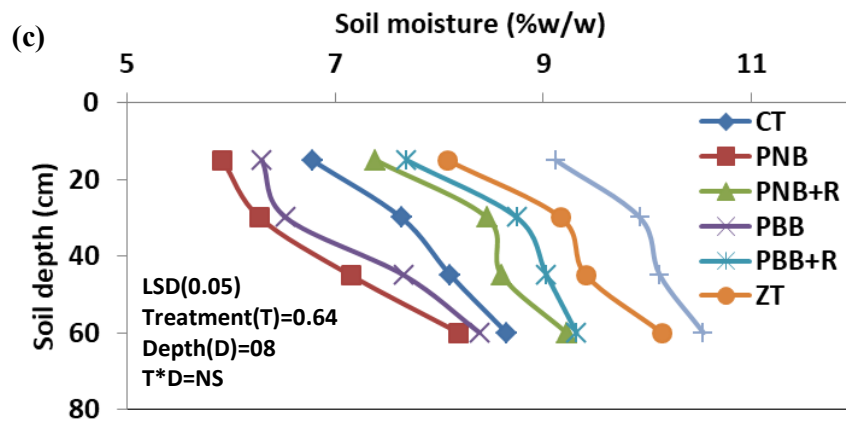
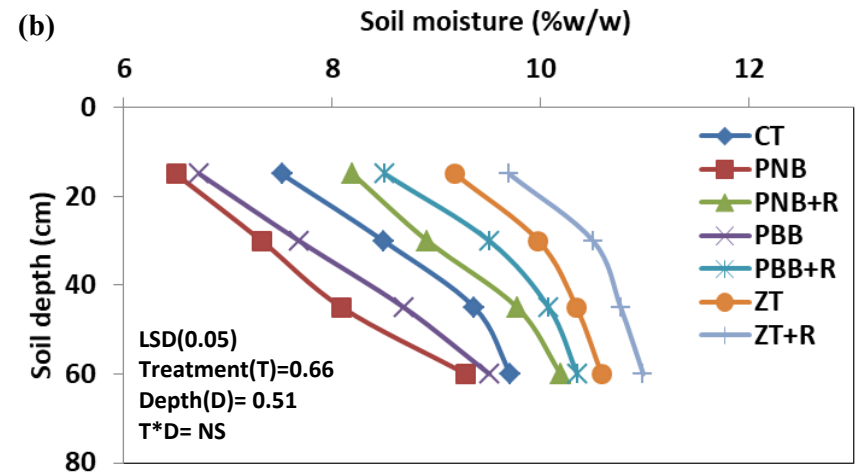
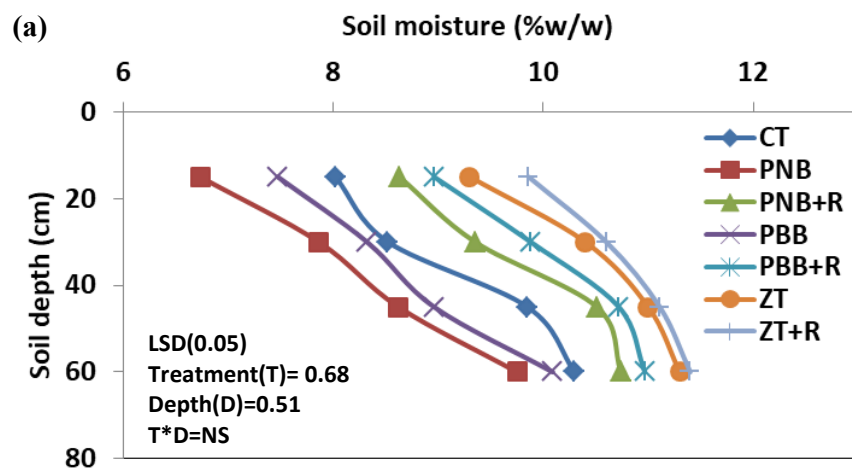


Fig.4. Soil moisture under different conservation practices along with conventional practice in wheat during crop growing season in maize -wheat cropping system at (a) 20 DAS (b) 50 DAS (c) 75 DAS and (d) 95 DAS

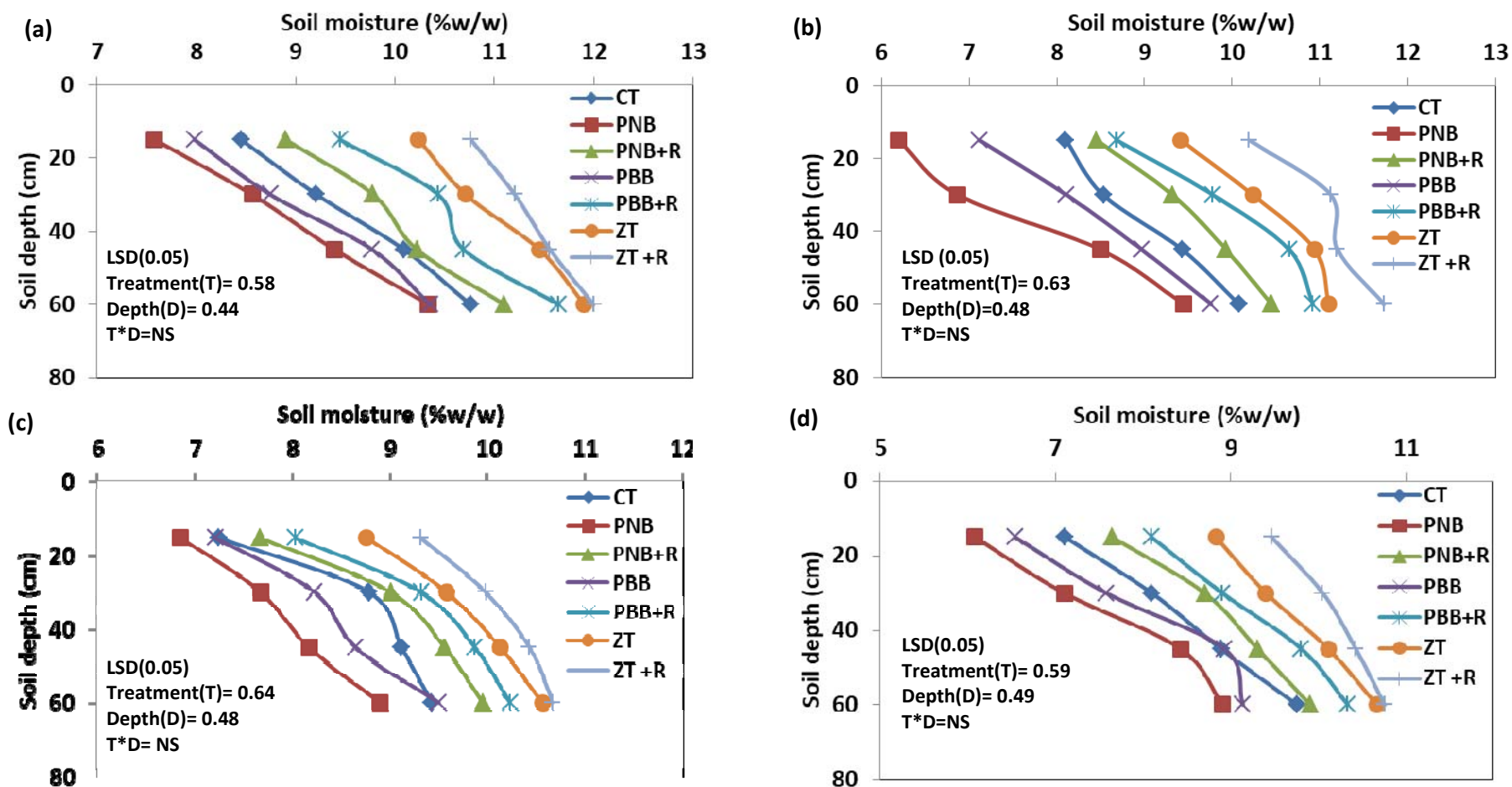


Fig.6. Soil moisture under different conservation practices along with conventional practice in wheat during crop growing season in pigeonpea-wheat cropping system at (a) 25 DAS (b) 45 DAS (c) 65 DAS and (d) 90 DAS

4.1.4.3 Thermal indices in pigeonpea crop under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

Pigeonpea crop required GDD nearly 4917 °C days to reach physiological maturity in PBB+R and lowest amount of GDD required in CT treatment (4843 °C days). HTU within conservation treatments were between 28434-28089 °C day hours and within CT treatment it was 27967 °C day hours. The PTI ranged between 30.0-30.3 °C day/day within different tillage treatments. RTD found maximum under PBB+R treatment (5335) followed by ZT+R (5290). PTU was maximum under PBB+R treatment (61939 °C day hours) and minimum in CT treatment (61209 °C day hour) (Table. 6).

4.1.4.4 Thermal indices in wheat crop under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

Wheat crop after pigeonpea required lesser number of GDD to reach physiological maturity since the crop variety was short duration. GDD value required to reach maturity was 1351 °C days in CT and PNB treatments. Other conservation treatments required higher amount of GDD to reach physiological maturity (1365-1396 °C days). CT and PNB treatments had HTU value 6705 °C day hours, PTI value 11.5 °C day/day, RTD value 8042 and PTU value 14730 °C day hours. In other conservation treatments HTU ranged between 6854-7274 °C day hours and PTI ranged within 11.7-12.0. Similarly RTD varied within 8067-8162 and PTU ranged between 14811-15121 °C day hours. Among different treatments PBB+R treatment reached physiological maturity at last, so accumulated thermal indices values were found maximum under this treatment (Table. 7).

4.1.5 Heat use efficiency (HUE) under different conservation practices along with convention practice in different cropping system

4.1.5.1 Heat use efficiency (HUE) in maize crop under maize-wheat cropping system

HUE was found higher under different conservation treatments as compared to CT treatment. PBB+R and PBB treatments had non-significant difference but they had higher HUE values than other treatments. Conservation treatments had HUE value between 1.56-1.84 kg/ha/°C days. The maximum value of HUE was found

under PBB+R treatment (1.84 kg/ha/⁰C days) and minimum value of HUE was found in CT treatment (1.37 kg/ha/⁰C days) (Table. 4).

4.1.5.2 Heat use efficiency (HUE) in wheat crop under maize-wheat cropping system

Wheat crop had HUE between 3.26-3.52 kg/ha/⁰C days. Maximum HUE was found under PBB+R treatment. Among conservation treatments PNB treatment had lowest HUE, it was 3.32 kg/ha/⁰C days. For CT and PNB treatment, HUE value was non-significant and CT had lowest value (3.26 kg/ha/⁰C days) as compared to other treatments (Table. 5).

4.1.5.3 Heat use efficiency (HUE) in pigeonpea crop under pigeonpea-wheat cropping system

HUE was non-significant ranged between 0.41-0.44 kg/ha/⁰C days under different conservation treatments but it had significantly higher value as compared to CT treatment. Highest value of HUE among conservation treatments was found under PBB+R treatment followed by ZT+R and PNB+R treatment and lesser value was found under PNB, PBB and ZT treatments (0.41kg/ha/⁰C days). HUE value in CT treatment was 0.32 kg/ha/⁰C days (Table. 6).

4.1.5.4 Heat use efficiency (HUE) in wheat crop under pigeonpea-wheat cropping system

Wheat sown after pigeonpea had higher HUE than wheat grown after maize crop. HUE value was ranged between 3.20-3.77 kg/ha/⁰C days among different conservation treatments. Under CT treatment it was 3.09kg/ha/⁰C. Higher HUE was found under PBB+R followed by ZT+R and ZT treatments. HUE value was found at par in these treatments but had significantly higher value than other treatments (Table. 7).

Table 4: Thermal indices in maize crop under different conservation practices along with conventional practice in maize-wheat cropping system

Treatment	GDD (⁰ C day)	HTU (⁰ C day hour)	PTI (⁰ C day/day)	RTD	PTU (⁰ C day hour)	HUE (kg/ha/ ⁰ C day)
CT	3098	18613	29.34	3083	39874	1.37 ^e
PNB	3130	18778	29.39	3168	40223	1.56 ^d
PNB+R	3130	18778	29.39	3168	40223	1.68 ^c
PBB	3204	18896	29.61	3299	41044	1.81 ^{ab}
PBB+R	3204	18896	29.61	3299	41044	1.84 ^a
ZT	3155	18797	29.43	3213	40490	1.71 ^c
ZT+R	3179	18797	29.55	3260	40759	1.77 ^b
LSD (0.05)	NS	NS	NS	NS	NS	0.16

Table 5: Thermal indices in wheat crop under different conservation practices along with conventional practice in maize-wheat cropping system

Treatment	GDD (⁰ C day)	HTU (⁰ C day hour)	PTI (⁰ C day/day)	RTD	PTU (⁰ C day hour)	HUE (kg/ha/ ⁰ C day)
CT	1418	7437	10.19	7064	16156	3.26 ^e
PNB	1438	7558	10.37	7101	16410	3.32 ^{de}
PNB+R	1438	7558	10.37	7101	16410	3.38 ^{cd}
PBB	1499	8011	10.41	7222	17190	3.39 ^{bc}
PBB+R	1499	8011	10.41	7222	17190	3.52 ^a
ZT	1458	7759	10.39	7141	16667	3.42 ^{bc}
ZT+R	1499	8011	10.41	7222	17190	3.45 ^b
LSD (0.05)	NS	NS	NS	NS	NS	0.15

Table 6: Thermal indices in pigeonpea crop under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

Treatment	GDD (⁰ C day)	HTU (⁰ C day hour)	PTI (⁰ C day/day)	RTD	PTU (⁰ C day hour)	HUE (kg/ha/ ⁰ C day)
CT	4843	27967	30.01	5145	61209	0.32 ^b
PNB	4860	28089	30.11	5219	61385	0.41 ^a
PNB+R	4877	28212	30.25	5290	61574	0.42 ^a
PBB	4860	28089	30.11	5219	61385	0.41 ^a
PBB+R	4917	28434	30.32	5335	61939	0.44 ^a
ZT	4860	28089	30.11	5219	61385	0.41 ^a
ZT+R	4877	28212	30.25	5290	61574	0.43 ^a
LSD (0.05)	NS	NS	NS	NS	NS	0.10

Table 7: Thermal indices in wheat crop under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

Treatment	GDD (⁰ C day)	HTU (⁰ C day hour)	PTI (⁰ C day/day)	RTD	PTU (⁰ C day hour)	HUE (kg/ha/ ⁰ C day)
CT	1351	6705	11.51	8042	14730	3.09 ^d
PNB	1351	6705	11.51	8042	14730	3.20 ^d
PNB+R	1365	6854	11.72	8067	14811	3.35 ^c
PBB	1381	7184	11.89	8096	14924	3.58 ^b
PBB+R	1396	7274	12.01	8162	15121	3.77 ^a
ZT	1365	6854	11.72	8067	14811	3.65 ^{ab}
ZT+R	1396	7274	12.01	8162	15121	3.67 ^{ab}
LSD (0.05)	NS	NS	NS	NS	NS	0.29

4.1.6 Soil temperature measured under different conservation practices along with conventional practices in different cropping system

4.1.6.1 Soil temperature measured in maize crop under different conservation practices along with conventional practice in maize-wheat cropping system

Soil temperature was measured in maize crop at 30, 60, 90 and 105 DAS. At 30 DAS, PNB and PBB treatments were found at par but other treatments were significantly differed to each other. Maximum soil temperature was found in PNB treatment followed by PBB, CT, PNB+R, PBB+R, ZT and ZT+R treatment. Variation in soil temperature between ZT+R and PNB treatment was 3.4 °C. At initial period, soil temperature variation between treatments was more because at that time crop residue effect was dominant and crop shading effect was less. When crop growth increases crop residue degraded and due to crop shading soil temperature difference within treatments decreased. At 60 DAS, CT treatment had similar value as that of PBB and PNB+R treatments. PNB and PBB treatments had non-significant differences. PNB+R and PBB+R treatments also had non-significant differences for soil temperature at 60 DAS. ZT treatment was significantly differed to ZT+R but non-significant with PBB+R treatment. Similar results were found at 90 DAS. The difference in soil temperature between ZT+R and PNB treatments at 60 DAS was 2.8 °C which was lower than soil temperature measured at 30 DAS. Variation in soil temperature between ZT+R and PNB was 3.1 °C at 90 DAS. At 105 DAS the soil temperature variation between PNB and ZT+R treatment was 2.1 °C. Soil temperature in case of residue treatments were significantly differs than the non residue treatments (Fig. 7).

4.1.6.2 Soil temperature measured in wheat crop under different conservation practices along with conventional practice in maize-wheat cropping system

Soil temperature measured at 30, 60, 90 and 120 DAS in wheat crop under maize-wheat cropping system. At 30 DAS the crop residue and tillage practices effect on soil temperature was significant. Maximum soil temperature was found under PNB treatment followed by PBB, CT, PNB+R, PBB+R and ZT treatment. Lowest soil temperature was under ZT+R treatment. The variation of soil temperature between

ZT+R and PNB treatments was 3.7 °C. At physiological maturity crop residue degraded, therefore difference in soil temperature was minimum. At 60 DAS, treatments were significantly differed to each other and the variation of soil temperature between ZT+R and PNB treatments was 3.1 °C. PNB and PBB treatments had non-significant difference in soil temperature at 90 DAS. Similarly CT and PNB+R treatments had non-significant value. Other treatments were significantly differed to each other. At 120 DAS the variation of soil temperature between ZT+R and PNB treatments was 2.8 °C which was minimum difference throughout the growing period. Soil temperature value for ZT and ZT+R treatments, PNB and PBB treatments, PNB+R and PBB+R treatments were non-significant (Fig. 8).

4.1.6.3 Soil temperature measured in pigeonpea crop under different conservation practices along with conventional practice in pigeon pea-wheat cropping system

The effect of crop residue and tillage practices on soil temperature was significant in pigeonpea crop during initial crop growth stage. Residue plots had lower soil temperature than non residue plots. At 35 DAS all tillage treatments were significantly differed to each other. The variation in soil temperature between PNB and ZT+R treatment was 3.6 °C which was maximum difference among treatments. PNB had highest temperature followed by PBB and CT treatments. At 70 DAS PBB+R and PNB+R treatments had non-significant difference and similar results were also found in PBB+R and ZT treatments. At 105 the variation in soil temperature between PNB and ZT+R treatment was 3.0 °C. At that time CT and PNB+R treatments were significantly differed. PBB+R and ZT, ZT and ZT+R treatments were non-significant. PNB+R and PBB+R treatments were non-significant to each other at 140 DAS. Minimum temperature was found under ZT+R treatment. The variation in soil temperature between PNB and ZT+R treatment was 3.5 °C (Fig. 9).

4.1.6.4 Soil temperature measured in wheat crop under different conservation practices along with conventional practice in pigeon pea-wheat cropping system

Maximum soil temperature was under PNB treatment followed by PBB, CT, PNB+R, PBB+R, ZT and ZT+R at 30 DAS. At 30 DAS soil temperature under ZT

and ZT+R treatments was non-significant. Similarly in CT and PBB treatments value of soil temperature was found at par. The soil temperature variation between ZT+R and PNB treatment was 3.6 °C. All treatments had significantly different values at 60 DAS. Residue treatments had lower temperature than non residue treatments. At 90 DAS the CT and PBB, PNB and PBB, PNB+R and PBB+R treatments were non-significant. The soil temperature decreased under ZT+R (around 2.8 °C) as compared to PNB treatment. PNB treatment had 3.2 °C higher soil temperature than ZT+R treatment at 120 DAS. As compared to CT treatment, PNB and PBB treatments had around 1-1.7 °C higher soil temperature (Fig. 10).

4.1.7 Air temperature within the crop canopy under different conservation practices along with conventional practice in different cropping system

4.1.7.1 Air temperature within the maize crop canopy under different conservation practices along with conventional practice in maize-wheat cropping system

There was non-significant difference in air temperature on above the crop canopy among different treatments. Air temperature recorded within the canopy showed differences among the treatments. Initially when crop plant growth was less there were non-significant differences but when plant growth increases leaf area also increases resulting increases in shading effect (Table 8). The temperature within the canopy after 40 DAS ranged between 38.4 °C to 39 °C. Most of conservation treatment had non-significant difference but PBB+R and CT treatment had 0.6 °C temperature difference. Similar trend of results was found at 65 DAS. The difference within PBB+R and CT treatment increased up to 1.4 °C at 85 DAS because PBB+R treatment had better plant height and LAI than CT. At this time PBB+R and PBB treatments had non-significant difference but they had significantly lower temperature within canopy than other treatment. Maximum temperature was found under CT treatment. At 95 DAS when maize plant reached near to physiological maturity there was non-significant difference in temperature within canopy because at that time most of leaves dried and senescence.

Table 8: Temporal variation in air temperature ($^{\circ}\text{C}$) within crop canopy in maize under different conservation practices along with conventional practice in maize-wheat cropping system

Treatment	40 DAS	65 DAS	85 DAS	95 DAS
CT	39.03 ^a	34.23 ^a	36.80 ^a	36.23
PNB	39.01 ^a	34.03 ^{ab}	36.50 ^{ab}	36.20
PNB+R	38.67 ^b	33.69 ^{bc}	36.10 ^{bc}	36.11
PBB	38.55 ^{bc}	33.79 ^{bc}	35.60 ^{de}	35.72
PBB+R	38.42 ^c	33.20 ^d	35.40 ^e	35.68
ZT	38.50 ^{bc}	33.60 ^c	36.10 ^{bc}	36.22
ZT+R	38.57 ^{bc}	33.49 ^{cd}	35.90 ^{cd}	35.91
LSD(0.05)	0.55	0.61	0.52	NS

4.1.7.2 Air temperature within the wheat crop canopy under different conservation practices along with conventional practice in maize-wheat cropping system

There was non-significant difference in air temperature within canopy at 40 DAS. Air temperature within canopy ranged between 26.8-27.6 $^{\circ}\text{C}$ at 60 DAS. Differences in the temperature within canopy between PBB+R and CT treatment was 0.8 $^{\circ}\text{C}$. It gradually increased with plant growth because PBB+R treatment had higher LAI than CT treatment. At 80 DAS the air temperature variation within canopy was 1.0 $^{\circ}\text{C}$ between PBB+R and CT treatment and at 95 DAS it was 1.2 $^{\circ}\text{C}$. Air temperature within canopy ranged 30.4-31.4 $^{\circ}\text{C}$ at 80 DAS and it was 33.3-34.5 $^{\circ}\text{C}$ at 95 DAS. Maximum air temperature within canopy was found under CT treatment and lowest value was found under PBB+R treatment (Table 9).

4.1.7.3 Air temperature within the pigeonpea crop canopy under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

At 65 DAS conservation treatments had 32.8- 32.4 $^{\circ}\text{C}$ temperature variation within canopy. Maximum temperature was found under CT treatment (33.1 $^{\circ}\text{C}$). Similar trend was found at 80 DAS, temperature ranged between 34.4-33.5 $^{\circ}\text{C}$ in different treatments. CT and ZT treatment had non-significant difference and other treatments had lower values than these treatments. PBB+R, PBB and PNB+R

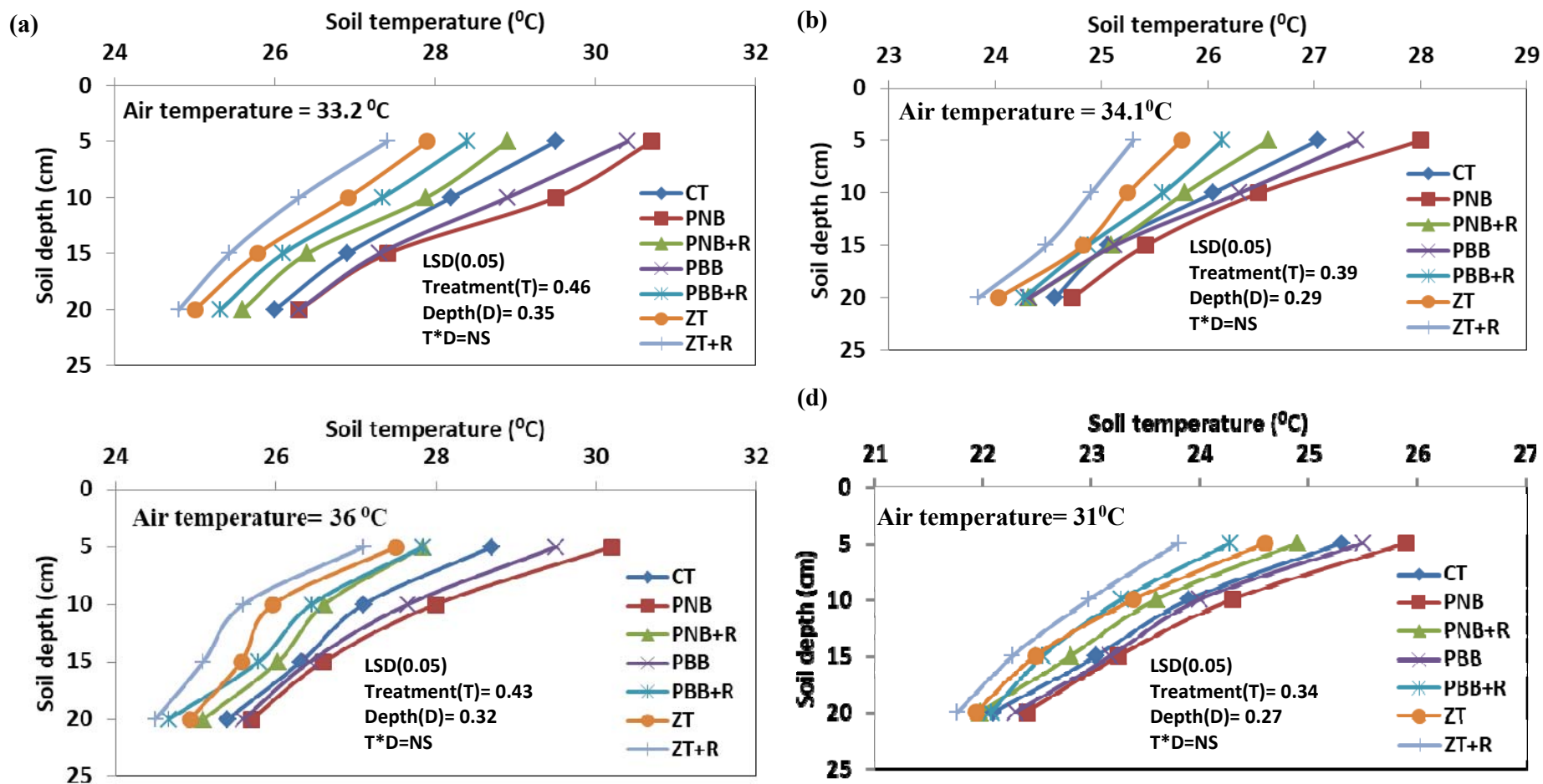


Fig.7. Soil temperature ($^{\circ}\text{C}$) under different conservation practices along with conventional practice in maize during crop growing season in maize-wheat cropping system at (a) 30 DAS (b) 60 DAS (c) 90 DAS and (d) 105 DAS

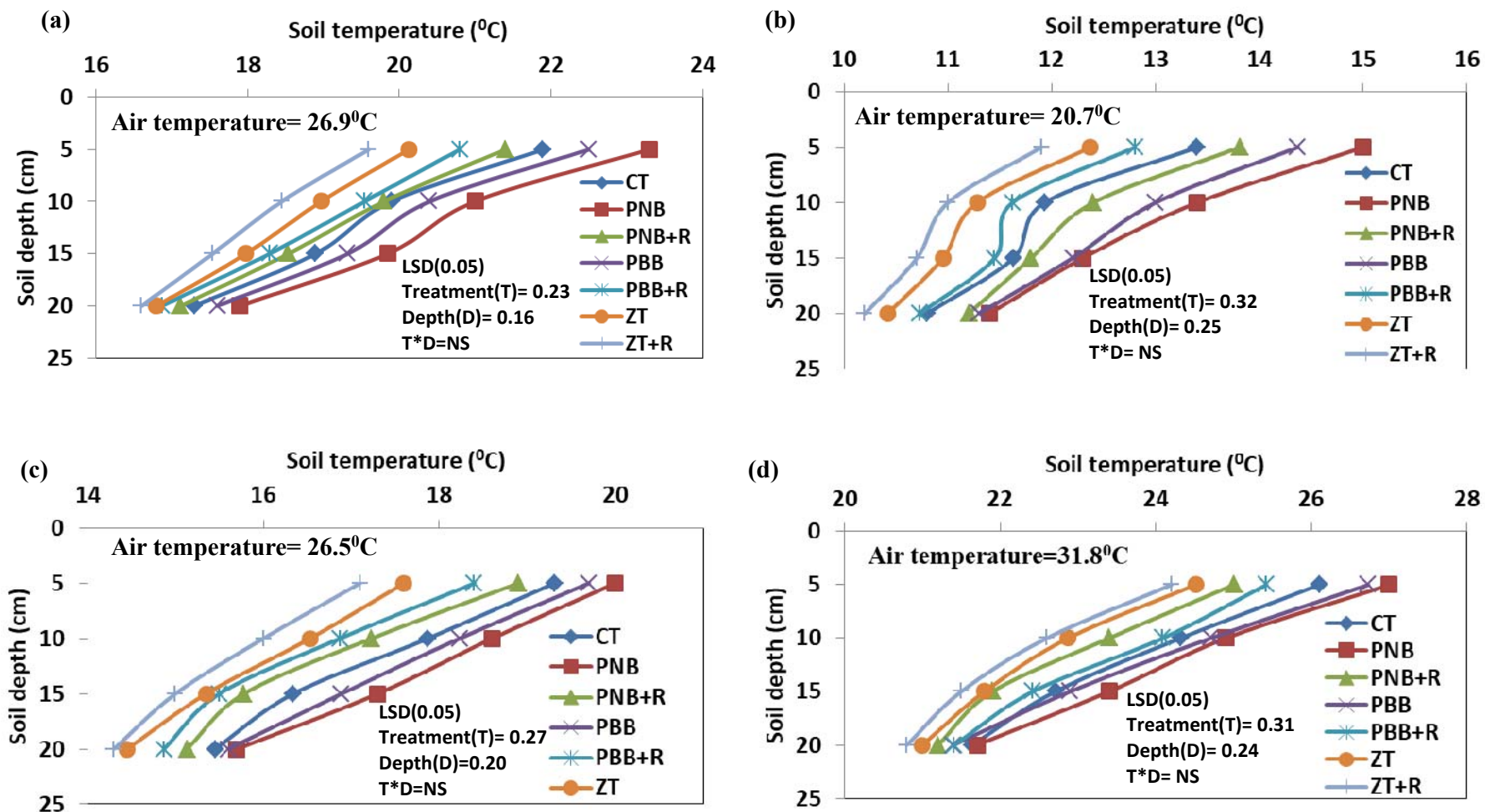


Fig.8. Soil temperature ($^{\circ}\text{C}$) under different conservation practices along with conventional practice in wheat during crop growing season in maize-wheat cropping system at (a) 30 DAS (b) 60 DAS (c) 90 DAS and (d) 120 DAS

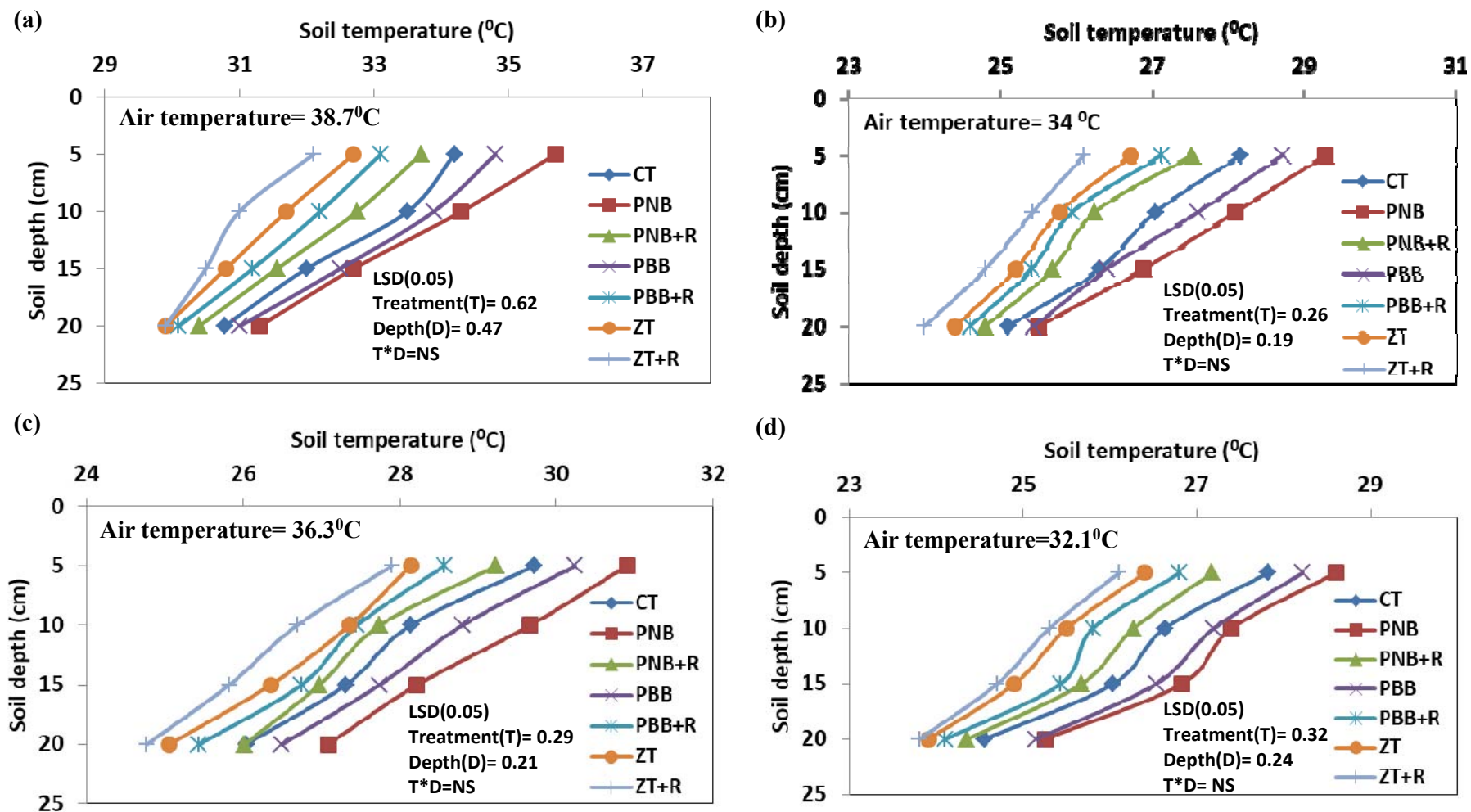


Fig.9. Soil temperature ($^{\circ}\text{C}$) under different conservation practices along with conventional practice in pigeonpea during crop growing season in pigeonpea-wheat cropping system at (a) 35 DAS (b) 70 DAS (c) 105 DAS and (d) 140 DAS

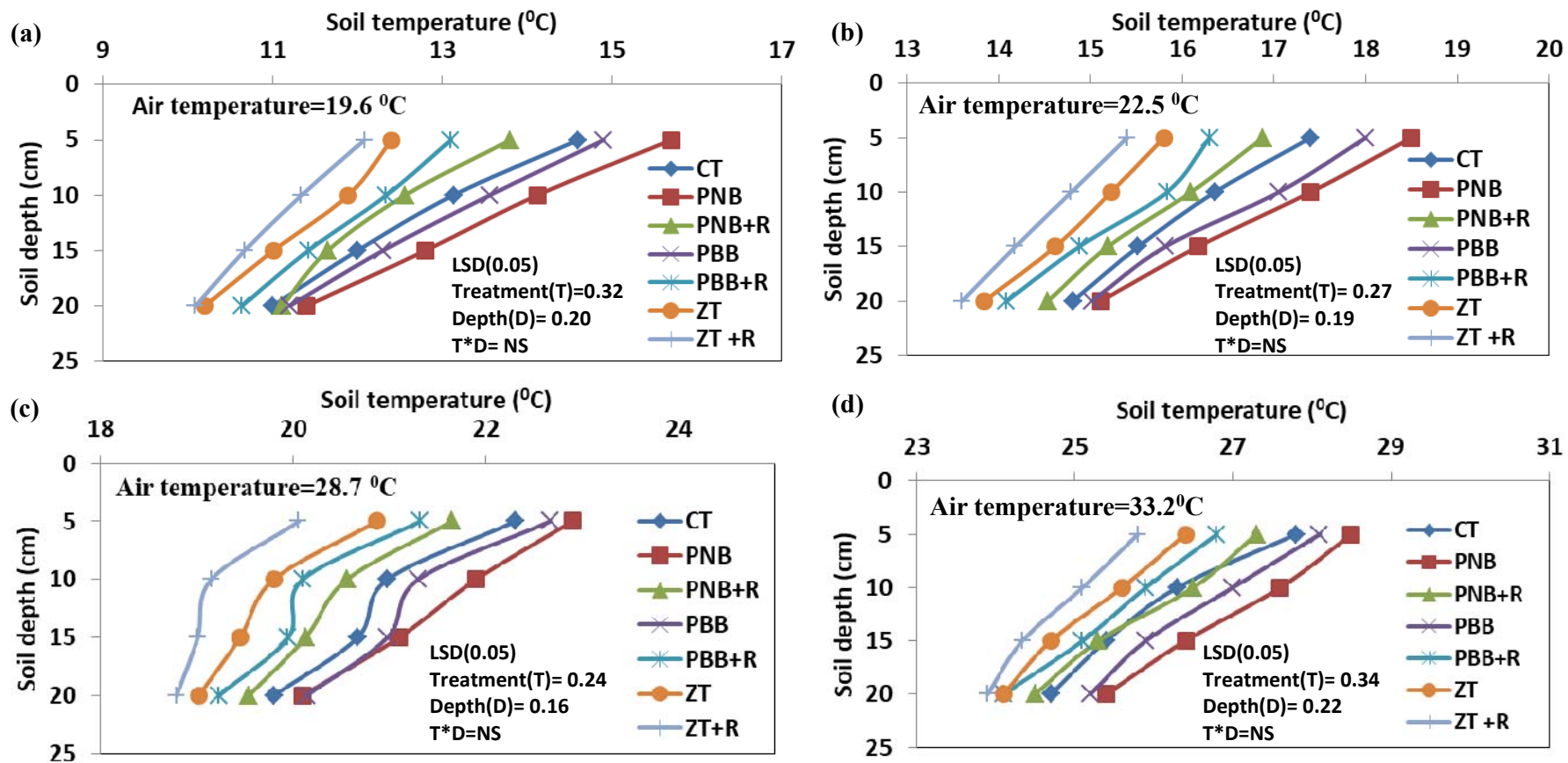


Fig.10. Soil temperature ($^{\circ}\text{C}$) under different conservation practices along with conventional practice in wheat during crop growing season in pigeonpea-wheat cropping system at (a) 30 DAS (b) 60 DAS (c) 90 DAS and (d) 120 DAS

treatment had air temperature within canopy ranged between 30.3-30.6 °C at 95 DAS. Other treatments had higher temperature within canopy ranged between 30.9-31.5 °C. At 105 DAS temperature within canopy ranged between 33.5- 35.0 °C. Maximum temperature variation within CT and PBB+R treatment was 1.6 °C. Under residue treatments (PBB+R, ZT+R, PNB+R) had non-significant difference and they had lowest temperature than other treatments. Air temperature within canopy ranged between 33.5-34.1 °C in residue treatments. Other treatments had air temperature within canopy ranged between 34.3-35.0 °C (Table 10).

Table 9: Temporal variation in air temperature (°C) within crop canopy in wheat under different conservation practices along with conventional practice in maize-wheat cropping system

Treatment	40 DAS	60 DAS	80 DAS	95 DAS
CT	24.70	27.60 ^a	31.40 ^a	34.50 ^a
PNB	24.70	27.50 ^{ab}	31.10 ^{ab}	34.30 ^a
PNB+R	24.59	27.40 ^{abc}	31.10 ^{abc}	34.10 ^a
PBB	24.36	26.90 ^{cd}	30.60 ^{bc}	33.40 ^b
PBB+R	24.30	26.80 ^d	30.40 ^c	33.30 ^b
ZT	24.51	27.20 ^{abcd}	31.10 ^{abc}	34.10 ^a
ZT+R	24.57	27.10 ^{bcd}	30.80 ^{abc}	33.90 ^{ab}
LSD(0.05)	NS	0.63	0.64	0.74

Table 10: Temporal variation in air temperature (°C) within crop canopy in pigeonpea under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

Treatment	65 DAS	80 DAS	95 DAS	105 DAS
CT	33.11 ^a	34.43 ^a	31.53 ^a	35.03 ^a
PNB	32.83 ^{abc}	33.73 ^{bc}	30.97 ^{bc}	34.60 ^{ab}
PNB+R	32.63 ^{bc}	33.60 ^c	30.63 ^{cd}	33.82 ^{cd}
PBB	32.50 ^c	33.87 ^{bc}	30.43 ^{cd}	34.33 ^{abc}
PBB+R	32.43 ^c	33.53 ^c	30.33 ^d	33.47 ^d
ZT	32.97 ^{ab}	34.23 ^{ab}	31.23 ^{ab}	34.53 ^{abc}
ZT+R	32.67 ^{bc}	33.83 ^{bc}	30.87 ^{bcd}	34.13 ^{bcd}
LSD(0.05)	0.54	0.46	0.40	0.67

4.1.7.4 Air temperature within wheat crop canopy under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

Air temperature within wheat canopy had 0.6 °C difference between PBB+R and CT treatment at 40 DAS, which increased up to 0.9 °C at 60 DAS. Minimum temperature was found under PBB+R treatment followed by ZT+R, PBB and ZT. Air temperature within crop canopy ranged between 27.0-27.7 °C under different conservation treatments. Maximum temperature was observed under CT (27.9 °C) treatment. Variation of air temperature within canopy between CT and PBB+R treatment was 1.2 °C at 90 DAS. Minimum temperature was observed under PBB+R followed by ZT+R, ZT and PBB+R treatments. These treatments had non- significant difference in air temperature within canopy but they had lower temperature than other treatments. Maximum temperature was observed under CT treatment may be due to poor canopy cover and low leaf area (Table 11).

Table 11: Temporal variation in air temperature (°C) within crop canopy in wheat under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

Treatment	40 DAS	60 DAS	75 DAS	90 DAS
CT	25.00 ^a	26.63 ^a	27.93 ^a	30.73 ^a
PNB	24.87 ^b	26.50 ^a	27.70 ^{ab}	30.60 ^a
PNB+R	24.70 ^{bc}	26.37 ^{ab}	27.40 ^{abc}	30.33 ^{ab}
PBB	24.50 ^{cde}	25.90 ^{ab}	27.07 ^{bc}	30.23 ^{abc}
PBB+R	24.40 ^e	25.70 ^b	27.00 ^c	29.53 ^c
ZT	24.67 ^{bcd}	26.10 ^{ab}	27.50 ^{abc}	30.07 ^{abc}
ZT+R	24.47 ^{de}	26.09 ^{ab}	27.10 ^{bc}	29.73 ^{bc}
LSD(0.05)	0.40	0.41	0.52	0.61

4.1.8 Relative humidity Profile within crop canopy under different conservation practices along with conventional practice in different cropping system

4.1.8.1 Relative humidity (RH) within maize crop canopy under different conservation practices along with conventional practice under maize-wheat cropping system

Relative humidity (RH) profile showed opposite trend with respect to that of temperature profile i.e., RH measured within the canopy was higher than the value measured above the canopy in different treatments because of shading effect of leaves, lesser transmission of solar radiation, less air movement and accumulation of high water vapour from evapotranspiration. PBB+R treatment had maximum RH. On a clear day RH within the canopy ranged between 46.3% and 52.4% at 40 DAS. The variation within CT and PBB+R treatment was found around 5.6%. With plant growth the RH variation within treatments increased (Table 12).

Table 12: Temporal variation in relative humidity (%) within crop canopy in maize under different conservation practices along with conventional practice in maize-wheat cropping system

Treatment	40 DAS	60 DAS	80 DAS	95 DAS
CT	46.33 ^e	40.77 ^e	45.20 ^e	52.80 ^f
PNB	48.77 ^d	42.30 ^d	46.40 ^d	54.37 ^e
PNB+R	49.33 ^d	44.50 ^c	48.77 ^c	55.43 ^d
PBB	50.20 ^c	46.50 ^{ab}	51.61 ^{ab}	56.80 ^{ab}
PBB+R	52.37 ^a	46.93 ^a	52.17 ^a	57.20 ^a
ZT	49.33 ^d	45.63 ^b	50.70 ^{ab}	55.57 ^{cd}
ZT+R	51.23 ^b	46.07 ^{ab}	51.07 ^{ab}	56.17 ^{bc}
LSD(0.05)	2.20	1.58	2.74	1.81

At 80 DAS maximum RH was found under PBB+R treatment (52.1%) followed by PBB (51.6%), ZT+R (51.1%) and ZT (50.7%). These four treatments had non-significant difference in RH but they had significantly higher values of RH than rest of treatments. Lowest RH value was found under CT treatment (45.2%). At 95 DAS when maize plant near to physiological maturity and most of leaves dried and

shaded than RH difference decreased. PBB+R treatment had RH value 57.2% followed by PBB (56.8%), ZT+R (56.2%), ZT (55.6%), PNB+R (55.4%), PNB (54.3%) and lowest value of RH was found under CT (52.8%) treatment. CT treatment had significantly lower RH value as compared to other conservation treatments.

4.1.8.2 Relative humidity (RH) within wheat crop canopy under different conservation practices along with conventional practice under maize-wheat cropping system

RH was found maximum under PBB+R treatment and minimum under CT treatment because RH had reversed trend as that of air temperature within canopy. Initial RH difference was less within treatments which gradually increased with plant growth. The RH variation from CT to PBB+R treatment was between 50.7-54.5% at 40 DAS (Table 13).

Table 13: Temporal variation in relative humidity (%) within crop canopy in wheat under different conservation practices along with conventional practice in maize-wheat cropping system

Treatment	40 DAS	65 DAS	85 DAS	95 DAS
CT	50.73 ^f	40.63 ^d	43.00 ^e	47.73 ^g
PNB	52.07 ^e	42.70 ^e	44.30 ^d	48.60 ^f
PNB+R	52.63 ^{de}	43.13 ^e	45.63 ^c	49.70 ^e
PBB	53.50 ^{bc}	45.33 ^b	49.27 ^a	53.53 ^b
PBB+R	54.47 ^a	46.10 ^a	49.35 ^a	54.93 ^a
ZT	52.97 ^{cd}	43.30 ^e	47.23 ^b	52.70 ^c
ZT+R	54.04 ^{ab}	44.93 ^b	47.80 ^b	52.03 ^d
LSD(0.05)	1.41	1.42	3.67	1.83

At 65 DAS when plant height and leaf area slightly increased the RH differences within treatments also increased. The variation in RH value within CT and PBB+R treatment was 5.5%. PBB+R treatment had maximum RH value (46.1%) followed by PBB (45.3%), ZT+R (44.9%), ZT (43.3%), PNB+R (43.1%), PNB (42.7%) and lowest value of RH was found under CT treatment. At 85 DAS variation

of RH between PBB+R and CT treatment was 6.4%. At 95 DAS value of RH was within 47.7-54.9%, RH variation within PBB+R and CT treatment was 7.2%. Wheat crop had maximum difference in RH between PBB+R and CT at 95 DAS. After flowering stage variation in RH values gradually decreased within treatments.

4.1.8.3 Relative humidity (RH) within pigeonpea crop canopy under different conservation practices along with conventional practice under pigeon pea-wheat cropping system

At 65 DAS variation within PBB+R and CT treatment was around 5.1% which gradually increased with plant growth. Maximum value of RH was found under PBB+R (66.8%) treatment followed by PNB+R (66.5%), ZT+R (65.7%), PBB (65.1%), PNB (63.1%), ZT (62.7%) and CT (61.8%) treatment at 65 DAS. RH difference within PBB+R and CT treatment increased up to 6.5% at 80 DAS. RH value within different treatments was ranged between 43.8-51% at 95 DAS. Highest RH value was found under PBB+R treatment (51%) followed by PNB+R (49.8%). PBB+R and PNB+R treatments had higher RH values than other treatments. At 105 DAS there was maximum variation in RH values among different treatments. Value of RH ranged between 45.3-50.4% within conservation treatments (Table 14). Maximum RH value was found under PBB+R treatment (50.4%) followed by PNB+R (49.2%), ZT+R (48.2%), PBB (47.4%), PNB (47.3%), ZT (45.3%) treatment. Lowest value was found under CT treatment (42.3%). PBB+R treatment had significantly higher RH values than other treatments.

4.1.8.4 Relative humidity (RH) within wheat crop canopy under different conservation practices along with conventional practice under pigeonpea-wheat cropping system

Relative humidity had higher value under conservation treatments than CT treatment. Initial stage of vegetative phase had lesser difference in RH values among different treatments. Maximum RH value was observed under PBB+R (66.7%) followed by ZT+R (66.4%), PBB (65.8%), ZT (64.6%), PNB+R (64.5%), PNB (64.1%) and lowest value under CT (63.6%) treatment at 40 DAS. CT and PBB+R treatments had 3.2% variation in RH, which gradually increase at 60 DAS (5.1%). At 75 DAS, CT treatment had RH value 47.1% and PBB+R treatment had 53.4% followed by other conservation treatments. Maximum variation was observed around

90 DAS (flowering stage) when plant height and leaf area at their peak value. RH difference among CT and PBB+R treatment was 6.9%. Maximum RH value was found under PBB+R treatment (58.8%) followed by PBB (58.6%), ZT+R (57.8%), ZT (56.2%), PNB+R (55.8%), PNB (52.6%) and CT (51.9%) treatment at 90 DAS. PBB+R and PBB treatments had significantly higher RH values than other treatments. CT and PNB treatments had non-significant difference in RH values (Table 15).

Table 14: Temporal variation in relative humidity (%) within crop canopy in pigeonpea under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

Treatment	65 DAS	80 DAS	95 DAS	105 DAS
CT	61.81 ^c	42.90 ^c	43.80 ^f	42.33 ^f
PNB	63.17 ^d	43.47 ^{de}	45.10 ^{de}	47.30 ^d
PNB+R	66.57 ^{ab}	47.83 ^b	49.83 ^b	49.17 ^b
PBB	65.07 ^c	44.60 ^d	45.83 ^d	47.37 ^{cd}
PBB+R	66.83 ^a	50.37 ^a	51.03 ^a	50.40 ^a
ZT	62.77 ^{de}	47.40 ^b	44.50 ^{ef}	45.30 ^e
ZT+R	65.70 ^{bc}	46.00 ^c	48.63 ^c	48.23 ^c
LSD(0.05)	2.78	2.46	1.98	2.01

Table 15: Temporal variation in relative humidity (%) within crop canopy in wheat under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

Treatment	40 DAS	60 DAS	75 DAS	90 DAS
CT	63.60 ^b	43.20 ^e	47.13 ^d	51.90 ^d
PNB	64.10 ^b	44.07 ^d	47.40 ^d	52.60 ^d
PNB+R	64.53 ^b	45.90 ^c	49.70 ^c	55.83 ^c
PBB	65.83 ^a	46.90 ^b	52.83 ^a	58.47 ^{ab}
PBB+R	66.70 ^a	48.30 ^a	53.40 ^a	58.80 ^a
ZT	64.60 ^b	46.17 ^c	50.80 ^b	56.17 ^c
ZT+R	66.40 ^a	48.30 ^a	51.30 ^b	57.80 ^b
LSD(0.05)	1.82	2.22	2.10	1.76

4.1.9 Photosynthesis rate, stomatal conductance and transpiration rate of crops under different conservation practices along with conventional practices in different cropping systems

4.1.9.1. Photosynthesis rate, stomatal conductance and transpiration rate of maize crop under different conservation practices along with conventional practices in maize-wheat cropping system

Photosynthesis rate, stomatal conductance and transpiration rate was measured at post anthesis stage. In maize crop photosynthesis rate at post anthesis stage varied from 17.8 to 24.2 $\mu\text{mol Co}_2/\text{m}^2/\text{s}$ under different conservation treatments with lowest (17.6 $\mu\text{mol Co}_2/\text{m}^2/\text{s}$) under CT treatment. Maximum photosynthesis rate was found under PPB+R treatment (24.2 $\mu\text{mol Co}_2/\text{m}^2/\text{s}$) followed by ZT+R (24 $\mu\text{mol Co}_2/\text{m}^2/\text{s}$) treatment. These two treatments performed similar for photosynthesis rate and showed higher values than other treatments. Stomatal conductance had values between 0.48- 0.72 $\text{mol H}_2\text{O}/\text{m}^2/\text{s}$. Maximum values was found under PBB+R treatment followed by ZT+R treatment. Under conservation practices lowest stomatal conductance was found under PNB treatment. PBB+R, ZT+R and PBB treatments had non-significant values. PBB+R treatment had significantly higher transpiration rate (5.97 $\text{mmol H}_2\text{O}/\text{m}^2/\text{s}$) than the other treatments. ZT+R (5.53 $\text{mmol H}_2\text{O}/\text{m}^2/\text{s}$) and ZT (5.50 $\text{mmol H}_2\text{O}/\text{m}^2/\text{s}$) treatment had non-significant difference. Similarly PNB+R (4.91 $\text{mmol H}_2\text{O}/\text{m}^2/\text{s}$) and PNB (4.83 $\text{mmol H}_2\text{O}/\text{m}^2/\text{s}$) treatments performed similarly. CT treatment had lowest transpiration rate (4.49 $\text{mmol H}_2\text{O}/\text{m}^2/\text{s}$) (Fig. 11).

4.1.9.2 Photosynthesis rate, stomatal conductance and transpiration rate of wheat crop under different conservation practices along with conventional practices in maize-wheat cropping system

Photosynthesis rate, stomatal conductance and transpiration rate was measured at post anthesis stage. Photosynthesis rate was maximum under PBB+R treatment (16.22 $\mu\text{mol Co}_2/\text{m}^2/\text{s}$) followed by ZT+R (15.82 $\mu\text{mol Co}_2/\text{m}^2/\text{s}$) and ZT (15.72 $\mu\text{mol Co}_2/\text{m}^2/\text{s}$). PBB+R, ZT+R and ZT treatments were non-significant and had higher photosynthesis rates than other treatments. CT treatment had lowest photosynthesis rate (12.18 $\mu\text{mol Co}_2/\text{m}^2/\text{s}$). Stomatal conductance in PBB+R treatment had value 0.56 $\text{mol H}_2\text{O}/\text{m}^2/\text{s}$. In other conservation treatments the value of stomatal conductance was ranged between 0.41- 0.54 $\text{mol H}_2\text{O}/\text{m}^2/\text{s}$. PBB+R, ZT+R, ZT and PBB treatment

had non-significant difference. Transpiration rate was ranged between 1.97- 3.40 mmol H₂O/m²/s. The maximum transpiration rate was under PBB+R treatment (3.40 mmol H₂O/m²/s) followed by ZT+R (3.19 mmol H₂O/m²/s), ZT (2.97 mmol H₂O/m²/s), PBB (2.64 mmol H₂O/m²/s) treatment. PBB+R treatment had significantly higher values than other treatments (Fig. 12).

4.1.9.3 Photosynthesis rate, stomatal conductance and transpiration rate of pigeonpea crop under different conservation practices along with conventional practices in pigeonpea-wheat cropping system

In pigeonpea crop photosynthesis rate, stomatal conductance and transpiration rates were measured at flowering stage. Residue treatments had non-significant difference. Highest photosynthesis rate was found under PBB+R treatment (29.8 μmol Co₂/m²/s) followed by PNB+R (29.1 μmol Co₂/m²/s) and ZT+R (28.7 μmol Co₂/m²/s) treatment. CT, PNB and ZT treatments had values at par. Photosynthesis rate had lowest value under CT treatment (23.5 μmol Co₂/m²/s). Stomatal conductance had non-significant value within residue treatments (PBB+R, PNB+R, ZT+R). These treatments had stomatal conductance ranged between 0.81-0.87 mol H₂O/m²/s. Lowest stomatal conductance found under CT (0.74 mol H₂O/m²/s) treatment. Transpiration rate was found within 3.82- 4.32 mmol H₂O/m²/s. Maximum transpiration rate was found in PBB+R treatment (4.32 mmol H₂O/m²/s) followed by PNB+R (4.31 mmol H₂O/m²/s), ZT+R (4.28 mmol H₂O/m²/s), PBB (4.18 mmol H₂O/m²/s), PNB (4.08 mmol H₂O/m²/s), ZT (3.92 mmol H₂O/m²/s) and CT (3.82 mmol H₂O/m²/s) treatment. CT and ZT treatments had similar transpiration rate. Transpiration rate in PBB+R, PNB+R, ZT+R, PBB treatments had non-significant difference (Fig. 13).

4.1.9.4 Photosynthesis rate, stomatal conductance and transpiration rate of wheat crop under different conservation practices along with conventional practices in pigeonpea-wheat cropping system

Photosynthesis rate, stomatal conductance and transpiration rate measured in wheat crop sown after pigeonpea at post anthesis stage. Value of photosynthesis rate ranged between 13.41-16.93 μmol Co₂/m²/s under different conservation treatments. CT treatment had photosynthesis rate of 12.73 μmol Co₂/m²/s. PBB+R, ZT+R, PNB+R and PBB treatments had non-significant difference in photosynthesis rate.

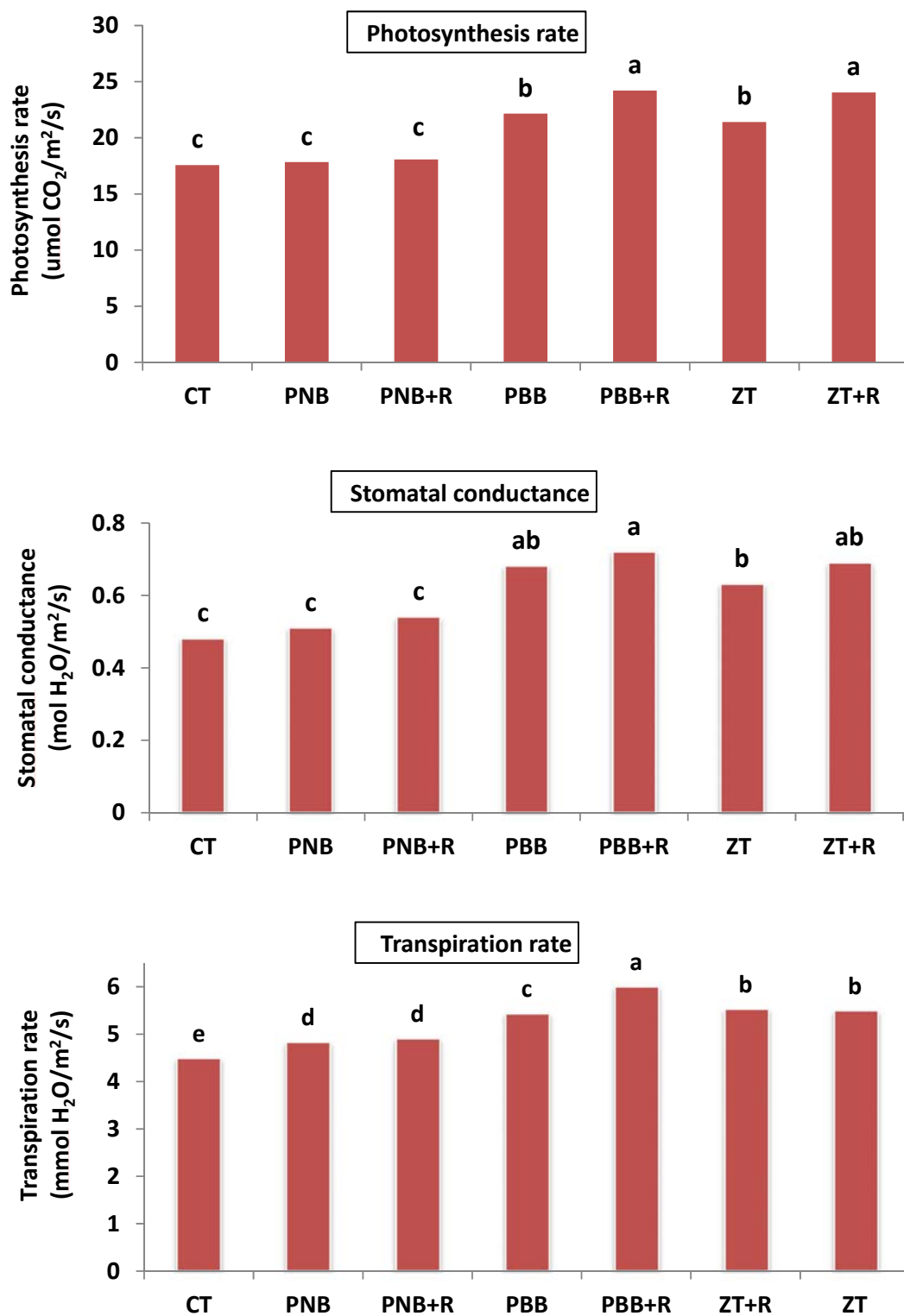


Fig.11. Photosynthesis rate, stomatal conductance and transpiration rate under different conservation practices along with conventional practice in maize during post anthesis stage in maize–wheat cropping system

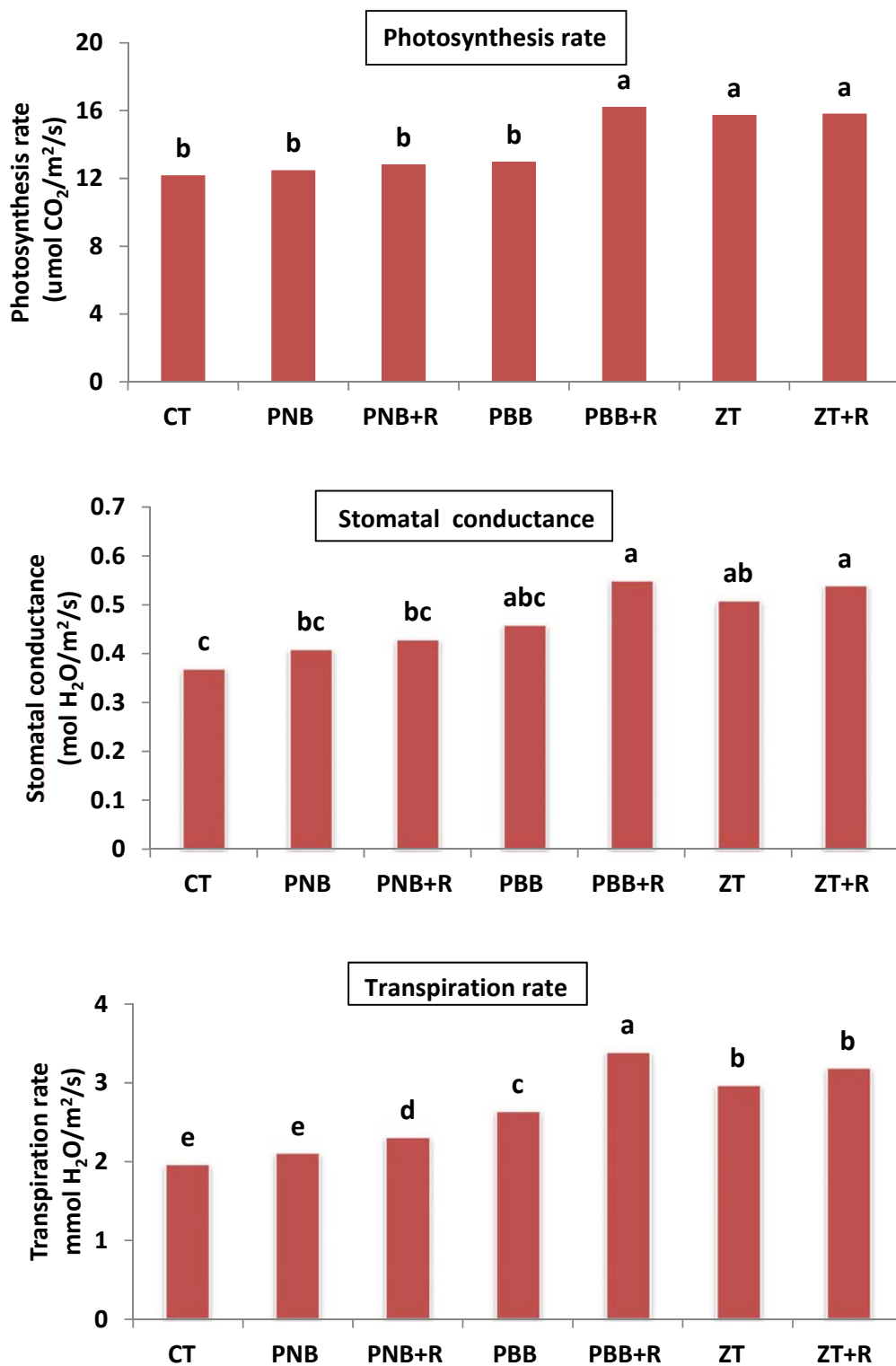


Fig.12. Photosynthesis rate, stomatal conductance and transpiration rate under different conservation practices along with conventional practice in wheat during post anthesis stage in maize–wheat cropping system

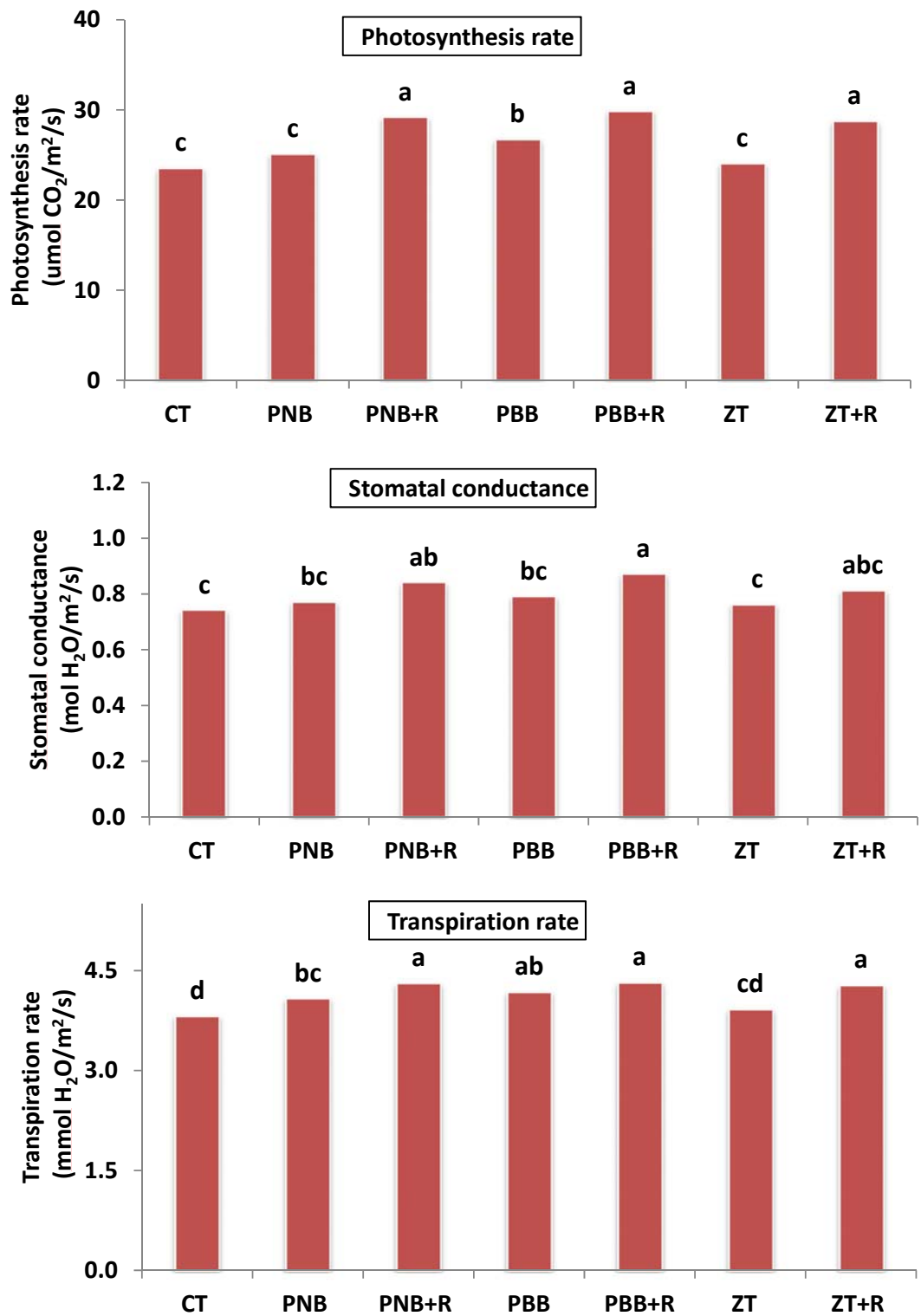


Fig.13. Photosynthesis rate, stomatal conductance and transpiration rate under different conservation practices along with conventional practice in pigeonpea during flowering stage in pigeonpea–wheat cropping system

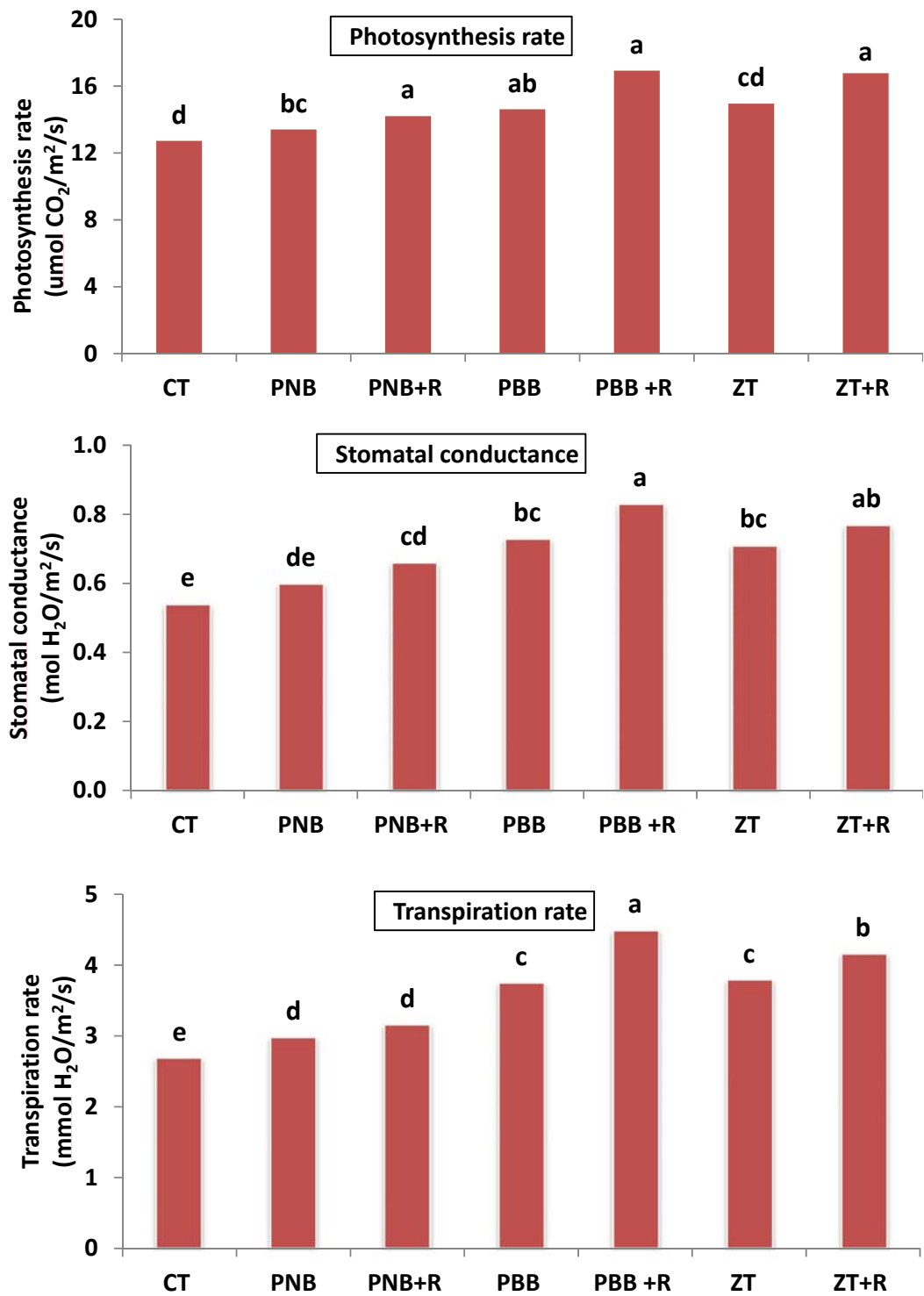


Fig.14. Photosynthesis rate, stomatal conductance and transpiration rate under different conservation practices along with conventional practice in wheat during post anthesis stage in pigeonpea–wheat cropping system

Stomatal conductance was maximum under PBB+R treatment (0.83 mol H₂O/m²/s) followed by ZT+R (0.77 mol H₂O/m²/s) and PBB (0.75 mol H₂O/m²/s) treatment. The lower value of stomatal conductance was under CT treatment (0.58 mol H₂O/m²/s) which showed similar stomatal conductance value as PNB treatment (0.60 mol H₂O/m²/s). Transpiration rate was maximum under PBB+R treatment (4.49 mmol H₂O/m²/s) followed by ZT+R (4.16 mmol H₂O/m²/s), ZT (3.79 mmol H₂O/m²/s), PBB (3.75 mmol H₂O/m²/s), PNB+R (3.16 mmol H₂O/m²/s), PNB (2.98 mmol H₂O/m²/s) and CT (2.69 mmol H₂O/m²/s) treatment. CT treatment had lowest transpiration rate as compared to other treatments (Fig. 14).

4.2 Objective 2: To study effect due to crop microenvironment under different treatments on biophysical parameters, crop productivity and radiation use efficiency

4.2.1 Leaf area index (LAI) in different conservation practices along with convention practice in different cropping system

4.2.1.1 Leaf area index (LAI) of maize in different conservation practices along with conventional practices in maize-wheat cropping system

At 30 DAS, PBB+R treatment showed significantly higher LAI (2.95) followed by PBB (2.81), ZT+R (2.74), ZT (2.67), PNB+R (2.53), PNB (2.48) and CT (2.47) treatment. At 60 DAS, LAI value increased up to 4.58 in PBB+R treatment followed by PBB (4.52), ZT+R (4.41) and ZT (4.33) treatment. CT and PNB treatment had non-significant difference in LAI at 30 and 60 DAS. At 90 DAS, maximum LAI was observed in PBB+R treatment (5.18) followed by PBB (5.05), ZT+R (4.87), ZT (4.77), PNB +R (4.63) and PNB (4.54) treatment. Significantly higher LAI was observed in PBB+R treatment and lowest value was found in CT (4.46) treatment at 90 DAS (Fig. 15).

4.2.1.2 Leaf area index (LAI) of wheat in different conservation practices along with conventional practices in maize-wheat cropping system

Wheat crop followed the similar pattern of LAI as of maize crop. The LAI increased rapidly during initial vegetative phase and maximum LAI found at flowering stage. The maximum LAI (1.88) was observed in PBB+R and ZT+R (1.79) treatments, both were at par but significantly higher over rest of the treatments at 30 DAS. Similar kind of trend was observed at 60 and 90 DAS. PBB+R showed highest

LAI (3.69) as compared to the corresponding value of other treatments, followed by ZT+R treatment (3.60) at 60 DAS. Among other treatments, ZT had significantly higher LAI (3.49). Rest of the treatments had LAI ranged within 3.13 to 3.44. Peak value of LAI was observed at 90 DAS in PBB+R treatment (4.41) followed by ZT+R treatment (4.32) and lowest value of LAI was in PNB treatment (3.87) under conservation treatments. LAI value under CT treatment was 3.75, which was lowest among all the treatments (Fig. 16).

4.2.1.3 Leaf area index (LAI) of pigeonpea in different conservation practices along with conventional practices in pigeonpea-wheat cropping system

The maximum LAI was observed under PBB+R treatment (0.86) followed by PNB+R (0.82), ZT+R (0.78), PBB (0.76), PNB (0.72), ZT (0.70) treatment and minimum value of LAI was found in CT treatment (0.66) at 35 DAS. Similar trend was also observed at 70 and 105 DAS. At 70 DAS, maximum LAI was found in PBB+R (2.48) treatment which had significantly higher value than other treatments. For other treatments LAI ranged within 1.78 to 2.23. Maximum value of LAI was observed at 105 DAS in PBB+R treatment (3.17) followed by PNB+R (3.16). These two treatments had non-significant difference. Lowest value of LAI was observed in CT treatment (2.69). LAI in treatments with residue retention (PNB+R, PBB+R and ZT+R) had higher value than corresponding value without residue (PNB, PBB and ZT) treatments (Fig. 17).

4.2.1.4 Leaf area index (LAI) of wheat in different conservation practices along with conventional practices in pigeonpea-wheat cropping system

PBB+R treatment had significantly higher LAI value than other treatments (Fig. 18). Initially, at 30 DAS, PBB+R treatment showed higher LAI (1.88) followed by ZT+R (1.80), PBB (1.76), ZT (1.75), PNB +R (1.73), PNB (1.61) and CT (1.56) treatment. PBB+R and ZT+R treatment had non-significant difference. At 60 DAS PBB+R treatment had highest LAI (2.45) followed by ZT+R (2.33), ZT (2.28), PBB (2.28), PNB+R (2.24), PNB (2.09) and CT (2.03) treatment. Maximum value was observed at 90 DAS in PBB+R treatment (3.57) followed by ZT+R (3.41), PBB (3.34), ZT (3.31), PNB +R (3.28), PNB (3.05) treatment. CT treatment had lowest LAI value (2.96). PNB+R, PBB and ZT treatments showed nearly similar LAI value,

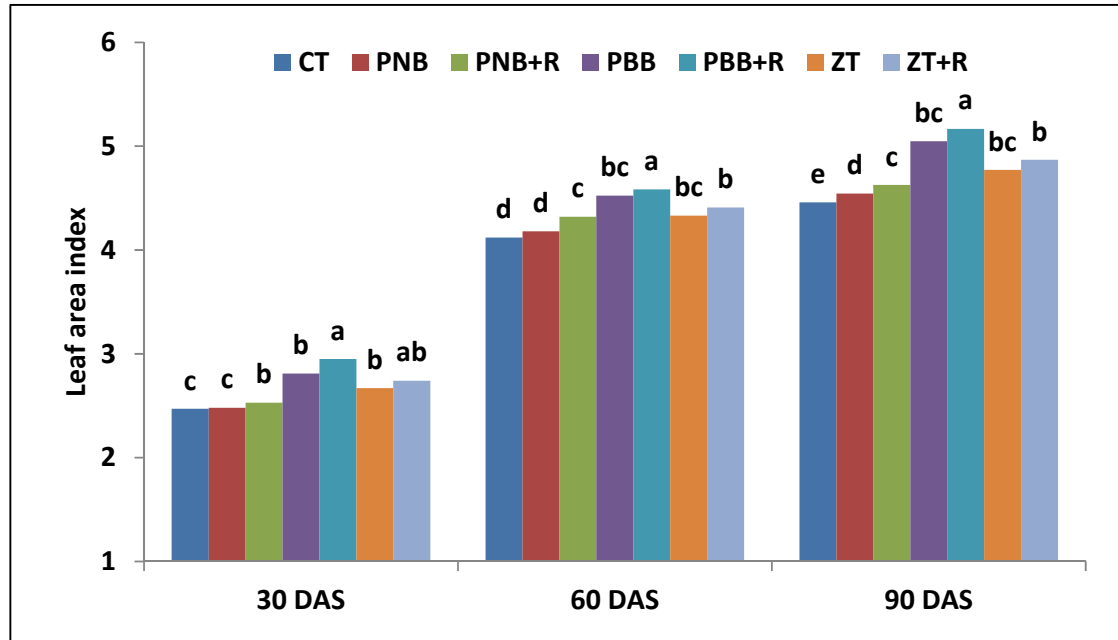


Fig.15. Leaf area index under different conservation practices along with conventional practice in maize during crop growing season in maize – wheat cropping system

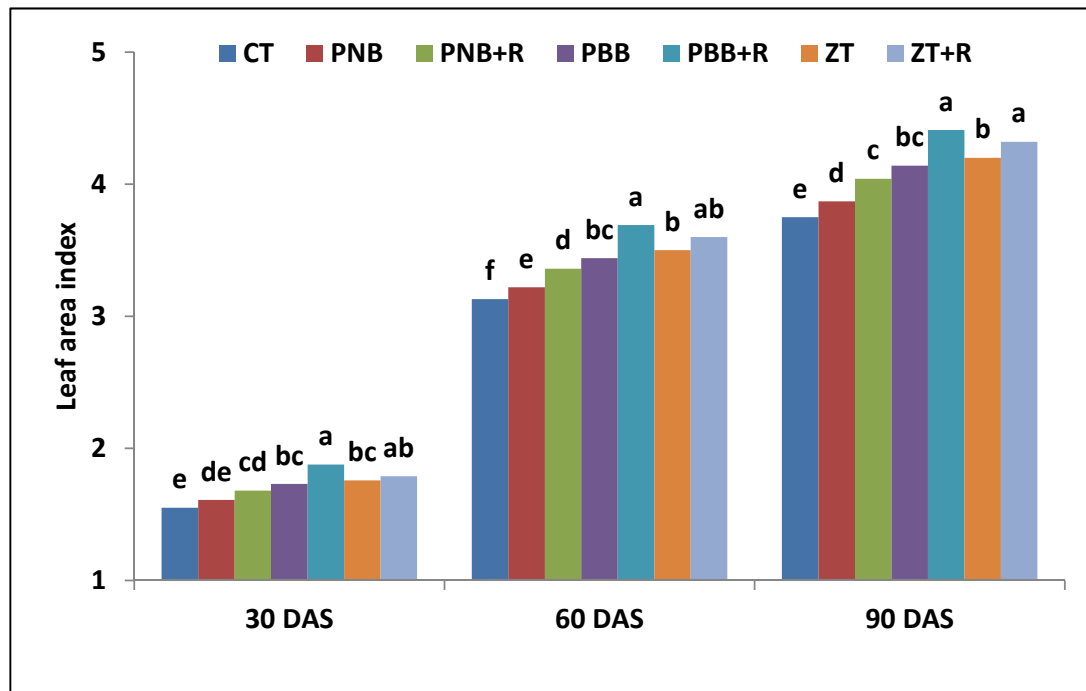


Fig.16. Leaf area index under different conservation practices along with conventional practice in wheat during crop growing season in maize – wheat cropping system

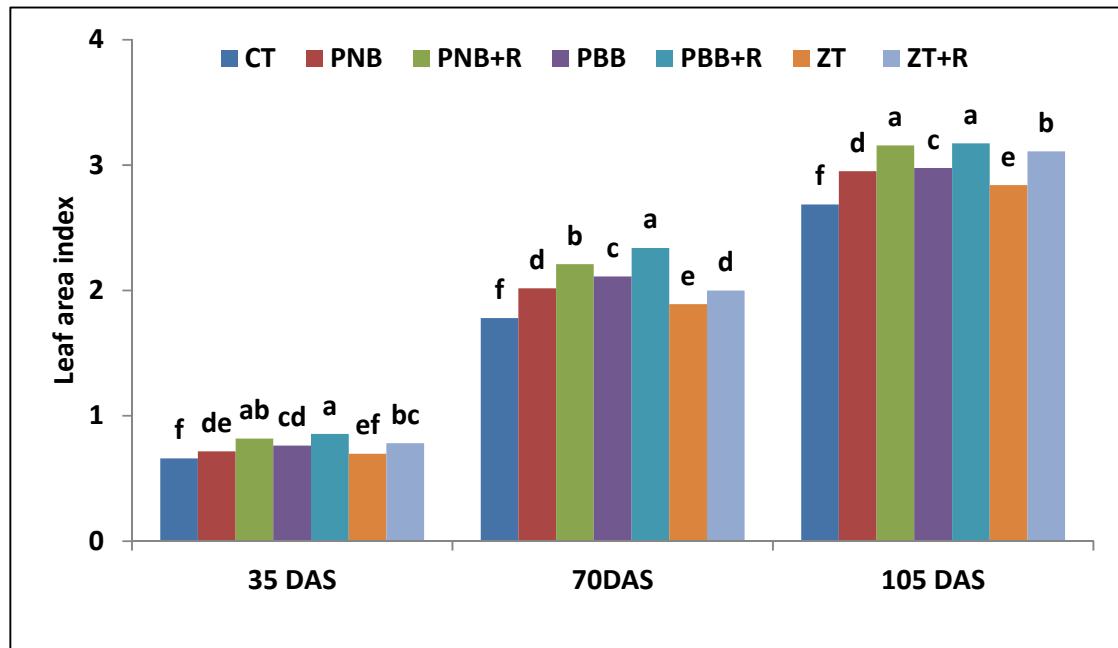


Fig.17. Leaf area index under different conservation practices along with conventional practice in pigeonpea during crop growing season in pigeonpea –wheat cropping system

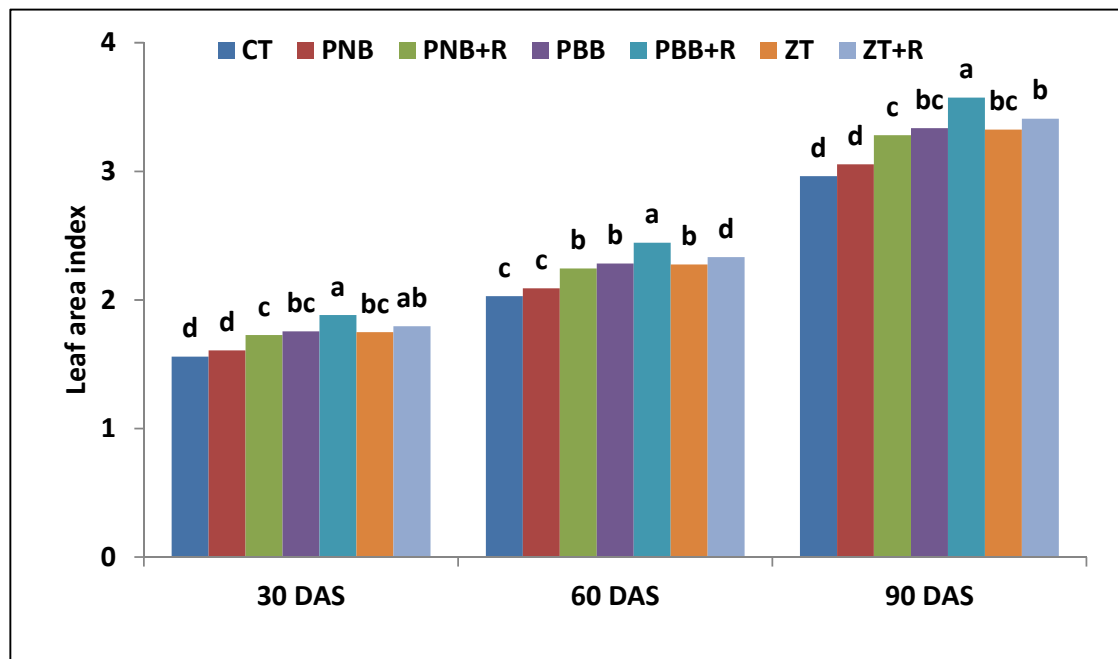


Fig.18. Leaf area index under different conservation practices along with conventional practice in wheat during crop growing season in pigeonpea –wheat cropping system

these three treatments had non-significant difference in LAI throughout the growing period. Similar results were observed for CT and PNB treatments.

4.2.2 Plant height measured under different conservation practices along with conventional practice in different cropping system

4.2.1.1 Plant height of maize in different conservation practices along with conventional practices in maize-wheat cropping system

The height of maize increased slowly in initial stages, than increase rapidly and after starting of flowering stage it becomes constant with respect to different tillage and residue treatments. At 30 DAS, PBB+R treatment had maximum plant height (75 cm) followed by PBB (73.4 cm) and ZT+R (72.6 cm), ZT (68.3 cm), PNB+R (67.3 cm), PNB (62.7 cm) and CT (60.3 cm) treatment. The PBB+R and ZT+R, PBB treatment had non-significant difference at 5% level of significance. At 60 DAS, plant height increased maximum in PBB+R plot (153 cm) followed by PBB (152 cm), ZT+R (145 cm), ZT (141 cm), PNB+R (139 cm), PNB (127 cm) and CT (123 cm) treatment. Maximum plant height was observed at 90 DAS, after that it was constant. PBB+R treatment showed highest plant height (168 cm) followed by PBB (167.5 cm), ZT+R (163cm), ZT (158 cm), PNB+R (156 cm) and PNB (148 cm). Lowest plant height was observed in CT treatment (140 cm). PBB+R and PBB treatment had non-significant difference in plant height throughout the growing period (Fig. 19).

4.2.2.2 Plant height of wheat in different conservation practices along with conventional practices in maize-wheat cropping system

Lowest plant height was observed in CT treatment (21.8 cm), it increased gradually among conservation treatments 22.9 cm in PNB to 27.1 cm in PBB+R treatment at 30 DAS. CT, PNB, PNB+R and ZT treatments had non-significant difference. PBB+R and ZT+R treatment also showed similar result at 30 DAS. Plant height at 60 DAS was maximum in PBB+R (52.7 cm) followed by ZT+R (51.5 cm), ZT (50.8 cm), PBB (48.6 cm), PNB+R (45.2 cm), PNB (44.4 cm) and CT (42.1 cm) treatments. PBB+R, ZT+R and ZT treatments had non-significant difference in plant height but had higher plant height than corresponding value in other treatments. Maximum plant height was observed at flowering stage (90 DAS). PBB+R had maximum plant height (101.9 cm) followed by ZT+R (101.2 cm), ZT (99.5 cm), PBB (97.3 cm), PNB+R (91.2 cm), PNB (88.6 cm) and CT (85.3 cm) treatment. PBB+R,

ZT+R and ZT treatments had non-significant difference and showed significantly higher plant height over rest of the treatments (Fig. 20).

4.2.2.3 Plant height of pigeonpea in different conservation practices along with conventional practices in pigeonpea-wheat cropping system

Plant height was measured at 35, 70, 105 and 140 DAS. Plant height increased rapidly in vegetative phase than the reproductive phase. Plant height at 30 DAS was highest in PBB+R treatment (61 cm) followed by PNB+R (59 cm), ZT+R (58 cm), PBB (55cm), PNB(52cm), ZT (50 cm) and CT (42 cm) treatment. At 70 DAS, PBB+R treatment had 124.7 cm plant height followed by 117 cm in PNB+R, 114 cm in ZT+R, 112 cm in PBB+R, 108 cm in PNB, 102 cm in ZT and 99 cm in CT treatment. Plant height at 105 DAS increased up to 135 cm to 169 cm in different treatments. Residue treatments (PBB+R, PNB+R and ZT+R) had higher plant height than other treatments throughout the growing period. Among conservation treatments highest plant height was found under PBB+R treatment and lowest under ZT treatment. CT treatment showed lowest plant height throughout growing period. Plant height at 140 DAS increased up to 189 cm in PBB+R treatment, followed by PNB+R (181 cm), ZT+R (179 cm), PBB (175 cm), PNB (166 cm), ZT (163 cm) and CT (154 cm) treatment. The PBB+R treatment showed significantly higher plant height than the corresponding value in other treatments (Fig. 21).

4.2.2.4 Plant height of wheat in different conservation practices along with conventional practices in pigeonpea-wheat cropping system

Wheat plant height increased from emergence to starting of flowering stage than after it become constant. Plant height differs to each other due to different tillage and residue treatments. Maximum plant height at 30 DAS was observed in PBB+R (31 cm) treatment followed by ZT+R treatment (29 cm). Other treatments showed lower values of plant height than these two treatments. The plant height at 60 DAS varied from 44 cm to 54 cm among conservation treatments. CT treatment had lowest plant height (41 cm). Plant height had maximum values in all treatments at 90 DAS after that it become constant. PBB+R had maximum plant height (104 cm) followed by ZT+R (102.8 cm), PBB (99 cm), ZT (97 cm), PNB+R (94.2 cm) and PNB (88.3 cm). Lowest value of plant height was found under CT treatment (83 cm). PBB+R treatment showed maximum plant height throughout the growing period. There was

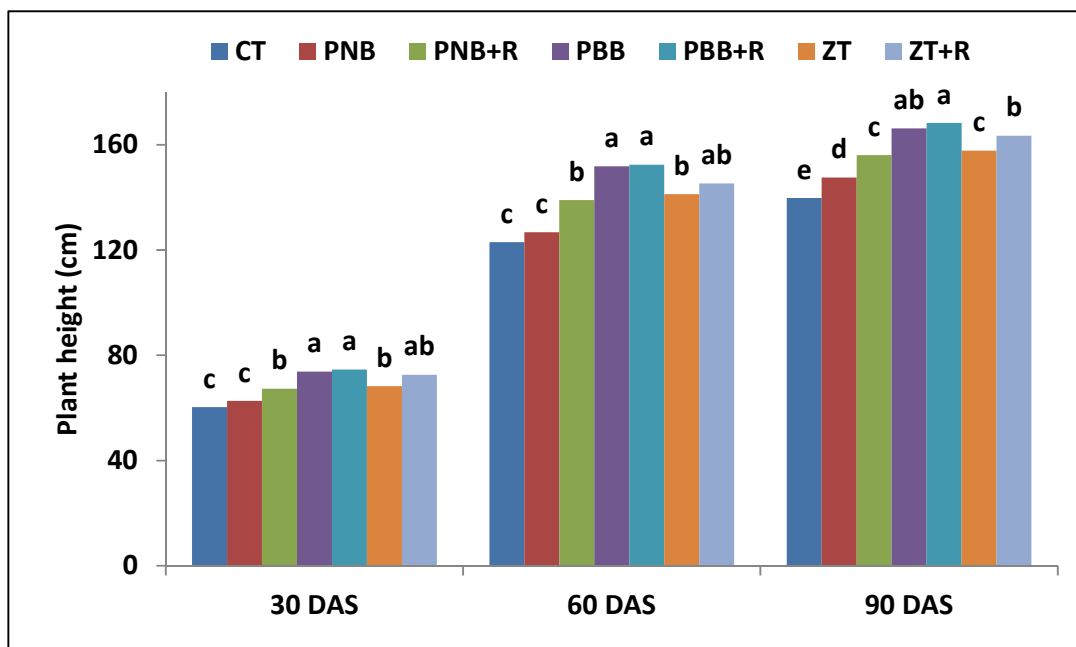


Fig.19. Plant height under different conservation practices along with conventional practice in maize during crop growing season in maize – wheat cropping system

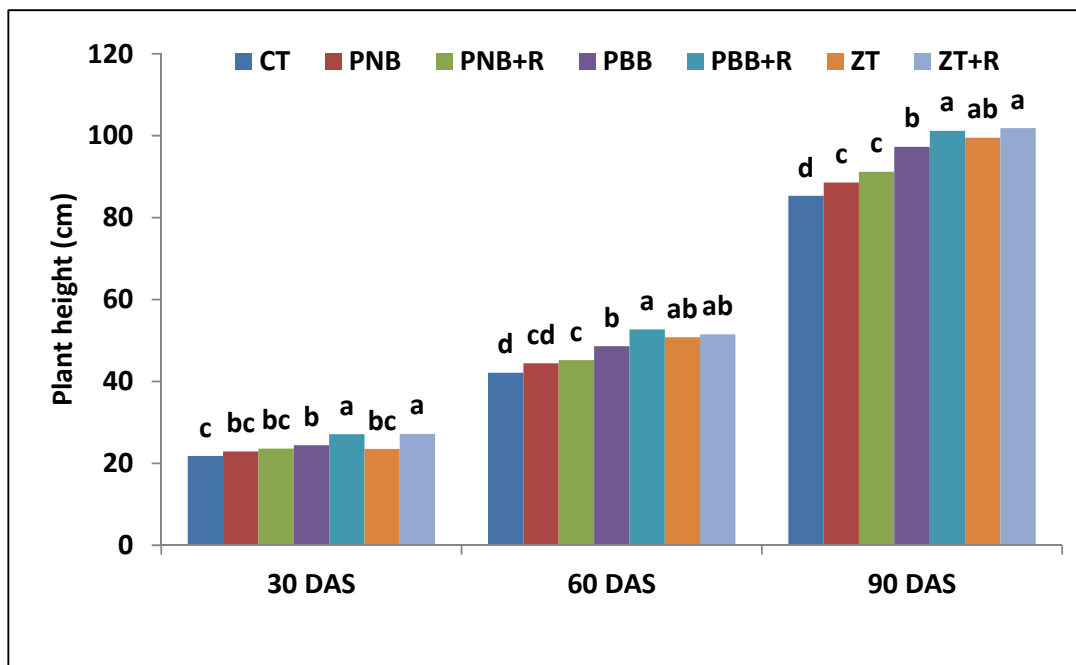


Fig.20. Plant height under different conservation practices along with conventional practice in wheat during crop growing season in maize – wheat cropping system

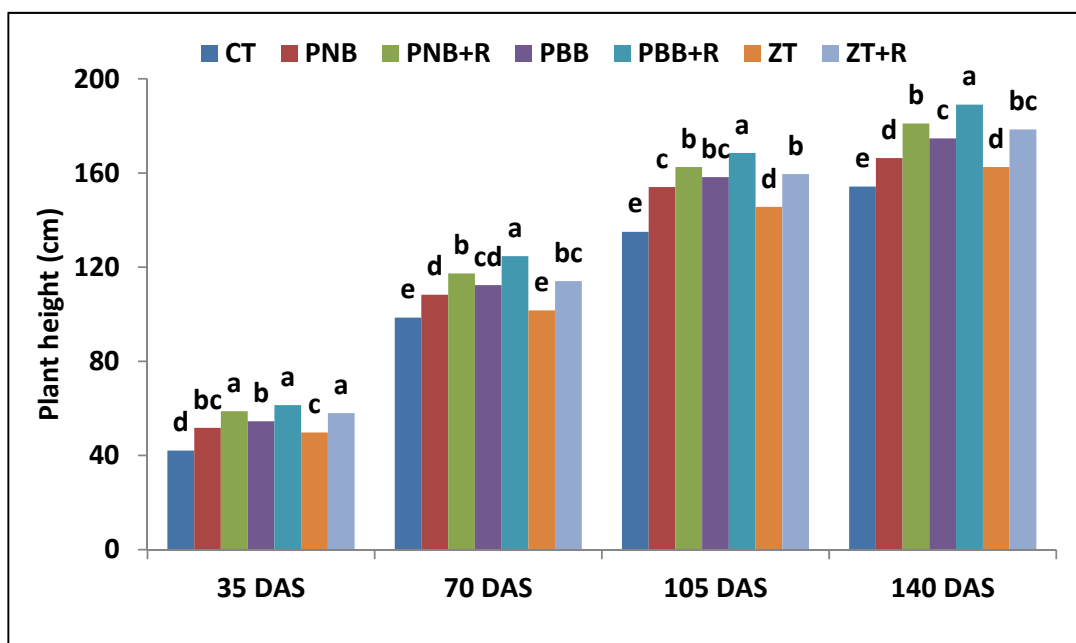


Fig.21. Plant height under different conservation practices along with conventional practice in pigeonpea during crop growing season in pigeonpea –wheat cropping system

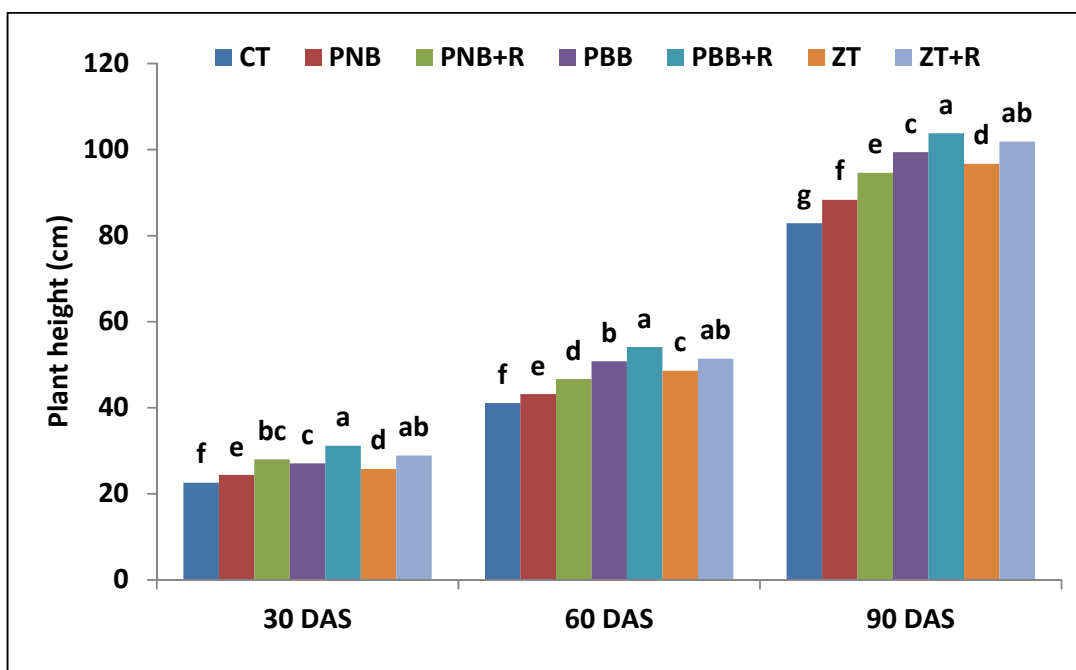


Fig.22. Plant height under different conservation practices along with conventional practice in wheat during crop growing season in pigeonpea –wheat cropping system

non-significant difference among PBB+R and ZT+R treatment but plant height of these two treatments were significantly higher than other treatments (Fig. 22).

4.2.3 Biomass measured in different conservation practices along with conventional practice in different cropping system

4.2.3.1 Biomass of maize in different conservation practices along with conventional practices in maize-wheat cropping system

Significant differences in biomass accumulation were observed for different treatments at 30 DAS. Initially, higher biomass accumulation was recorded in PBB, PBB+R, ZT and ZT+R ($3.1-3.5 \text{ t ha}^{-1}$). These four treatments had higher biomass over PNB+R, PNB and CT treatments. These three treatments had biomass accumulation in between $2.5-2.9 \text{ t ha}^{-1}$. At 60 DAS, higher biomass was accumulated in PBB+R treatment (6.9 t ha^{-1}) followed by PBB (6.7 t ha^{-1}) and ZT+R (6.5 t ha^{-1}). However at 60 DAS, biomass of PBB+R and PBB was non-significant. But at 90 DAS marked differences were observed with significantly higher biomass accumulation in PBB+R treatment (9.1 t ha^{-1}) followed by PBB treatment (8.8 t ha^{-1}) over other treatments. The lowest biomass accumulation was obtained in CT treatment (6.7 t ha^{-1}) (Fig. 23). At harvest similar pattern was observed with significantly higher biomass in case of PBB+R (14.64 t ha^{-1}) followed by PBB (14.39 t ha^{-1}) (Table 23).

4.2.3.2 Biomass of wheat in different conservation practices along with conventional practices in maize-wheat cropping system

Wheat biomass had low values at initial vegetative phase. At 30 DAS, accumulated biomass ranged between $2.2-3.6 \text{ t ha}^{-1}$. Maximum biomass was accumulated in PBB+R treatment followed by ZT+R, ZT and PBB. Biomass accumulation gradually increased with crop growth. At 60 DAS, accumulated biomass ranged between $4.1-5.9 \text{ t ha}^{-1}$. Maximum biomass at 60 DAS was produced in PBB+R treatment (5.9 t ha^{-1}) followed by ZT+R (5.6 t ha^{-1}), ZT (5.5 t ha^{-1}) and PBB (5.2 t ha^{-1}) treatment. However, accumulated biomass of PBB+R, ZT+R, ZT and PBB was non-significant at 60 DAS. At 90 DAS, the maximum biomass was accumulated in PBB+R plot (9.4 t ha^{-1}) followed by ZT+R (9.3 t ha^{-1}) and ZT (9.0 t ha^{-1}). The minimum biomass was in CT treatment (6.8 t ha^{-1}). Other conservation treatments had accumulated biomass ranged between $7.5- 8.6 \text{ t ha}^{-1}$. PBB+R and ZT+R treatment had non-significant difference at 90 DAS but they had significantly

higher biomass as compared to the corresponding value of other treatments (Fig. 24). Biomass in conservation treatments ranged between 10.3-13.3 t ha⁻¹ at harvest. Lowest accumulated biomass was found within CT treatment (10.2 t ha⁻¹). However biomass of PBB+R and ZT+R was non-significant (Table 16).

4.2.3.3 Biomass of pigeonpea in different conservation practices along with conventional practices in pigeonpea-wheat cropping system

Pigeonpea had accumulated biomass ranged between 0.8-1.2t ha⁻¹at 35 DAS. Maximum biomass accumulation at 70 DAS was found in PBB+R treatment (4.2 t ha⁻¹) followed by PNB+R (3.8 t ha⁻¹), ZT+R (3.7 t ha⁻¹), PBB (3.6t ha⁻¹), PNB (3.4 t ha⁻¹), ZT (3.3 t ha⁻¹) and CT (2.9 t ha⁻¹). Accumulated biomass of PBB+R had significantly higher value as compared to the corresponding value in other treatments. Maximum biomass at 105 DAS was accumulated in PBB+R treatment (5.8 t ha⁻¹) and lowest in CT treatment (4.1 t ha⁻¹). Conservation treatments had biomass accumulation ranged between 7.1-7.6 t ha⁻¹ at 140 DAS (Fig. 25). CT and ZT had non-significant difference in biomass accumulation, similarly other treatments (PBB+R, PNB+R, ZT+R, PBB, PNB, ZT) had significantly higher values over CT and ZT treatments. At harvest, biomass was maximum in PBB+R treatment (9.89 t ha⁻¹) followed by PNB+R (9.34 t ha⁻¹). These two treatments had biomass at par but they had higher biomass accumulation over rest of the treatments (Table 16).

4.2.3.4 Biomass of wheat in different conservation practices along with conventional practices in pigeonpea-wheat cropping system

At 30 DAS highest biomass accumulation was found under PBB+R treatment (3.16 t ha⁻¹) followed by ZT+R (2.89 t ha⁻¹), ZT (2.67 t ha⁻¹), PBB (2.60t ha⁻¹), PNB+R (2.49 t ha⁻¹), PNB (2.23 t ha⁻¹) and CT (1.96t ha⁻¹) treatment. Similar trend was observed at 60 DAS. Accumulated biomass at 60 DAS was increase up to 3.85-5.55 t ha⁻¹ in different treatments. PBB+R treatment had highest biomass accumulation and CT treatment had lowest value throughout the growing period. At 90 DAS, PBB+R treatment had biomass 8.56 t ha⁻¹ followed by ZT+R (8.42 t ha⁻¹), ZT (8.38 t ha⁻¹), PBB (7.50 t ha⁻¹), PNB+R (7.0 t ha⁻¹) and PNB (6.96 t ha⁻¹). Lowest value was found under CT (6.88 t ha⁻¹) (Fig. 26). At harvest maximum biomass was accumulated in PBB+R treatment (13.6 t ha⁻¹) followed by ZT+R (13.1 t ha⁻¹) and ZT (12.7 t ha⁻¹) treatment. These three treatments had higher biomass accumulation than

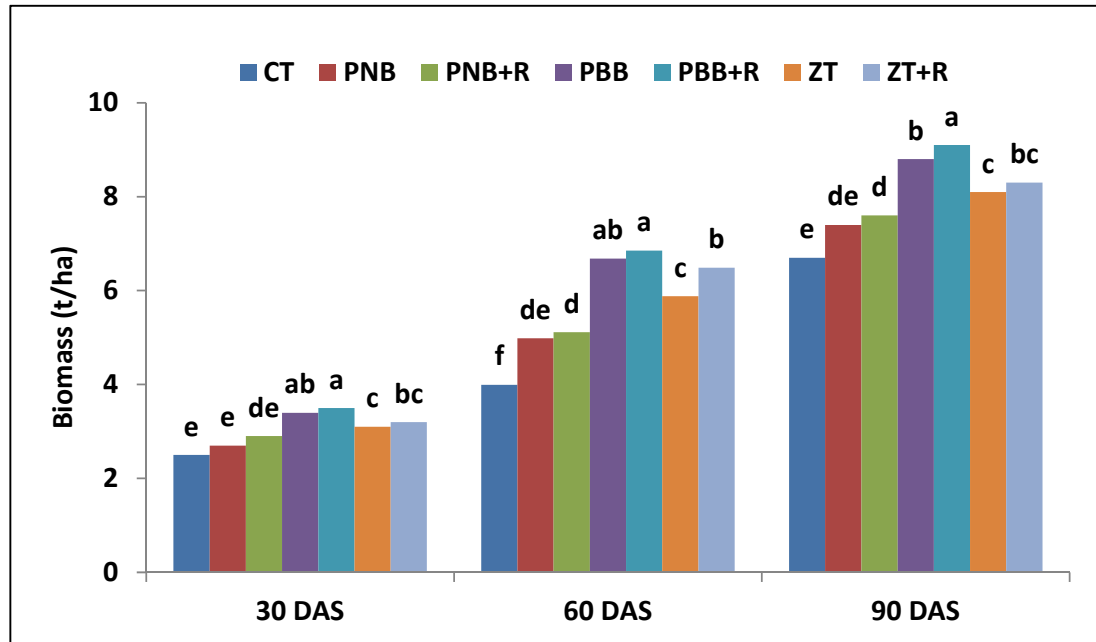


Fig.23. Biomass under different conservation practices along with conventional practice in maize during crop growing season in maize–wheat cropping system

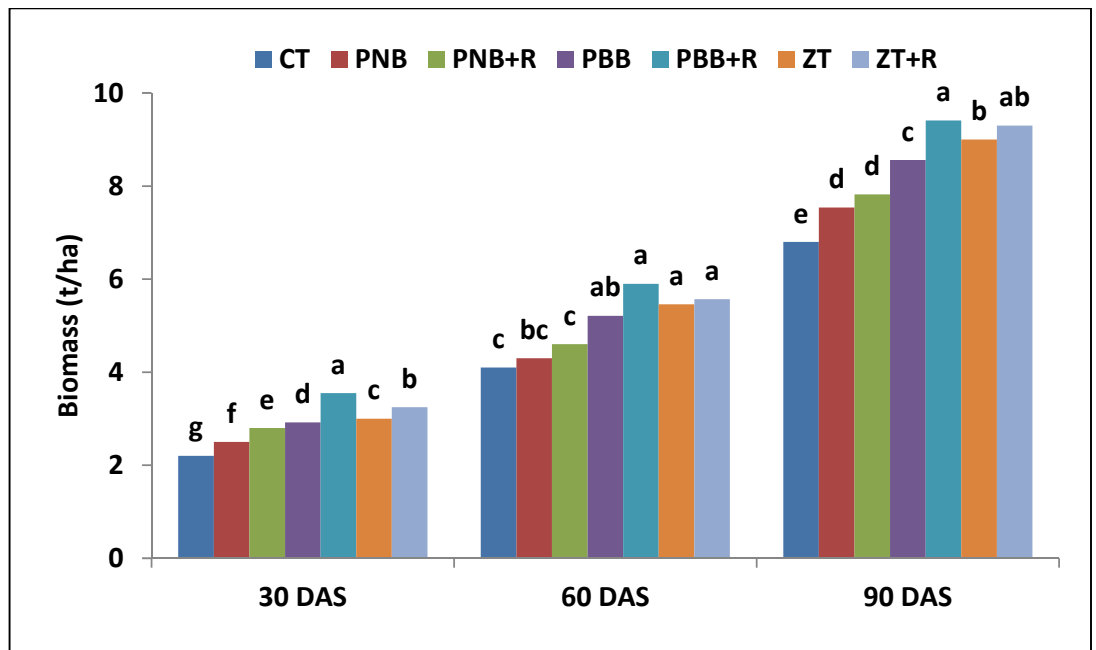


Fig.24. Biomass under different conservation practices along with conventional practice in wheat during crop growing season in maize–wheat cropping system

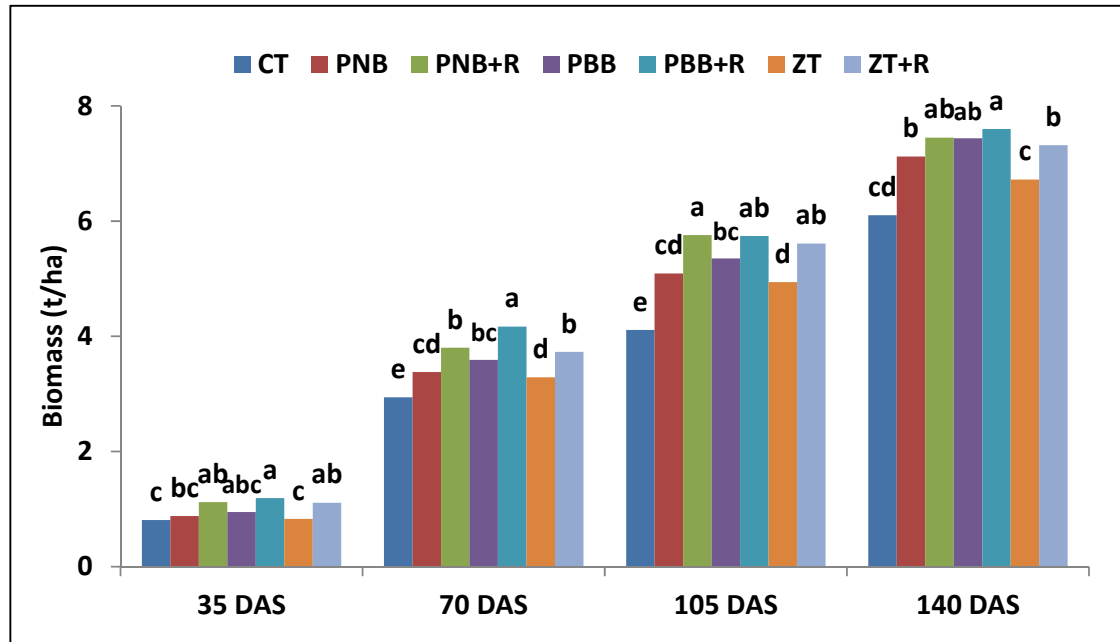


Fig.25. Biomass under different conservation practices along with conventional practice in pigeonpea during crop growing season in pigeonpea–wheat cropping system

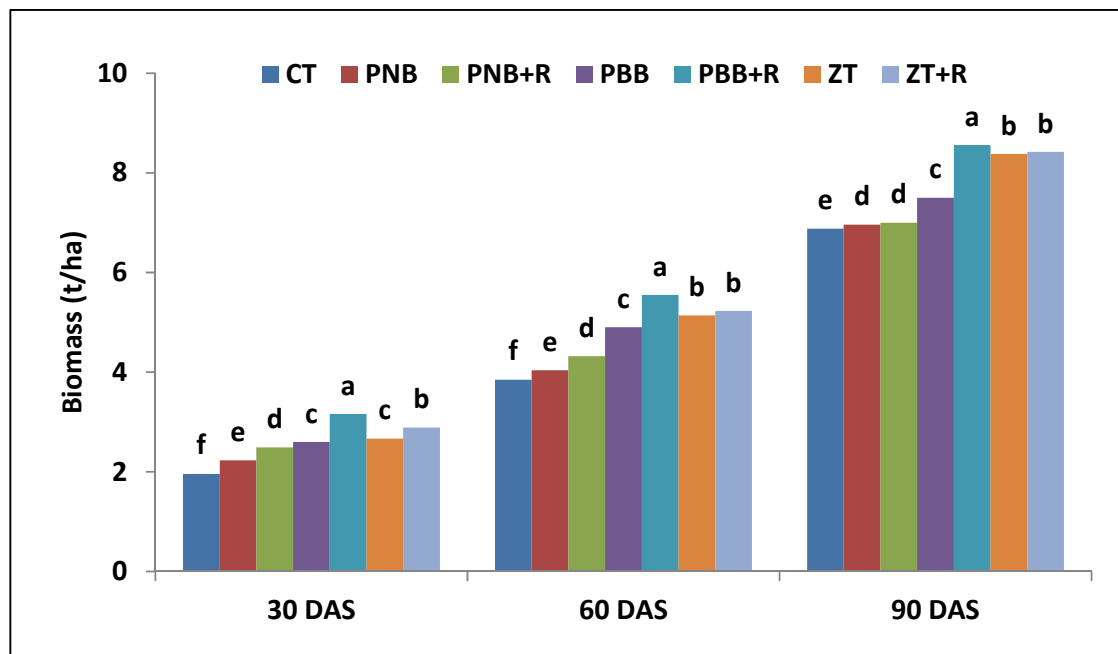


Fig.26. Biomass under different conservation practices along with conventional practice in wheat during crop growing season in pigeonpea–wheat cropping system

corresponding values in other treatments. PBB+R and ZT+R treatments had non-significant biomass accumulation. Lowest biomass accumulation was observed in CT treatment (10.03 t ha⁻¹). CT and PNB treatments had non-significant difference in biomass accumulation (Table 16).

Table 16: Final biomass (t ha⁻¹) at harvest under different conservation practices along with conventional practice in different cropping system

Treatment	Maize-wheat cropping system		Pigeonpea-wheat cropping system	
	Maize	Wheat	Pigeonpea	Wheat
CT	9.37 ^c	10.25 ^d	7.35 ^c	10.03 ^e
PNB	10.60 ^d	10.30 ^d	7.89 ^d	10.50 ^{de}
PNB+R	12.04 ^c	11.08 ^c	9.34 ^{ab}	11.12 ^d
PBB	14.38 ^{ab}	11.71 ^c	8.56 ^c	11.79 ^c
PBB+R	14.43 ^a	13.33 ^a	9.89 ^a	13.62 ^a
ZT	12.57 ^c	12.50 ^b	7.56 ^{de}	12.67 ^b
ZT+R	13.97 ^b	12.93 ^{ab}	8.86 ^c	13.13 ^{ab}
LSD(0.05)	0.76	1.05	0.65	1.55

4.2.4 Chlorophyll content measured under different conservation practices along with conventional practices in different cropping system

4.2.4.1 Chlorophyll content of maize in different conservation practices along with conventional practices in maize-wheat cropping system

Chlorophyll content increased up to flowering stage after that yellowing of leaves, reduction in photosynthesis pigments and senescence started. Maximum chlorophyll content was found at 30 DAS in PBB+R treatment (1.60 mg/g) followed by PBB (1.56 mg/g), ZT+R (1.53 mg/g), ZT (1.52 mg/g), PNB+R (1.50 mg/g) and PNB (1.47 mg/g). Lowest value of chlorophyll content was found in CT treatment (1.41 mg/g). Chlorophyll content gradually increased at 60 DAS up to 1.79 mg/g in PBB+R treatment, followed by PBB (1.75 mg/g), ZT+R (1.73 mg/g), ZT (1.71 mg/g), PNB+R (1.67 mg/g), PNB (1.63 mg/g) and CT (1.59 mg/g) treatment. Maximum chlorophyll content was observed at 90 DAS, in PBB+R (1.94 mg/g), PBB (1.90

mg/g), ZT+R (1.87mg/g), ZT (1.84mg/g), PNB+R (1.76 mg/g) and PNB (1.72 mg/g). Lowest value was found under CT treatment (1.65 mg/g). PBB+R and PBB treatment had non-significant difference (Fig. 27).

4.2.4.2 Chlorophyll content of wheat in different conservation practices along with conventional practices in maize-wheat cropping system

The chlorophyll content at 30 DAS was maximum under PBB+R treatment (1.29mg/g) followed by ZT+R (1.27 mg/g). These two treatments had non-significant difference in chlorophyll content. In other treatments chlorophyll content varied from 1.19 mg/g to 1.06 mg/g. Chlorophyll content at 60 DAS was found maximum under PBB+R (1.51 mg/g), followed by PBB (1.50 mg/g) and ZT (1.47 mg/g). CT treatment had lowest value (1.28 mg/g). Maximum chlorophyll content was at flowering stage (around 90 DAS) under PBB+R treatment (1.62 mg/g) followed by ZT+R (1.60 mg/g), ZT (1.58 mg/g), PBB (1.55 mg/g), PNB+R (1.51 mg/g), PNB (1.47 mg/g) and CT (1.45 mg/g) treatment. The PBB+R, ZT+R and ZT had non-significant difference in chlorophyll content at 60 and 90 DAS (Fig. 28). Similarly CT treatment had non-significant value for chlorophyll content with PNB treatment.

4.2.4.3 Chlorophyll content of pigeonpea in different conservation practices along with conventional practices in pigeonpea-wheat cropping system

Highest chlorophyll content was observed in residue treatments. At 35 DAS, chlorophyll content was highest under PBB+R treatment (1.83 mg/g), followed by PNB+R (1.79 mg/g) and ZT+R (1.71 mg/g). In other conservation treatments it varied from 1.58 mg/g to 1.63 mg/g of leaf fresh weight. Least value of chlorophyll content was found under CT treatment (1.54 mg/g). At 70 DAS, PBB+R treatment had 2.17 mg/g chlorophyll content followed by PNB+R (2.12 mg/g) and in other treatments varied from 2.09 mg/g to 1.82 mg/g. At 105 DAS, it was increased up to 2.23 mg/g in PBB+R treatment followed by PNB+R (2.20 mg/g), ZT+R (2.13 mg/g), PBB (2.05 mg/g), PNB (1.94 mg/g) and ZT (1.90 mg/g) treatment. The lower value of chlorophyll content was found under CT treatment (1.87 mg/g). There was non-significant difference among residue treatments (PBB+R, PNB+R, ZT+R) but these treatments had higher values than corresponding value in other treatments. The CT treatment had lowest chlorophyll content but it was non-significant from PNB treatment (Fig. 29).

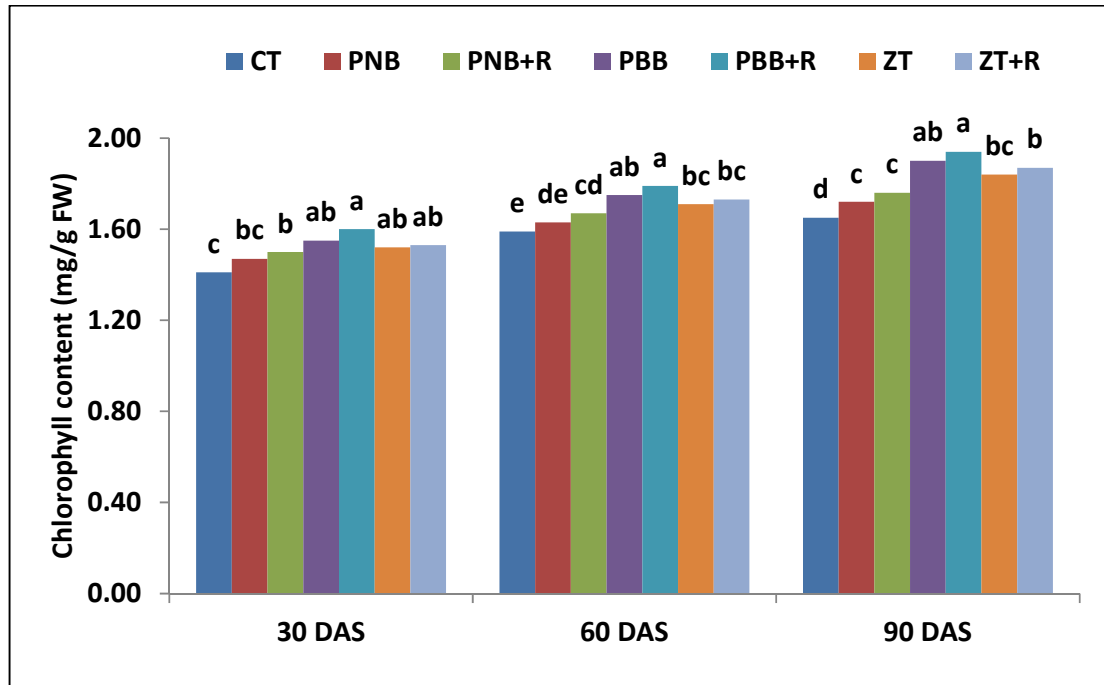


Fig.27. Chlorophyll content under different conservation practices along with conventional practice in maize during crop growing season in maize – wheat cropping system

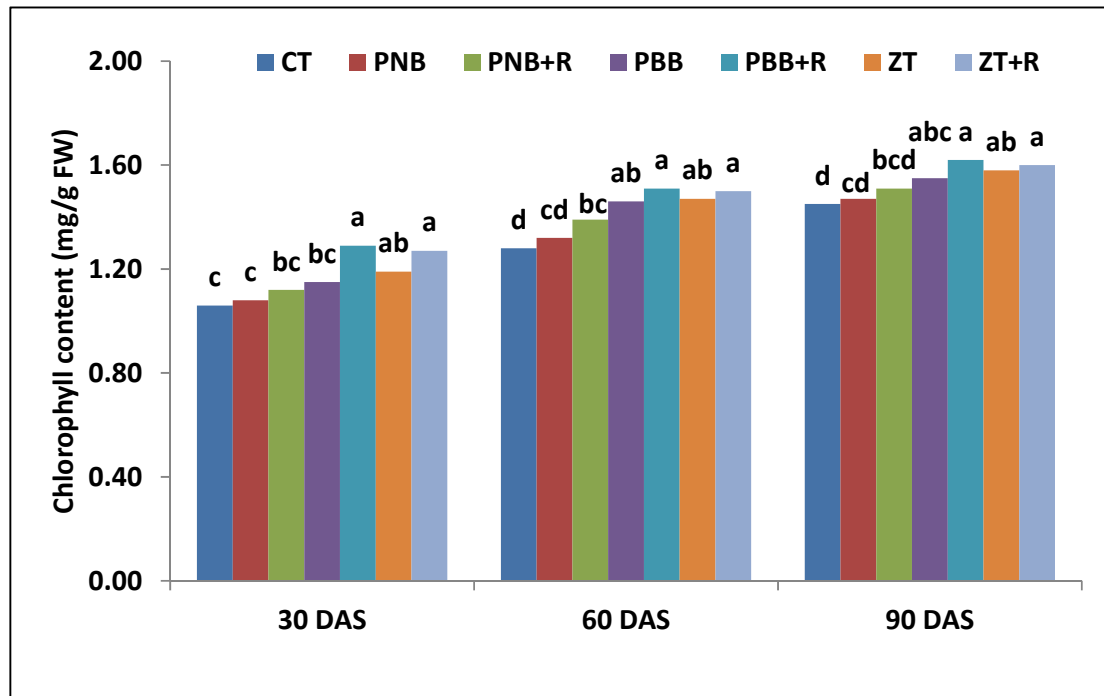


Fig.28. Chlorophyll content under different conservation practices along with conventional practice in wheat during crop growing season in maize – wheat cropping system

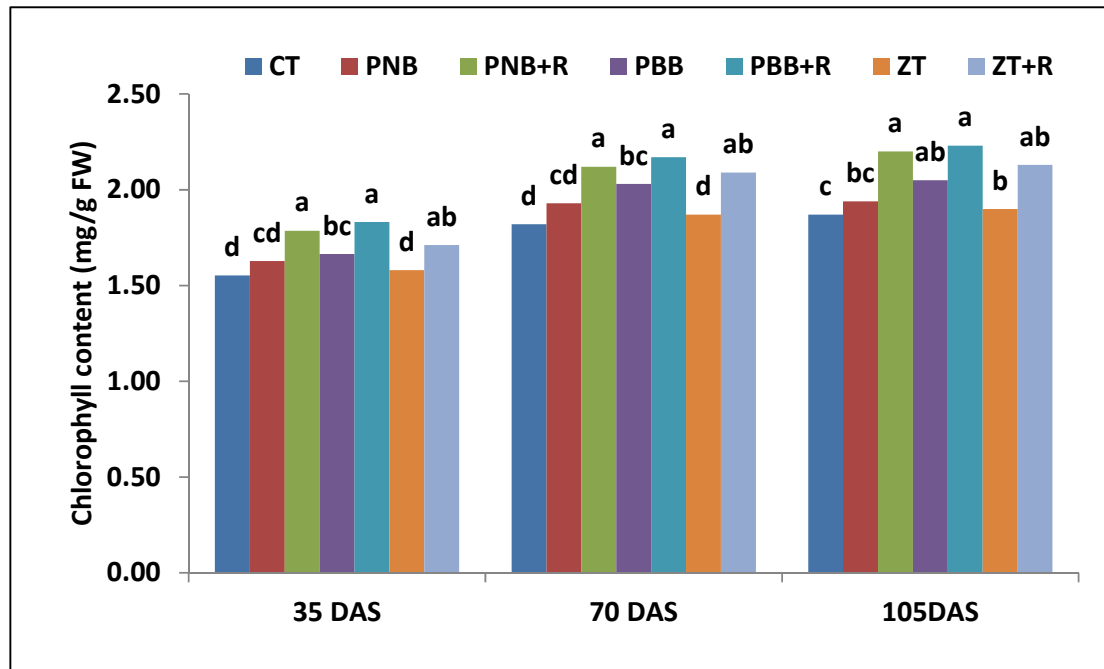


Fig.29. Chlorophyll content under different conservation practices along with conventional practice in pigeonpea during crop growing season in pigeonpea–wheat cropping system

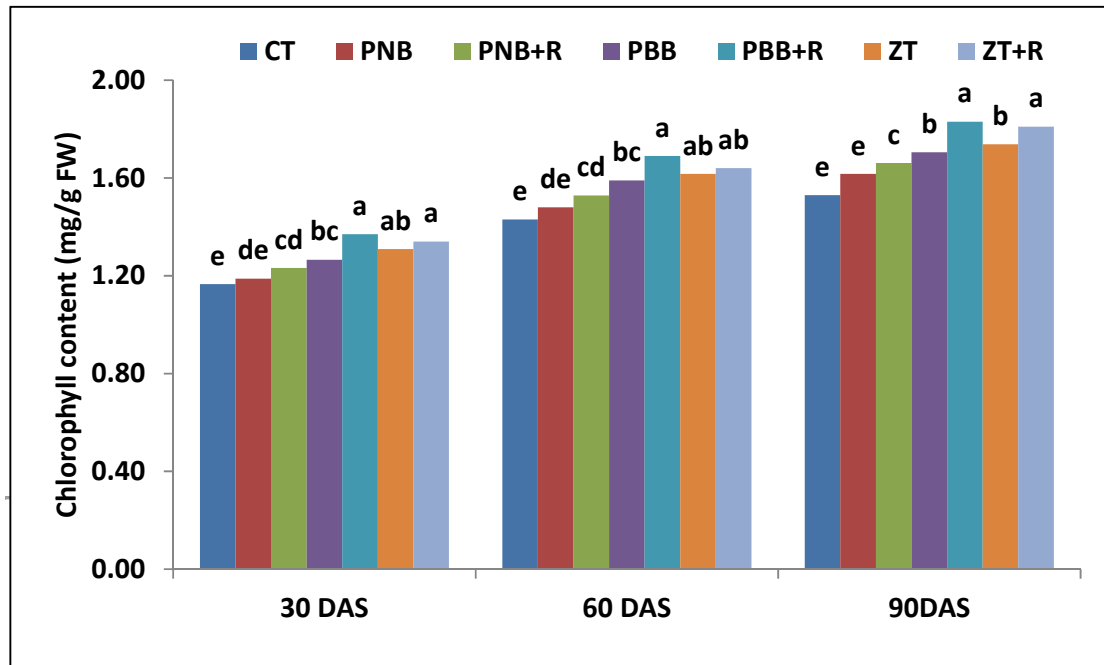


Fig.30. Chlorophyll content under different conservation practices along with conventional practice in wheat during crop growing season in pigeonpea–wheat cropping system

4.2.4.4 Chlorophyll content of wheat in different conservation practices along with conventional practices in pigeonpea-wheat cropping system

Maximum chlorophyll content was found in PBB+R treatment (1.37 mg/g) followed by ZT+R treatment (1.34 mg/g) at 30 DAS. Other treatments had chlorophyll content between 1.17-1.31 mg/g. Chlorophyll content gradually increased at 60 DAS up to 1.69 mg/g in PBB+R treatment followed by ZT+R (1.67 mg/g), ZT (1.62 mg/g), PBB (1.59 mg/g), PNB+R (1.53 mg/g) and PNB (1.48 mg/g) treatment. Lowest value was found in CT treatment (1.43 mg/g). Maximum chlorophyll content was found at 90 DAS under PBB+R treatment (1.83 mg/g) followed by ZT+R (1.80 mg/g), ZT (1.74 mg/g), PBB (1.71 mg/g), PNB+R (1.66 mg/g), PBB (1.62 mg/g) and CT (1.53 mg/g) treatment. PBB+R and ZT+R treatment had non-significant difference in chlorophyll content but these two treatments had higher value of chlorophyll content as compared to corresponding value in other treatments throughout the crop growing period (Fig. 30).

4.2.5 Leaf water potential measured under different conservation practices along with convention practice in different cropping system

4.2.5.1 Leaf water potential in maize under different conservation practices along with convention practice in maize-wheat cropping system

Leaf water potential values gradually decreased from initial vegetative phase to physiological maturity. Leaf water potential ranged between -1.11MPa to -1.44MPa at 30 DAS. Maximum leaf water potential was found under PBB+R treatment (-1.11MPa) followed by PBB treatment (-1.16 MPa), ZT+R (-1.21MPa), ZT (-1.30 MPa), PNB+R (-1.36 MPa), PNB (-1.41 MPa) and CT (-1.44 MPa) treatment. At 60 DAS leaf water potential was -1.37 MPa in PBB+R treatment followed by PBB (-1.41 MPa) treatment. Rest of the treatments had leaf water potential ranged between -1.45 MPa to -1.69MPa. Leaf water potential at 90 DAS was found between -1.52MPa to -1.83 MPa. Maximum values was found under PBB+R treatment (-1.52 MPa) followed by PBB (-1.54 MPa), ZT+R (-1.61 MPa), ZT (-1.72 MPa), PNB+R (-1.77MPa), PNB (-1.81 MPa) and CT (-1.83 MPa) treatment. Water potential gradually decreased from 30 to 90 DAS. PBB+R and PBB treatments had non-significant difference in water potential values but had significantly higher values as compared to corresponding value in other treatments (Fig. 31).

4.2.5.2 Leaf water potential in wheat under different conservation practices along with convention practice in maize-wheat cropping system

Leaf water potential at 30 DAS in wheat crop sown after maize had highest value under PBB+R treatment (-1.57MPa) and lowest values under CT (-1.79MPa). Other conservation treatments had leaf water potential values between -1.58MPa to -1.78MPa. PBB+R and ZT+R treatments had non-significant difference in leaf water potential. Leaf water potential at 60 DAS varied between -1.69 MPa to -1.84 MPa. At 90 DAS leaf water potential had maximum values in PBB+R treatment (-1.76 MPa) followed by ZT+R (-1.78 MPa), ZT (-1.81 MPa), PBB (-1.83 MPa), PNB+R (-1.85 MPa) and PNB (-1.93MPa) treatment. Lowest value was found in CT treatment (-1.94 MPa). PBB+R treatment had highest leaf water potential values followed by ZT+R treatment during crop growing period. These two treatments had non-significant difference but had higher values than corresponding values in other treatments. CT and PNB treatment had non-significant difference (Fig. 32).

4.2.5.3 Leaf water potential in pigeonpea under different conservation practices along with convention practice in pigeon pea-wheat cropping system

In pigeonpea leaf water potential measured at 45, 90 and 135 DAS. Maximum leaf water potential was found at 45 DAS which was gradually decreased up to physiological maturity. Residue treatments had highest values of leaf water potential than corresponding value in other treatments. At 45 DAS, PBB+R treatment had highest value (-0.70 MPa) followed by PNB+R (-0.72 MPa) and ZT+R (-0.75 MPa) treatment. In other treatments leaf water potential values varied from -0.82 MPa to -0.86 MPa. Value of leaf water potential in PBB+R was -0.82 MPa followed by PNB (-0.83MPa), ZT (-0.85 MPa) and CT (-0.86MPa) treatment. At 90 DAS leaf water potential gradually decreased as compared to leaf water potential at 45 DAS. Maximum values of leaf water potential was found under PBB+R (-0.91MPa) followed by PNB+R (-0.93 MPa) and ZT+R (-0.98 MPa) treatment. Lowest value of leaf water potential was found under CT treatment (-1.12 MPa). Leaf water potential was found lowest at 135 DAS and decreased from -0.70MPa (at 45 DAS) to -1.12MPa (at 135 DAS) in PBB+R treatment. Other treatments had water potential within -1.15 MPa to -1.36 MPa. Residue treatments (PBB+R, PNB+R and ZT+R) had higher leaf water potential values than corresponding value in other treatments (Fig. 33).

4.2.5.4 Leaf water potential in wheat under different conservation practices along with convention practice in pigeon pea-wheat cropping system

Leaf water potential at 30 DAS was highest under PBB+R treatment (-1.61MPa) followed by ZT+R (-1.62 MPa), ZT (-1.66 MPa), PBB (-1.69 MPa), PNB+R (-1.70MPa) and PNB (-1.71 MPa) treatment. CT treatment had lowest value (-1.74MPa) of leaf water potential. As plant growth increased the leaf water potential decreased and had higher negative values. At 60DAS, leaf water potential ranged between -1.72 MPa to -1.88MPa. Leaf water potential at 90 DAS decreased upto -1.92 MPa in PBB+R treatment followed by ZT+R (-1.95 MPa), ZT (-1.92 MPa), PBB (-2 MPa), PNB+R (-2.06MPa), PNB (-2.09MPa) and CT (-2.11MPa) treatment. Among all the treatments PBB+R treatment had highest value of leaf water potential followed by ZT+R treatment. PBB+R and ZT+R treatments had non-significant difference but had higher value of leaf water potential than corresponding value in other treatments (Fig. 34).

4.2.6 Relative water content measured under different conservation practices along with convention practice in different cropping system

4.2.6.1 Relative water content in maize under different conservation practices along with convention practice in maize-wheat cropping system

Relative water content (RWC) of leaves varied among different treatments as well as at different stages of crop growth. Higher value of RWC was observed under residue treatments and lowest value of RWC was observed under CT treatment. In initial stages of crop growth leaves had higher water content which gradually decrease with plant growth. Maximum RWC at 30 DAS was observed under PBB+R treatment (92.4%) followed by PBB (90%), ZT+R (89.4%), ZT (87.9%), PNB+R (85.5%) and PNB (82.4%) treatment. Lowest value was observed in CT treatment (81.8%). PBB+R and PBB treatments had non-significant difference but had higher RWC than corresponding value in other treatments. RWC values at 60 DAS, decreased up to 87.8% under PBB+R treatment. In other conservation treatments it varied within 85.5 to 78.3% and lowest value was found under CT treatment (77.7%). At 90 DAS, RWC decreased up to 83% in PBB+R treatment followed by PBB (80.9%), ZT (80.5%), ZT (78.9%), PNB+R (76.8%) and PNB (75%) treatment. Lowest value was observed under CT treatment (73.6%). The PBB+R, ZT+R and PBB treatments had non-

significant difference at 90 DAS. Similarly CT and PNB treatment had non-significant difference throughout the crop growing period (Fig. 35).

4.2.6.2 Relative water content in wheat under different conservation practices along with convention practice in maize-wheat cropping system

Different conservation practices significantly affect the soil hydrological properties which affect relative water content (RWC) in crops. Maximum RWC at 30 DAS was found under PBB+R treatment (93.5%) followed by ZT+R (92.7%), ZT (92%), PBB (89.3%), PNB+R (87.4%) and PNB (85.2%) treatment. CT treatment had lowest value of RWC (83.3%). At 60 DAS, RWC values decreased up to 92.5% in PBB+R treatment followed by ZT+R (91.8%). In other conservation treatments, RWC value was between 90.2 to 84% and CT treatment had lowest RWC value (80.4%). At 90 DAS, RWC values further decreased from 88.5 to 79.1%. Maximum RWC was observed under PBB+R (88.5%) followed by ZT+R (86.8%), ZT (85.6%), PBB (84.7%), PNB+R (83.6%), PNB (80.1%) and CT (79.1%) treatment. PBB+R and ZT+R treatments had non-significant difference but these treatments had higher value than corresponding value in other treatments (Fig. 36).

4.2.6.3 Relative water content in pigeonpea under different conservation practices along with convention practice in pigeonpea-wheat cropping system

RWC was measured at 35, 70, 105 and 140 DAS in pigeonpea. RWC gradually decreased from vegetative stage to physiological maturity. Maximum RWC was found at 35 DAS and lowest value was found at 140 DAS. RWC value at 35 DAS varied between 87.5 to 76.4%. Highest value was found under PBB+R treatment (87.5%) followed by PNB+R (85.5%) and ZT+R (83.1%) treatment. At 70 DAS, RWC decreased from 85.2 to 74.5% under different treatments. At 105 DAS, RWC values ranged between 80.4 to 70.3%. At 140 DAS, highest value was found under PBB+R treatment (77.8%) followed by PNB+R (76.1%), ZT+R (73.98%), PBB (73.4%), PNB (72.9%) and ZT (70.3%) treatment. Lowest value of RWC was found under CT treatment (70%) (Fig. 37). PBB+R and PNB+R treatment had non-significant difference but had significantly higher RWC than corresponding value in other treatments at 140 DAS.

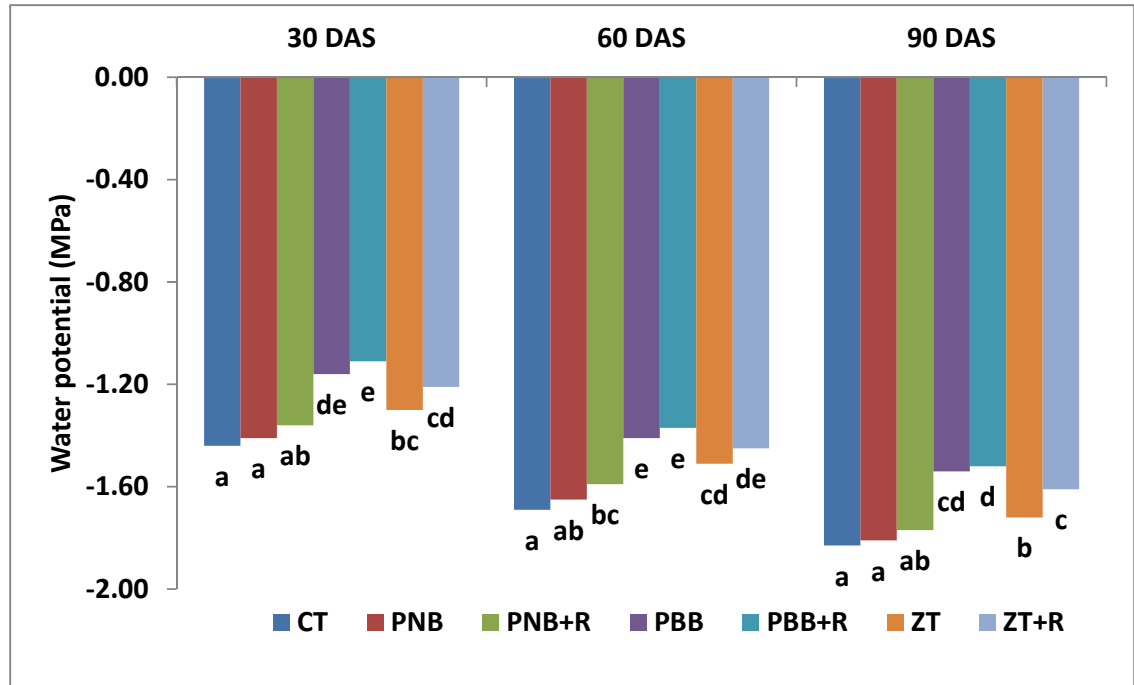


Fig.31. Water potential under different conservation practices along with conventional practice in maize during crop growing season in maize – wheat cropping system

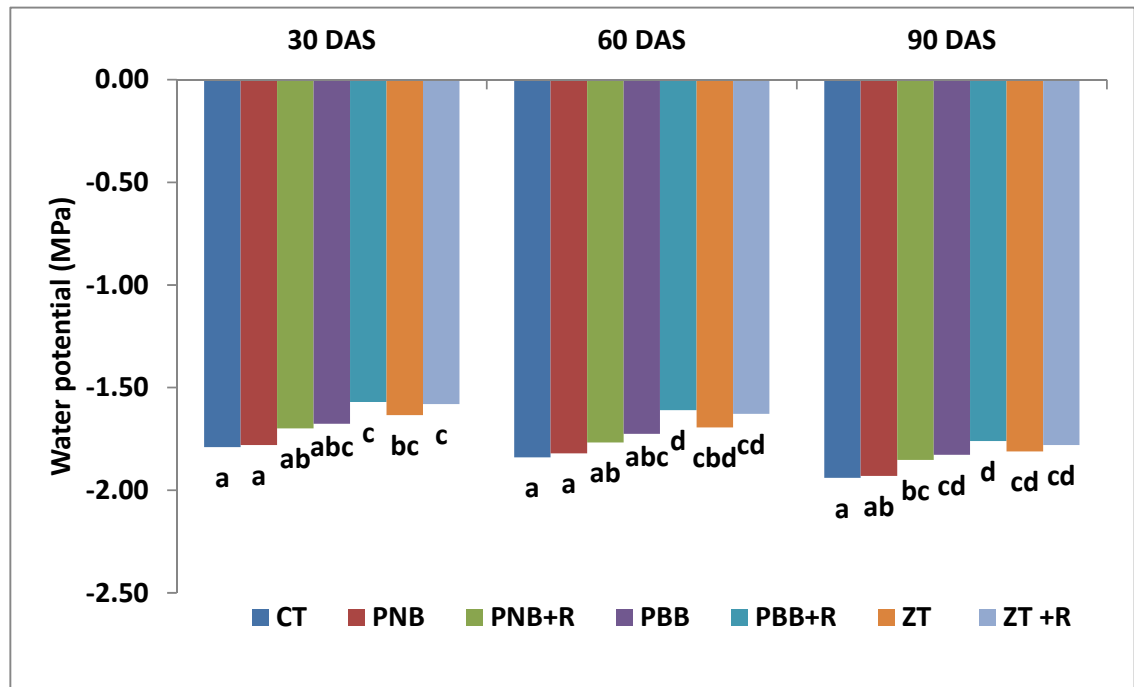


Fig.32. Water potential under different conservation practices along with conventional practice in wheat during crop growing season in maize – wheat cropping system

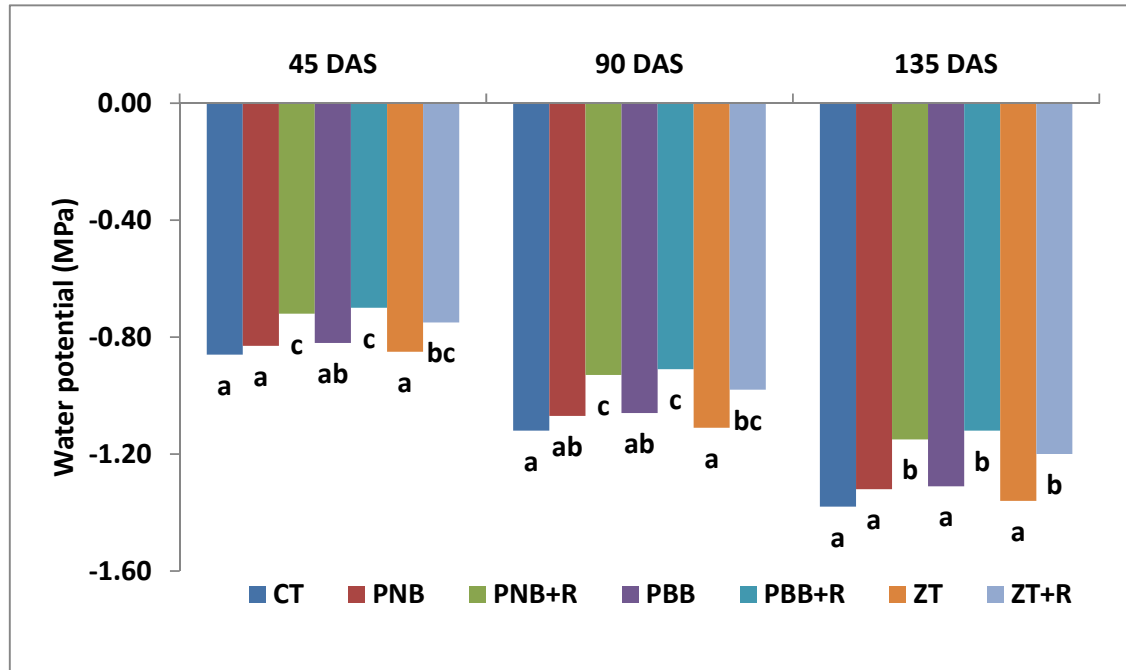


Fig.33. Water potential under different conservation practices along with conventional practice in pigeonpea during crop growing season in pigeonpea –wheat cropping system

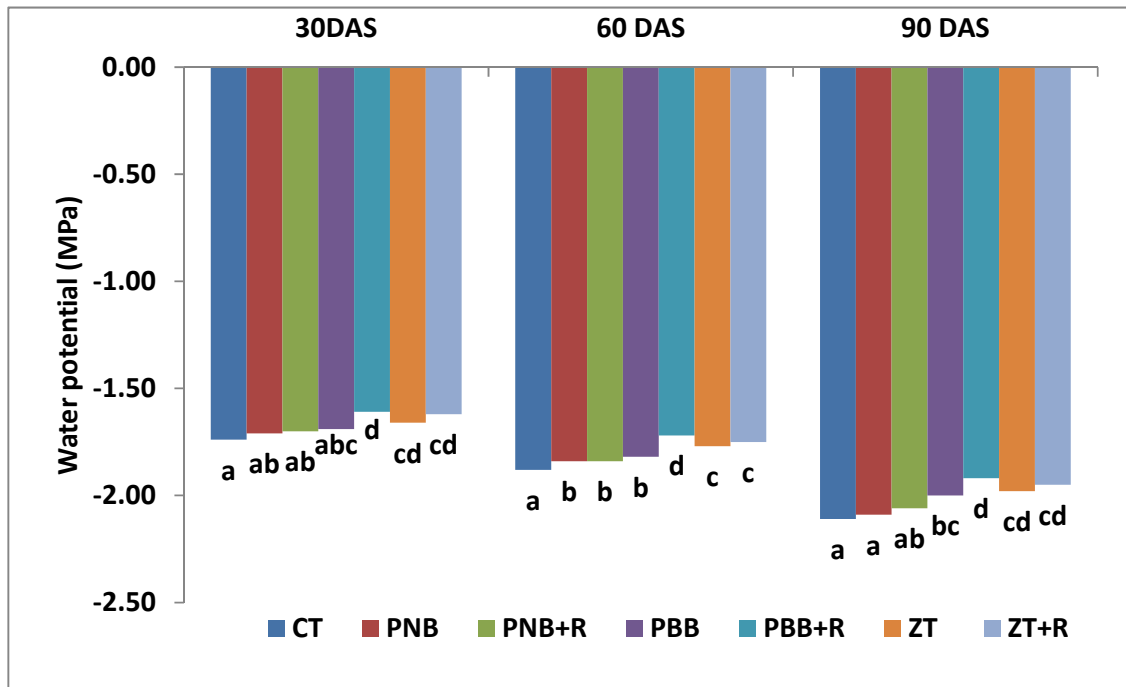


Fig.34. Water potential under different conservation practices along with conventional practice in wheat during crop growing season in pigeonpea –wheat cropping system

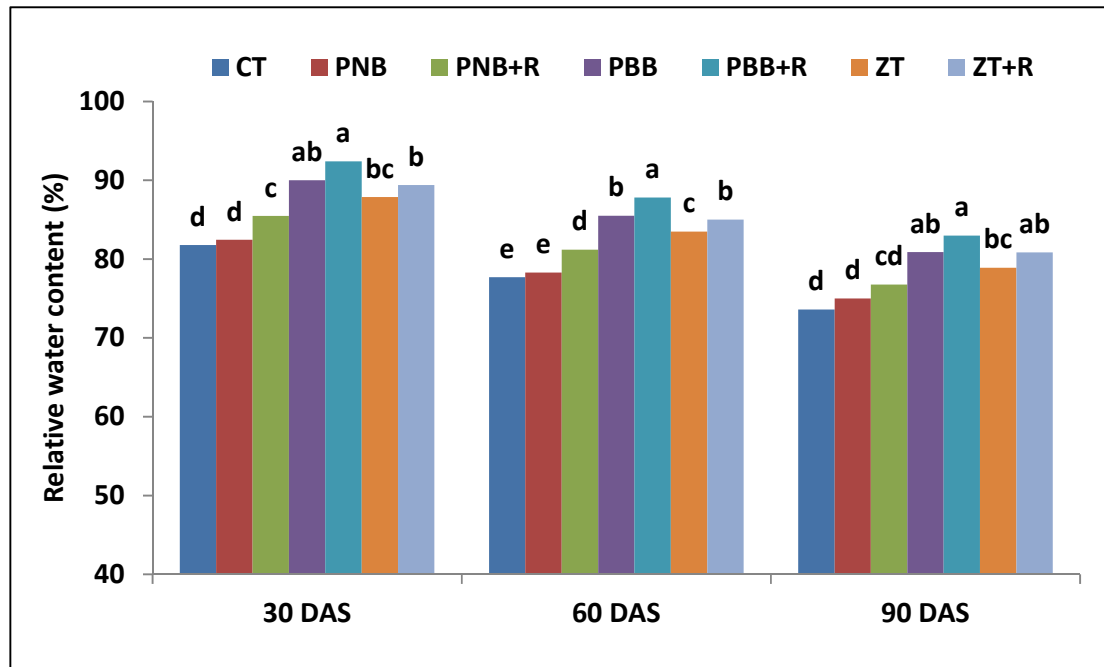


Fig.35. Relative water content under different conservation practices along with conventional practice in maize during crop growing season in maize-wheat cropping system

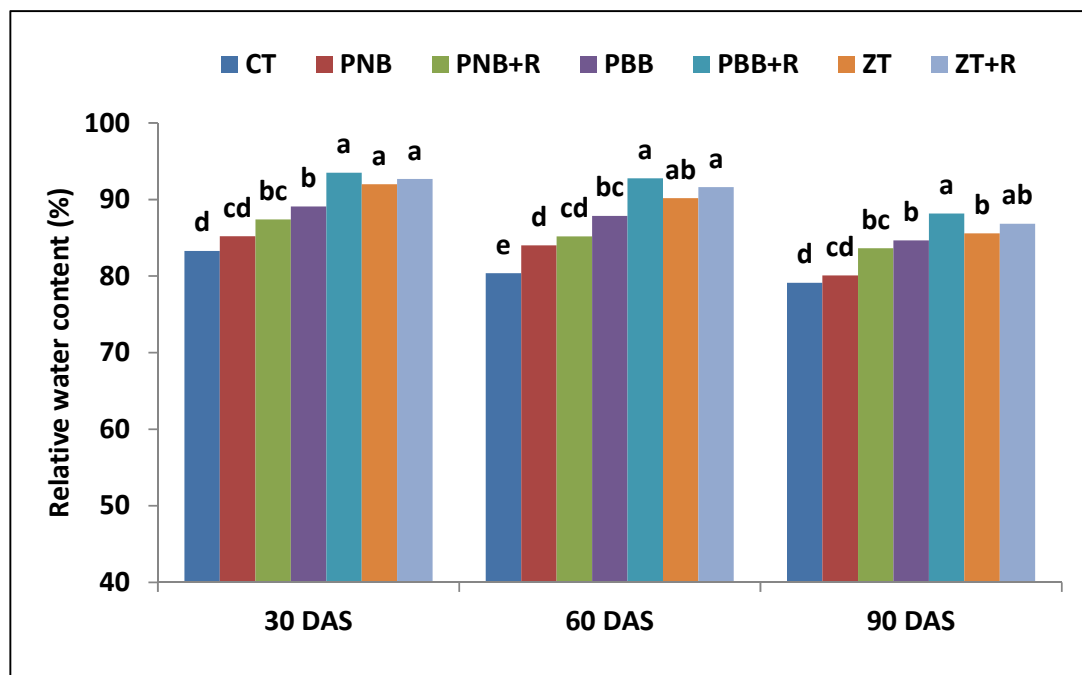


Fig.36. Relative water content under different conservation practices along with conventional practice in wheat during crop growing season in maize-wheat cropping system

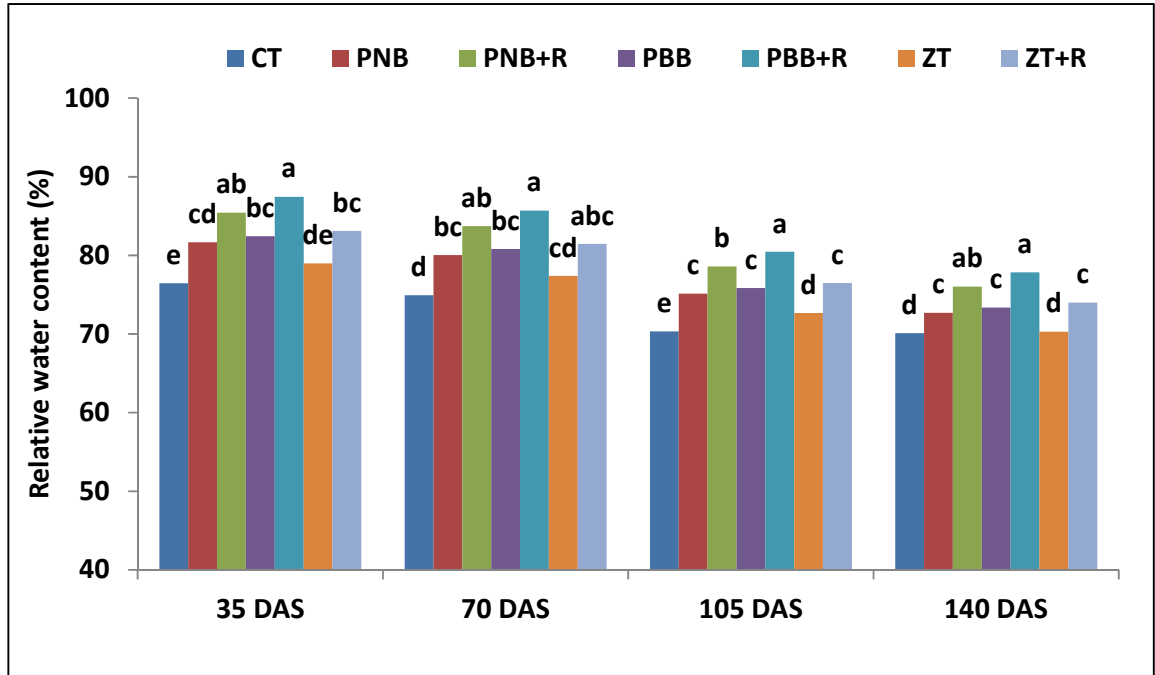


Fig.37. Relative water content under different conservation practices along with conventional practice in pigeonpea during crop growing season in pigeonpea –wheat cropping system.

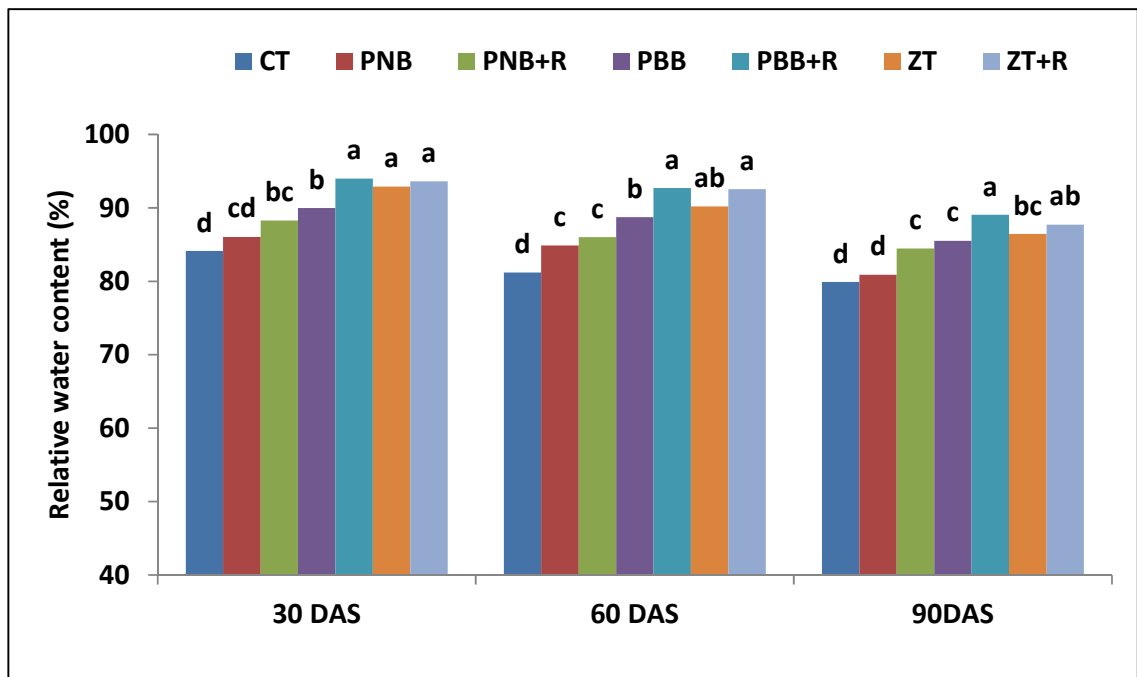


Fig.38. Relative water content under different conservation practices along with conventional practice in wheat during crop growing season in pigeonpea – wheat cropping system

4.2.6.4 Relative water content in wheat under different conservation practices along with convention practice in pigeon pea-wheat cropping system

RWC values at 30 DAS ranged within 94 to 84.4%. At 30 DAS, highest value was found in PBB+R treatment (94%) followed by ZT+R (93.6%), ZT (92.9%), PBB (90%), PNB+R (88.3%) and PNB (86.2%) treatment. Lowest value was found under CT (84.1%) treatment. PBB+R, ZT+R and ZT treatments had non-significant difference but had significantly higher values as compared to corresponding value in other treatments. At 60 DAS, RWC decreased from 92.7 to 81.2%. Highest value was found under PBB+R treatment (92.7%) followed by ZT+R (92.5%) and ZT (90.2%) treatment. Lowest value was found under CT treatment (81.2%). PBB+R and ZT+R treatments had non- significant difference. At 90 DAS, RWC decreased up to 89% in PBB+R treatment followed by ZT+R (87.7%), ZT(86.5%), PBB(85.5%), PNB+R (84.5%) and PNB(80.9%) treatment. RWC values had non-significant difference within PBB+R and ZT+R treatments but these treatments had higher RWC as compared to corresponding value in other treatments (Fig. 38).

4.2.7 Radiation use efficiency (RUE) in different conservation practices along with conventional practice under different cropping system

4.2.7.1 Radiation use efficiency (RUE) in maize under different conservation practices along with conventional practice in maize-wheat cropping system

RUE had lower values at 30 DAS which gradually increased up to flowering stage. Maximum RUE was found in PBB+R treatment (1.30 g/MJ) followed by PBB (1.24 g/MJ) and ZT+R (1.18 g/MJ). Lowest value of RUE was found in CT treatment (1.05 g/MJ) at 30 DAS. At 60 DAS, RUE gradually increased under PBB+R treatment (2.98 g/MJ). Other treatments had RUE between 2.42- 2.97 g/MJ. In case of maize crop, maximum RUE was found at 90 DAS. Maximum RUE was found in PBB+R treatment (3.35 g/MJ) followed by PBB (3.26 g/MJ), ZT+R (3.21 g/MJ), ZT (3.17 g/MJ), PNB+R (2.97 g/MJ) and PNB (2.89 g/MJ) treatment. Lowest RUE value was found in CT treatment (2.78 g/MJ). PBB+R, PBB and ZT+R treatments had significantly higher RUE than other treatments (Fig. 39). Radiation use efficiency at total dry matter (RUE_{TDM}) was 2.95 g/MJ under PBB+R treatment that was highest

over rest of the treatments. Other treatments had RUE_{TDM} values ranged between 2.35- 2.85 g/MJ (Table 17).

4.2.7.2 Radiation use efficiency in wheat under different conservation practices along with conventional practices in maize-wheat cropping system

RUE had lowest values (<1.0 g/MJ) in most of the treatments at 30 DAS. PBB+R (1.10 g/MJ) and ZT+R (1.07 g/MJ) treatments had RUE value higher than 1.0 g/MJ. At 60 DAS, values of RUE under different conservation treatments ranged between 1.87 to 2.32 g/MJ. CT treatment had minimum value of RUE (1.71 g/MJ). At 90 DAS, maximum RUE was observed in PBB+R treatment (2.59 g/MJ) followed by ZT+R (2.54 g/MJ), ZT(2.44g/MJ), PBB(2.35g/MJ), PNB+R (2.25 g/MJ) and PNB (2.10 g/MJ) treatment. Lowest value was found under CT treatment (1.92 g/MJ) (Fig. 40). Radiation use efficiency calculated at total dry matter (RUE_{TDM}) was ranged between 1.67 to 2.07 g/MJ in different conservation treatments. Highest value was found in PBB+R treatment (2.07 g/MJ) followed by ZT+R (2.04 g/MJ) treatment. These two treatments had non-significant difference but they had higher RUE than other treatments. Minimum value of RUE at total dry matter (RUE_{TDM}) was found in CT treatment (1.60 g/MJ) which had non-significant value with PNB treatment (1.67 g/MJ) (Table 17).

4.2.7.3 Radiation use efficiency in pigeonpea under different conservation practices along with conventional practice in pigeon pea-wheat cropping system

Pigeonpea crop had lower RUE values as compared to wheat and maize. At 35 DAS pigeonpea had RUE less than 1.0 g/MJ. At 70 DAS, RUE gradually increased and ranged between 1.14-1.39 g/MJ under different treatments. Residue treatments had higher RUE than other treatments. Maximum RUE at 105 DAS was found under PBB+R treatment (1.62 g/MJ) followed by PNB+R (1.60 g/MJ) and ZT+R (1.54 g/MJ) treatment. Other conservation treatments had RUE between 1.36-1.50 g/MJ. Minimum RUE was found in CT treatment (1.28g/MJ) (Fig. 41). Radiation use efficiency value at total dry matter (RUE_{TDM}) was ranged between 1.01g/MJ to 1.22 g/MJ. CT (1.01 g/MJ) and PNB (1.07 g/MJ) treatment had non-significant difference for RUE_{TDM} . Maximum value of RUE_{TDM} was found under PBB+R treatment (1.22 g/MJ) followed by ZT+R (1.20 g/MJ) and PNB+R (1.18 g/MJ) treatment. These three

treatments performed similar RUE but had significantly higher values as compared to corresponding value in other treatments (Table 17).

4.2.7.4 Radiation use efficiency in wheat under different conservation practices along with conventional practice in pigeon pea-wheat cropping system

RUE calculated at 30 DAS in wheat crop sown after pigeonpea was ranged between 0.86g/MJ to 1.11g/MJ. Maximum value of RUE was found in PBB+R treatment followed by ZT+R treatment. At 30 DAS there was non-significant difference in RUE under most of treatments. At 60 DAS, lower RUE value was 1.72 g/MJ in CT treatment while higher RUE was found under PBB+R treatment (2.18 g/MJ). In other treatments value of RUE ranged between 1.76-2.14 g/MJ. At 90 DAS, maximum RUE occurred in PBB+R treatment (2.71 g/MJ) followed by ZT+R (2.69 g/MJ) treatment. PBB+R and ZT+R treatments had non-significant difference at 90 DAS (Fig. 42). These treatments had higher values of RUE as compared to corresponding value in other treatments. Radiation use efficiency at total dry matter (RUE_{TDM}) was maximum under PBB+R treatment (2.13 g/MJ) followed by ZT+R (2.10 g/MJ), ZT (1.97 g/MJ), PBB(1.92 g/MJ) PNB+R (1.81 g/MJ) and PNB (1.72 g/MJ). Lowest value was found in CT treatment (1.66 g/MJ) which perform similar to PNB treatment. PBB+R and ZT+R treatments had non-significant difference in RUE_{TDM} but they had significantly higher values as compared to corresponding value in other treatments (Table. 17).

4.2.8 Radiation use efficiency for grain yield (RUE_{GY}) under different conservation practices along with conventional practice in different cropping system

4.2.8.1 Radiation use efficiency for grain yield (RUE_{GY}) in maize crop under different conservation practices along with conventional practice in maize-wheat cropping system

The effect of different tillage and residue treatments on RUE_{GY} are shown in table 18. In maize crop, RUE_{GY} value ranged between 1.02- 1.17 g/MJ. Value of RUE_{GY} under PBB+R (1.17 g/MJ) followed by PBB (1.16 g/MJ), ZT+R (1.16 g/MJ), ZT (1.14 g/MJ), PNB+R (1.13 g/MJ), PNB (1.10 g/MJ) and CT (1.02 g/MJ) treatment. PBB+R, PBB, ZT+R and ZT treatments had significantly higher RUE_{GY} than CT treatment.

Table 17: Radiation use efficiency for total dry matter (g/MJ) under different Conservation practices along with conventional practice in maize-wheat and pigeonpea-wheat cropping system

Treatment	Maize-wheat cropping system		Pigeonpea-wheat cropping system	
	Maize	Wheat	Pigeonpea	Wheat
CT	2.35 ^e	1.60 ^d	1.01 ^c	1.66 ^e
PNB	2.46 ^d	1.67 ^d	1.07 ^{bc}	1.72 ^e
PNB+R	2.64 ^c	1.76 ^{cd}	1.18 ^{ab}	1.81 ^{de}
PBB	2.85 ^b	1.86 ^c	1.10 ^{abc}	1.92 ^{cd}
PBB+R	2.95 ^a	2.07 ^a	1.22 ^a	2.13 ^a
ZT	2.72 ^c	1.91 ^{bc}	1.04 ^c	1.97 ^{bc}
ZT+R	2.82 ^b	2.04 ^{ab}	1.20 ^{ab}	2.10 ^{ab}
LSD(0.05)	0.15	0.13	0.11	0.18

4.2.8.2 Radiation use efficiency for grain yield (RUE_{GY}) in wheat crop under different conservation practices along with conventional practices in maize-wheat cropping system

RUE_{GY} was maximum under PBB+R treatment (0.85g/MJ) followed by ZT+R (0.82 g/MJ), ZT (0.80 g/MJ),PBB (0.80 g/MJ), PNB+R (0.77 g/MJ) and PNB(0.73 g/MJ) treatment. Lowest value was found under CT treatment (0.72g/MJ). PBB+R, ZT+R, PBB and ZT treatments had non-significant difference. Similarly CT treatment was non-significant with PNB and PNB+R treatments (Table. 18).

4.2.8.3 Radiation use efficiency for grain yield (RUE_{GY}) in pigeonpea crop under different conservation practices along with conventional practices in maize-wheat cropping system

Pigeonpea had lowest RUE at grain yield as compared to corresponding values in wheat and maize crop. Maximum RUE_{GY} was under PBB+R treatment (0.32 g/MJ) followed by PNB+R (0.30 g/MJ), ZT+R (0.28 g/MJ), PBB (0.27 g/MJ), PNB (0.24 g/MJ) and ZT (0.23 g/MJ) treatment. Residue treatments had higher RUE_{GY} than

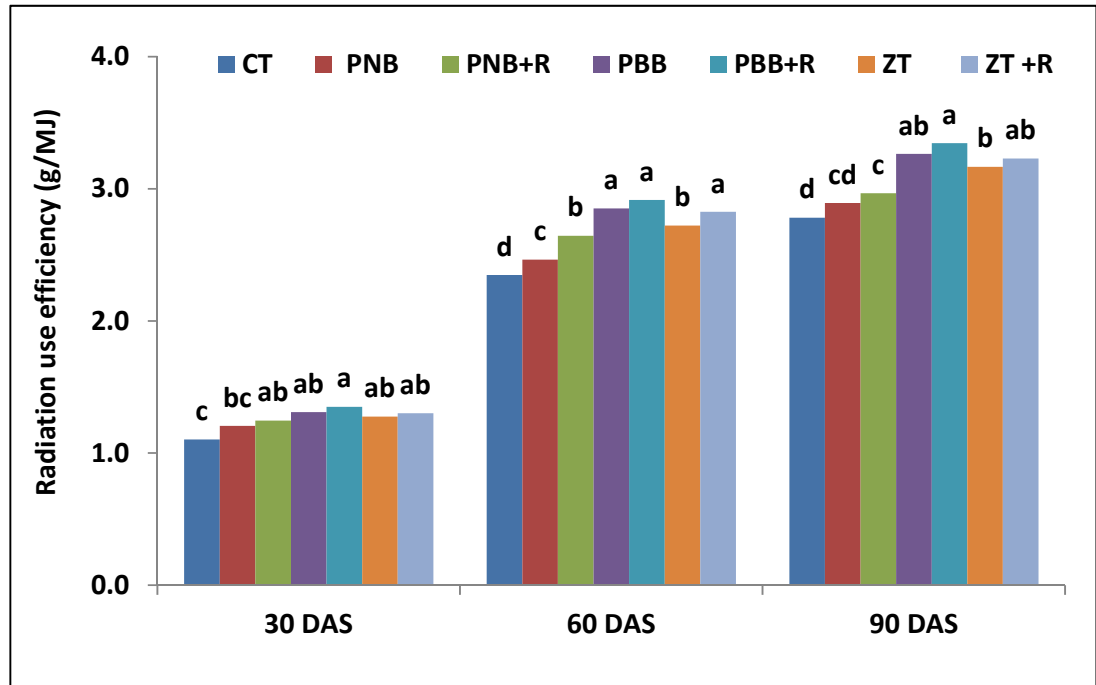


Fig.39. Radiation use efficiency (RUE_{DM}) under different conservation practices along with conventional practice in maize during crop growing season in maize –wheat cropping system

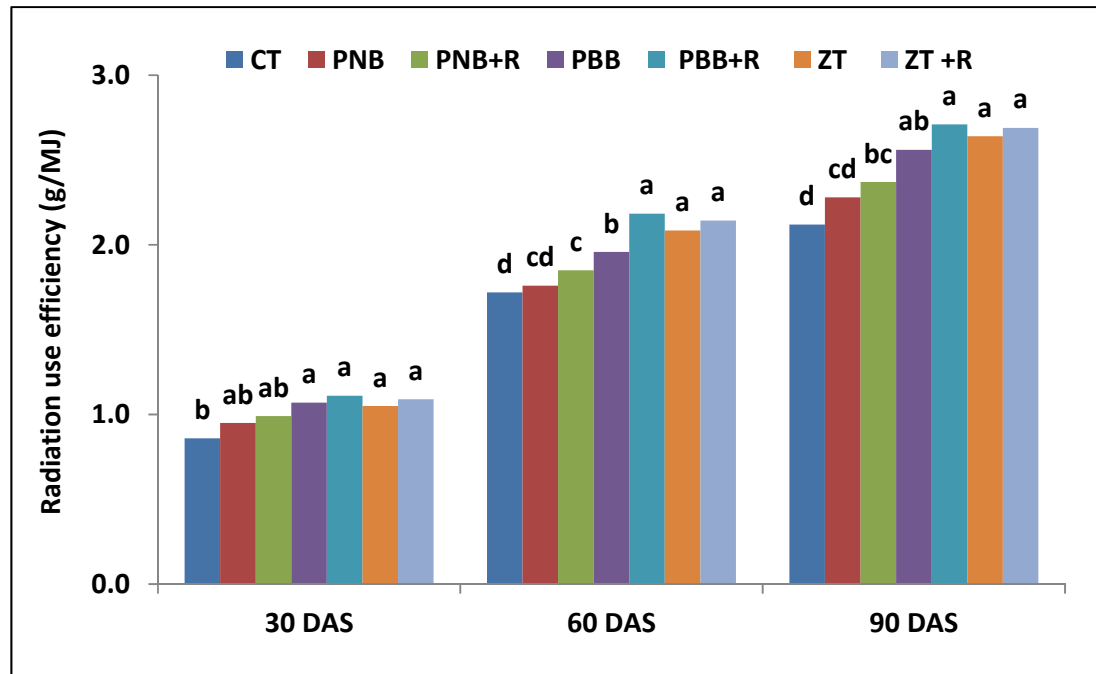


Fig.40. Radiation use efficiency (RUE_{DM}) under different conservation practices along with conventional practice in wheat during crop growing season in maize –wheat cropping system

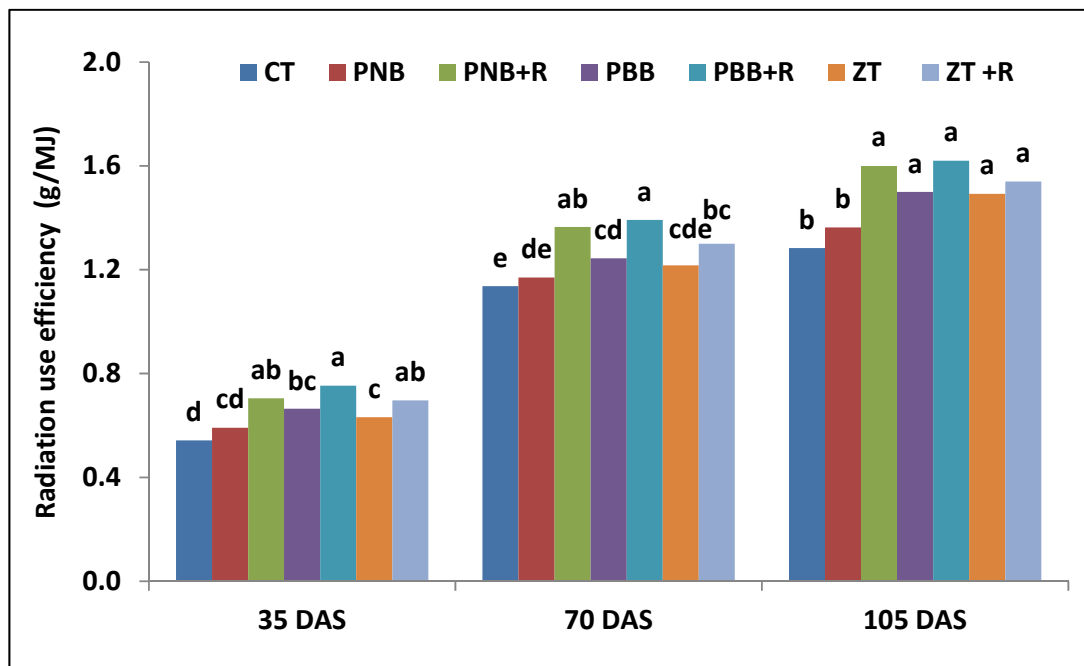


Fig.41. Radiation use efficiency (RUE_{DM}) under different conservation practices along with conventional practice in pigeonpea during crop growing season in pigeonpea –wheat cropping system

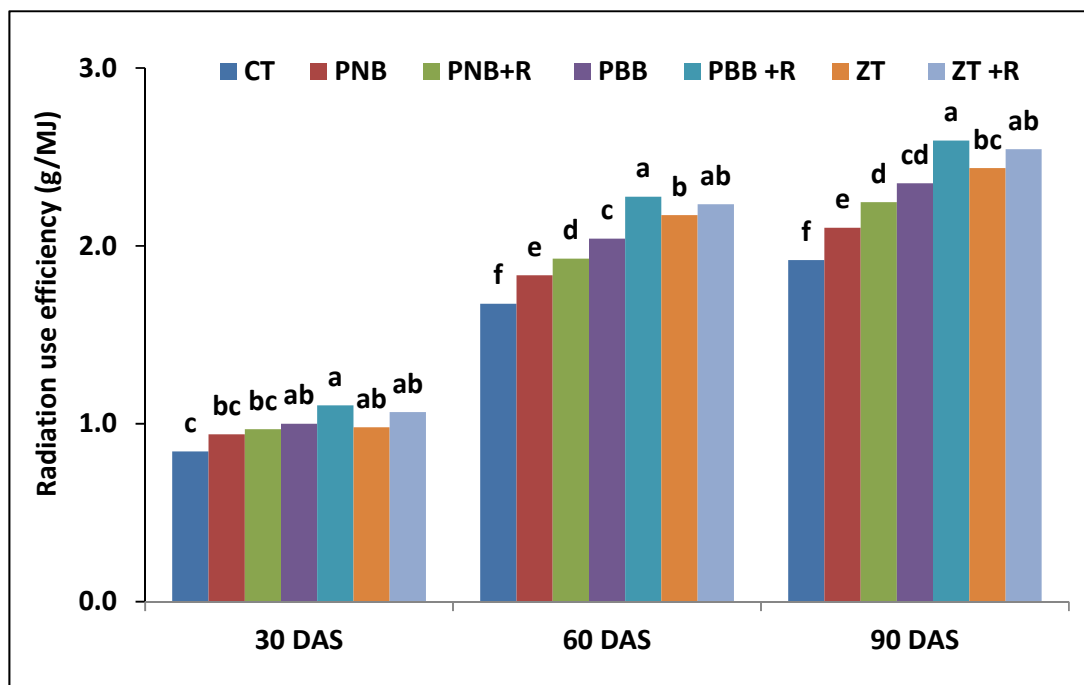


Fig.42. Radiation use efficiency (RUE_{DM}) under different conservation practices along with conventional practice in wheat during crop growing season in pigeonpea –wheat cropping system

other treatments. Lowest RUE_{GY} was found under CT treatment (0.21 g/MJ) (Table 18).

4.2.8.4 Radiation use efficiency for grain yield (RUE_{GY}) in wheat crop under different conservation practices along with conventional practices in pigeonpea-wheat cropping system

Maximum RUE_{GY} was under PBB+R treatment (0.88 g/MJ) followed by ZT+R (0.87 g/MJ), ZT (0.86 g/MJ), PBB (0.84 g/MJ), PNB+R (0.79 g/MJ) and PNB (0.78 g/MJ) treatment. CT treatment (0.76 g/MJ) had lowest RUE_{GY} than other treatments (Table. 18). PBB+R, ZT+R, ZT and PBB treatments had non-significant difference and PBB+R treatment had significantly higher RUE_{GY} than CT treatment.

Table 18: Radiation use efficiency for grain yield (g/MJ) under different Conservation practices along with conventional practice in maize-wheat and pigeonpea-wheat cropping system

Treatment	Maize-wheat cropping system		Pigeonpea-wheat cropping system	
	Maize	Wheat	Pigeonpea	Wheat
CT	1.02 ^b	0.72 ^d	0.21 ^c	0.76 ^c
PNB	1.10 ^{ab}	0.73 ^{cd}	0.24 ^{bc}	0.78 ^c
PNB+R	1.13 ^{ab}	0.77 ^{bcd}	0.30 ^{ab}	0.79 ^{bc}
PBB	1.16 ^a	0.80 ^{abc}	0.27 ^{abc}	0.84 ^{abc}
PBB+R	1.17 ^a	0.85 ^a	0.32 ^a	0.88 ^a
ZT	1.14 ^a	0.80 ^{abc}	0.23 ^{bc}	0.86 ^{ab}
ZT+R	1.16 ^a	0.82 ^{ab}	0.28 ^{abc}	0.87 ^{ab}
LSD(0.05)	0.03	0.07	0.04	0.08

4.2.9 Yield and yield attributes measured under different conservation practices along with conventional practice in different cropping system

4.2.9.1 Yield and yield attributes of maize crop under different conservation practices along with conventional practice in maize-wheat cropping system

Different Conservation treatments improved soil condition which effects the crop growth, resulting increased crop yield, one thousand seed weight, cob weight and seeds per cob under different conservation practices as compared to conventional treatment. PBB+R had maximum yield (5736 kg/ ha) followed by PBB (5632 kg/ ha), ZT+R (5598 kg/ ha), ZT (5411 kg/ ha), PNB+R (5286 kg/ ha) and PNB (4924 kg/ ha) treatment. Lowest yield was found under CT treatment (4246 kg/ ha) (Table 19). PBB had 35% more yield as compared to CT treatment. PBB had 32.6%, ZT+R had 31.8%, ZT had 27.4%, PNB+ R had 24.5% and PNB had 15.9% more yield as compared to CT treatment. Similar to yield, PBB+R had maximum 1000 seed weight (296 g), cob weight (147 g) and seeds per cob (393). CT treatment had minimum values for 1000 seed weight (231 g), cob weight (109 g) and seeds per cob (277). PBB, PBB+R, ZT and ZT+R treatment had non-significant difference but these treatments had higher value of yield as compared to corresponding value in other treatments.

4.2.9.2 Yield and yield attributes of wheat crop under different conservation practices along with conventional practice in maize-wheat cropping system

In wheat crop maximum grain yield was observed in PBB+R treatment (5294 kg/ha) followed by ZT+R (5174 kg/ha), ZT (5012kg/ha) and PBB (4912 kg/ha) treatment. These treatments had significantly higher value than other three treatments but within these treatments there was non- significant difference. PNB+R had 4862 kg/ha, PNB had 4782 kg/ha and CT had 4635 kg/ha grain yield. CT treatment had lowest yield as compared to other treatments. 1000 seed weight within different treatments ranged between 40.8- 43.3 g. 1000 seed weight had higher value in PBB+R treatment. 1000 seed weight values had non-significant difference among all treatments. Number of spike/m² was found higher value in PBB+R treatment (365) followed by ZT+R (358) and ZT (351) treatment. Number of spike/m² in other treatments ranged between 339 to 348. Number of spike/m² in PBB+R and ZT+R

treatment was non-significant. Number of grains/spike in different treatments ranged within 43.8-49.1. Maximum value was found in PP+B treatment (49.1) and lowest value was found in CT treatment (43.8). PBB+R, ZT+R, ZT, PBB and PNB+R treatment had non-significant difference (Table 20).

Table 19: Yield and yield attributes in maize crop under different Conservation practices along conventional practice in maize-wheat cropping system

Treatment	Seed yield (kg/ha)	1000 seed weight (g)	Cob weight (g)	Seeds/cob
CT	4246 ^c	231 ^e	109 ^c	277 ^f
PNB	4924 ^b	244 ^d	114 ^c	299 ^e
PNB+R	5286 ^{ab}	257 ^c	120 ^c	322 ^d
PBB	5632 ^a	292 ^{ab}	145 ^a	390 ^a
PBB+R	5736 ^a	296 ^a	147 ^a	393 ^a
ZT	5411 ^{ab}	265 ^c	132 ^b	340 ^c
ZT+R	5598 ^a	283 ^b	139 ^{ab}	368 ^b
LSD(0.05)	341	38	18	56

Table 20: Yield and yield attributes of wheat crop under different conservation practices along with conventional practice in maize-wheat cropping system

Treatment	Grain yield (kg/ha)	1000 seed weight (g)	No. of spike/m ²	No. of grains/spike
CT	4635 ^d	40.8	339 ^d	43.8 ^c
PNB	4782 ^{cd}	41.4	342 ^{cd}	45.7 ^{bc}
PNB+R	4862 ^{bcd}	41.6	346 ^{cd}	46.3 ^{abc}
PBB	4912 ^{bcd}	42.4	348 ^{bcd}	47.9 ^{ab}
PBB+R	5294 ^a	43.3	365 ^a	49.1 ^a
ZT	5012 ^{abc}	42.1	351 ^{bc}	48.3 ^{ab}
ZT+R	5174 ^{ab}	42.8	358 ^{ab}	48.6 ^a
LSD(0.05)	373	NS	16	2.11

4.2.9.3 Yield and yield attributes of pigeonpea crop under different conservation practices along with conventional practice in pigeonpea -wheat cropping system

Residue treatments (PBB+R, PNB+R and ZT+R) provided better microenvironment. These three treatments had better growth resulting higher yield. PBB+R had maximum yield (2211 kg/ha) followed by PNB+R (2072 kg/ha), ZT+R (2064 kg/ha), PBB (2035 kg/ha), PNB (2032 kg/ha) and ZT (1992 kg/ha) treatment. Lowest yield was found in CT treatment (1816 kg/ha). 1000 seed weight ranged from 90.5 g to 82.7 g within different conservation treatments. Lowest value for 1000 seed weight was found in CT (80.4 g) treatment. Number of pods per plant had maximum value 164 in PBB+R treatment followed by PNB+R (154) and ZT+R (145) treatment. Yield, 1000 seed weight and number of pods per plant had higher values in PBB+R and PNB+R treatment as compared to corresponding value in other treatments. These two treatments had non-significance difference at 5% level of significance. Number of seeds/ 100 pods had maximum value 407 under PBB+R treatment and lowest value under CT treatment (365). CT and ZT treatments were at par (Table 21).

4.9.2.4 Yield and yield attributes of wheat crop under different conservation practices along with conventional practice in pigeonpea -wheat cropping system

Seed yield had higher values in different conservation treatments as compared to CT treatment. PBB+R treatment had maximum yield (5308 kg/ha) followed by ZT+R (5243 kg/ha), ZT (5071 kg/ha) and PBB (4950 kg/ha) treatment. These treatments had non-significant difference but had higher values than other treatments. Lowest yield was found in CT treatment (4533 kg/ha). 1000 seed weight had non-significant difference in all treatments. Number of spike/m² ranged within 308 to 377. CT treatments had lowest value of number of spike/m² (308). Number of grains/spike had maximum value in PBB+R treatment (50.3). In other conservation treatments value of grain/spike ranged within 43.6 to 50.3. Lowest number of grains/spike was found in CT treatment (42.9). PBB+R and ZT+R treatment had non-significance difference in number of grains/ spike (Table 22).

Table 21: Yield and yield attributes in pigeonpea crop under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

Treatment	Seed yield (kg/ha)	1000 seed weight (g)	No. of pods/plant	No. of seeds/100 pods
CT	1816 ^b	80.4 ^d	116 ^d	365 ^c
PNB	2032 ^{ab}	82.7 ^{cd}	126 ^d	387 ^{ab}
PNB+R	2072 ^{ab}	87.3 ^{ab}	154 ^{ab}	395 ^{ab}
PBB	2035 ^{ab}	85.6 ^{bc}	137 ^c	390 ^{ab}
PBB+R	2211 ^a	90.5 ^a	164 ^a	407 ^a
ZT	1992 ^{ab}	80.5 ^d	119 ^d	377 ^{bc}
ZT+R	2064 ^{ab}	86.3 ^{bc}	145 ^{bc}	393 ^{ab}
LSD(0.05)	149	4.6	22	31

Table 22: Yield and yield attributes of wheat crop under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

Treatment	Yield (kg/ha)	1000 seed weight (g)	No. of spike/m ²	No. of grains/spike
CT	4533 ^c	40.8	308 ^f	42.9 ^d
PNB	4873 ^{bc}	41.4	323 ^e	43.6 ^{cd}
PNB+R	4877 ^{bc}	41.6	337 ^d	44.2 ^{cd}
PBB	4950 ^{ab}	42.4	344 ^{cd}	44.9 ^{bcd}
PBB+R	5308 ^a	43.3	377 ^a	50.3 ^a
ZT	5071 ^{ab}	42.1	351 ^c	46.7 ^{bc}
ZT+R	5243 ^a	42.8	362 ^b	48.3 ^{ab}
LSD(0.05)	517	NS	26	3.9

4.2.10 System productivity measured under different conservation practices along with conventional practice in different cropping system

4.2.10.1 System productivity measured under different conservation practices along with conventional practice in maize-wheat cropping system

Maize crop had wheat equivalent yield (WEY) ranged from 3.57- 4.82 t ha⁻¹. PBB+R treatment had maximum WEY (4.82 t ha⁻¹) followed by PBB (4.75 t ha⁻¹), ZT+R (4.69 t ha⁻¹), ZT (4.55 t ha⁻¹), PNB+R (4.44 t ha⁻¹) and PNB (4.14 t ha⁻¹) treatment. Lowest value of WEY was found in CT treatment (3.57 t ha⁻¹). PBB+R, PBB, ZT+R, ZT, PNB+R treatments had non-significant difference but they had higher value than other treatments. Final WEY or system productivity was found maximum in PBB+R treatment (10.1 t ha⁻¹) and lowest WEY in CT treatment (8.2 t ha⁻¹). PBB, PBB+R, ZT and ZT+R treatment had similar value and these treatments had higher WEY than PNB+R, PNB and CT treatment (Table 23).

Table 23: System productivity measured under different conservation practices along with conventional practice in maize-wheat cropping system

Treatment	Maize yield (t/ha)	Wheat equivalent yield of maize (t/ha)	Wheat yield (t/ha)	System productivity (WEY)
CT	4.25 ^c	3.57 ^c	4.64 ^d	8.20 ^d
PNB	4.92 ^b	4.14 ^a	4.78 ^{cd}	8.92 ^d
PNB+R	5.29 ^{ab}	4.44 ^{ab}	4.86 ^{bcd}	9.30 ^{bc}
PBB	5.63 ^a	4.75 ^a	4.91 ^{bcd}	9.65 ^{ab}
PBB+R	5.74 ^a	4.82 ^a	5.29 ^a	10.10 ^a
ZT	5.41 ^{ab}	4.55 ^{ab}	5.01 ^{abc}	9.55 ^{abc}
ZT+R	5.60 ^a	4.69 ^a	5.17 ^{ab}	9.86 ^{ab}
LSD(0.05)	0.34	0.40	0.37	0.55

4.2.10.2 System productivity measured under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

Pigeonpea crop had maximum wheat equivalent yield (WEY) in PBB+R treatment (6.87 t ha⁻¹) followed by ZT+R (6.54 t ha⁻¹), PNB+R (6.44 t ha⁻¹), PBB (6.33 t ha⁻¹), PNB (6.31 t ha⁻¹), ZT (6.19 t ha⁻¹) and CT (5.64 t ha⁻¹) treatment. PBB,

ZT+R, PNB+R and PNB perform similar to PBB+R treatment. These treatments had non-significant difference. Lowest WEY was found in CT treatment (5.64 t ha⁻¹). Final WEY or system productivity had maximum value in PBB+R (12.18 t ha⁻¹) treatment. Other conservation treatments had system productivity ranged between 10.69 to 11.78 t ha⁻¹. System productivity had lowest value in CT treatment (9.82 t ha⁻¹). PBB+R, ZT+R, PBB and ZT treatments had non-significant difference (Table 24).

Table 24: System productivity measured under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

Treatment	Pigeonpea yield (t/ha)	Wheat equivalent yield of pigeonpea (t/ha)	Wheat yield (t/ha)	System productivity (WEY)
CT	1.82 ^b	5.64 ^b	4.53 ^c	9.82 ^c
PNB	2.03 ^{ab}	6.31 ^{ab}	4.87 ^{bc}	10.69 ^{bc}
PNB+R	2.07 ^{ab}	6.44 ^{ab}	4.88 ^{bc}	10.97 ^{bc}
PBB	2.04 ^{ab}	6.33 ^{ab}	4.95 ^{ab}	11.28 ^{ab}
PBB+R	2.21 ^a	6.87 ^a	5.31 ^a	12.28 ^a
ZT	1.99 ^{ab}	6.19 ^{ab}	5.07 ^{ab}	11.26 ^{ab}
ZT+R	2.06 ^{ab}	6.54 ^a	5.24 ^a	11.78 ^{ab}
LSD(0.05)	0.15	0.57	0.52	0.76

4.1.11 Relationship between different crop biophysical and micrometeorological Parameters

4.1.11.1 Pearson correlation coefficients of grain yield with agro-meteorological indices at harvest in maize-wheat cropping system

The results obtained from the correlation analysis indicates that grain yield were highly significant and positively correlated with growing degree days at harvest. In maize crop GDD, HTU, PTI, RTD, PTU, HUE and yield relationship were found significant. Maize yield was positively correlated with GDD ($r = 0.921^{**}$), HTU ($r = 0.927^{**}$), PTI ($r = 0.874^{**}$), RTD ($r = 0.891^{*}$), PTU ($r = 0.906^{**}$) and HUE ($r = 0.936^{**}$) (Table 25). Similarly wheat yield was positively correlated with GDD (r

=0.916**), HTU ($r = 0.843^{**}$), PTI ($r = 0.842^*$), RTD ($r = 0.835^{**}$), PTU ($r = 0.837^{**}$) and HUE ($r = 0.915^{**}$) (Table 26).

Table 25: Pearson correlation coefficients of maize grain yield with agrometeorological indices in maize-wheat cropping system at harvest

	YIELD	GDD	HTU	PTI	RTD	PTU	HUE
YIELD	1						
GDD	0.921 ^{**}	1					
HTU	0.927 ^{**}	0.918 ^{**}	1				
PTI	0.874 ^{**}	0.877 ^{**}	0.850 ^{**}	1			
RTD	0.891 [*]	0.955 ^{**}	0.957 ^{**}	0.846 [*]	1		
PTU	0.906 ^{**}	0.943 ^{**}	0.958 ^{**}	0.876 ^{**}	0.985 ^{**}	1	
HUE	0.936 ^{**}	0.924 ^{**}	0.945 [*]	0.845 [*]	0.795 [*]	0.853 [*]	1

*: Correlation is significant at the 0.05 level; **: Correlation is significant at the 0.01 level

Table 26: Pearson correlation coefficients of wheat grain yield with agrometeorological indices in maize-wheat cropping system at harvest

	YIELD	GDD	HTU	PTI	RTD	PTU	HUE
YIELD	1						
GDD	0.916 ^{**}	1					
HTU	0.843 ^{**}	0.854 ^{**}	1				
PTI	0.842 [*]	0.690 [*]	0.747 [*]	1			
RTD	0.835 ^{**}	0.852 ^{**}	0.917 ^{**}	0.771 [*]	1		
PTU	0.837 ^{**}	0.853 ^{**}	0.931 ^{**}	0.754 [*]	0.939 ^{**}	1	
HUE	0.915 ^{**}	0.919 ^{**}	0.803 [*]	0.775 [*]	0.791 [*]	0.794 [*]	1

*: Correlation is significant at the 0.05 level; **: Correlation is significant at the 0.01 level

4.1.11.2 Pearson correlation coefficients of grain yield with agro-meteorological indices at harvest in pigeonpea-wheat cropping system

In pigeonpea crop GDD, HTU, PTI, RTD, PTU, HUE and grain yield relationship were found significant. Pigeonpea yield was positively correlated with GDD ($r = 0.709^{**}$), HTU ($r = 0.825^{**}$), PTI ($r = 0.691^{**}$), RTD ($r = 0.736^{**}$), PTU ($r = 0.815^{**}$) and HUE ($r = 0.895^{**}$) (Table 27). Similarly wheat grain yield in pigeonpea-wheat cropping system was positively correlated with GDD ($r = 0.908^{**}$), HTU ($r = 0.822^{**}$), PTI ($r = 0.852^{**}$), RTD ($r = 0.867^{**}$), PTU ($r = 0.862^{**}$) and HUE ($r = 0.963^{**}$) (Table 28). Thermal indices were better correlated with grain yield in wheat crop than pigeonpea crop.

Table 27: Pearson correlation coefficients of pigeonpea grain yield with agro-meteorological indices in pigeonpea-wheat cropping system at harvest

	YIELD	GDD	HTU	PTI	RTD	PTU	HUE
YIELD	1						
GDD	0.709**	1					
HTU	0.825**	0.918**	1				
PTI	0.691**	0.863*	0.877**	1			
RTD	0.736**	0.931**	0.919**	0.914**	1		
PTU	0.815**	0.891**	0.909**	0.905**	0.911**	1	
HUE	0.895**	0.711*	0.753*	0.831**	0.885**	0.865**	1

*: Correlation is significant at the 0.05 level; **: Correlation is significant at the 0.01 level

Table 28: Pearson correlation coefficients of wheat grain yield with agro-meteorological indices in pigeonpea-wheat cropping system at harvest

	YIELD	GDD	HTU	PTI	RTD	PTU	HUE
YIELD	1						
GDD	0.908**	1					
HTU	0.822**	0.918**	1				
PTI	0.852**	0.928**	0.951**	1			
RTD	0.867**	0.911**	0.948**	0.957**	1		
PTU	0.862**	0.953**	0.908**	0.892**	0.901**	1	
HUE	0.923**	0.857**	0.848**	0.904**	0.823**	0.726*	1

*: Correlation is significant at the 0.05 level; **: Correlation is significant at the 0.01 level

4.1.12: Relationship between cumulative intercepted photosynthetically active radiation (CIPAR) and crop biomass under different treatments

4.1.12.1 Relationship between cumulative intercepted photosynthetically active radiation (CIPAR) and maize crop biomass under different conservation practices along with conventional practice in maize-wheat cropping system

Linear relationship was found between CIPAR and crop biomass. The regression equation slope showed radiation use efficiency (RUE) within treatments. CT treatment had minimum value of RUE (2.76g/MJ) with R^2 value 0.90 ($p = 0.020$). PBB+R treatment had maximum RUE (3.48 g/MJ) with R^2 value 0.99 ($p = 0.004$). It was due to more accumulation of biomass at less IPAR values in PBB+R treatment as compared to the other conservation treatments (Table 29). Other treatments had regression equation slope between 3.03 to 3.39 g/MJ.

Table 29: Relationship between cumulative intercepted photosynthetically active radiation (CIPAR) and maize crop biomass under different conservation practices along with conventional practice in maize-wheat cropping system

Treatment	Regression equation	R^2	p-value
CT	$y=2.76x-192.7$	0.90	0.020
PNB	$y=3.03x- 289.2$	0.92	0.022
PNB+R	$y=3.17x-331.2$	0.93	0.020
PBB	$y=3.39x-376.4$	0.91	0.033
PBB+R	$y=3.48x-412.2$	0.99	0.004
ZT	$y=3.31x-354.1$	0.92	0.030
ZT+R	$y=3.42x-383.4$	0.95	0.007

4.1.12.2 Relationship between cumulative intercepted photosynthetically active radiation (CIPAR) and wheat crop biomass under different conservation practices along with conventional practice in maize-wheat cropping system

There was linear relationship between CIPAR and wheat crop biomass in maize-wheat cropping system. Slope of regression equation was maximum in PBB+R treatment (2.56 g/MJ) with R^2 value 0.99 ($p = 0.001$) followed by ZT+R (2.54g/MJ)

with R^2 value 0.99 ($p = 0.003$). Minimum slope was found under CT treatment (2.01 g/MJ) with R^2 value of 0.87 ($p = 0.043$) (Table 30). Conservation treatments had more slope because in these treatments biomass production was more at low interception of photo synthetically active radiation as compared to corresponding value in conventional treatment.

Table 30: Relationship between cumulative intercepted photosynthetically active radiation (CIPAR) and wheat crop biomass under different conservation practices along with conventional practice in maize-wheat cropping system

Treatment	Regression equation	R^2	p- value
CT	$y=2.01x-122.7$	0.87	0.043
PNB	$y=2.26x-146.3$	0.98	0.004
PNB+R	$y=2.34x-151.0$	0.95	0.013
PBB	$y=2.42x-153.8$	0.99	0.002
PBB+R	$y=2.56x-209.8$	0.99	0.001
ZT	$y=2.49x-167.2$	0.97	0.009
ZT+R	$y=2.54x-189.7$	0.99	0.003

4.1.12.3 Relationship between cumulative intercepted photosynthetically active radiation (CIPAR) and pigeonpea crop biomass under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

Linear regression equations were applied to develop the relationship between crop biomass and CIPAR to estimate RUE. Slope gives a specific value of the increment by intercepting more units of PAR, which can evaluate the productivity of the crop. Slope for CT treatment had lowest value (1.10 g/MJ) with R^2 value of 0.90 ($p = 0.005$). Conservation treatments had higher slope than CT treatment indicates that they had higher RUE than CT treatment. Among conservation treatments, PBB+R had maximum slope 1.56 g/MJ with R^2 value 0.98 ($p = 0.007$) followed by ZT+R (1.50 g/MJ) with R^2 value 0.97 ($p = 0.0015$) (Table 31).

Table 31: Relationship between cumulative intercepted photosynthetically active radiation (CIPAR) and pigeonpea crop biomass in different conservation practices along with conventional practice in pigeonpea-wheat cropping system

Treatment	Regression equation	R ²	p- value
CT	y=1.10x-134.9	0.90	0.005
PNB	y=1.23x- 163.7	0.89	0.003
PNB+R	y=1.49x-211.2	0.94	0.007
PBB	y=1.38x-198.7	0.91	0.001
PBB+R	y=1.56x-236.1	0.98	0.007
ZT	y=1.47x-215.7	0.92	0.010
ZT+R	y=1.50x-231.6	0.97	0.0015

4.1.12.4 Relationship between cumulative intercepted photosynthetically active radiation (CIPAR) and wheat crop biomass under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

There was linear relationship between crop biomass and CIPAR values in wheat crop under different treatments (Table 32).

Table 32: Relationship between cumulative intercepted photosynthetically active radiation (CIPAR) and wheat crop biomass in different conservation practices along with conventional practice in pigeonpea-wheat cropping system

Treatment	Regression equation	R ²	p-value
CT	y=2.30x-246.9	0.94	0.018
PNB	y=2.37x-238.1	0.98	0.004
PNB+R	y=2.46x-248.0	0.96	0.012
PBB	y=2.51x-270.5	0.98	0.004
PBB+R	y=2.67x-335.6	0.99	0.002
ZT	y=2.56x-270.9	0.96	0.011
ZT+R	y=2.63x-320.5	0.99	0.002

Maximum slope was found under PBB+R treatment (2.67 g/MJ) with R² value 0.99 (p= 0.002) followed by ZT+R (2.63 g/MJ) with R² value 0.99 (p= 0.002). CT treatment had minimum slope (2.30 g/MJ) with R² value 0.94 (p= 0.018). Under

conservation treatments PNB had lowest slope 2.37 g/MJ with R^2 value 0.98 ($p=0.004$).

4.3 Objective 3: To calculate crop water requirement and water use efficiency using single crop coefficient, dual crop coefficient and water balance method under different crop micro environments.

4.3.1 Net radiation under different conservation practices along with conventional practice in maize-wheat and pigeonpea-wheat cropping system

The net radiation, the difference between the incoming net shortwave radiation and the outgoing net long wave radiation, is the fundamental variable for calculation of evapotranspiration. However, direct measurements were not available for the study area therefore equation 8 given in the chapter 3 was used for estimating net radiation. The terms in equation 8 were calculated from meteorological data. Net radiation for maize, wheat in maize-wheat cropping system and for pigeonpea, wheat in pigeonpea-wheat cropping system during crop growing period are shown in the Fig. 43, 44 respectively.

4.3.2 Reference evapotranspiration (ET_0) under different conservation practices along with conventional practice in maize-wheat and pigeonpea-wheat cropping system

The Penman-Monteith equation was used for calculating the reference evapotranspiration. The value of estimated reference evapotranspiration calculated daily by Penman-Monteith equation for maize, wheat crop in maize-wheat cropping system and for pigeonpea, wheat crop in pigeonpea-wheat cropping system are given in Fig. 45, 46 respectively. Estimated reference crop evapotranspiration was validated by pan evaporation by multiplying the pan evaporation data with correction factor. The Figure 47 showed the relationship between estimated reference evapotranspiration and calculated by pan evaporation had good correlation at R^2 of 0.87 for maize, 0.89 for wheat in maize-wheat cropping system and 0.86 for pigeonpea, 0.92 for wheat crop in pigeonpea-wheat cropping system. For maize crop ET_0 ranged between 1.8 to 7.6 mm day⁻¹ during crop growing period in *kharif* 2014 and for wheat ET_0 ranged between 1.34 to 7.77 mm day⁻¹ during the crop growing period in *rabi* 2014-15. ET_0 ranged from 2.76 to 9.6 mm day⁻¹ for pigeonpea crop

during crop growing season in *kharif* 2015 and ET_0 ranged between 1.87 to 7.6 mm day⁻¹ in wheat crop during crop growing season in *rabi* 2015-16.

4.3.3 Length of crop development stages under different conservation practices along with conventional practice in maize-wheat and pigeonpea-wheat cropping system

The numbers of days taken to reach different stages during the crop growth period were noted carefully from day-to-day observations. The different crop growth stages initial, development, mid season, and late season stages were calculated based on the crop coverage data as suggested by FAO-56.

4.3.3.1 Length of crop development stages under different conservation practices along with conventional practice in maize-wheat cropping system

Maize had initial stage up to 20 days after sowing. Development stage was between 20 to 45 days after sowing, mid season stage was between 45 to 85 days after sowing and the late season stage was between 85 to 105 days after sowing in different treatments.

Wheat sown after maize crop had initial stage upto 40 days after sowing. Crop development stage was between 40 to 70 days after sowing, mid season stage was between 70 to 120 days after sowing and the late season stage was between 120 to 150 days after sowing in different treatments (Table 33).

4.3.3.2 Length of crop development stages under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

Pigeonpea had initial stage up to 35 days after sowing. Development stage was between 35 to 70 days after sowing, mid season stage was between 70 to 150 days after sowing and the late season stage was between 150 to 180 days after sowing in different treatments.

Wheat sown after pigeonpea crop had initial stage upto 40 days after sowing. The development stage was between 40 to 65 days after sowing, mid season stage was between 65 to 110 days after sowing and the late season stage was between 110 to 130 days after sowing in different treatments (Table 33). Different treatments did not have any significant effect on different development stages of crops.

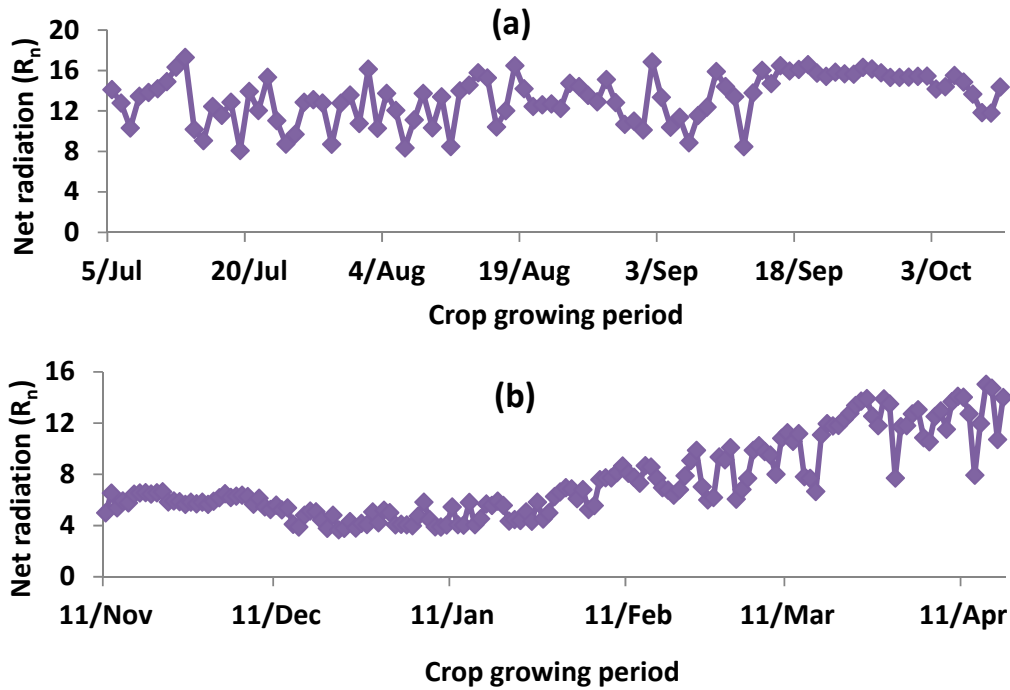


Fig. 43. Net radiation (R_n) in (a) maize and (b) wheat under maize-wheat cropping system during crop growing period

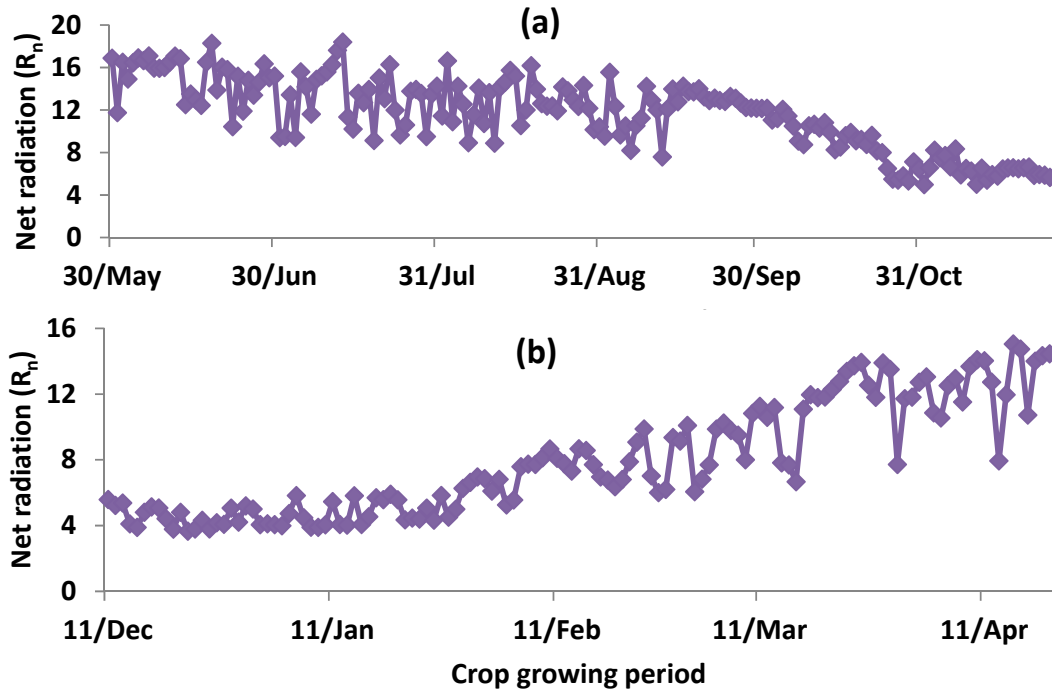


Fig. 44. Net radiation (R_n) in (a) pigeonpea and (b) wheat under pigeonpea-wheat cropping system during crop growing period

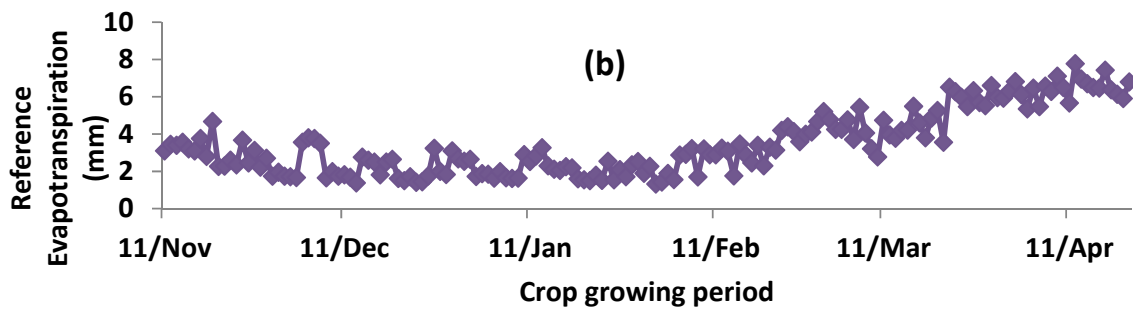
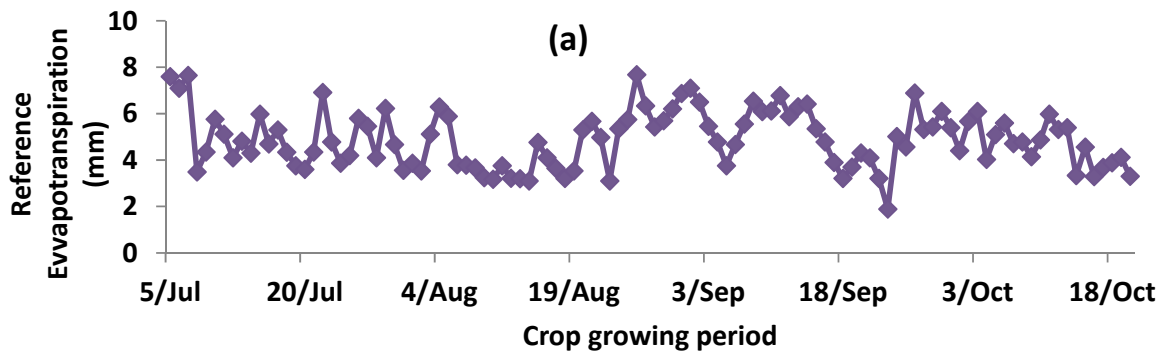


Fig. 45. Reference evapotranspiration (mm/day) calculated in (a) maize and (b) wheat crop at experimental site in maize-wheat cropping system during crop growing period

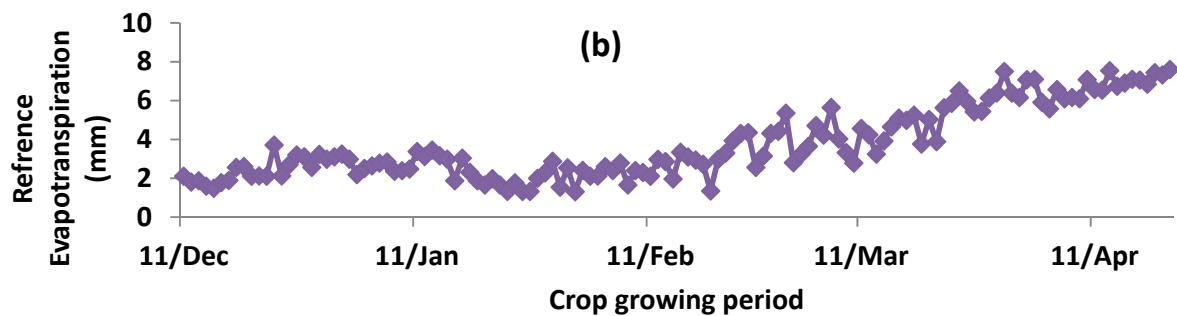
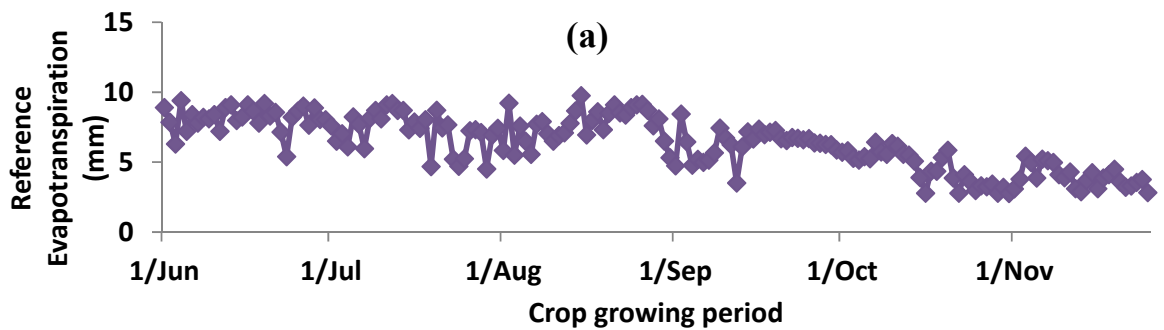


Fig.46. Reference evapotranspiration (mm/day) calculated in (a) pigeonpea and (b) wheat crop at experimental site in pigeonpea-wheat cropping system during crop growing period

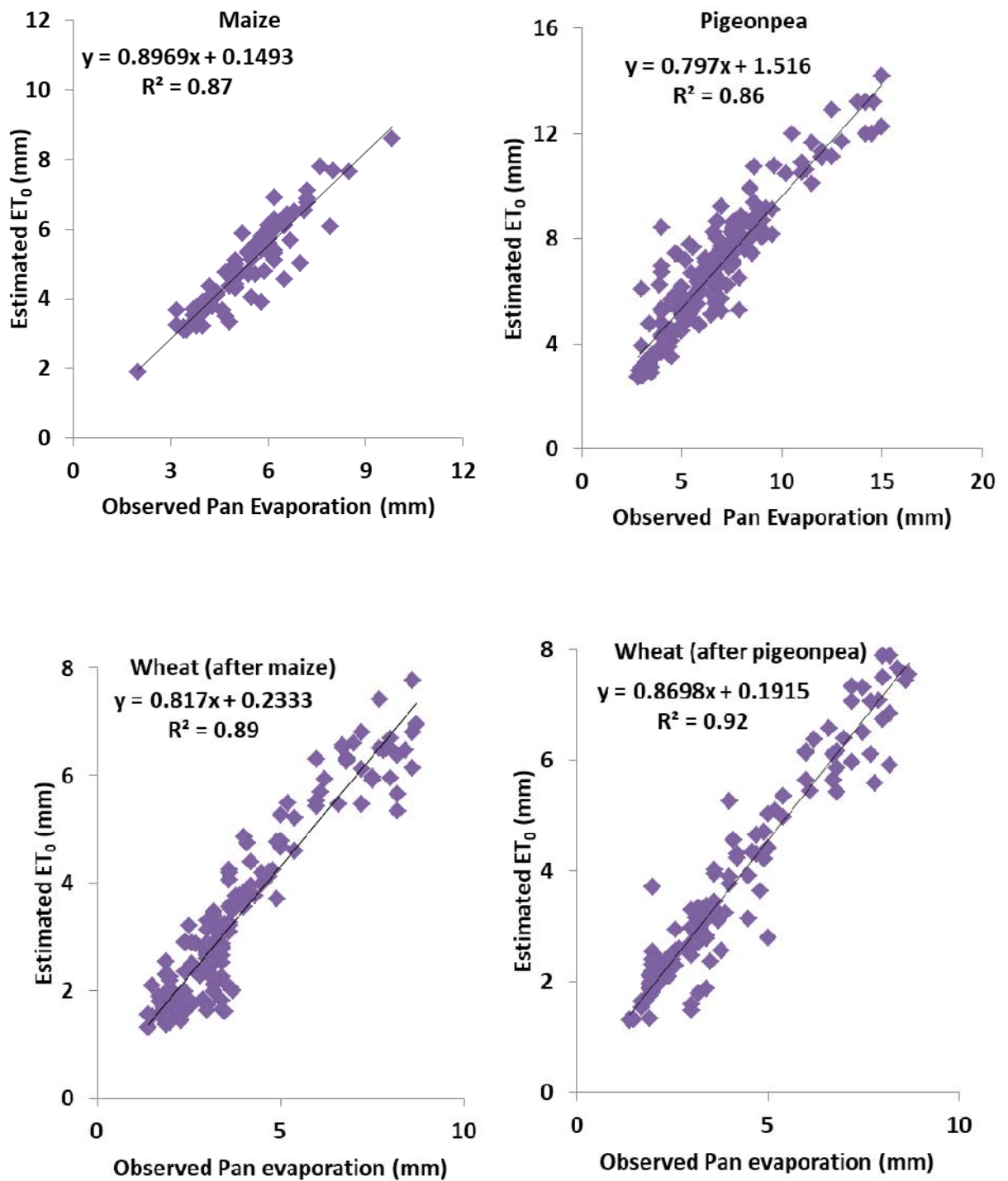


Fig.47. Relationship between reference evapotranspiration calculated through Penman-Monteith equation and pan evaporation in maize-wheat and pigeonpea-wheat cropping systems

Table 33: Length of different crop development stages under maize-wheat and pigeonpea-wheat cropping system

Crop development stages	Maize-wheat cropping system		Pigeonpea-wheat cropping system	
	Maize	Wheat	Pigeonpea	Wheat
Initial stage	20	40	35	40
Development stage	20-45	40-70	35-70	40-65
Mid season stage	45-85	70-120	70-150	65-110
Late season stage	85-105	120-150	150-180	110-130

4.3.4. Single crop coefficient (K_c) approach under different conservation practices along with conventional practice in maize-wheat and pigeonpea-wheat cropping system

4.3.4.1. Single crop coefficient (K_c) in maize crop under different conservation practices along with conventional practice in maize-wheat cropping system

Single crop coefficient (K_c) values suggested by FAO-56 are 0.30, 1.20, and 0.35 respectively, for the initial, mid-season and late season stages in maize crop. They were adjusted for the semi- arid climatic conditions. Adjusted crop coefficient for initial stage, mid season stage and late season stage for maize crop under different treatment are shown in table 34. The value of K_c for maize crop under different treatments during initial stage was 0.30 under CT, ZT and ZT+R treatments, 0.21 under PNB and PNB+R treatments and 0.15 under PBB and PBB+R treatments. The value of K_c during mid season stage was 1.355 under PBB+R treatment, 1.354 under PBB, 1.352 under ZT+R, 1.350 under ZT, 1.348 under PNB+R, 1.347 under PNB and 1.339 under CT treatment. At late season stage the K_c value was 0.430 under PBB+R, 0.428 under PBB, 0.427 under ZT+R, 0.425 under ZT, 0.424 under PNB+R, 0.422 under PNB and 0.421 under CT treatment.

Table 34: Adjusted single crop coefficient (K_c) of maize crop at different crop growth stages under different conservation practices along with conventional practice in maize- wheat cropping system

Treatment	Initial stage	Mid season stage	Late season stage
CT	0.30	1.339	0.421
PNB	0.21	1.347	0.422
PNB+R	0.21	1.348	0.424
PBB	0.15	1.354	0.428
PBB+R	0.15	1.355	0.430
ZT	0.30	1.350	0.425
ZT +R	0.30	1.352	0.427

4.3.4.2. Single crop coefficient (K_c) in wheat crop under different conservation practices along with conventional practice in maize-wheat cropping system

Single crop coefficient (K_c) values suggested by FAO-56 are 0.30, 1.15, and 0.25 respectively, for the initial, mid-season and late season stages in wheat crop. After adjustment crop coefficient for initial, midseason and late season stage for wheat crop in maize-wheat cropping system under different tillage practices are shown in table 35. The value of K_c for wheat crop in maize-wheat cropping system under different treatment during initial stage was 0.30 under CT, ZT and ZT+R treatment, 0.15 under PBB and PBB+R treatment and 0.21 under PNB and PNB+R treatment. The value of K_c during mid season stage was 1.276 under PBB+R, 1.274 under ZT+R, 1.269 under ZT, 1.264 under PBB, 1.261 under PNB+R, 1.249 under PNB and 1.245 under CT treatment. At late season stage the K_c value was 0.331 under PBB+R and PBB, 0.330 under ZT+R, 0.329 under ZT and PNB+R, 0.331 under PNB and 0.321 under CT treatment.

Table 35: Adjusted single crop coefficient (K_c) of wheat crop at different crop growth stages under different conservation practices along with conventional practice in maize-wheat cropping system

Treatment	Initial stage	Mid season stage	Late season stage
CT	0.30	1.245	0.321
PNB	0.21	1.249	0.331
PNB+R	0.21	1.261	0.329
PBB	0.15	1.264	0.331
PBB+R	0.15	1.276	0.331
ZT	0.30	1.269	0.329
ZT +R	0.30	1.274	0.330

4.3.4.3. Single crop coefficient (K_c) in pigeonpea crop under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

Single crop coefficient (K_c) values suggested by FAO-56 are 0.40, 1.15, and 0.35 respectively, for the initial, mid season and late season stages in pigeonpea crop. Adjusted K_c for pigeonpea crop under different tillage practices during initial stage was 0.40 under CT, ZT and ZT+R treatment, 0.20 under PBB and PBB+R treatment and 0.28 under PNB and PNB+R treatment. The value of K_c during mid season stage was 1.134 under PNB+R and PBB+R treatment, 1.333 under ZT+R, 1.133 under PBB, 1.131 under PNB, 1.130 under ZT and 1.129 under CT treatment. At late season stage the K_c value was 0.446 under PBB+R, 0.445 under PNB+R and ZT+R, 0.443 under PBB, 0.442 under ZT and PNB and 0.439 under CT treatment (Table 36).

4.3.4.4. Single crop coefficient (K_c) in wheat crop under different conservation practices along with conventional practice in maize-wheat cropping system

Single crop coefficient (K_c) values suggested by FAO-56 are 0.30, 1.15, and 0.25 respectively, for the initial, mid season and late season stages in wheat crop. The adjusted value of K_c for wheat crop in pigeonpea-wheat cropping system under different tillage practices during initial stage was 0.30 under CT, ZT and ZT+R treatments, 0.15 under PBB and PBB+R treatments and 0.21 under PNB and PNB+R

treatments. The value of K_c during mid season stage was 1.239 under PBB+R, 1.237 under ZT+R, 1.232 under ZT, 1.227 under PBB, 1.224 under PNB + R, 1.213 under PNB and 1.213 under CT treatment. At late season stage the K_c value was 0.328 under PBB+R, 0.326 under ZT+R, 0.325 under ZT, 0.323 under PBB, 0.322 under PNB+R, 0.321 under PNB and 0.318 under CT treatment (Table 37).

Table 36: Adjusted single crop coefficient (K_c) of pigeonpea crop at different crop growth stages under different conservation practices along conventional practice in pigeonpea-wheat cropping system

Treatment	Initial stage	Mid season stage	Late season stage
CT	0.40	1.129	0.439
PNB	0.28	1.131	0.442
PNB+R	0.28	1.134	0.445
PBB	0.20	1.133	0.443
PBB+R	0.20	1.134	0.446
ZT	0.40	1.130	0.442
ZT +R	0.40	1.133	0.445

Table 37: Adjusted single crop coefficient (K_c) of wheat crop at different crop growth stages under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

Treatment	Initial stage	Mid season stage	Late season stage
CT	0.30	1.213	0.321
PNB	0.21	1.208	0.318
PNB+R	0.21	1.224	0.322
PBB	0.15	1.227	0.323
PBB+R	0.15	1.239	0.328
ZT	0.30	1.232	0.325
ZT +R	0.30	1.237	0.326

4.3.5. Basal crop coefficient (K_{cb}) approach in different conservation practices along with conventional practice in maize-wheat and pigeonpea-wheat cropping system

4.3.4.1. Basal crop coefficient (K_{cb}) in maize crop under different conservation practices along with conventional practice in maize-wheat cropping system

Basal crop coefficient (K_{cb}) values suggested by FAO-56 are 0.15, 1.15, and 0.50 respectively, for the initial, mid season and late season stages in maize crop. They were adjusted using equation (14) for the climatic conditions of the study area. After adjustment, the K_{cb} of maize in the initial stage was 0.15 for all tillage treatments under different weather conditions but the K_{cb} value in mid stage was different for different treatments. The value for K_{cb} in mid season stages for maize was 1.237 under PBB+R, 1.235 under PBB, 1.233 under ZT+R, 1.232 under ZT, 1.230 under PNB+R, 1.229 under PNB and 1.227 under CT treatment. The K_{cb} values for late stage was need to adjust according to climatic conditions as FAO-56. The values of K_{cb} in late season stage for maize crop was 0.627 under PBB+R, 0.626 under ZT+R, 0.625 under PBB, 0.624 under ZT, 0.622, under PNB+R, 0.621 under PNB and 0.614 under CT treatment (Table 38).

Table 38: Adjusted basal crop coefficient (K_{cb}) of maize crop at different crop growth stages under different conservation practices along with conventional practice in maize-wheat cropping system

Treatment	Initial stage	Mid season stage	Late season stage
CT	0.15	1.227	0.614
PNB	0.15	1.229	0.621
PNB+R	0.15	1.230	0.622
PBB	0.15	1.235	0.625
PBB+R	0.15	1.237	0.627
ZT	0.15	1.232	0.624
ZT +R	0.15	1.233	0.626

4.3.4.2. Basal crop coefficient (K_{cb}) in wheat crop under different conservation practices along with conventional practice in maize-wheat cropping system

Basal crop coefficient (K_{cb}) values suggested by FAO-56 are 0.15, 1.10, and 0.30 respectively, for the initial, mid season and late season stages in wheat crop. After adjustment for the climate conditions of the study area, the K_{cb} of wheat in the initial stage was 0.15 for all treatments but the K_{cb} value in mid stage was different for different treatments. The value for K_{cb} in mid season stages for wheat under maize-wheat cropping system was 1.172 under PBB+R, 1.171 under ZT+R and ZT, 1.170 under PBB, 1.167 under PNB+R, 1.166 under PNB and 1.164 under CT treatment after adjustment according to climatic conditions. The K_{cb} values for late season stage was no need to adjusted according to climatic conditions as FAO-56 K_{cb} value is less than 0.45. The values of K_{cb} in late season stage for wheat crop were 0.30 under all treatments (Table 39).

Table 39: Adjusted basal crop coefficient (K_{cb}) of wheat at different crop growth stages under different conservation practices along with conventional practice in maize-wheat cropping system

Treatment	Initial stage	Mid season stage	Late season stage
CT	0.15	1.164	0.30
PNB	0.15	1.166	0.30
PNB+R	0.15	1.167	0.30
PBB	0.15	1.170	0.30
PBB+R	0.15	1.172	0.30
ZT	0.15	1.171	0.30
ZT +R	0.15	1.171	0.30

4.3.4.3. Basal crop coefficient (K_{cb}) in pigeonpea crop under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

The basal crop coefficient (K_{cb}) values suggested by FAO-56 are 0.15, 1.10, and 0.50 respectively for the initial, mid season and late season stages in pigeonpea crop. After adjustment for the climate conditions of the study area, the K_{cb} of pigeonpea in the initial stage was 0.15 for all treatments but the K_{cb} value in mid stage

was different for different treatments. The value for K_{cb} in mid season stages for pigeonpea was 1.169 under PBB+R and PNB+R, 1.168 under ZT+R and PBB, 1.167 under PNB, 1.166 under ZT and 1.165 under CT treatment. The K_{cb} values for late stage was need to adjusted according to climatic conditions as FAO-56. The values of K_{cb} in late season stage for pigeonpea crop was 0.567 under PBB+R, 0.566 under ZT+R and PNB+R, 0.565 under PBB, 0.564 under ZT and PNB and 0.562 under CT treatment (Table 40).

Table 40: Adjusted basal crop coefficient (K_{cb}) of pigeonpea at different crop growth stages under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

Treatment	Initial stage	Mid season stage	Late season stage
CT	0.150	1.165	0.562
PNB	0.150	1.167	0.564
PNB+R	0.150	1.169	0.566
PBB	0.150	1.168	0.565
PBB+R	0.150	1.169	0.567
ZT	0.150	1.166	0.564
ZT +R	0.150	1.168	0.566

4.3.4.4. Basal crop coefficient (K_{cb}) in wheat crop under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

The basal crop coefficient (K_{cb}) values suggested by FAO-56 are 0.15, 1.10, and 0.30 respectively, for the initial, mid season and late season stages in wheat crop. After adjustment for the climate conditions of the study area, the K_{cb} of wheat in the initial stage was 0.15 for all treatments but the K_{cb} value in mid season stage was different for different treatments. The value for K_{cb} in mid season stage for wheat under pigeonpea- wheat cropping system after adjustment was 1.169 under PBB+R, 1.168 under ZT+R, 1.167 under ZT, 1.166 under PBB, 1.163 under PNB+R, 1.161 under PNB and 1.159 under CT treatment. There was no need to adjust K_{cb} value for late season stage because at that stage FAO-56 K_{cb} value is less than 0.45. Therefore K_{cb} values at late stage for wheat crop were 0.30 under all treatments (Table41).

Table 41: Adjusted basal crop coefficient (K_{cb}) of wheat at different crop growth stages under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

Treatment	Initial stage	Mid season stage	Late season stage
CT	0.15	1.159	0.30
PNB	0.15	1.161	0.30
PNB+R	0.15	1.163	0.30
PBB	0.15	1.166	0.30
PBB+R	0.15	1.169	0.30
ZT	0.15	1.167	0.30
ZT +R	0.15	1.168	0.30

4.3.5. Soil evaporation coefficient (K_e) under different conservation practices along with conventional practice in maize-wheat and pigeonpea-wheat cropping system

Soil evaporation coefficient (K_e), as a function of growth period, is affected by the soil water characteristics, exposed and wetted soil fraction, and soil water balance. In the initial stage, the effective fraction of soil surface covered by crop plants was small and thus, soil evaporation losses were considerable during this period. After irrigation, K_e reached its maximum values 1.04-1.11 in maize, 1.10-1.15 in wheat under maize-wheat cropping system and 1.20-1.28 in pigeonpea and 1.09-1.14 in wheat under pigeonpea-wheat cropping system. The cumulative depth of evaporation from the topsoil layer was small because of the low water retention capacity. K_e had a sharp fall when the soil evaporation switched from initial to developing stage. In the development stage, the effective fraction of soil surface covered by crop plants gradually increased and the K_e value decreased step by step. In the mid season stage, the effective fraction of soil surface covered by crop plants reached above 0.9. The soil water losses mainly depended on the crop transpiration. The small exposed soil fraction resulted in a small K_e value. The K_e values ranged between 0.25-0.33 in maize, between 0.15-0.19 in wheat under maize-wheat cropping system and between

0.48-0.55 in pigeonpea and 0.14-0.19 in wheat under pigeonpea-wheat cropping system. In the late season stage, the K_c value was greater than that in the mid season stage because of the drooping of the main leaves.

4.3.6. Crop evapotranspiration (ET_c) using single crop coefficient under different conservation practices along with conventional practice in maize-wheat and pigeonpea-wheat cropping system

4.3.6.1. Crop evapotranspiration (ET_c) using single crop coefficient in maize crop under different conservation practices along with conventional practice in maize-wheat cropping system

During the initial stage of maize crop growth, which was the period from sowing to 20 days of crop growth, the ET_c values were very low except during irrigation events. The ET_c values increased during crop development stage (20-45 days) of crop growth and reached its peak during the midseason stage (45-85 days) due to maximum canopy cover and leaf area index. The ET_c values decline rapidly during the late stage, the period from 85 to 105 days of crop growth because leaves were dried and senescence. Sum of daily values of ET_c for maize crop in initial, development, mid and late stage are given in table 42. Maximum ET_c values were found under CT treatment in all stages of crop growth followed by ZT, ZT+R, PNB, PNB+R, PBB and PBB+R treatment. At initial stage ET_c was found maximum under CT treatment (53.1 mm) followed by ZT (50.3 mm) treatment. ZT+R, PNB, PNB+R had ET_c value nearly 48mm and PBB, PBB+R had ET_c nearly 47 mm. At development stage ET_c increased up to 104.6 mm in CT, 102.7 mm in ZT, 101.8 mm in ZT+R, 99.4 mm in PNB, 98.9 mm in PNB+R, 97.7 mm in PBB and 96.6 mm in PBB+R treatment. Maximum ET_c values in mid season stage were up to 269.7 mm in CT, 264.5 mm in ZT, 262.1 mm in ZT+R, 257.1 mm in PNB, 254.7 in PNB+R, 252.2 mm in PBB and 249.3 mm in PBB+R treatment. At late season stage ET_c gradually decreased up to 55mm in CT, ZT and ZT+R treatments followed by 53 mm in PNB and PNB+R treatment, 52 mm in PBB and PBB+R treatments. Total ET_c value was maximum under CT treatment (483 mm) followed by ZT (473 mm), ZT+R (467 mm), PNB (459 mm), PNB+R (455 mm), PBB (450 mm) and lowest under PBB+R (446 mm).

Table 42: Crop evapotranspiration (ET_c) (mm) using single crop coefficient in maize at different growth stages under maize-wheat cropping system

Treatment	Initial stage ET _c	Development stage ET _c	Mid season stage ET _c	Late season stage ET _c	Total ET _c
CT	53.1 ^a	104.5 ^a	269.7 ^a	55.4 ^a	483 ^a
PNB	48.7 ^c	99.4 ^{bc}	257.1 ^c	53.4 ^a	459 ^c
PNB+R	48.2 ^{cd}	98.9 ^c	254.7 ^{cd}	52.9 ^{ab}	455 ^{cd}
PBB	47.8 ^{cd}	97.7 ^c	252.2 ^{de}	52.4 ^{ab}	450 ^{de}
PBB+R	47.6 ^d	96.6 ^c	249.3 ^e	52.1 ^b	446 ^e
ZT	50.3 ^b	102.7 ^a	264.5 ^b	55.1 ^a	473 ^b
ZT+R	48.9 ^{cd}	101.8 ^{ab}	262.1 ^b	54.8 ^a	467 ^b

4.3.6.2. Crop evapotranspiration (ET_c) using single crop coefficient in wheat crop under different conservation practices along with conventional practice in maize-wheat cropping system

During the initial stage of wheat crop growth, which was the period from sowing to 40 days of crop growth, the ET_c values were very low except during irrigation events. The Etc values were also low in crop development stage (40-70 days) of crop growth and reached its peak value during the midseason stage (70-120 days) of crop growth due to maximum canopy cover and leaf area index. The ET_c values were found more during late season stage, the period from 120 to 150 days of crop growth because of more evapotranspiration losses during March- April month. The sum of daily values of ET_c for wheat in the initial stage, development stage, mid season stage and late season stage are given in table 43. Maximum ET_c values were found under CT treatment in all crop growth stages followed by ZT, ZT+R, PNB, PNB+R, PBB and PBB+R treatment. At initial stage ET_c was found maximum under CT treatment (83.3 mm) followed by ZT (80.5 mm), ZT+R (79.5 mm), PNB (78.6 mm), PNB+R (76.9 mm), PBB (77.7 mm) and PBB+R (74.3 mm). At development stage ET_c decreased up to 64.5 mm in CT, 62.7 mm in ZT, 61.2 mm in ZT+R, 60.1 mm in PNB, 58.6 mm in PNB+R, 57.7 mm in PBB and 55.1 mm in PBB+R treatment. Maximum ET_c values in mid season stage was 211.7 mm in CT, 206.7 mm

in ZT, 204.8 mm in ZT+R, 201.1 mm in PNB, 198.8 mm in PNB+R, 196.1 mm in PBB and 192.8 mm in PBB+R treatment. At late season stage ET_c was 128.3 mm in CT, 125.7 mm in ZT, 120.7 mm in ZT+R, 118.2 mm in PNB, 117.5 mm in PNB+R, 115.6 mm in PBB and 115.4mm in PBB+R treatment. Total ET_c value was maximum under CT treatment (488 mm) followed by ZT (477 mm), ZT+R (466 mm), PNB (458 mm), PNB+R (452 mm), PBB (447 mm) and PBB+R (438 mm) treatment.

Table 43: Crop evapotranspiration (ET_c) (mm) using single crop coefficient in wheat at different growth stages under maize-wheat cropping system

Treatment	Initial stage ET_c	Development stage ET_c	Mid season stage ET_c	Late season stage ET_c	Total ET_c
CT	83.3 ^a	64.5 ^a	211.7 ^a	128.3 ^a	488 ^a
PNB	78.6 ^{bc}	60.1 ^{bcd}	201.1 ^c	118.2 ^{bc}	458 ^d
PNB+R	76.9 ^{bc}	58.6 ^{cd}	198.8 ^{cd}	117.5 ^c	452 ^{de}
PBB	77.7 ^{bc}	57.7 ^{de}	196.1 ^d	115.6 ^c	447 ^e
PBB+R	74.3 ^c	55.1 ^e	192.8 ^e	115.4 ^c	438 ^f
ZT	80.5 ^{ab}	62.7 ^{ab}	206.7 ^b	125.7 ^a	477 ^b
ZT+R	79.5 ^{ab}	61.2 ^{bc}	204.8 ^b	120.7 ^b	466 ^c

4.3.6.3. Crop evapotranspiration (ET_c) using single crop coefficient in pigeonpea crop under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

In pigeonpea crop during the initial stage which was the period from sowing upto 35 days of crop growth, the ET_c values were high because of higher evaporation losses in month of June. At development stage (35-70 days) of crop growth, ET_c was low and reached its peak value during the midseason stage (70-150 days) of crop growth. The ET_c value was found less during the last season stage, the period from 150 to 180 days of crop growth. The sum of daily values of ET_c for pigeonpea in the initial stage, development stage, mid season stage and late season stage are given in table 44. Maximum ET_c values were found under CT treatment at all stages of crop growth followed by ZT, ZT+R, PNB, PNB+R, PBB and PBB+R treatment. At initial stage ET_c was found maximum under CT treatment (163.9 mm) followed by ZT (159.8 mm), ZT+R (157.8 mm), PNB (155.9 mm), PNB+R (153.8 mm), PBB (153.2

mm) and PBB+R (152.6 mm). At development stage ET_c decreased up to 84.6 mm in CT and ZT, 82.9 mm in ZT+R, 82.1 mm in PNB, 79.1 mm in PNB+R, 80.7 mm in PBB and 78.9 mm in PBB+R treatment. Maximum ET_c values were found in mid season stage up to 384.6 mm in CT, 381.2 mm in ZT, 378.9 mm in ZT+R, 375.3 mm in PNB, 374.3 mm in PNB+R, 366.2 mm in PBB and 362.8 mm in PBB+R treatment. At late season stage ET_c was 69.8 mm in CT, 68.7 mm in ZT, 67.9 mm in ZT+R, 66.5 mm in PNB, 65.6 mm in PNB+R, 60.7 mm in PBB and 58.7 mm in PBB+R treatment. Total ET_c value was maximum under CT treatment (703 mm) followed by ZT (694 mm), ZT+R (688 mm), PNB (680 mm), PNB+R (672 mm), PBB (664 mm) and PBB+R (653 mm) treatment.

Table 44: Crop evapotranspiration (ET_c) (mm) using single crop coefficient in pigeonpea at different growth stages under pigeonpea-wheat cropping system

Treatment	Initial stage ET_c	Development stage ET_c	Mid season stage ET_c	Late season stage ET_c	Total ET_c
CT	163.9 ^a	84.6 ^a	384.6 ^a	69.8 ^a	703 ^a
PNB	155.9 ^d	82.1 ^{abc}	375.3 ^d	66.5 ^b	680 ^d
PNB+R	153.8 ^e	79.1 ^c	374.3 ^d	65.6 ^b	672 ^e
PBB	153.2 ^{ef}	80.7 ^{bc}	366.2 ^e	60.7 ^c	664 ^f
PBB+R	152.6 ^f	78.9 ^c	362.8 ^f	58.7 ^c	653 ^g
ZT	159.8 ^b	84.6 ^a	381.2 ^b	68.7 ^{ab}	694 ^b
ZT+R	157.8 ^c	82.9 ^{ab}	378.9 ^c	67.9 ^{ab}	688 ^c

4.3.6.4. Crop evapotranspiration (ET_c) using single crop coefficient in wheat crop under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

During the initial stage of wheat crop growth, which was the period from sowing up to 40 days of crop growth, the ET_c values were very low except during irrigation events. The ET_c values were also low in crop development stage (40-65 days) of crop growth and reached its peak value during the midseason stage (65-110 days) of crop growth due to maximum canopy cover and leaf area index. The ET_c values were found more during the late season stage, the period from 110 to 130 days

of crop growth, during March- April month due to more evapotranspiration losses. Sum of daily values of ET_c for wheat in the initial, development, mid season and late season stages are given in table 45. Maximum ET_c values were found under CT treatment at all stages of crop growth followed by ZT, ZT+R, PNB, PNB+R, PBB and PBB+R treatment. At initial stage ET_c was found maximum under CT treatment (79.7 mm) followed by ZT (77.0 mm), ZT+R (76.1 mm), PNB (75.2 mm), PNB+R (73.5 mm), PBB (74.4 mm) and PBB+R (71.0 mm). At development stage ET_c decreased up to 57.7 mm in CT, 56.3 mm in ZT, 55.8 mm in ZT+R, 55.4 mm in PNB, 54.8 mm in PNB+R, 54.9 mm in PBB and 53.8 mm in PBB+R treatment. Maximum ET_c values was found in mid season stage up to 194.2 mm in CT, 189.7 mm in ZT, 187.8 mm in ZT+R, 184.5 mm in PNB, 182.3 mm in PNB+R, 179.8 mm in PBB and 176.8 mm in PBB+R treatment. At late season stage ET_c was 123.3 mm in CT, 120.8 mm in ZT, 116.1 mm in ZT+R, 113.6 mm in PNB, 112.9 mm in PNB+R, 111.1 mm in PBB and 110.9 mm in PBB+R treatment. Total ET_c value was maximum under CT treatment (455 mm) followed by ZT (444 mm), ZT+R (432 mm), PNB (429 mm), PNB+R (424 mm), PBB (420 mm) and PBB+R (413 mm) treatment.

Table 45: Crop evapotranspiration (ET_c) (mm) using single crop coefficient in wheat crop at different growth stages under pigeonpea-wheat cropping system

Treatment	Initial stage ET_c	Development stage ET_c	Mid season stage ET_c	Late season stage ET_c	Total ET_c
CT	79.7 ^a	57.7 ^a	194.2 ^a	123.3 ^a	455 ^a
PNB	75.2 ^d	55.4 ^{cd}	184.5 ^{cd}	113.6 ^{bc}	429 ^{cd}
PNB+R	73.5 ^f	54.8 ^{bcd}	182.3 ^{de}	112.9 ^{cd}	424 ^{de}
PBB	74.4 ^e	54.9 ^{bcd}	179.8 ^{ef}	111.1 ^d	420 ^e
PBB+R	71.0 ^g	53.8 ^d	176.8 ^f	110.9 ^d	413 ^f
ZT	77.0 ^b	56.3 ^{ab}	189.7 ^b	120.8 ^a	444 ^b
ZT+R	76.1 ^c	55.8 ^{bc}	187.8 ^{Bc}	116.1 ^b	432 ^c

4.3.7. Crop evapotranspiration (ET_c) using dual crop coefficient under different conservation practices along with conventional practice in maize-wheat and pigeonpea-wheat cropping system

4.3.7.1. Crop evapotranspiration (ET_c) using dual crop coefficient in maize crop under different conservation practices along with conventional practice in maize-wheat cropping system

During the initial stage of maize crop growth, which is the period from sowing up to 20 days of crop growth, the ET_c values were very low except during irrigation events. The ET_c values increased during the crop development stage (20-45 days) of crop growth and reached its peak during the mid season stage (45-85 days) of crop growth. The ET_c values decline rapidly during the late season stage, the period from 85 to 105 days of crop growth because leaves were dried and senescence. The sum of daily values of ET_c for maize in the initial stage, development stage, mid season stage and late season stage are given in table 46. Maximum ET_c value was found under CT treatment at all stages of crop growth followed by ZT, ZT+R, PNB, PNB+R, PBB and PBB+R treatment. At initial stage ET_c was found maximum under CT treatment (58.8 mm) followed by ZT (58.1mm), ZT+R (57.8 mm), PNB (57.2 mm), PNB+R (56.3 mm), PBB (56.1 mm) and PBB+R (55.3 mm) treatment. At development stage ET_c increased up to 124.7 mm in CT, 122.8 mm in ZT, 120 mm in ZT+R, 118.5 mm in PNB, 115.3 mm in PNB+R, 114.3 mm in PBB and 112.8 mm in PBB+R treatment. Maximum ET_c values in mid season stage was up to 268.4 mm in CT, 266.7 mm in ZT, 262.8 mm in ZT+R, 260.9 mm in PNB, 259.4 mm in PNB+R, 255.8 mm in PBB and 253.7 mm in PBB+R treatment. At late season stage ET_c gradually decreased up to 47.7 mm in CT, 47.3 mm in ZT, 46.7 mm in ZT+R, 45.6 mm in PNB, 45.3 mm in PNB+R, 45.3 mm in PBB and 44.7mm in PBB+R treatment. Total ET_c value was maximum under CT treatment (500 mm) followed by ZT (495 mm), ZT+R (487 mm), PNB (482 mm), PNB+R (476 mm), PBB (472 mm) and PBB+R (467 mm) treatment.

Table 46: Crop evapotranspiration (ET_c) (mm) using dual crop coefficient in maize at different growth stages under maize-wheat cropping system

Treatment	Initial stage ET _c	Development stage ET _c	Mid season stage ET _c	Late season stage ET _c	Total ET _c
CT	58.8 ^a	124.7 ^a	268.4 ^a	47.7 ^a	500 ^a
PNB	57.2 ^{abc}	118.5 ^d	260.9 ^d	45.6 ^{ab}	482 ^b
PNB+R	56.3 ^{bc}	115.3 ^e	259.4 ^e	45.3 ^{ab}	476 ^c
PBB	56.1 ^{bc}	114.3 ^e	255.8 ^f	45.3 ^{ab}	472 ^{cd}
PBB+R	55.3 ^c	112.8 ^f	253.7 ^g	44.7 ^b	467 ^d
ZT	58.1 ^{ab}	122.8 ^b	266.7 ^b	47.3 ^a	495 ^a
ZT+R	57.8 ^{ab}	120.0 ^c	262.8 ^c	46.7 ^{ab}	487 ^b

4.3.7.2. Crop evapotranspiration (ET_c) using dual crop coefficient in wheat crop under different conservation practices along with conventional practice in maize-wheat cropping system

During the initial stage of wheat crop growth from sowing up to 40 days of crop growth, the ET_c values were very low except during irrigation events. The ET_c values were also low in development stage (40-70 days) of crop growth and reached its peak during the mid season stage (70-120 days) of crop growth due to maximum canopy cover and leaf area index. The ET_c values were found more during the late season stage, the period from 120 to 150 days of crop growth, because of more evapotranspiration losses during March- April month. The sum of daily values of ET_c for wheat in the initial stage, development stage, mid season stage and late season stage are given in table 47. Maximum ET_c values were found under CT treatment at all stages of crop growth followed by ZT, ZT+R, PNB, PNB+R, PBB and PBB+R treatment. At initial stage ET_c was found maximum under CT treatment (69.2 mm) followed by ZT (67.6 mm), ZT+R (67.2 mm), PNB (64.7 mm), PNB+R (63.3 mm), PBB (62.5 mm) and PBB+R (61.3 mm) treatment. At development stage ET_c value was decreased up to 54.0 mm in CT, 52.9 mm in ZT, 52.5 mm in ZT+R, 51.1 mm in PNB, 50.2 mm in PNB+R, 49.5 mm in PBB and 48.8 mm in PBB+R treatment. Maximum ET_c values were found in mid season stage up to 212.2 mm in CT, 207.7 mm in ZT, 205.5 mm in ZT+R, 199.5 mm in PNB, 195.5 mm in PNB+R, 192.6mm in

PBB and 189.7 mm in PBB+R treatment. At late season stage ET_c was 123.3 mm in CT, 121.9 mm in ZT, 118.3 mm in ZT+R, 115.9 mm in PNB, 114.3 mm in PNB+R, 112.6 mm in PBB and 111.7 mm in PBB+R treatment. Total ET_c value was maximum under CT treatment (459 mm) followed by ZT (450 mm), ZT+R (444 mm), PNB (431 mm), PNB+R (423 mm), PBB (417 mm) and PBB+R (411 mm) treatment.

Table 47: Crop evapotranspiration (ET_c) (mm) using dual crop coefficient in wheat at different growth stages under maize-wheat cropping system

Treatment	Initial stage ET_c	Development stage ET_c	Mid season stage ET_c	Late season stage ET_c	Total ET_c
CT	69.2 ^a	54.0 ^a	212.2 ^a	123.3 ^a	459 ^a
PNB	64.7 ^c	51.1 ^c	199.5 ^c	115.9 ^c	431 ^c
PNB+R	63.3 ^d	50.2 ^{cd}	195.5 ^d	114.3 ^{cd}	423 ^d
PBB	62.5 ^e	49.5 ^d	192.6 ^{de}	112.6 ^{de}	417 ^{de}
PBB+R	61.3 ^f	48.8 ^d	189.7 ^e	111.7 ^e	411 ^e
ZT	67.6 ^b	52.9 ^{ab}	207.7 ^b	121.9 ^a	450 ^b
ZT+R	67.2 ^b	52.5 ^b	205.5 ^b	118.3 ^b	444 ^b

4.3.7.3. Crop evapotranspiration (ET_c) using dual crop coefficient in pigeonpea crop under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

In pigeonpea crop during the initial stage which is the period from sowing up to 35 days of crop growth, the ET_c values were high because of higher evaporation losses in month of June. At crop development stage (35-70 days) of crop growth, ET_c was low and reached its peak value during the mid season stage (70-150 days) of crop growth. ET_c values were less during the late season stage, the period from 150 to 180 days of crop growth. Sum of daily values of ET_c for pigeonpea in initial, development, mid season and late season stage are given in table 48. Maximum ET_c values were found under CT treatment at all stages of crop growth followed by ZT, ZT+R, PNB, PNB+R, PBB and PBB+R treatment. At initial stage ET_c was found maximum under CT treatment (94.8 mm) followed by ZT (93.8 mm), ZT+R (92.9 mm), PNB (90.1 mm), PNB+R (88.9 mm), PBB (87.9 mm) and PBB+R (85.7 mm)

treatment. At development stage ET_c decreased up to 68.8 mm in CT, 68.2 mm in ZT, 67.5 mm in ZT+R, 66.8 mm in PNB, 65.7 mm in PNB+R, 63.6 mm in PBB and 60.8 mm in PBB+R treatment. Maximum ET_c values in mid season stage was up to 407.8 mm in CT, 404.7 mm in ZT, 398.9 mm in ZT+R, 394.5 mm in PNB, 389.7 mm in PNB+R, 386.8 mm in PBB and 384.7 mm in PBB+R treatment. At late season stage ET_c was 83.1 mm in CT, 83.7 mm in ZT, 81.9 mm in ZT+R, 80.7 mm in PNB, 78.6 mm in PNB+R, 75.8 mm in PBB and 73.3 mm in PBB+R treatment. Total ET_c value was maximum under CT treatment (655 mm) followed by ZT (651 mm), ZT+R (641 mm), PNB (633 mm), PNB+R (623 mm), PBB (614 mm) and PBB+R (605 mm) treatment.

Table 48: Crop evapotranspiration (ET_c) (mm) using dual crop coefficient in pigeonpea at different growth stages under pigeonpea-wheat cropping system

Treatment	Initial stage ET_c	Development stage ET_c	Mid season stage ET_c	Late season stage ET_c	Total ET_c
CT	94.8 ^a	68.8 ^a	407.8 ^a	83.1 ^a	655 ^a
PNB	90.1 ^d	66.8 ^{bc}	394.5 ^d	80.7 ^b	633 ^c
PNB+R	88.9 ^c	65.7 ^c	389.7 ^e	78.6 ^c	623 ^d
PBB	87.9 ^f	63.6 ^d	386.8 ^f	75.9 ^d	614 ^e
PBB+R	85.7 ^g	60.8 ^e	384.7 ^g	73.3 ^e	605 ^f
ZT	93.8 ^b	68.2 ^{ab}	404.7 ^b	83.7 ^a	651 ^a
ZT+R	92.9 ^c	67.5 ^{ab}	398.9 ^c	81.9 ^{ab}	641 ^b

4.3.7.4. Crop evapotranspiration (ET_c) using dual crop coefficient in wheat crop under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

During the initial stage of wheat crop growth, which is the period from sowing up to 40 days of crop growth, the ET_c values were very low except during irrigation events. The ET_c values were also low in crop development stage (40-65 days) of crop growth and reached its peak during the mid season stage (65-110 days) due to maximum canopy cover and leaf area index. The ET_c values were found more during late season stage, the period from 110 to 130 days of crop growth, in these days more

evapotranspiration losses because of high temperature and wind speed as well as bright sunshine in month of March- April. The sum of daily values of ET_c for wheat in the initial stage, development stage, mid season stage and late season stage are given in table 49. Maximum ET_c values were found under CT treatment at all stages of crop growth followed by ZT, ZT+R, PNB, PNB+R, PBB and PBB+R treatment. At initial stage ET_c was found maximum under CT treatment (76.5 mm) followed by ZT (75.9 mm), ZT+R (74 mm), PNB (70.3 mm), PNB+R (68.8 mm), PBB (67.7 mm) and PBB+R (66.6 mm). At developing stage ET_c values decreased up to 57.3 mm in CT, 57.1 mm in ZT, 55.7 mm in ZT+R, 55.2 mm in PNB, 54.2 mm in PNB+R, 53.5 mm in PBB and 52.7 mm in PBB+R treatment. Maximum ET_c value was found in mid season stage up to 226.7 mm in CT, 224.4 mm in ZT, 217.6 mm in ZT+R, 215.5 mm in PNB, 211.1 mm in PNB+R, 207.9 mm in PBB and 204.8 mm in PBB+R treatment. At late season stage ET_c was 129.4 mm in CT, 128.1 mm in ZT, 124.2 mm in ZT+R, 121.6 mm in PNB, 120.0 mm in PNB+R, 118.2 mm in PBB and 117.3 mm in PBB+R treatment. Total ET_c value was maximum under CT treatment (490 mm) followed by ZT (486 mm), ZT+R (472 mm), PNB (463 mm), PNB+R (454 mm), PBB (447 mm) and PBB+R (441 mm) treatment.

Table 49: Crop evapotranspiration (ET_c) (mm) using dual crop coefficient in wheat at different growth stages under pigeonpea-wheat cropping system

Treatment	Initial stage ET_c	Developing stage ET_c	Mid season stage ET_c	Late season stage ET_c	Total ET_c
CT	76.5 ^a	57.3 ^{ab}	226.7	129.4	490 ^a
PNB	70.3 ^c	55.2 ^{bcd}	215.5 ^d	121.6 ^c	463 ^c
PNB+R	68.8 ^{cd}	54.2 ^{cde}	211.1 ^e	120.0 ^d	454 ^d
PBB	67.7 ^{de}	53.5 ^{de}	207.9 ^f	118.2 ^{de}	447 ^e
PBB+R	66.6 ^e	52.7 ^e	204.8 ^g	117.3 ^e	441 ^e
ZT	75.9 ^a	57.1 ^a	224.4 ^b	128.1 ^a	486 ^a
ZT+R	74.0 ^b	55.7 ^{abc}	217.6 ^c	124.2 ^b	472 ^b

4.3.8. Actual evapotranspiration (ET_a) under different conservation practices along with conventional practice in maize-wheat and pigeonpea-wheat cropping system

4.3.8.1. Actual evapotranspiration (ET_a) in maize crop under different conservation practices along with conventional practice in maize-wheat cropping system

When rainfall or irrigation was low, water stress induced and the evapotranspiration dropped below the standard crop evapotranspiration (ET_c). The effect of soil water stress was described by multiplying the basal crop coefficient by the water stress coefficient (K_s). K_s describe the effect of water stress only on crop transpiration, rather than evaporation from soil. The water stress coefficient frequently dropped below one in initial and developing stage in maize crop indicate that crop plant suffered water stress especially at the end of developing stage. Due to water stress, actual evapotranspiration (ET_a) was decreased below the crop evapotranspiration (ET_c). ET_a from single crop coefficient (SCC) was found maximum under CT (438 mm) followed by ZT (429 mm), ZT+R (423 mm), PNB (419 mm), PNB+R (414 mm), PBB (411 mm) and PBB+R (404 mm) treatment. Similarly from dual crop coefficient (DCC), ET_a was found maximum under CT (449 mm) followed by ZT (441 mm), ZT+R (434 mm), PNB (431 mm), PNB+R (428 mm), PBB (422 mm) and PBB+R (415 mm) treatment. ET_a from water balance method was found maximum 445 mm in CT followed by 442 mm in ZT, 435 mm in ZT+R, 426 mm in PNB, 420 mm in PNB+R, 422 mm in PBB and 412 mm in PBB+R treatment (Table 50). Results showed that crop coefficient methods are useful for determining water stress in crop and daily evapotranspiration losses, water need of crop and irrigation scheduling.

4.3.8.2. Actual crop evapotranspiration (ET_a) in wheat crop under different conservation practices along with conventional practice in maize-wheat cropping system

After some days of irrigation, due to evapotranspiration (ET) losses, water stress induced and ET_a values dropped below the standard crop evapotranspiration, Etc. The effect of soil water stress was given by the water stress coefficient; K_s . The water stress coefficient frequently dropped below one in initial stage and developing

stage. At time of late stage also wheat plant feels water stress. At around 10% of total growing period wheat crop feel water stress. Due to water stress actual evapotranspiration (ET_a) was decreased below the crop evapotranspiration (ET_c). ET_a from single crop coefficient (SCC) was found maximum under CT treatment (437 mm) followed by ZT (426 mm), ZT+R (414 mm), PNB (411 mm), PNB+R (408 mm), PBB (403 mm) and PBB+R (394 mm) treatment. PBB+R treatment had significantly lower ET_a losses than other treatments. ET_a value calculated from dual crop coefficient (DCC) was found maximum under CT (419 mm) followed by ZT (412 mm), ZT+R (401 mm), PNB (395 mm), PNB+R (387 mm), PBB (383 mm) and PBB+R (377 mm) treatment. PBB+R and PBB treatments had similar values. ET_a value calculated from water balance method was found maximum 428 mm in CT followed by 419 mm in ZT, 407 mm in ZT+R, 402 mm in PNB, 393 mm in PNB+R, 389 mm in PBB and 381 mm in PBB+R treatment (Table 51).

Table 50: Actual evapotranspiration (ET_a) (mm) in maize crop under maize-wheat cropping system by single and dual crop coefficient and water balance method

Treatment	ET_c by single crop coefficient	ET_a by single crop coefficient	ET_c by dual crop coefficient	ET_a by dual crop coefficient	Water balance method
CT	483 ^a	438 ^a	500 ^a	449 ^a	445 ^a
PNB	459 ^c	419 ^{cd}	482 ^b	431 ^d	426 ^c
PNB+R	455 ^{cd}	414 ^{de}	476 ^c	428 ^d	420 ^c
PBB	450 ^{de}	411 ^e	472 ^{cd}	422 ^e	422 ^c
PBB+R	446 ^c	404 ^f	467 ^d	415 ^f	412 ^d
ZT	473 ^b	429 ^b	495 ^s	441 ^b	442 ^a
ZT+R	467 ^b	423 ^{bc}	487 ^b	434 ^c	435 ^b
LSD (0.05)	9.2	11.8	10.4	9.1	13.1

Table 51: Actual evapotranspiration (ET_a) (mm) in wheat crop under maize-wheat cropping system by single and dual crop coefficient and water balance method

Treatment	ET _c by single crop coefficient	ET _a by single crop coefficient	ET _c by dual crop coefficient	ET _a by dual crop coefficient	Water balance method
CT	488 ^a	437 ^a	459 ^a	419 ^a	428 ^a
PNB	458 ^d	411 ^{cd}	431 ^c	395 ^c	402 ^d
PNB+R	452 ^{de}	408 ^d	423 ^d	387 ^d	393 ^e
PBB	447 ^e	403 ^e	417 ^{de}	383 ^{de}	389 ^{ef}
PBB+R	438 ^f	394 ^f	411 ^e	377 ^e	381 ^f
ZT	477 ^b	426 ^b	450 ^b	412 ^b	419 ^b
ZT +R	466 ^c	414 ^c	444 ^b	401 ^c	407 ^c
LSD(0.05)	9.2	8.1	8.8	7.6	9.1

4.3.8.3. Actual crop evapotranspiration (ET_a) in pigeonpea crop under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

The water stress coefficient K_s frequently dropped below one in initial and developing stages in pigeonpea crop. Pigeonpea crop feel water stress mostly in initial stage. Due to water stress actual evapotranspiration (ET_a) was decreased below the crop evapotranspiration (ET_c). ET_a calculated from single crop coefficient (SCC) was found maximum under CT treatment (618 mm) followed by ZT (611 mm), ZT+R (601 mm), PNB (586 mm), PNB+R (576 mm), PBB (570 mm) and PBB+R (552 mm) treatment. PBB+R treatment had significantly lower ET_a losses than other treatments. Similarly ET_a calculated by dual crop coefficient (DCC) was found maximum under CT (563 mm) followed by ZT (556 mm), ZT+R (542 mm), PNB (546 mm), PNB+R (536 mm), PBB (531 mm) and PBB+R (525 mm). PBB+R and PBB had non-significant difference in evapotranspiration values but they had significantly lower values than other treatments. ET_a calculated from water balance method was found maximum 592 mm in CT followed by 581 mm in ZT, 574 mm in ZT+R, 572 mm in PNB, 562 mm in PNB+R, 552 mm in PBB and minimum value of ET_a was found

under PBB+R treatment (541 mm) which was significantly lower value than other treatments (Table 52).

Table 52: Actual evapotranspiration (ET_a) (mm) in pigeonpea crop under pigeonpea-wheat cropping system by single, dual crop coefficient and water balance method

Treatment	ET _c by single crop coefficient	ET _a by single crop coefficient	ET _c by dual crop coefficient	ET _a by dual crop coefficient	Water balance method
CT	703 ^a	618 ^a	655 ^a	563 ^a	592 ^a
PNB	680 ^d	586 ^d	633 ^e	546 ^c	572 ^c
PNB+R	672 ^e	576 ^e	623 ^d	536 ^{de}	562 ^d
PBB	664 ^f	570 ^f	614 ^e	531 ^{ef}	552 ^c
PBB+R	653 ^g	552 ^g	605 ^f	525 ^f	541 ^f
ZT	694 ^b	611 ^b	651 ^a	556 ^b	581 ^b
ZT +R	688 ^c	601 ^c	641 ^b	542 ^{cd}	574 ^c
LSD(0.05)	13.4	8.7	8.2	7.1	12.1

4.3.8.4. Actual crop evapotranspiration (ET_a) in wheat crop under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

When irrigation was low, water stress induced and the evapotranspiration dropped below the standard crop evapotranspiration, ET_c. The water stress coefficient frequently dropped below one in initial and developing stage in wheat crop. Due to water stress actual evapotranspiration (ET_a) was decreased below the crop evapotranspiration (ET_c). ET_a calculated from single crop coefficient (SCC) was found maximum under CT (414 mm) followed by ZT (401 mm), ZT+R (391 mm), PNB (387 mm), PNB+R (380 mm), PBB (375 mm) and PBB+R (368 mm). PBB+R treatment had significantly lower ET_a values. PBB and PNB+R treatments had non-significant difference in ET_a by SSC. ZT+R and PNB treatments had non-significant difference. ET_a value calculated from dual crop coefficient (DCC) was found maximum under CT (425 mm) followed by ZT (422 mm), ZT+R (410 mm), PNB (404 mm), PNB+R (397 mm), PBB (391 mm) and PBB+R (379

mm) treatment. PBB+R treatment had significantly lower ET_a values than other treatments. ET_a calculated from water balance method was found maximum 415 mm in CT treatment followed by 406 mm in ZT, 400 mm in ZT+R, 393 mm in PNB, 386 mm in PNB+R, 382 mm in PBB and minimum ET_a found under PBB+R treatment (376 mm) which was significantly differed to other treatments. PNB+R and PBB treatments had non- significant difference (Table 53).

Table 53: Actual evapotranspiration (ET_a) (mm) under wheat crop in pigeonpea-wheat cropping system by single, dual crop coefficient and water balance method

Treatment	ET_c by single crop coefficient	ET_a by single crop coefficient	ET_c by dual crop coefficient	ET_a by dual crop coefficient	Water balance method
CT	455 ^a	414 ^a	490 ^a	425 ^a	415 ^a
PNB	429 ^{cd}	387 ^c	463 ^c	404 ^c	393 ^d
PNB+R	424 ^{de}	380 ^d	454 ^d	397 ^d	386 ^e
PBB	420 ^e	375 ^d	447 ^e	391 ^e	382 ^e
PBB+R	413 ^f	368 ^e	441 ^e	379 ^f	376 ^f
ZT	444 ^b	401 ^b	486 ^a	422 ^a	406 ^b
ZT +R	432 ^c	391 ^c	472 ^b	410 ^b	400 ^c
LSD(0.05)	8.0	8.9	8.8	10.9	12.6

4.3.9. Water use efficiency (WUE) under different conservation practices along with conventional practice in maize-wheat and pigeonpea-wheat cropping system

4.3.9.1. Water use efficiency (WUE) in maize crop under different conservation practices along with conventional practice in maize-wheat cropping system

WUE in maize crop was found lowest under CT treatment by single crop coefficient, dual crop coefficient and water balance method. WUE from single crop coefficient was 9.70 Kg/ha/mm under CT treatment followed by PNB (11.75 Kg/ha/mm), PNB+R (12.78 Kg/ha/mm), ZT (12.61 Kg/ha/mm), ZT+R (13.23 Kg/ha/mm), PBB (13.69 Kg/ha/mm) and PBB+R (14.22 Kg/ha/mm) treatment. WUE calculated from dual crop coefficient was 9.45 Kg/ha/mm under CT treatment

followed by PNB (11.43 Kg/ha/mm), PNB+R (12.37 Kg/ha/mm), ZT (12.26 Kg/ha/mm), ZT+R (12.90 Kg/ha/mm), PBB (13.34 Kg/ha/mm) and PBB+R (13.81 Kg/ha/mm) treatment. WUE from water balance method was 9.54 Kg/ha/mm under CT treatment followed by PNB (11.56 Kg/ha/mm), PNB+R (12.59 Kg/ha/mm), ZT (12.25 Kg/ha/mm), ZT+R (12.88 Kg/ha/mm), PBB (13.34 Kg/ha/mm) and PBB+R (13.91 Kg/ha/mm) treatment. Increase in WUE was 21% under PNB, 31-32% under PNB+R, 28-30% under ZT, 35-37% under ZT+R, 40-41% under PBB, 46-47% under PBB+R estimated by single crop coefficient, dual crop coefficient and water balance method (Fig. 48).

4.3.9.2. Water use efficiency (WUE) in wheat crop under different conservation practices along with conventional practice in maize-wheat cropping system

WUE in wheat crop was found lowest under CT treatment by single crop coefficient, dual crop coefficient and water balance method. WUE calculated from single crop coefficient was 10.94 Kg/ha/mm under CT treatment followed by PNB (11.27 Kg/ha/mm), ZT (11.77 Kg/ha/mm), PNB+R (11.93 Kg/ha/mm), PBB (12.18 Kg/ha/mm), ZT+R (12.49 Kg/ha/mm) and PBB+R (13.41 Kg/ha/mm) treatment. WUE calculated from dual crop coefficient was 11.41 Kg/ha/mm under CT treatment followed by PNB (11.74 Kg/ha/mm), ZT (12.16 Kg/ha/mm), PNB+R (12.57 Kg/ha/mm), PBB (12.82 Kg/ha/mm), ZT+R (12.90 Kg/ha/mm) and PBB+R (14.02 Kg/ha/mm) treatment. WUE calculated from water balance method was 11.16 Kg/ha/mm under CT treatment followed by PNB (11.52 Kg/ha/mm), ZT (12.18 Kg/ha/mm), PNB+R (12.38 Kg/ha/mm), PBB (12.78 Kg/ha/mm), ZT+R (12.81 Kg/ha/mm) and PBB+R (13.95 Kg/ha/mm) treatment. Increase in WUE estimated by single crop coefficient, dual crop coefficient and water balance method was 3.0-3.2% under PNB, 6.5-9% under ZT, 9-11% under PNB+R, 11-14.5% under PBB, 13-14.7% under ZT+R, 22.5-25.0% under PBB+R treatment (Fig. 49).

4.3.9.3. Water use efficiency (WUE) in pigeonpea crop under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

WUE in pigeonpea crop was found lowest under CT treatment by single crop coefficient, dual crop coefficient and water balance method. WUE calculated from

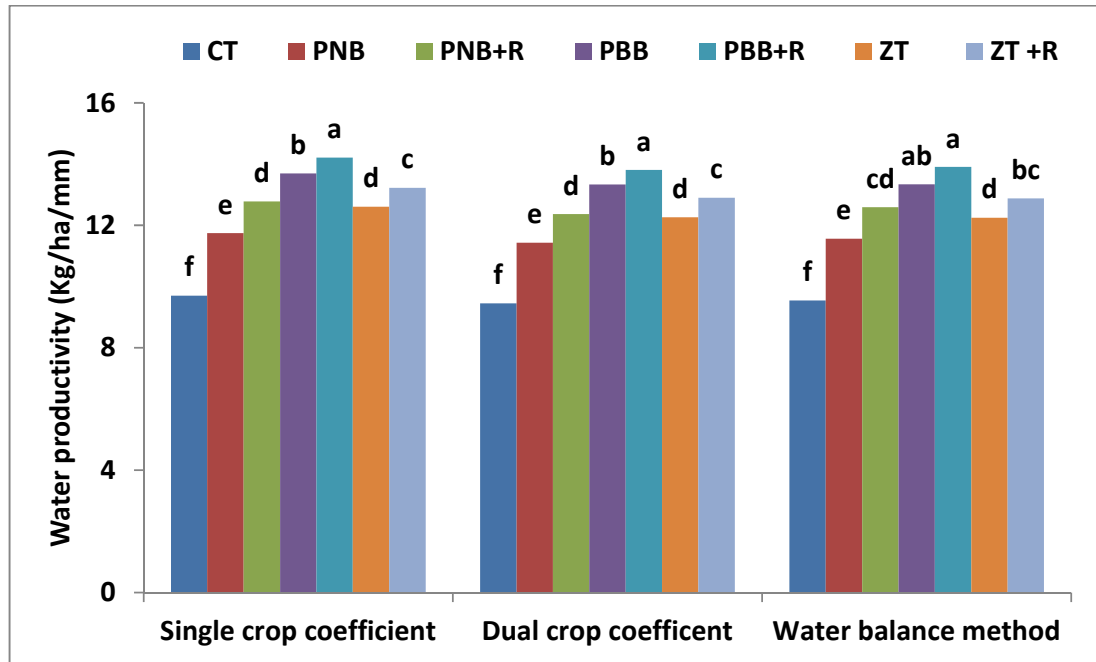


Fig.48. Water use efficiency (WUE) under different conservation practices along with conventional practice in maize during crop growing season in maize –wheat cropping system

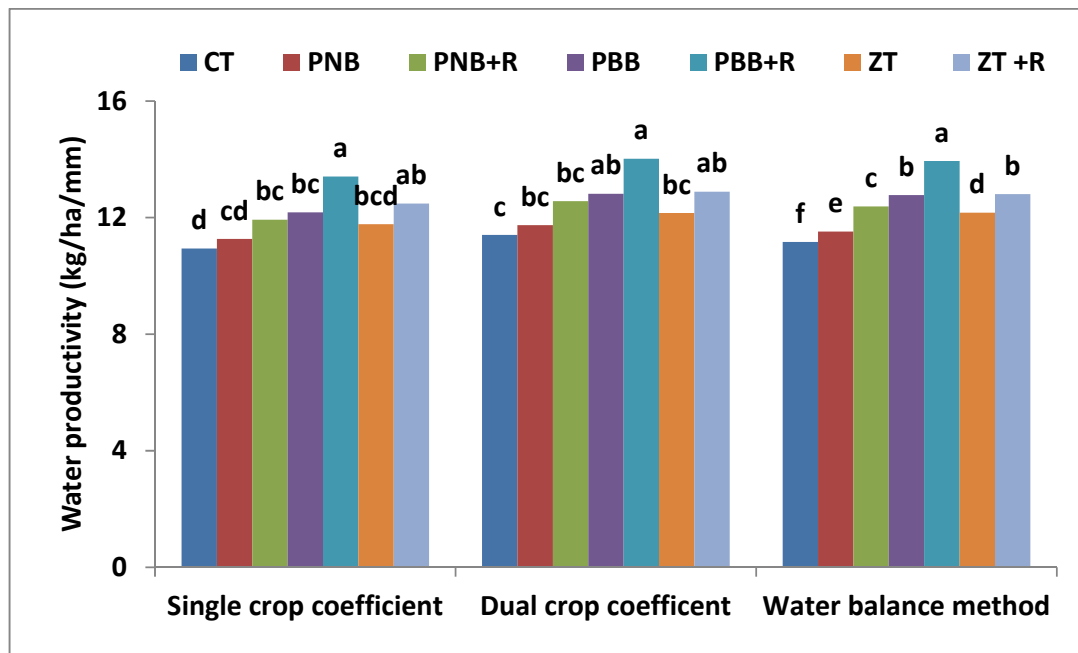


Fig.49. Water use efficiency (WUE) under different conservation practices along with conventional practice in wheat during crop growing season in maize –wheat cropping system

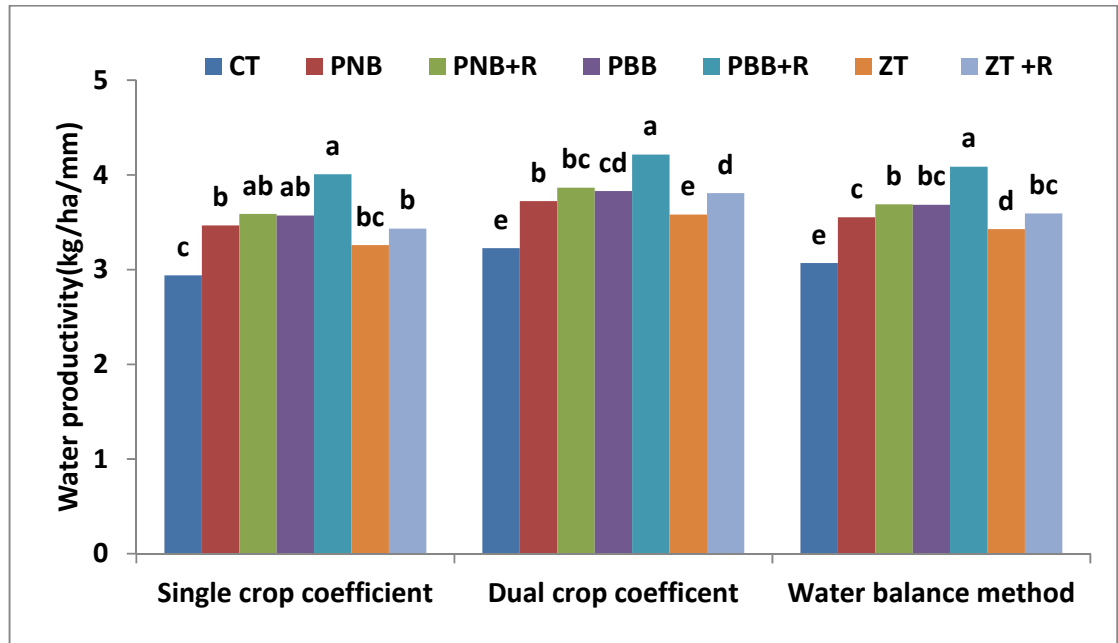


Fig.50. Water use efficiency (WUE) under different conservation practices along with conventional practice in pigeonpea during crop growing season in pigeonpea -wheat cropping system

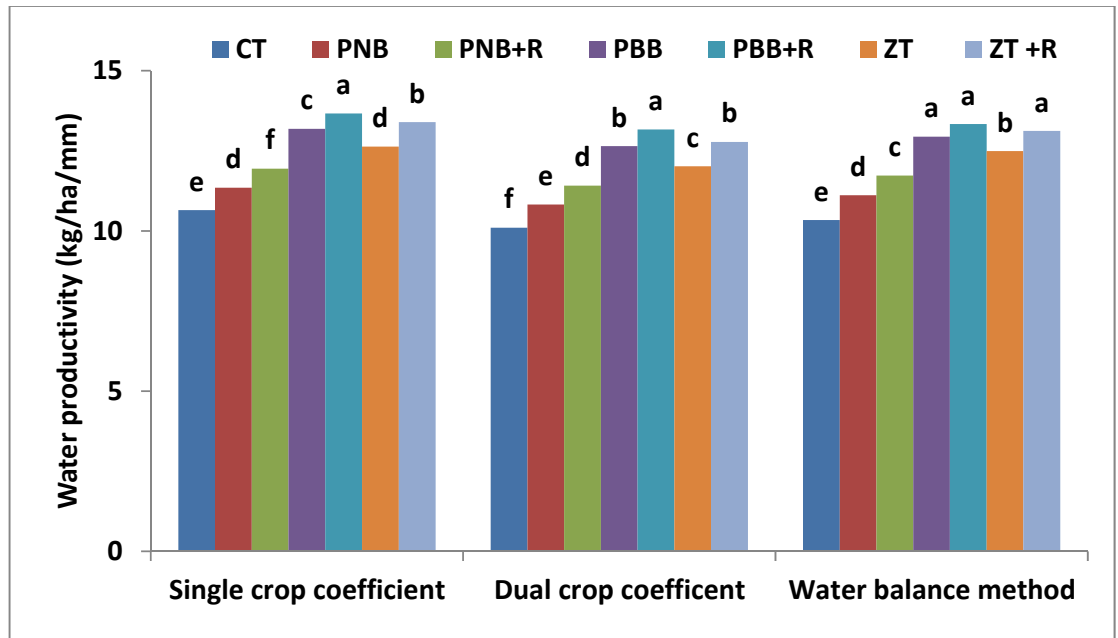


Fig.51. Water use efficiency (WUE) under different conservation practices along with conventional practice in wheat during crop growing season in pigeonpea -wheat cropping system

single crop coefficient was 2.94 Kg/ha/mm under CT treatment followed by ZT (3.26 Kg/ha/mm), ZT+R (3.43 Kg/ha/mm), PNB (3.47 Kg/ha/mm), PBB (3.57 Kg/ha/mm), PNB+R (3.59 Kg/ha/mm) and PBB+R (4.01 Kg/ha/mm) treatment. WUE calculated from dual crop coefficient was 3.23 Kg/ha/mm under CT treatment followed by ZT (3.58 Kg/ha/mm), PNB (3.72 Kg/ha/mm), ZT+R (3.81 Kg/ha/mm), PBB (3.83 Kg/ha/mm), PNB+R (3.87 Kg/ha/mm), and PBB+R (4.22 Kg/ha/mm). WUE calculated from water balance method was 3.07 Kg/ha/mm under CT treatment followed by ZT (3.43 Kg/ha/mm), PNB (3.55 Kg/ha/mm), ZT+R (3.59 Kg/ha/mm), PBB (3.68 Kg/ha/mm), PNB+R (3.69 Kg/ha/mm) and PBB+R (4.09 Kg/ha/mm) treatment. Increase in WUE calculated by single crop coefficient, dual crop coefficient and water balance method was 15-18 % under PNB, 11-12% under ZT, 19.7-22.0% under PNB+R, 18.6-22.0 % under PBB, 17-18% under ZT+R, 31-36% under PBB+R treatment (Fig. 50).

4.3.9.4. Water use efficiency (WUE) in wheat crop under different conservation practices along with conventional practice in pigeonpea-wheat cropping system

WUE in wheat crop was found lowest under CT treatment by single crop coefficient, dual crop coefficient and water balance method. WUE calculated from single crop coefficient was 10.65 Kg/ha/mm under CT treatment followed by PNB (11.35 Kg/ha/mm), PNB+R (11.94 Kg/ha/mm), ZT (12.64 Kg/ha/mm), PBB (13.19 Kg/ha/mm), ZT+R (13.40 Kg/ha/mm) and PBB+R (13.67 Kg/ha/mm). WUE calculated from dual crop coefficient was 10.10 Kg/ha/mm under CT treatment followed by PNB (10.83 Kg/ha/mm), PNB+R (11.42 Kg/ha/mm), ZT (12.02 Kg/ha/mm), PBB (12.65 Kg/ha/mm), ZT+R (12.78 Kg/ha/mm) and PBB+R (13.17 Kg/ha/mm) treatment. WUE calculated from water balance method was 10.34 Kg/ha/mm under CT treatment followed by PNB (11.12 Kg/ha/mm), PNB+R (11.73 Kg/ha/mm), ZT (12.49 Kg/ha/mm), PBB (12.94 Kg/ha/mm), ZT+R (13.12 Kg/ha/mm) and PBB+R (13.34 Kg/ha/mm) treatment. Increase in WUE calculated by single crop coefficient, dual crop coefficient and water balance method was 6.5-8% under PNB, 12-13.5% under PNB+R, 18.6-21% under ZT, 23.5-25% under PBB, 25.6-27% under ZT+R and 28-30% under PBB+R treatment (Fig .51).

5. Discussion

Agriculture cannot sustain the growing human population on current damaging rate of natural resources. But with the burgeoning population, food security would be the major issue which the world will have to face in coming decades. Due to over exploitation, natural resources are degrading at an alarming rate. The main challenge for agricultural scientists is to increase food production on sustainable way without increase in crop acreage. So, the modern agricultural practices like conservation agriculture may help farmers to accomplish the goal of sustainable agricultural production. Studies have been conducted on various aspects of conservation agriculture, such as agronomy, soil nutrients, physical, chemical and biological properties of soil. No study has been done till now on how microenvironment within crop canopies is being modified by this practice and its implications on growth and yield as well as biotic and abiotic stresses. Apart from increase in food production, conservation agriculture is expected to have positive impacts on environment including reversing/mitigation of climate change effects. These are reduction in greenhouse gases, maintenance of soil health and quality and is less dependent on harmful chemicals such as pesticides.

Conservation agriculture which includes reduced tillage, residue incorporation and crop rotation offers vast potential in this respect which is still untapped. It is a known fact that weather and climate have main influence on crop production. But more specifically, it is the microenvironment which depends on weather of the location and the crop management practices that plays the most vital role in overall production. In this study, investigation was done on the effects of various conservation practices showing differences in microenvironment within the crop canopy and quantified through micrometeorological parameters, such as soil temperature and moisture, heat indices, air temperature and relative humidity within canopy and photosynthetically active radiation etc. which influence the microenvironment of the crop to a great extent.

In this research under maize-wheat and pigeonpea-wheat cropping system includes seven treatments like permanent narrow bed with and without residue (PNB+R, PNB), zero tillage flat bed with and without residue (ZT+R, ZT) and permanent broad bed with and without residue (PBB+R, PBB) including conventional

treatment (CT). Soil moisture is the most limiting factor in semi-arid and rainfed areas. In the present study efficient use of water is addressed through permanent bed systems in which ridge and furrow were used to raise the soil bed following the tillage. During the study, we found minimum soil moisture under PNB and PBB treatments before application of irrigation but they had sufficient soil moisture to fulfill crop water requirements. ZT, ZT+R and CT treatments had flood irrigation but under PBB, PBB+R, PNB and PNB+R treatments, water application was in furrows. Similar result observed by Aggarwal and Goswami (2003). According to them the lower application of water and the higher and increased infiltration due to highly porous soil leads to low soil moisture in the bed. As the irrigation was applied at around 20-22 days intervals, the soil moisture in the bed was less in comparison to conventional planting but it always remained higher than its value at wilting point (4-5% w/w). Residue plots had higher soil moisture content than CT and non residue plots because residue reflect solar radiation, resist heat and vapour transfer lead to adjustment in energy balance, reduce soil degradation by increase organic matter in soil and improve soil water holding capacity. Limon-Ortega *et al.* (2002) indicated the minimum soil disturbances, retained crop residue at the surface and needful restructuring of beds between two crop successions were the main reason behind the maximum soil moisture in the PBB+R treatment. Diaz Zorita *et al.* (2002), He *et al.* (2006) and Bhattacharyya *et al.* (2008) observed higher soil water storage under ZT+R than CT treatment.

According to Radke (1982), Mascagni and Sabbe (1990) the higher soil temperature was found under PNB and PBB treatments was due to the lower soil moisture in the soil bed in comparison to conventional treatment. Thus in comparison to conventional planting the soil temperature will be always higher in bed as compared to corresponding value of aerial temperature. At initial stage, soil temperature variation between treatments was more because at that time crop residue effect was dominant and crop shading effect was less. When crop growth increases crop residue degraded and due to crop shading soil temperature difference within treatments decreased.

Growing degree days values were lower under conventional than conservation treatment because due to heat stress, plant maturity reached early as compared to conservation treatment. Under conservation treatments crop had slightly longer crop

growing period because they need more accumulation of heat from germination to maturity. Among all treatments PBB+R treatment took maximum time to reach physiological maturity in both cropping systems. According to BK *et al.* (2013), longer days to maturity were observed in treatment which retains the residue than the treatment without residue, this might be due to the availability of moisture in no tillage and residue used treatments which caused longer time for physiological maturity. Long-time retention of crop residue may have increased organic matter in soil leading to higher mineralization of nutrient. Delayed senescence and higher succulence of plants retained the green colour for longer time due to higher nitrogenous level. GDD, HTU, PTI, PTU and RTD indices were found higher in conservation treatments as compared to corresponding value in CT treatment. The characterization and understanding of crop phenology is most important for fertilization and irrigation practices (Streck *et al.*, 2008). It is useful to assess if the most critical stages of growth occur during periods of favourable weather and soil fertility conditions. Air temperature based agro meteorological indices *viz.*, growing degree days (GDD) and photothermal index (PTI) have been used to describe changes in phenological behaviour and growth parameters (Streck *et al.*, 2008; Kumar *et al.*, 2010). Crop phenology is primarily affected by the air temperature and secondarily by the soil temperature.

During initial crop growth period, there was no difference in air temperature and relative humidity within canopy but with crop growth plant height increased, leaf area expanded so on a clear day, the canopy temperature is supposed to decrease from the top to the bottom as the shading effect of leaves cool down the canopy downwards because less penetration of solar radiation occurs due to dense canopy. During this period of crop growth there was significant difference in air temperature and relative humidity within crop canopy. Kredl *et al.* (2012) suggested that ground level had lower temperature and increased with increasing effective canopy height in the wheat and rape stands. Relative humidity (RH) profile showed opposite trend with respect to that of temperature profile i.e. RH within the canopy was higher than above the canopy in all treatments because less sensible heat within the crop canopy and lesser temperature variations from top to bottom of canopy by lesser transmission of solar radiation to bottom of canopy and higher water vapour accumulation due to transpiration losses from crop plants, less air movement. At later stages of crop

growth when crop near to maturity due to senescence of leaves again the temperature and relative humidity difference within treatments gradually decreased and become negligible. Under Conservation treatments due to favourable microenvironment conditions, the stomatal conductance had more value which controls both photosynthetic assimilation and water losses through transpiration. The crop residue restricted evaporation and conserve soil moisture, while water moves from deeper soil layers to topsoil by capillarity action, thereby more topsoil-water promote more transpiration in conservation treatments.

Biophysical parameters had better performance under conservation treatments than CT treatment. Biomass, LAI, plant height etc had maximum values under PBB+R treatment under both maize-wheat and pigeonpea-wheat cropping system. In both cropping system for wheat crop, the biophysical parameters were better under PBB+R treatment followed by ZT+R, ZT, PBB, PNB+R and PNB treatment. In maize crop the biophysical parameters were better under PBB+R treatment followed by PBB, ZT+R, ZT, PNB+R and PNB treatment. In pigeonpea crop residue treatments performed better than other treatments. In conservation tillage nearly 30% crop residue was put in plots. Due to the cellulose in plant residue, returning this material as compost decreases the bulk density, endorses the creation of soil aggregate organization and enhancement in the efficiency of water in soil (Edwards *et al.*, 2000; Tejada and Gonzalez, 2006). Soil fertility was enhanced due to transfer of certain quantity of carbohydrate, N, P, K, and additional nutrients in residues applied to soil was transferred to organic matter (Zayed and Abdel-Motaal, 2005; Benito *et al.*, 2006; Ribeiro *et al.*, 2007; Roca-Pérez *et al.*, 2009). Increased organic matter and improved physico-chemical properties of soil provides better environment to beneficial microorganisms which returns the residue as compost (Zayed and Abdel-Motaal, 2005; Ros *et al.*, 2006; Bougnom *et al.*, 2010). Ros *et al.* (2006) reported that the returned compost further enhances the soil enzyme activity by increasing the extent of enzymes and their substrates in the soil. Joshi *et al.* (2009) and Yogev *et al.* (2009) observed that the above mentioned improvements finally enhances the root vigour and physiological parameters, chlorophyll content, photosynthetic rate and carbohydrate content of plants. Other parameter such as growth rate, plant performance, quality and yield also increase simultaneously (Tejada and Gonzalez, 2006; Roca-Pérez *et al.*, 2009). The results obtained from the correlation analysis indicates that grain yield was

highly significant and positively correlated with growing degree days at harvest showed that more accumulation of thermal indices result higher grain yield, because more temperature accumulation increase physiological activities, which results higher grain yield. Higher amount of chlorophyll content was recorded in conservation treatments compared to conventional treatment. Beltrano and Ronco (2008) reported that moderate to severe water stress reduces the chlorophyll content in wheat leaves which is further supported by the results that water deficit inhibits the chlorophyll synthesis and sensitive wheat unable to withstand with this condition (Jones, 1985; Sikuku *et al.*, 2010)

Relative water content, water potential, transpiration rate etc were maximum under PBB+R treatment followed by other ZT treatments. Lower Relative water content under CT showed that crop was exposed to higher degree of water stress as compared to conservation treatments. Hence the crop under conservation system was able to better supplement demand for the transpiration compared to CT. This was due to results of greater amount of conserved water in soil and sufficient accessible nitrogen, particularly in later growth period. Leaf water potential is widely used to quantify the water deficit in leaf tissues; it measures the energetic status of water inside the leaf cells. This showed that due to deteriorated soil condition in conventional treatment plants were in more stress than the plant grown under other conservation treatments.

Due to favourable microenvironment conditions under CA treatments, yield was more than CT. Straw mulching was found to increase 100-seed weight and yield attributes (Yi *et al.*, 2007 and Wang *et al.*, 2011). Further they confirmed that instead of half straw mulching the effects of full-straw mulching were superior, due to increased soil moisture content by 27.9 and 27.6% for two consecutive years of experimentation. Khan and Pervej (2010) and Wang *et al.* (2011) indicated optimum soil temperature and soil moisture due to wheat straw mulches were the probable reason for increased in the dry matter accumulation in plant.

The nitrogen from the left over crop residue (stubble) supplements the *N* requirement of developing plant. It is established that minimum tillage mixes crop residues more in top soil then the other tillage operations which accumulate more residue in deeper layers. Steiner *et al.* (1999) revealed that top soil decomposes the crop residues faster than deeper soil. This is well revealed that the inorganic N

fertilizer releases the N rapidly than plant and microbial residues but the need based supply is better of organic N from plant and microbial residues (Dinnes *et al.*, 2002). Thus during the late growth stage of plant growth the residue behave as potential nitrogen source which is effectively enhancing grain protein and yield, which further support that the decomposition of residue in late crop growth phase of maize (when the soil N content is low) is responsible for higher grain yield through minimum tillage and residue retention treatment. Izumi *et al.* (2004) reported that uninterrupted no-tillage practice progressively enriched the soil state for the root system development and also, improve the crop growth and yield, through improving the growth attributes.

During the present study conservation treatments had more plant height as compared to conventional treatment. Maximum plant height was obtained under PBB+R treatment which may be attributed by means of reduced soil compaction, improved soil aeration and uniform distribution of nutrients particularly in early growth phase of the crop (Bennie & Botha, 1986). According to Pervez *et al.* (2009) maize crop was found taller due to availability of higher moisture content under the greater level of mulch. Gajri *et al.* (1994) reported that higher water infiltration and moderates soil temperature in the course of intensive rain under the conservation tillage. According to Smart and Bradford (1999) conservation tillage decreases the economical cost through subsiding the number of field operations, labour cost, fuel, tractors in comparison with conventional tillage system hence providing the greater returns. Although without sufficient organic mulch possibility of conserving soil moisture with only tillage treatment will not be adequate in comparison to conventional tillage system (Gicheru *et al.*, 1998). Vidhana Arachchi and Liyanage (2003) revealed that additional build-up of leaf litter conserved the soil moisture through reducing the evapotranspiration from the compact soil layer. Crop residues reduced wind speed and increased photosynthetic area that enhances the efficiency of net carbon assimilation (Cutforth *et al.*, 1997). Scopel *et al.* (1998) studied the effect of the mulch on radiation in their experiment and found that interception was significant and varied with residue quality and with the percentage of soil cover. Osei-Bonsu *et al.* (1996) reported that in conservation practices, legume green manures is used for nitrogen fixation which further covers the ground which cuts soil erosion, assists in weed control and reduces compactness of intensely cultivated soils.

Aggarwal & Goswami (2003) and Gupta *et al.* (2007) reported that practice of rising of seedling in raised bed- furrow seeding system in northwest India gave significant reduction of water utilization and obtaining higher yields for a range of crops, in comparison with the flat bed with flood irrigation traditional system followed by the farmers.

Afuakwa and Crookston, (1984) reported increased leaf area under conservation treatment plots sighting the reason of various environmental factor. Increased quantity of surface residue was found to have a significant effect on plant available water, thus lowering the water stress and causing increase in LAI (Scopel *et al.*, 2004). Leaf area index (LAI) is an important parameter for the crop growth studies since it is useful in interpreting the capacity of a crop for producing dry matter in terms of the intercepted utilization of radiation and amount of photosynthesis synthesized. The seasonal profile of LAI showed a rapid increase during vegetative phase (seedling to flowering) then reached a peak and thereafter it decreases due to senescence. Sangakkara *et al.* (2004) observed 21 and 10 % increase in leaf area indices of cassava and sweet potato respectively due to incorporation of legume leaf mulch. Supply of nitrogen from rapid decay of legume leaves and conserved moisture could be the reason behind the better plant growth of the plant which is similar to our findings.

Faster leaf area growth caused higher PAR interception in field crops during the vegetative stage (Tsubo *et al.*, 2001). Natarajan and Willey (1980) and Sivakumar and Virmani, (1980) reported that variation in radiation interception, depends on canopy leaf area from seedling emergence to crop harvest. According to Addo-Quaye *et al.* (2011) during initial growth phases the greater PAR conversion efficiencies may be obtained through higher distribution efficiency of light over the greater leaf area of crop canopies. Furthermore, several workers (Reddy and Willey, 1981; Sivakumar and Virmani, 1984; Watiki *et al.*, 1993) revealed that leaf area and radiation interception follow the same patterns. Bonhomme (2000) suggested that crop canopy could intercept 85% PAR only when crop had larger leaf area and this supported our finding that less fIPAR was observed in treatments which had less leaf area in conventional treatment and zero tillage narrow bed treatment. These treatments showed slow initial growth which produced lower leaf area resulting in lesser interception of photosynthetically active radiation. Radiation use efficiency (RUE) in

different crops under both cropping systems increases gradually from vegetative stage to flowering stage because after that assimilated biomass transfer to grain formation to fulfil nitrogen needed for grain filling which cause leaves yellowing and senescence so declines leaf photosynthesis capacity and RUE. Long *et al.* (2006) had mentioned in their study that changes in the efficiency of light interception as well as light utilization could improve photosynthesis and yield potential up to 50%. Difference in biomass accumulation over the years were also observed by Lindquist *et al.* (2005) due to variations in radiation interception, which further vary particularly because of variations in leaf area indices. The shoot mass was found to be increased in both the summer and winter crops by 20 and 9% respectively (Shah *et al.*, 2003).

Incorporation of legume leaves enhanced dry matter accumulation in cassava and sweet potato Sangkarra *et al.* (2004) reported significant correlation existed between crop growth rates and leaf area indices for both cassava and sweet potato ($r^2=0.714$ and $r^2= 0.843$ respectively). The yields of field pea, flax and spring wheat in zero tillage and minimum tillage were found to be increased by 9%, 23% and 21% over conventional tillage respectively (Lafond *et al.*, 1991). Interaction of tillage and straw application was significant with 46% to 70% grain yield (Mesfine *et al.*, 2005). Scopel *et al.* (2004) revealed that effective reduction in water loss and increment in yield might be a result of small quantity of crop residue. Khan *et al.* (2008) observed in their study that emergence was significantly delayed (12.1 day) in deep ploughed (DT) plots in comparison to minimum ploughed (MT) plots (11.3 day). Energy reaching to surface can be limited by surface residue which decreases soil water evaporation. Thus, this water was prevented from being lost into the atmosphere and was stored (Scopel *et al.*, 2004). According to Mulumba and Lal (2007) water availability can be increased by 18–35%, total porosity by 35–46% and soil moisture retention at low suctions from 29 to 70% through use of mulching. Therefore, residues made more availability of moisture to plants during crop growth period that resulted in higher biomass accumulation and higher yield. The above mentioned results are reinforced by Khan *et al.* (2009) who further revealed that in zero tillage crops produced higher grain yield in comparison to conventional and deep tillage crop. Habtegebrial *et al.* (2007) states that nitrogen contributes significantly in improving soil fertility hence resulting enhanced vegetative growth and biomass of maize (Ogola *et al.*, 2002). Deficiency of nitrogen delays plant growth and

development leads to reduction in yield. Tolk *et al.* (1999) compared the mulched soil with bare soil for grain yield and reported significant increase in grain yield in case of mulched soil. Reddy *et al.* (2002) further reinforced that soil physical characteristics like infiltration rate, bulk density and hydraulic conductivity can be improved by incorporation of crop residues like wheat straw combined with fertilizer and zero tillage practices. According to Khurshid *et al.* (2006) increased tillage practice can significantly reduce the bulk density. According to Aulakh *et al.* (2000) mulch aid in improved root and augmented maize grain yield by increasing plant N-uptake competence, dropping N release losses and improving nutrient preservation over un-mulched plots.

Now days many advanced countries like America and Australia are following the practices of straw mulch magnificently to improve soil characteristics such as ability to retained moisture, prevention of wind erosion, weeds control, nutrient supplying ability and finally the improvement in soil structure. Higher level of conserved water and better soil physical conditions in conservation tillage and wheat straw mulch might be the reason for taller plant. Some other worker (Pervez *et al.*, 2009; Vetsch & Randall, 2002) also observed that mulching with tillage induces greater plant height, grain yield and biological yield. Stone *et al.* (1999) reported that maize development is controlled by the temperature of the meristem. Rosner *et al.* (2008) reported that tillage is most important among insect pest, diseases, weeds influx, seasonal changes, irrigation and post-harvest losses which is accountable for lowering maize yield. Tillage is the foundation of any crop production system and is the principal factor in maize production. It upholds the available structure or improves the ailing structured soils. Nill and Nill (1993) reported that changed soil physical, chemical and biological characteristics due to wheat straw mulch treatments leads to higher number of grains per cob. Shirani *et al.* (2002) and Albuquerque *et al.* (2001) supported these findings by reporting that zero tillage and mulch application increase the height of plant, number of green leaves, number of grains per ear and grain weight. Khurshid *et al.* (2006) reported significant correlation between number of cobs per plant and interaction effect of mulching and tillage. Gaultney *et al.* (1980) also reported 45-50 per cent yield reduction in maize due to subsoil compaction. Allmaras *et al.* (1988) also found lower yield as a result of root growth restrictions under subsoil compaction. Boomsma *et al.* (2009) reported that maize grown in zero

tillage might utilised the nitrogen and water up to 40 cm of deep root zone leading to increase in chlorophyll contents and finally higher protein content. Minimum photosynthesis in conventional treatment found in maize-wheat and pigeonpea-wheat cropping system. Lawlor (2002) termed the decline in photosynthesis in water stress as metabolic limitations, whereas Tezara *et al.* (1999) cited ATP synthesis deterioration as main reason. On the other hand, Cornic and Fresneau (2002) intense lycited the stomatal closure as main reason for reduced photosynthesis rates in water stressed condition. They explained that the higher value of photosynthesis can be obtained by supplying adequate quantity of CO₂ to the leaves. Flexas *et al.* (2004) stated that the lower photosynthesis rates under water deficit conditions is the combined result of water stress and plant species or cultivars, age of the plant and leaves, the light intensity and other factors.

Various methods are used to estimate ET_c, but the most popular and widely used technique relies on empirical crop coefficients (K_c) (Jensen and Allen, 2000). In our research single and dual crop coefficient methods were used to calculate ET_c which was adjusted by water stress coefficient to calculate ET_a. Although the K_c and K_{cb} exhibited similar kind of response to different treatments but K_{cb} was able to produce some higher difference during mid season stage with respect to different tillage and residue treatments. During this active growth period the percentage of bare ground was very less due to the faster development of canopy which made the transpiration component much higher than that of evaporation. K_{cb} is more related to transpiration than K_c which integrates both the transpiration and evaporation components, that indicates that K_{cb} better indicator of crop water use.

Plant parameters influencing the crop coefficient calculation are soil cover and plant height and climatic correction for relative humidity and wind speed. Similarly methods of irrigation also influence the K_c values. Bandyopadhyay and Mallick (2003) observed that non- significant difference existed between estimated and FAO reported K_c values of predetermined four stages for wheat but our results suggest that the estimated K_c and K_{cb} values in maize-wheat and pigeonpea-wheat cropping system were differed from FAO values. This may be attributed to the fact that earlier study was made under the humid tropical climatic conditions whereas our study was conducted under the semi-arid subtropical climatic regions of Delhi.

This ushered the need of development of regional and growth stage-specific crop coefficient values of different crops for precise application of irrigation water which otherwise lead to over or under irrigation having negative impacts. Su *et al.* (2002) reported the seasonal maximum water use of maize under surface irrigation conditions at the experimental site was 651.6 mm, with the average values of water in the initial, development, mid-season and late season stages were 1.2, 2.7, 5.3, and 3.3 mm day⁻¹ respectively. Cai *et al.* (2003) reported 600 mm ET_c value for the maize growing season at Jingtai irrigation district. At Hexi area of Gansu province 621 mm average ET_c value was reported by Liu *et al.* (2005). Variation in crop canopy, climatic conditions, soil-crop management and irrigation method regulates the crop water requirement which may vary with growing period of the crop. Approximately 99% of water intake by plants accounts for evapotranspiration (ET) and hence that the control of actual crop evapotranspiration (ET_c) at regular scale over the entire vegetative cycle can be assumed as equivalent to the water for a given crop. Evapotranspiration losses were found maximum under CT, ZT treatment where flood irrigation was given. Under residue practices less evapotranspiration was found. In our study water use efficiency was found maximum under PBB+R treatment. Residue helps to retain more soil moisture, reduce evapotranspiration and increase capacity of soil to provide more water to crop. Higher water use efficiency is indicated by higher grain yield by means of application of equal water. The results are further supported with the outcomes of Limon-Ortega *et al.* (2002), increased in the grain yield of maize was due to retained residue in summer planting. Conservation agriculture is most important management practices in agriculture for increasing the water use efficiency through decreasing the soil evaporation with retained crop residue. The crop residue cover helps in decreasing soil temperature, retention of soil moisture and decrease in soil evaporation and soil erosion (Wilhelm *et al.*, 1986; Gajri *et al.*, 1994; Fawcett and Towery, 2002).

Permanent soil cover can be maintained with the help of permanent raised beds for better rainwater harvest and conservation (Govaerts *et al.*, 2005, 2007). The advantages of permanent raised beds are better than conventional zero tillage (ZT with flat planting) in terms of saving irrigation water and weeding. Akbar *et al.* (2007) pointed the advantages of broad-beds and narrow-beds in the maize-wheat cropping system where they reported about 36 and 10 % water saving under broad-beds and

narrow-beds respectively compared to flat sowing. They further observed an increase of 6 and 33% in grain yield for wheat and maize respectively in Pakistan. In broad-beds and narrow-beds systems the furrows act as rain harvesting and conserving structure in dryer spells and drainage structure during excessive rains (Astatke *et al.*, 2002).

Information of accurate crop water requirement is vital for water resources management and irrigation scheduling in order to enhance water use efficiency at regional, national and global scale (Hamdy and Lacirignola, 1999; Katerji and Rana, 2008). Therefore, it is necessary to improve the water use efficiency in agriculture to sustain the natural input resource (water) and the crop production in order to meet the demand of food for billions of people in coming future. This can only be achieved by employing proper technologies for saving of irrigation water at the time of each application.

6. Summary & Conclusions

Conservation agriculture offers a powerful option for meeting future food demands while also contributing to sustainable agriculture and rural development. Conservation agriculture methods can improve the efficiency of input, increase farm income, improve or sustain crop yields, protect and revitalize soil, biodiversity and the natural resource base. Conservation agriculture provides knowledge and tools to enable farmers to achieve acceptable profits from high and sustained crop production levels, conserving resources and protecting the environment. Conservation agriculture methods enhanced natural biological processes above and below the ground by reducing interventions such as mechanical soil tillage to an absolute minimum. They also ensure that application of external inputs, such as agrochemicals and mineral or organic nutrients, does not interfere with, or disrupt, biological processes. To study impact of different conservation treatments along with conventional treatment on microenvironment and biophysical parameters of maize, wheat crop in maize-wheat cropping system and pigeonpea, wheat crop in pigeonpea-wheat cropping system, experiments were conducted during *kharif* and *rabi* season of 2014-15 and 2015-16 at research farm of ICAR- Indian Agricultural research Institute, New Delhi.

During *kharif* (2014), Maize (*Zea mays* L.) variety BIO 9637 was sown on 5th July and during *rabi* (2014-15) wheat (*Triticum aestivum* L.) variety CSW 18 was sown on 10th November in the maize-wheat cropping system. In 2015-16 during *kharif* season Pigeonpea (*Cajanus cajan* L.) variety Pusa 992 was shown on 30th May 2015 and during *rabi* wheat (*Triticum aestivum* L.) variety HD 3117 shown on 11th December 2015 in the pigeon pea-wheat cropping system. The field experiment was conducted with sowing of crop in seven treatments, conventional tillage (CT), permanent narrow-bed without residue (PNB), permanent narrow-bed with residue (PNB+R), permanent broad-bed without residue (PBB), permanent broad-bed with residue (PBB+R), zero tilled flat bed without residue (ZT), zero tilled flat bed with residue (ZT+R) with three replications arranged in a randomized block design (RBD).

Different micrometeorological parameters viz., soil moisture and temperature at different soil depth, heat indices, air temperature and relative humidity within crop canopy etc were measured at experimental site in both the season at different interval for knowing the microenvironment under different conservation treatments along with

conventional treatment. Different growth parameters viz., leaf area, plant height, biomass, leaf water potential, relative water content, chlorophyll content etc were measured at different days after sowing for understanding the effect of different microenvironment under different conservation treatments along with conventional treatment on crop growth. Yield and yield attributes calculated after harvesting of crop. Intercepted photosynthetically active radiation and radiation use efficiency, photosynthesis rate, stomatal conductance, transpiration rate were also measured at different days after sowing. Water use efficiency was calculated by soil water balance method, single crop coefficient and dual crop coefficient. From the study following results were drawn:

- Soil moisture content under different treatments was found to be highest value under ZT+R followed by ZT, PBB+R, PNB+R, CT, PBB and PNB treatment.
- Soil moisture had more value under residue treatments (13-22%) because they reflect solar radiation, resist heat vapour transfer and improve water holding capacity of soil.
- PNB, PBB treatments had 10-20% lower soil moisture as compared to CT treatment but it was sufficient to fulfil crop water demand resulting saving of irrigation water.
- Soil temperature had reverse trend of soil moisture. PNB treatment had maximum temperature followed by PBB, CT, PNB+R, PBB+R, ZT and ZT+R treatment.
- Soil temperature on the bed remained always 0.5–3.7 °C higher than on the flat surface therefore planting on beds is preferred in winters when soil temperatures are suboptimal, as seed germination, growth of the seedlings in the initial stage and root as well as crop growth improved in the conservation treatments.
- Different thermal indices like GDD, HTU, PTU, PTI and RTD had higher values under different conservation treatments than conventional treatment because physiological maturity delay under conservation treatments due to better crop microenvironment as compared to conventional treatment (CT).

- Heat use efficiency (HUE) had significantly higher value under conservation treatments than CT.
- Air temperature within canopy measured at 2.30 PM was lower under conservation treatments than CT and relative humidity (RH) showed reverse trend. PBB+R had 1-1.4 °C lower air temperature and 6-7.7% higher RH than CT at flowering stage.
- Photosynthesis rate, stomatal conductance and transpiration rate had significantly lower value under conventional treatment as compared to corresponding value in different conservation treatments.
- In maize, PBB+R and PBB treatments had better result followed by ZT+R. In wheat crop PBB+R and ZT+R treatments had better values as compared to other treatments in both cropping systems. For pigeonpea PBB+R, PNB+R and ZT+R treatments showed best results as compared to corresponding value in other treatments.
- Biomass and other biophysical parameters like, LAI, plant height, RWC, water potential and chlorophyll content had maximum values under PBB+R treatment followed by other conservation treatments. Least values were found under conventional treatment.
- Increase in biomass under PBB+R was 37% in maize, 29% in wheat under maize-wheat cropping system and 21% in pigeonpea and 32% in wheat under pigeonpea-wheat cropping system as compared to CT.
- LAI under PBB+R was 16% higher in maize, 15% in wheat under maize-wheat cropping system and 18% in pigeonpea and 21% in wheat under pigeonpea-wheat cropping system as compared to CT.
- Increase in plant height under PBB+R treatment was 20-25% than corresponding value in CT in maize-wheat and pigeonpea-wheat cropping system.
- RWC was 10-15% higher in PBB+R treatment over CT under both cropping systems.
- Increase in water potential was 17% in maize, 19% in pigeonpea and 10-12% in wheat crops under PBB+R treatment than corresponding value in CT.
- Chlorophyll content under PBB+R was 18% higher in maize, 15% higher in

wheat under maize-wheat cropping system and 19% higher in pigeonpea and 20% higher in wheat under pigeonpea-wheat cropping system as compared to CT.

- Maximum LAI under PBB+R treatment indicates more interception of photosynthetically active radiation resulting higher CIPAR and RUE under PBB+R treatment as compared to other treatments.
- Increase in RUE under PBB+R was 20% in maize, 23% in wheat under maize-wheat cropping system and 26% in pigeonpea and 28% in wheat under pigeonpea-wheat cropping system as compared to CT.
- Yield and yield attributes had maximum values under PBB+R treatment. Grain yield under PBB+R was 25% higher in maize, 16% higher in wheat under maize-wheat cropping system and 17% higher in pigeonpea and 19% higher in wheat under pigeonpea-wheat cropping system as compared to corresponding values in CT.
- System productivity had more values in pigeonpea-wheat cropping system than maize-wheat cropping system.
- Estimated reference evapotranspiration and pan evaporation had good correlation at R^2 value of 0.87 for maize and 0.89 for wheat crop in maize-wheat cropping system and R^2 value of 0.86 for pigeonpea and 0.92 for wheat in pigeonpea-wheat cropping system.
- Different stages, initial, development, mid and late season stages were calculated based on the crop coverage data as suggested by FAO-56 had different value for different crops under different treatments.
- The adjusted value of single and basal crop coefficient had initially lower value, increase during development phase reached maximum during mid season stage and then decline during late stage.
- Soil evaporation coefficient K_e was low except during irrigation and precipitation events.
- The value of crop evapotranspiration was found to be more during mid season stage in all crops with respect to different treatments and weather condition.
- The value of crop evapotranspiration was decreased due to water stress in field and calculated with help of soil water stress coefficient K_s .

- The crop evapotranspiration (ET_c) and actual evapotranspiration (ET_a) values calculated by single crop coefficient, dual crop coefficient and water balance method were found higher values under CT, ZT and ZT+R treatments because they had flood irrigation. PNB, PNB+R, PBB and PBB+R had less value due to furrow irrigation. Residue treatment had lower water loss by residue and improvement in water holding capacity.
- Water requirement in crops can be estimated more accurately by dual crop coefficient approach as compared to single crop coefficient and water balance method as it includes both soil and crop coefficient.
- Water use efficiency by single crop coefficient, dual crop coefficient and water balance method had maximum values under PBB+R treatment and lowest value under conventional treatment.
- PBB+R treatment had 30-33% higher WUE in maize, 23-27% higher value in wheat as compared to corresponding value in conventional treatment under maize- wheat cropping system.
- In pigeonpea-wheat cropping system, PBB+R had 30-35% higher WUE in pigeonpea and 28-30% higher WUE in wheat as compared to conventional treatment.

From the above result following conclusion can be draw:

- Incorporation of conservation treatments helps to maintain favourable microenvironment like improving soil moisture, RH, soil and air temperature than conventional treatment.
- The effect of favourable microenvironment under conservation treatments led to better resource use efficiency in term of higher HUE, RUE and WUE in both cropping system.
- PBB+R management practice is recommended for adoption by farmers for improving productivity under maize-wheat and pigeon pea-wheat cropping system in semi arid region of Indo-Gangetic area.
- Pigeonpea-wheat cropping system has relative advantage over maize-wheat cropping system in term of overall system productivity.
- Dual crop coefficient method is useful for determine water stress in crop and to calculate daily evapotranspiration losses, water need of crop and for irrigation scheduling.

Characterization of micrometeorology under different crop environments

ABSTRACT

Conservation agriculture comprises three principles: reduced soil disturbance, maintaining soil cover with crop residues or green manures, and diversifying cropping systems. The practice is widely promoted around the world, in both developed and developing countries. It is promoted for its natural resource saving practice; maintain soil fertility, to fight against soil erosion, desertification and better use of scarce water resources. It also recognise due to its economic benefits, increase production, reduce production cost and labour reduction, increase farm income and better production stability, hence better food security. CA also shows a new benefit in fighting against global warming by increase carbon sequestration in soil.

Keeping these in mind experiments were conducted during *kharif* and *rabi* season of 2014-15 & 2015-16 at research farm of ICAR- Indian Agricultural research Institute, New Delhi to study microenvironments under different conservation treatments along with conventional treatment and their effect on biophysical parameters and yield of maize, wheat crop in maize-wheat cropping system and pigeonpea, wheat crop in pigeon pea-wheat cropping system. During *kharif* (2014), Maize variety BIO 9637 was shown on 5th July and during *rabi* (2014-15) wheat variety CSW 18 sown on 10th November in the maize-wheat cropping system. In 2015-16 during *kharif* season, Pigeonpea variety Pusa 992 was shown on 30th May and during *rabi* wheat variety HD 3117 shown on 11th December in pigeon pea-wheat cropping system.

The field experiment was conducted with sowing of crop in seven treatments, conventional tillage (CT), narrow-bed without residue (PNB), narrow-bed with residue (PNB+R), permanent broad-bed without residue (PBB), permanent broad-bed with residue (PBB+R), zero tilled flat bed without residue (ZT), zero tilled flat bed with residue (ZT+R) arranged in a randomized block design (RBD) with three replications. Observations on different weather parameters (air temperature and relative humidity within crop canopy), soil moisture and soil temperature, heat indices, photosynthesis rate, stomatal conductance, transpiration rate, crop growth parameters like leaf area, biomass, plant height, chlorophyll content, leaf water

potential, relative water content and Intercepted photosynthetically active radiation, RUE were measured at different days after sowing. Adjusted single and dual crop coefficient values for semi-arid climate of Delhi were calculated with help of FAO-56 method. Water use and water use efficiency were computed by single crop coefficient and dual crop coefficient and water balance method.

Results showed that the microenvironment was improved under different conservation practices. Soil moisture had more value under residue treatments due to reflect solar radiation and improve water holding capacity of soil. Soil temperature showed opposite trend of soil moisture. Thermal indices like GDD, HTU, PTU and PTI had non-significant difference under different conservation treatments as compare to conventional treatment but HUE had significantly higher value under conservation treatments as compared to conventional treatment. Air temperature within canopy had lower value in conservation practices as compared to conventional treatment and relative humidity showed opposite trend. Stomatal conductance, Photosynthesis rate, transpiration rate, biomass, plant height, water potential, relative water content, leaf area, different yield attributes and grain yield was found higher value under conservation treatments than conventional treatment. Better crop growth, yield and RUE in conservation treatments over conventional treatment could be due to the additional nutrient by crop residue, improved soil physical properties and water regimes, better water extraction, aeration and nutrient use in conservation treatments. System productivity had higher value in pigeonpea-wheat cropping system than maize-wheat system. Lower evapotranspiration was observed in PBB+R, PBB, PNB+R and PNB treatment due to less water application and reflection of radiation by residue etc. Among all treatments, PBB+R showed better microenvironment for crop growth and gave higher grain yield, WUE, RUE and HUE than the other treatments. Thus, PBB+R management practice could be adopted by farmers for improving crop productivity in the maize-wheat and pigeon pea-wheat cropping system in semi-arid region of Indo-Gangetic area.

From the above studies it can be concluded that conservation practices provide a new, multi-benefit tool for crop production. It provides favourable microenvironment for crop growth, increase crop production, better use of scarce water resources, hence give better food security at sustainable use of natural resources.

सूक्ष्म मौसम विज्ञान का विभिन्न फसलीय वातावरणों के अंतर्गत विवरण

सारांश

संरक्षित कृषि के तीन सिद्धान्तों में मृदा का अतिशेष खलल, फसल अवशेषों तथा हरित खाद द्वारा आच्छादन एवं फसल प्रणालियों में विविधता शामिल हैं। इस पद्धति को विश्वभर के विकसित एवं विकासशील देशों में व्यापक रूप से बढ़ावा दिया जा रहा है। यह प्रणाली प्राकृतिक संसाधनोंकी बचत के लिए, मृदा उर्वरकता संरक्षण, मृदा अपरदन, मरुस्थलीकरण के प्रतिरोध एवं दुर्लभ जल संसाधनों के बेहतर उपयोग के लिए प्रेरित करती है। इसकी पहचान अपने आर्थिक लाभो, कृषि उत्पादन वृद्धि, उत्पादन लागत में कमी, श्रम में कमी, बेहतर कृषि आय, बेहतर उत्पादन स्थिरता अंततः बेहतर खाद्य सुरक्षा के रूप में की जाती है। संरक्षित कृषि मृदा में अधिक कार्बन अधिग्रहण वृद्धि के द्वारा ग्लोबल वार्मिंग के विरुद्ध लड़ने में भी सहायक सिद्ध प्रतीत होती है।

उपरोक्त तथ्यों को ध्यान में रखते हुए वर्ष २०१४-१५ एवं २०१५-१६ के खरीफ तथा रबी मौसम के दौरान भारतीय कृषि अनुसन्धान परिषद्-भारतीय कृषि अनुसन्धान संस्थान, नई दिल्ली के अनुसन्धान क्षेत्र में परंपरागत तथा संरक्षित उपचारों का सूक्ष्म वातावरणीय परिवेश में मक्का-गेंहू फसल चक्र में मक्का एवं गेंहू तथा अरहर एवं गेंहू का अरहर-गेंहू फसल चक्र में जैव-भोतकीय मापदंडों एवं उपज का अध्ययन किया गया। इस अध्ययन में मक्का-गेंहू फसल चक्र में खरीफ, २०१४ के दौरान मक्के की बायो ९६३७ किस्म की ५ जुलाई तथा रबी, २०१४-१५ के दौरान १० नवंबर को गेंहू की किस्म सीएसडब्ल्यू १८ की बुवाई की गई। अरहर-गेंहू फसल चक्र में खरीफ, २०१५-१६ के दौरान ३० मई को अरहर की किस्म पुसा ९९२ तथा रबी के दौरान ११ दिसंबर को गेंहू की किस्म एचडी ३११७ की बुवाई की गई।

सात उपचारों क्रमशः परंपरागत जुताई (सी.टी.), अवशेष अवधारण रहित संकीर्ण शय्या (पी.एन.बी.), अवशेष अवधारण सहित संकीर्ण शय्या (पी.एन.बी.+आर.), अवशेष अवधारण रहित व्यापक शय्या (पी.बी.बी.), अवशेष अवधारण सहित व्यापक शय्या (पी.बी.बी.+आर.), अवशेष रहित शुन्य जुताई वाली सपाट शय्या (जेड.टी.), अवशेष सहित शुन्य जुताई वाली सपाट शय्या (जेड.टी.) पर तीन प्रतिकृतियों में आर.बी.डी. व्यवस्था में बुवाई की गई। फसल की बुवाई तिथि के उपरांत विभिन्न मौसमीय मापदंडो जैसे कि फसल पादपों के अंदर तापमान एवं सापेक्षित आद्रता, मृदा आद्रता एवं मृदा तापमान, तापीय सुचकांक, प्रकाश संश्लेषण दर, रन्दीय संचालन, प्रस्वेदन दर तथा फसल वृद्धि मापदंड जैसे पत्ती क्षेत्रफल सुचकांक, पौधे की ऊंचाई, पर्णहरित मात्रा, पत्ती जल क्षमता, सापेक्षीय जल मात्रा, अवरोधित प्रकाश संश्लेषण विकिरण मात्रा, विकिरण उपयोग दक्षता आदि का अलग अलग दिनों में माप लिया गया।

दिल्ली के अर्ध-शुष्क जलवायु के लिए समायोजित एकल एवं दोहरे फसल गुणांक मान की एफ़.ए.ओ.-५६ विधि की सहायत से गणना की गई। जल उपयोग एवं जल उपयोगी दक्षता

की एकल फसल गुणांक तथा जल संतुलन विधि द्वारा गणना की गई। परिणामों में विभिन्न संरक्षण परिपाटियों के कारण सूक्ष्म वातावरणीय परिवेश में सुधार पाया गया। परिवर्तित सोर विकिरणों एवं बेहतर जल धारण क्षमता के कारण अवशेष उपचारों में मृदा आद्रता का माप अधिक पाया गया जबकि मृदा तापमान में विपरीत रुझान प्रतीत हुए। परंपरागत उपचारों की तुलना में तापीय सूचकांक जैसे जी.डी.डी., एच.टी.यु. एवं पि.टी.आई. में कोई महत्वपूर्ण अंतर नहीं पाया गया लेकिन परंपरागत उपचारों की तुलना में संरक्षण उपचारों में एच.ई.यु., का स्तर उल्लेखनीय ढंग से अधिक पाया गया। संरक्षित उपचारों में परंपरागत उपचारों की तुलना में फसल के अंदर वायवीय तापमान कम पाया गया जबकि सापेक्षित आद्रता के रुझान विपरीत पाए गये। परंपरागत उपचारों की तुलना में संरक्षित उपचारों में रन्ध्रिय संचालन, प्रकाश संश्लेषण दर, प्रस्वेदन दर, बायोमास, पत्ती जल क्षमता, पौधों की ऊंचाई, सापेक्षीय जल मात्रा, पत्ती क्षेत्रफल सूचकांक, विभिन्न उपज विशेषांक तथा उपज में अधिकता पाई गई।

संरक्षित उपचारों में बेहतर फसल वृद्धि, आर.यु.ई. एवं उपज का कारण फसल अवशेषों से अतिरिक्त पोषकों की आपूर्ति, मृदा के बेहतर भौतिक गुण, जल संगठन, बेहतर जल खिंचाव, मृदा में हवा का बेहतर संचालन एवं पोषक उपयोगिता हैं। मक्का-गेहूँ फसल चक्र की तुलना में अरहर-गेहूँ फसल चक्र में तंत्रीय उत्पादकता का मान अधिक पाया गया है। पी.बी.बी.+आर., पी.बी.बी., पी.एन.बी. + आर. एवं पी.एन.बी. उपचारों में कम पानी तथा फसल अवशेषों के द्वारा सोर विकिरणों के परावर्तन के कारण वाष्पीकरण कम पाया गया। सभी उपचारों सभी की तुलना में पी.बी.बी.+आर., फसल वृद्धि, उच्चतम उपज, डब्लू.यु.ई. तथा आर.यु.ई. बेहतर सूक्ष्म वातावरणीय परिवेश प्रदान करता है। अंततः किसान पी.बी.बी.+आर. प्रबंधन प्रणाली को भारतीय अर्ध-शुष्क गंगा नदी क्षेत्रों के मक्का-गेहूँ एवं अरहर-गेहूँ फसल चक्र में फसल उत्पादकता में सुधार हेतु अपना सकते हैं।

उपरोक्त अध्ययनों से यह निष्कर्ष निकाला जा सकता है कि संरक्षण प्रणाली फसल उत्पादन के लिए एक नया, बहु-लाभकारी विकल्प है। यह प्राकृतिक संसाधनों के संपोषणीय उपयोग के द्वारा दुर्लभ जल संसाधनों का बेहतर इस्तेमाल, फसलों के विकास एवं उत्पादन वृद्धि के लिए अनुकूल सूक्ष्म वातावरणीय परिवेश प्रदान करती है, इसलिए खाद्य सुरक्षा के लिए यह एक बेहतरीन विकल्प है।

Bibliography

- Aase, J.K. and Siddoway, F.H. (1990). Stubble height effects on seasonal microclimate, water balance, and plant development of no-till winter wheat. *Agricultural and Forest Meteorology* **21**: 1-20.
- Abdelhadi, A.W., Hata, T., Tanakamaru, H., Tada, A. and Tariq, M.A. (2000). Estimation of cropwater requirements in arid region using Penman–Monteith equation with derived crop coefficients: a case study on Acala cotton in Sudan Gezira irrigated scheme. *Agricultural Water Management* **45**: 203-214.
- Addo-Quaye, A. A., Darkwa, A. A., and Ocloo, G. K. (2011). Yield and productivity of component crops in a maize-soybean intercropping system as affected by time of planting and spatial arrangement. *Journal of Agricultural and Biological Science* **6**(9): 50-57.
- Afuakwa, J. J. and Crookston, N. R. (1984). Using the kernel milk Line to monitor grain maturity in Maize. *Crop Science* **24**(4): 687-691.
- Agenbag, G.A. and Maree, P.C.J. (1991). Effect of tillage on some soil properties, plant (*Triticum aestivum* L.) in Arid Northwest China. *Journal Integrated Agriculture* **11**: 1286-1296.
- Aggarwal, P. and Goswami, B. (2003). Bed planting system for increasing water-use efficiency of wheat (*Triticum aestivum* L.) grown on Inceptisol (Typic Ustochrept). *Indian Journal of Agricultural Sciences* **73**:422-425.
- Aggarwal, P., Choudhary, K.K., Singh, A.K. and Chakraborty, D. (2006). Variation in soil strength and rooting characteristics of wheat in relation to soil management. *Geoderma* **136**: 353-363.
- Aikins, S.H.M, Afuakwa, J.J. and Akuoko, O.O. (2012). Effect of four different tillage practices on maize performance under rainfed conditions. *Agriculture and Biology Journal of North America* **3**(1): 25-30.
- Akbar, G., Hamilton, G., Hussain, Z. and Yasin, M. (2007). Problems and potentials of permanent raised bed cropping systems in Pakistan. *Pakistan Journal of Water Research* **11**: 11–21.

- Albright, L.D., Wolfe, D. And Novak, S. (1989). Modelling row straw mulch effects on microclimate and yield II. *Journal of the American Society for Horticultural Science* **114**: 569-578.
- Albrizio, R. and Steduto, P. (2005). Resource use efficiency of field-grown sunflower, sorghum, wheat and chickpea. I. Radiation use efficiency. *Agricultural and Forest Meteorology* **130**: 254-268.
- Albuquerque, J.A., Sangoi, L. and Ender, M. (2001). Modification in the soil physical properties and maize parameters including by cropping and grazing under two tillage systems. *Revista- Brasileira- de- Ciencia- do- Solo* **25**(3): 717-723.
- Ali, M., Joshi, P.K., Pande, S., Asokan, M., Virmani, S.M., Kumar, R. and Kandpal, B.K. (2000). Legumes in Rice and Wheat Cropping Systems of the Indo-Gangetic Plain-Constraints and Opportunities, International Crops Research Institute for the Semiarid Tropics/Cornell University, Patancheru, India/Ithaca, New York, USA pp. 35-70.
- Allen, R.G., Pereira, L.S., Raes, D., and Smith, M. (1998). Crop evapotranspiration– Guidelines for Computing Crop Water Requirements. Irrigation and Drainage. Paper No. 56, FAO, Rome, Italy.
- Allmaras, R.R., Kraft, J.M. and Miller, D.E. (1988). Effects of soil compaction and incorporated crop residue on root health. *Annal Review Phytopathology* **26**: 219-43.
- Alvear, M., Rosas, A., Rouanet, J.L. and Borie, F. (2005). Effects of three soil tillage systems on some biological activities in an Ultisol from southern Chile. *Soil Tillage Research* **82**: 195–202.
- Andrade, F.H., Uhart, S.A. and Cirilo, A. (1993). Temperature affects radiation use efficiency in maize. *Field Crops Research* **32**: 17-25.
- Anwer, R., Mckenzie, B.A. and Hill, G.D. (2003). Water use efficiency and the effect of water deficits on crop growth and yield of Kabuli chickpea (*Cicer arietinum* L.) in a cool-temperate subhumid climate. *The Journal of Agricultural Science* **141**: 285-301.
- Arnon, D.I. (1949). Copper enzymes in isolated chloroplasts. Polyphenoloxidases in *Betavulgaris*. *Plant Physiology* **24**:241-249.

- Arora, V.K., Gajri, P.R. and Prihar, S.S. (1991). Tillage effects on corn in sandy soils in relation to water retentivity, nutrient and manure on some soil physical properties and wheat root growth in a sandy loam soil in western Iran. *Soil Tillage Research* **104**: 173–179.
- Arshad, M.A. and Martin, S. (1999). Identifying critical limits for soil quality indicators in agro-ecosystems. *Agriculture, Ecosystems and Environment* **88**(2):153-160.
- Aslam, M., Hashmi, N.I., Majid, A. and Hobbs, P.R. (1993). Improving wheat yield in the rice-wheat cropping system of the Punjab through fertilizer management. *Pakistani Journal of Agricultural Research* **14**: 1-7.
- Astatke, A., Jabbar, M., Mohamed, M.A. and Erkossa, T. (2002). Technical and economical performance of animal drawn implements for minimum tillage-experience on vertisols in Ethiopia. *Experimental Agriculture* **38**: 185-196.
- Aulakh, S.M., Khera, T.S., Doran, J.W., Singh, K. and Singh, B. (2000). Yields and nitrogen dynamics in a rice-wheat system using green manure and inorganic fertilizer. *Soil Science Society of American Journal* **64**:1867-1876.
- Azam-Ali, S.N., Crout, N.M.J. and Bradley, R.G. (1994). Perspectives in modelling resource capture by crops. In: Monteith, J.L., Scott, R.K., Unsworth, M.H. (Eds.), *Resource Capture by Crops*. Nottingham University Press, Nottingham, pp. 125–148.
- Baez-Gonzalez, A.D., Kiniry, J.R., Maas, S.J., Tiscareno, M.L., Macias, C., Mendoza, J.L., Richardson, C.W., Salinas, J.G. and Manjarrez, J.R. (2005). Large-area maize yield forecasting using leaf area index based yield model. *Agronomy Journal* **97**:418-425.
- Baker, C.J., Saxton, K.E. and Ritchie, W.R. (2002). No-tillage seeding, science and practice. In *CAB International 2nd edn*. Oxford, UK.
- Ball-Coelho, B.R., Roy, R.C. and Swanton, C.J. (1998). Tillage alters corn root distribution in coarse-textured soil. *Soil Tillage Research* **45**: 237–249.
- Bandyopadhyay, P.K. and Mallick, S. (2003). Actual evapotranspiration and crop coefficients of wheat (*Triticum aestivum* L.) under varying moisture levels of

- humid tropical canal command area. *Agricultural Water Management* **59**:33–47.
- Barrs, H.D. (1968). Determination of water deficits in plant tissue. In: Kozlowski, T.T. (Ed) *Water deficits and plant growth*. New York, Academic Press. **1**: 235-368.
- Barrs, H.D. and Weatherley, P.E. (1962). Re-examination of the relative turgidity technique for estimating water deficits in leaves. *Australian Journal of Biological Sciences* **15**:413-428.
- Baumhardt, R.L. and Jones, O.R. (2002). Residue management and tillage effects on soil-water storage and grain yield of dryland wheat and sorghum for a clay loam in Texas. *Soil Tillage Research* **68**: 71-82.
- Bavec, F. And Bavec, M. (2002). Effect of plant population on leaf area index, cob characteristics and grain yield of early maturing maize cultivars (FAO 100-400). *European Journal of Agronomy* **16**: 151-159.
- Begum, F.A. and Paul, N.K. (1993). Influence of soil moisture on growth, water use and yield of mustard. *Journal of Agronomy and Crop Science* **170**: 136-141.
- Beltrano, J. and Ronco, M.G. (2008). Improved tolerance of wheat plants (*Triticum aestivum* L.) to drought stress and rewatering by the arbuscular mycorrhizal fungus *Glomus claroideum*: Effect on growth and cell membrane stability. *Brazilian Journal of Plant Physiology* **20**: 29-37.
- Benbi, D.K. (1994). Prediction of leaf area indices and yield of wheat. *Journal of Agricultural Sciences Cambridge* **122**: 13-20.
- Benito, M., Masaguer, A., Moliner, A. and Antonio, R.D. (2006). Chemical and physical properties of pruning waste compost and their seasonal variability. *Bioresource Technology* **97**: 2071-2076.
- Bennie, T.P. and Botha, F.J.P. (1986). Effect of deep tillage and controlled traffic on root growth, water use efficiency and yield of irrigated maize and wheat. *Soil Tillage Research* **7**: 85-95.
- Benson, G.O. (1985). Why the reduced yields when corn follows corn and possible management responses. Proceedings of the *Corn and Sorghum Research* held at Chicago. pp. 971-972

- Bezerra, F.M.L. and Oliveira, C.H.C. (1998). Evapotranspirac,ã o ma'xima e coeficientes de cultura nos esta'dios fenolo'gicos da melancia (*Citrullus vulgaris* L.) irrigada atrave's de tre^s me'todos. In: Anais do 278 Congresso Brasileiro de Engenharia Agri'cola, 1998, Poc,os de Caldas, Brazil, SBEA, pp 242-244.
- Bhattacharya, R., Tuti, M.D., Kundu, S., Bisht, J.K. and Bhatt, J.C. (2012). Conservation tillage impacts on soil aggregation and carbon pools in a sandy clay loam soil of the Indian Himalayas. *Soil Science Society of American Journal* **76**(2):1-11.
- Bhattacharyya, R.S., Kundu, S.C., Pandey, K.P., Singh and Gupta, H. S. (2008).Tillage and irrigation effects on crop yields and soil properties under the rice-wheat system in the Indian Himalayas. *Agricultural Water Management* **95**: 993-1002.
- Bianchi, C.A.M. *et al.* (2003). Potencial da água na folha e ajuste osmótico em milho cultivado em diferentes sistemas de cultivo e níveis de água. In "Anais", *XIII Congresso Brasileiro de Agrometeorologia*. 631-632. Sociedade Brasileira de Agrometeorologia, Santa Maria.
- Bing, D., Wenying, D.L., Zhixi, L., Du, B., Deng, J., Wy, L. and Liao Z.X.(2000). Field experiments for comparison of winter wheat conservation tillage and conventional tillage. *Journal of China Agricultural University* **5**:55-58.
- Bissett, M.J. and O'Leary, G.J. (1996). Effects of conservation tillage on water infiltration in two soils in south-eastern Australia. *Australian Journal of Soil Research* **34**: 299-308.
- BK, S.B., Srivastav, S.B., Gurung, S.B., Ferrara, G.O. and Shrestha, J. (2013). Effect of conservation agriculture on growth and productivity of maize in Terai region of Nepal. *Merit Research Journal of Agricultural Science and Soil Sciences* **1**(5):66-77.
- Black, C. And Ong, C. (2000). Utilisation of light and water in tropical agriculture. *Agricultural and Forest Meteorology* **104**: 25-47.

- Blaise, D. and Ravindran, C. D. (2003). Influence of tillage and residue management on growth and yield of cotton grown on vertisol over 5 years in a semi-arid region of India. *Soil & Tillage Research* **70**: 163-173.
- Board, J.E. and Harville, B.G. (1993). Soybean yield components responses to a light interception gradient during the reproductive period. *Crop Science* **33**:772-777.
- Board, J.E. and Tan, Q. (1995). Assimilatory capacity effects on soybean yield components and pod number. *Crop Science* **35**:846-851.
- Bockus, W.W. and Shroyer, J.P. (1998). The impact of reduced tillage on soil borne plant pathogens. *Annual Review of Phytopathology* **36**: 485-500.
- Bodner, G., Loiskandl, W. and Kaul, H.P. (2007). Cover crop evapotranspiration under semi-arid conditions using FAO dual crop coefficient method with water stress compensation. *Agricultural Water Management* **93**: 85-98.
- Bonfil, D.J., Mufradi, I., Klitman, S. and Asido, S. (1999). Wheat grain yield and soil profile water distribution in a no-till arid environment. *Agronomy Journal* **91**: 368-373.
- Bonhomme, R. (2000). Beware of comparing RUE values calculated from PAR vs. solar radiation or absorbed vs. intercepted radiation. *Field Crops Research* **68**: 247-252.
- Boogaard, R., Alewijnse, D., Veneklaas, E. J. And Lambers, H. (1997). Growth and water-use efficiency of *Triticum aestivum* cultivars at different availability in relation to allocation of biomass. *Plant, Cell and Environment* **20**: 200-210.
- Boomsma C.R., Santini, J.B., Tollenaar, M. and Vyn, T.J. (2009). Maize morpho-physiological response to intense crowing and low nitrogen availability: an analysis and review. *Agronomy Journal* **101**: 1426-1452.
- Bota, J., Flexas, J. and Medrano, H. (2001). Genetic variability of photosynthesis and water use in Balearic grapevine cultivars. *Annals of Applied Biology* **138**:353-361.
- Bougnom, B.P., Knapp, B.A., Elhottová, D., Koubová, A., Etoa, F.X. and Insam, H. (2010). Designer compost with biomass ashes for ameliorating acid tropical soils, Effects on the soil microbiota. *Applied Soil Ecology* **45**: 319-324.

- Bouzza, A. (1990). Water conservation in wheat rotations under several management and tillage systems in semiarid areas. Ph.D. Dissertation, University of Nebraska, Lincoln, USA,). pp200.
- Brady and Weil (1996). Earthworms, mulching, soil moisture and grape yields, earthworm responses to soil management practices in vineyards, Barossa Valley, South Australia. *Australian and New Zealand Wine Industry Journal* **11**: 47–53.
- Bragagnolo, N. *et al.* (1990). Cobertura do solo por palha da trigo e seu relacionamento com a temperatura e umidade do solo. *Revista Brasileira de Ciência do Solo* **14**:369-374.
- Brown, S.C., Gregory, P.J, Copper, P.J.M. and Keating, J.D.H. (1989). Root and shoot growth and water use of chickpea (*Cicer arietinum* L.) grown in dryland condition: effects of sowing date and genotype. *Journal of Agricultural Science* **113**: 41-49.
- Burman, R.D., Nixon, P.R., Wright, J.L. and Pruitt, W.O. (1980).Water requirements. In:Jensen, M.E.(Ed.),Design and Operation of Farm Irrigation Systems, ASAE Monograph, No3, pp.189-232.
- Cai Jiabing, Liu Yu, Zhou Jincheng (2003). Research on Crop Water Requirement and Irrigation Procedure in Jingtai Pumping Irrigation District of Gansu Province (in Chinese with English abstract). *Journal of China Country Water Resources and Hydropower* **8**: 35-39.
- Cantero-Martinez, C., Angas, P. and Lampurlanes, J. (2007). Long-term yield and water use efficiency under various tillage systems in Mediterranean rainfed conditions. *Annals of Applied Biology*. **150**(3): 293-305.
- Carriglia, O.P., Sadras, V.O. and Andrade, F.H. (2004). Intensification of agriculture in south eastern Pampas: Capture and efficiency in the use of water and radiation in double-cropped wheat-soybean. *Field crops research*. **87**:117-129.
- Casa, R., Russell, G. and Casio, B.L. (2000). Estimation of evapotranspiration from a field of linseed in central Italy. *Agricultural Forest Meteorology* **104**: 289-301.

- Cassel, D.K., Raczkowski, C.W. and Denton, H.P. (1995). Tillage effects on corn production and soil physical conditions. *Soil Science Society of American Journal* **59**: 1436-1443.
- Catsky, J. (1967). Determination of water deficit in disks cut out from leaf blades. *Biologia Plantarum* **2**:76-78.
- Ceccato, P., Flasse, S., Tarantola, S., Jaquemoud, S. and Gregoire, J.M. (2001). Detecting vegetation leaf water content using reflectance in the optical domain. *Remote Sensing of Environment* **77**: 22-33.
- Chalk, P.M. (1998). Dynamics of biologically fixed N in legume- cereal rotations: a review. *Australian Journal of Agricultural Research* **49**: 303-316.
- Chaudhary, V.P., Gangwar, B., Pandey, D.K. and Gangwar, K.S. (2009). Energy auditing of diversified rice-wheat cropping systems in Indo-gangetic plains. *Energy* **34**:1091-6.
- Chiew, F.H.S., Kamaladasa, N.N., Malano, H.M., McMahon, T.A. (1995). Penman-Monteith, FAO-24 reference crop evapotranspiration and class-A pan data in Australia. *Agricultural Water Management* **28**: 9-21.
- Clarke and Russell (1977). Yield and nutritive value of irrigated winter cereal forage grass-legume intercrops in the Southern High Plains, USA. *Agronomy Journal* **96**: 352.
- Cogle, A.L., Rao, K.P.C., Yule, D.F., George, P.J., Srinivasan, S.T., Smith, G.D. and Jangawad, L. (1997). Soil management options for Alfisol in the semi-arid tropics: annual and perennial crop production. *Soil Tillage Research* **44**: 235-253.
- Cornelis, W.M., Araya, T., Wildermeersch, J., Mloza-Banda, M.K., Waweru, G., Obia, A. and Verbist, K. (2013). Building resilience against drought: the soil-water perspective. In: De Boever *et al.* (Eds). *Desertification and Land degradation: Processes and Mitigation*. UNESCO Chair of Eremology, Ghent University, Belgium. pp. 1-15.
- Cornic, G. and Fresneau, C. (2002). Photosynthetic carbon reduction and carbon oxidation cycles are the main electron sinks for photosystem II activity during a mild drought. *Annals of Botany* **89**: 887-894.

- Coyne, P.I., Bradford, J.A. and Dewald, C.I. (1982). Leaf water relations and gas exchange in relation to forage production in four Asiatic blue stems. *Crop Science* **22**: 1036-1040.
- Cruse, R.M., Mier, R. and Mize, C.W. (2001). Surface residue effects on erosion of thawing soils. *Soil Science Society of American Journal* **65**: 178-184.
- Cutforth, H.W. and McConkey, B.G. (1997). Stubble height effects on microclimate, yield and water use efficiency of spring wheat grown in a semi-arid climate on the Canadian prairies. *Canadian journal of plant sciences* **77**(3): 359-366.
- Dalal, R.C. and Chan, K.Y. (2001). Soil organic matter in rainfed cropping systems of the Australian cereal belt. *Australian Journal of Soil Research* **39**: 435-464.
- Dalirie, M.S., Sharifi, R.S. and Farzaneh, S. (2010). Evaluation of yield, dry matter accumulation and leaf area index in wheat genotypes as affected by terminal drought stress. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* **38**(1): 182-186.
- Dalmago, G.A. *et al.* (2003b). Diferenças na disponibilidade de água no solo entre sistemas de semeadura direta e convencional de milho. In “Anais”, *XIII Congresso Brasileiro de Agrometeorologia*. pp 293-294. Sociedade Brasileira de Agrometeorologia, Santa Maria.
- Dalmago, G.A. *et al.* (2003c). Transpiração do milho cultivado em sistema de semeadura direta e convencional. In “Anais”, *XIII Congresso Brasileiro de Agrometeorologia*. pp 297-298. Sociedade Brasileira de Agrometeorologia, Santa Maria.
- Dalton, L.G. (1967). A positive response of yield on maturity of Sorghum. *Crop Sciences* **7**: 721-26.
- Deng, X.P., Shan, L., Zhang, H.P. and Turner, N.C. (2006). Improving agricultural water in arid and semiarid areas of China. *Agricultural Water Management* **80**: 23-40.
- Derpsch, R. and Moriya, K. (1999). Implications of soil preparation as compared to no-tillage on the sustainability of crop production, experiences from South America. In: Reddy, M. V. and Enfield, N. H. (Eds). *Management of tropical agro-ecosystems and the beneficial soil biota*. Science Publishers. pp. 49-65.

- Diaz-Zorita, M. (2000). Effect of deep-tillage and nitrogen fertilization interactions on dry land corn (*Zea mays* L.) productivity. *Soil Tillage Research* **54**: 11-19.
- Diaz-Zorita, M., Duarte, G. and Grove, J. (2002). A review of no till systems and soil management for sustainable crop production in the sub-humid and semi-arid Pampas of Argentina. *Soil Tillage Research* **65**: 1-18.
- Dinnes, D.L., Karlen, D.L., Jayness, D.B., Kaspar, T.C., Hatfield, J.L. Colvin, T.S. and Cambardella, C.A. (2002). Nitrogen management strategies to reduce nitrate leaching in tile-drained midwestern soils. *Agronomy Journal* **94**: 153-71.
- Domua, C., Andor, M., Ciobanu, G., Ardelean, I., Ciobanu, C., Samuel, A., Bandici, G., Borza, L., Sabu, N.C., Brejia, R. and Vacan, A. (2009). Crop rotation and irrigation influence on wheat yield and the correlations climate yield in the criurilar or plain conditions. *Bulletin of university of agricultural sciences and veterinary medicineclu - napoca agriculture*. **66**(1).
- Doorenbos, J. and Kassam, A.H. (1979). Yield response to water: food and agriculture organisation of the United Nations, FAO Irrigation and Drainage Paper 33, Rome, 193 pp. (revised).
- Doorenbos, J. and Pruitt, W.O. (1977). Guidelines for predicting crop water requirements, FAO-ONU, Rome, Italy, 144 pp.
- Dormaar, J.F. and Carefoot, J.M. (1996). Implication of crop residue and conservation tillage on soil organic matter. *Canadian Journal of Plant Science* **76**: 627-634.
- Du Bing, D., Li Wenying, Liao Zhixi, Du B., Deng, J., Li Wy, Liao, Z.X. (2000). Field experiments for comparison of winter wheat conservation tillage and conventional tillage. *Journal of China Agricultural University* **5**:55-58.
- Dumanski, J., Peiretti, R., Benetis, J., McGarry, D. and Pieri.C. (2006). The paradigm of conservation tillage. *Proc. World Assoc. Soil and Water Conserv.* **1**: 58-64.
- Dwyer, L.M. and Stewart, D.W. (1986). Leaf area development in field grown maize. *Agronomy Journal* **78**: 334-348.
- Eck, H.V. (1984). Irrigated corn yield response to nitrogen and water. *Agronomy Journal* **76**: 421-428.

- Eck, H.V. (1986). Effect of water deficits on yield, yield components, and water use efficiency of irrigated corn. *Agronomy Journal* **78**(6): 1035-1040.
- Edwards, L., Burney, J.R., Richter, G. and MacRae, A.H. (2000). Evaluation of compost and straw mulching on soil-loss characteristics in erosion plots of potatoes in Prince Edward Island, Canada. *Agriculture Ecosystem Environment* **81**(3): 217-222.
- Ekaputa, U.N. (2004). *Agricultural systems*. Port Harcourt: UNIK Publishers. pp. 126-134.
- Elston, J. and Monteith, J.L. (1975). Micrometeorology and ecology. In: Monteith, J.L. (Ed.). *Vegetation and the Atmosphere*. Academic Press, New York. 1-11.
- Eltz, F.L.F. and Norton, L.D. (1997). Surface roughness changes as affected by rainfall erosivity, tillage, and canopy cover. *Soil Sci. Soc. Am. J.* **61**: 1746-1755.
- Erenstein, O., Malik, R.K. and Singh, S. (2007). *Adoption and Impacts of Zero-Tillage in the Rice-Wheat Zone of Irrigated Haryana, India*. Research Paper, CIMMYT.
- Evans, J., Hochman, Z., O'Connor, G.E. and Osborne G.J. (1991). Soil acidity and Rhizobium: their effect on nodulation of subterranean clover on the slopes of southern New South Wales. *Australian Journal of Agricultural Research* **38**: 605-618.
- Evans, J.R., von Caemmerer, S., Setchell, B.A. and Hudson, G.S. (1994). The relationship between CO₂ transfer conductance and leaf anatomy in transgenic tobacco with a reduced content of Rubisco. *Australian Journal of Plant Physiology* **21**: 475-495.
- Fan, S., Hazell, P. and Thorat, S. (1998). Government spending, growth and poverty: An analysis of inter linkages in rural India. Environment and Production Technology Division. Washington, D.C.: International Food Policy Research Institute. Discussion Paper 33.
- Farahani, H., Peterson, G., Wetfall, D., Sherrod, L. And Ahuja, L. (1998). Soil water storage in dryland cropping systems: the significance of cropping intensification. *Soil Science Society of American Journal* **62**: 984-991.

- Farahani, H.J., Peterson, G.A., Westfall, D.G., Sherrod, L.A. and Ahuja, L.R.(1998). Soil water storage in dryland cropping system: The significance of cropping intensification. *Soil Science Society of American Journal* **62**: 982-991.
- Fawcett, R. and Towery, D. (2002). Conservation tillage and plant biotechnology: how new technologies can improve the environment by reducing the need to plough. Conservation Technology Information Center, West Lafayette, IN.
- Fischer, R.A., Santiveri, F. and Vidal, I.R. (2002). Crop rotation, tillage and crop residue management for wheat and maize in the sub-humid tropical highlands I. Wheat and legume performance. *Field Crops Research* **79**: 107-122.
- Flexas, J., Bota J. and Cifre J. (2004). Understanding down-regulation of photosynthesis under water stress: Future prospects and searching for physiological tools for irrigation management. *Annals of Applied Biology* **144**: 273–283
- Follet, R.H., Murphy, L.S. and Donalue, R.L. (1981). Soil-fertilizer-plant relationship. *Fertilizer Soil Amendment* **6** (16): 478-481.
- Fortin, M.C. (1993). Soil temperature, soil water, and no-till corn development following in-row residue removal. *Agronomy Journal* **85**: 571-576.
- Freebairn, D.M. and Boughton, W.C. (1985). Hydrologic effects of crop residue management practices. *Australian Journal of Soil Research* **23**: 23-55.
- Gajri, P.R., Arora, V.K. and Chaudhary, M.R. (1994). Maize growth response to deep tillage, straw mulching and farmyard manure in coarse textured soils of N.W. India. *Soil Use Management* **10**: 1520.
- Garcia M., Raes, D., Allen, R. and Herbas, C. (2004). Dynamics of reference evapotranspiration in the Bolivian highlands (Altiplano). *Agricultural Forest and Meteorology* **125**: 67-82.
- Garrity, D.P., Watts, D.G., Sullivan, C.Y. and Gilley, J.R. (1982). Moisture deficits and grain sorghum performance: evapotranspiration–yield relation. *Agronomy Journal* **74** (5): 815-820.
- Gaultney, L., Krutz, G.W., Steinhardt, G.C. and Liljedahl (1980). Field and laboratory tests to determine effects of subsoil compaction on corn yield. *ASAE paper no 80- 1011*. ASAE St. Joseph, MI. USA.

- Gavilan, P., Lorite, I.J., Tornero, S. and Berengena, J. (2006). Regional calibration of Hargreaves equation for estimation of reference ET in a semiarid environment. *Agricultural Water Management* **81**: 257-281.
- Ghanbari, A., Dahmardeh, M., Siahsar, B.A. and Ramroudi, M. (2010). Effect of maize (*Zea mays* L.) cowpea (*Vignaun guiculata* L.) intercropping on light distribution, soil temperature and soil moisture in arid environment. *Journal of Food, Agriculture & Environment* **8**(1): 102-108.
- Ghosh, P.K., Das, A., Saha, R., Kharkrang, E., Tripathi, A.K., Munda, G.C. and Ngachan, S.V. (2010). Conservation agriculture towards achieving food security in North East India. *Current Science* **99**(7): 915-21.
- Gicheru, P. T., Gachene, C. K. K. and Biamah, E. K. (1998). Effects of tillage and mulching on soil moisture conservation and crop production. *Applied Plant Science* **12**(1): 5-9.
- Gifford, R.M., Thorne, J.H., Witz, W.D. and Giaquinta, R.T. (1984). Crop productivity and photo-assimilate partitioning. *Science* **225**: 801-808.
- Girijesh, G.K., Kumara wamy, A.S., Sridhara, S., Dinesh Kumar, M., Vageesh, T.S and Nataraju, S.P. (2011). Heat use efficiency and helio-thermal units for maize genotypes as influenced by dates of sowing under southern transitional zone of karnataka state. *International Journal of Science and Nature* **2**(3): 529-533.
- Good, L.C., and D.E. Smika. (1978). Chemical fallow for soil and water conservation in the Great Plains. *Journal of Soil Water Conservation* **33**: 89-90.
- Gouri, V., Reddy, D.R., Rao, S.B.S.N. and Rao, A.Y. (2005). Thermal requirement of rabi groundnut in southern Telangana zone of Andhra Pradesh. *Journal of Agrometeorology* **7**(1): 90-94.
- Govaerts, B., Sayre, K.D. and Deckers, J. (2005). Stable high yields with zero tillage and permanent bed planting? *Field Crops Research* **94**: 33-42.
- Govaerts, B., Sayre, K.D., Lichter, K., Dendooven, L. and Deckers, J. (2007). Influence of permanent raised bed planting and residue management on physical and chemical soil quality in rain fed maize/wheat systems. *Plant and Soil* **291**: 39-54.

- Grace, P.R., Harrington, L., Jain, M.C. and Robertson, G.P. (2003). Long-term sustainability of the tropical and subtropical rice-wheat system, an environment perspective. In: Ladha, J.K., Hill, J., Gupta, R.K., Duxbury, J. and Buresh, R.J. (Ed.) *Improving the productivity and sustainability of rice-wheat systems, issues and impact*. Madison, W. I., ASA special publications **65**: 27-43.
- Grattan, S.R., George, W., Bowers, W., Dong, A., Snyder, R.L. and Carrol, J. (1998). New crop coefficients estimate water use of vegetables row crops. *California Agriculture* **52**(1): 16-20.
- Greb, B.W. (1966). Effect of surface-applied wheat straw on soil water losses by solar distillation. *Soil Science Society of American Proceeding* **30**: 786-788.
- Gregory, P.J. (1989). Water-use efficiency of crops in the semi arid tropics. In: Soil, crop and water management in the Sudano-Sahelian zone. ICRISAT, Patancheru, India, pp. 85-98.
- Gupta, M., Bali, A.S., Sharma, S. and Dixit, A.K. (2007). Potential role and influence of zero tillage technology on energy saving in rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) system. *Indian Journal of Agricultural Science* **77**(10): 657-9.
- Habtegebrial, K., Singh, B.R. and Haile, M. (2007). Impact of tillage and nitrogen fertilization on yield, nitrogen use efficiency of Eragrostis, Trotter and soil properties. *Soil and Tillage Research* **94**: 55- 63.
- Haider, S.A., Alam, M.Z., Alam, M.F. and Paul, N.K. (2003). Influence of different sowing dates on the phenology and accumulated heat units in wheat. *Journal of Biological Science* **3**: 932-939.
- Halvorson, A.D., Black, A.L., Krupinsky, J.M. and Merrill, S.D. (1999). Dryland winter wheat response to tillage and nitrogen within an annual cropping system. *Agronomy Journal* **91**: 702-707.
- Hamdy, A. and Lacirignola, D. (1999). Mediterranean Water Resources: Major challenges toward 21st Century. CIHEAM-IAM Bari, Italy, p. 570.

- Han, H., Ning, T. and Li, Z. (2013). Effect of tillage and weed management on the vertical distribution of microclimate and grain yield in a winter wheat field. *Plant Soil Environment* **59**: 201-207.
- Hanks, R.J. and Ashcroft, G.L. (1980). *Applied Soil Physics*, Springer-Verlag, Berlin, 159 pp.
- Hanna, M. and Al-Kaisi, M. M. (2009). Resources conservation practices; Managing and understanding soil compaction. Iowa University Extension article PM 1094. On line, <http://www.extension.iastate.edu/Publications/PM1901B.pdf>
- Hargreaves, G.H. and Samani, Z.A. (1982). Estimating potential evapotranspiration. Tech. Note. *Journal of Irrigation and Drainage Engineering* **108**(3): 225-230. Irrigation and Drainage Paper no. 24 (rev.), 144 pp.
- Hatfield, J., Sauer, J.T. and Prueger, J.H. (2001). Managing Soils to Achieve Greater water Use efficiency: A Review. *Agronomy Journal* **93**: 271-280.
- Hatfield, J.L. and Prueger, H.J. (1996). Microclimate effects on crop residues on biological process. *Theoretical and Applied Climatology* **54**: 47-59.
- Hatfield, J.L., Sauer, T.J. and Prueger, J.H. (2001). Managing soils to archive greater water use efficiency: A review. *Agronomy Journal* **93**: 271-280.
- Hay, C.H. and Irmak, S. (2009). Actual and reference evaporative losses and surface coefficients of a maize field during non-growing dormant periods. *Journal of Irrigation and Drainage Engineering* **135**(3):313-322.
- He, J., Li, H.W. & Gao, H.W. (2006). Subsoiling effect and economic benefit under conservation tillage mode in Northern China. *CSAE* **22**: 62-67.
- He, J., Li, H., Rasaily, R.G., Wang, Q., Cai, G., Su, Y., Qiao, X. and Liu, L. (2011). Soil properties and crop yields after 11 years of no tillage farming in wheat-maize cropping system in North China Plain. *Soil and Tillage Research* **113**: 48-54.
- Heen, D.P. and Chan, K.Y. (1992). The long-term effect of rotation, tillage and stubble management on soil mineral nitrogen supply to wheat. *Australian Journal of Soil Research* **30**: 977-998.

- Hexem, R.W. and Heady, E.O. (1978). Water Production Functions for Irrigated Agriculture. Iowa State University Press, Ames, IA, 215 pp.
- Hiscox, J.D. and Israelstam, G.F. (1979). A method for the extraction of chlorophyll from leaf tissue without maceration. *Canadian Journal of Botany* **57**: 1332-1334.
- Hobbs, P.R. and Gupta, R.K. (2002). Rice–wheat cropping systems in the Indo-Gangetic plains, issues of water productivity in resource conserving technologies. In, *Proceedings of water productivity workshop, International Water Management Institute*, Colombo, Sri Lanka, 12–14 November 2001.
- Hobbs, P. R. and Gupta, R. K. (2003). Resource conserving technologies for wheat in rice–wheat systems. In *Improving the productivity and sustainability of rice–wheat systems, issues and impact*, Eds Ladha J. K, Hill J, Gupta R. K, Duxbury J, Buresh R. J. paper 7,ASA special publications Eds. Madison, WI,ASA 65, 149–171.
- Hobbs, P.R. and Gupta, R.K. (2004). Problems and challenges of no-till farming for the rice–wheat systems of the Indo-Gangetic Plains in South Asia. In: Lal. R., Hobbs, P., Uphoff, N., Hansen and Columbus, O.H. (Eds). *Sustainable agriculture and the rice–wheat system*. NY, Ohio State University, New York: Marcel Dekker, Inc. pp.101–119.
- Hongyi, L., Pengli, M., Xingguo, Y. and Qiguo, Y. (2005). Temporal and Spatial Analysis of the Water Requirements of Major Crops in Gansu Province (in Chinese with English Abstract). *Agricultural Research in the Arid Areas* **23**: 39-44.
- Horton, R., Bristow, K.L., Kluitenberg, G.J. and Sauer, J.J. (1995). Crop residues effects on surface radiation and energy balance. *Theoretical and Applied Climatology* **54**:27-37.
- Howell, T.A., Evett, S.R., Tolk, J.A. and Schneider, A.D. (2004). Evapotranspiration of full-deficit-irrigated, and dryland cotton on the northern Texas high plains. *Journal of Irrigation and Drainage Engineering* **130**: 277-285.
- Huang, G.B., Chai, Q., Fang, F.X. and Yu, A.Z. (2012). Effects of different tillage systems on soil properties root growth grain yield and water use efficiency of

- winter wheat (*Triticum aestivum* L.) in Arid Northwest China. *Journal of Integrated Agriculture* **11**: 1286-1296.
- Huang, Y.L., Chen, L.D., Fu, B.J., Huang, Z.L. and Gong, E. (2005). The wheat yields and water-use efficiency in the Loess Plateau: straw mulch and irrigation effects. *Agricultural Water Management* **72**: 209-222.
- Huang, Y.L., Chen, L.D., Fu, B.J., Huang, Z.L. and Gong, J. (2005). The wheat yields and water-use efficiency in the Loess Plateau: straw mulch and irrigation effects. *Agricultural Water Management* **72**: 209-222.
- Hundal, S.S. Kaur, P. and Malikpuri, S.D.S. (2003a). Agroclimatic models for prediction of growth and yield of Indian mustard (*Brassica juncea* L.). *Indian journal of agricultural science* **73** (3): 142-144.
- Hundal, S.S., Singh, H., Prabhjyot, K. and Dhaliwal, L.K. (2003b). Agroclimatic models for growth and yield of soybean (*Glycine max.*L.). *Indian Journal of Agricultural Sciences* **73**(12): 668-70.
- Hundal, S.S., Singh, R. and Dhaliwal, L.K. (1997). Agroclimatic indices for predicting phenology of wheat (*Triticum aestivum* L.) in Punjab. *Indian Journal of Agricultural Sciences* **67** (6): 265-8.
- Hunsaker, D.J., Kimball, B.A., Pinter Jr., P.J., La Morte, R.L. and Wall, G.W. (1996). Carbon dioxide enrichment and irrigation effects on wheat evapotranspiration and water use efficiency. *Trans. ASAE*. **39**(4): 1345-1355.
- Hunsaker, D.J., Kimball, B.A., Pinter Jr., P.J., La Morte, R.L., and Wall, G.W. (1996). Carbon dioxide enrichment and irrigation effects on wheat evapotranspiration and water use efficiency. *Trans. ASAE*. **39** (4): 1345-1355.
- Hunt, R. (1978). Plant growth analysis. Edward Arnold Publishers, London.
- Inyang, E.U. (2005). An evaluation of tillage and storage systems applied by traditional root crop Farmers in Cameroon. *Agriculture and Environment Journal* **7**(2): 15-22.
- IPCC. (2007). Climate Change: Impacts, adaptation and vulnerability. Contribution of working group ii to the fourth assessment report of the intergovernmental panel on climate Change. Parry, M.L., Canziani, O.F., Palutikof, J.P., van der

- Linden, P.J. and Hanson, C.E. (Eds). Cambridge, UK. Cambridge University Press. pp. 976.
- Ishaq, M., Ibrahim, M., Hassan, A., Saeed, M. and Lal, R. (2001). Subsoil compaction effects on crop in Punjab, Pakistan: II. Root growth and nutrient uptake of wheat and sorghum. *Soil Tillage Research* **60**: 153-161.
- Iwata, F. (1984). The heat unit concept of crop maturity. In: U.S. Gupta (Ed.), *physiological aspects of dryland farming*. Oxford & IBH Publishing Co., New Delhi, pp. 350-370.
- Izumi, Y, Uchida, K. and Iijima, M. (2004). Crop production in successive wheat-soybean rotation with no-tillage practice in relation to the root system development. *Plant Production Sciences* **7**(3):329-336.
- Jain, N., Mishra, J.S., Kewat, M.L. and Jain, V. (2007). Effect of tillage and herbicides on grain yield and nutrient uptake by wheat and weeds. *Indian Journal of Agronomy* **52**(2): 131-134.
- Jat, M.L., Saharawat, Y. S. and Gupta, R. (2011). Conservation agriculture in cereal systems of south Asia: Nutrient management perspectives. *Karnataka Journal of Agricultural Sciences* **24**(1): 100-105.
- Jensen, M.E. (1968). Water Consumption by Agricultural Plants. In: Kozlowski, T.T., Ed., *Water Deficits in Plant Growth*, Vol. 2, Academic Press, New York, 1-22.
- Jensen, M.E., and Allen, R.G. (2000). Evolution of practical ET estimating methods. In *Proc. 4th Natl. Irrig. Symp.*, 5265. R. G. Evans, B. L. Benham, and T. P. Trooien, eds. St. Joseph, Mich.: ASAE.
- Jensen, M.E., Burman, R.D. and Allen, R.G. (1990). *Evapotranspiration and Irrigation Water Requirements*. ASCE Manuals and Reports on Engineering Practices, No. 70. Amer. Soc. Civil.
- Jensen, M.E., Wright, J.L., and Pratt, B.J. (1971). Estimating soil moisture depletion from climate, crop and soil data. *Trans. ASAE*. **14**(6): 954-959.
- Jiabing, C., Yu, L. And Jincheng, Z. (2003). Research on Crop Water Requirement and Irrigation Procedure in Jingtai Pumping Irrigation District of Gansu Province (in Chinese with English abstract). *Journal of China Country Water Resources and Hydropower* **8**: 35-39.

- Jiang, X.D., Wang, Y., Hou, L.T., Li, Z.J., Wang, X. and Guo, Z.H. (2006). Effects of minimum tillage and no-tillage systems on photosynthetic characteristics at late growth stages of winter wheat. *Transactions of the CSAE* **22**: 66-69.
- Jones, C.A. C₄ grasses and cereals: growth, development and stress response. New York: John Wiley & Sons, 1985. 419 p.
- Joshi, D., Hooda, K.S., Bhatt, J.C., Mina, B.L. and Gupta, H.S. (2009). Suppressive effects of composts on soil-borne and foliar diseases of French bean in the field in the western Indian Himalayas. *Crop Protection* **28**: 608-615.
- Jung, W.S., Kim, K.H., Ahn, J.K., Hahn, S.J. and Chung, I.M. (2004). Allelopathic potential of rice (*Oryza sativa* L.) residues against *Echinochloa crusgalli*. *Crop Protect.* **23**: 211-218.
- Kadziene, G., Munkholm, L.J. and Mutegi, J.K. (2011). Root growth conditions in the topsoil as affected by tillage intensity. *Geoderma* **166**: 66-73.
- Kahle, K.W., Long Jr., J.H. and Todd, T.C. (2003). Long-term crop rotations affect soybean yield, seed weight, and soil chemical properties. *Field Crops Research* **83**: 41-50.
- Kamara, A.Y., Menkir, A., Badu-Apraku, B. And Ibikunle, A. (2003). Reproductive and stay-green traits responses of maize hybrids, improved open-pollinated varieties and farmer's local varieties to terminal drought stress. *Maydica*. **48**: 29-37.
- Kar, G., Kumar, A. and Martha, M. (2007). Water use efficiency and crop coefficients of dry season oilseed crops. *Agricultural Water Management* **87**:73–82.
- Kar, G., Singh, R. and Verma, H.N. (2005). Phenological based irrigation scheduling and determination of crop coefficient winter maize in rice fallow of eastern India. *Agricultural Water Management* **75**: 169-183.
- Kaspar, T.C., Erbach, D.C. and Cruse, R.M. (1990). Corn response to seed-row residue removal. *Soil Science Society of American Journal* **54**: 1112-1117.
- Kassam, A.H. and Friedrich, T. (2009). Perspectives on Nutrient Management in Conservation Agriculture. Invited paper "IV World Congress on Conservation Agriculture" 4-7 February 2009, New Delhi, India.

- Katerji, N., Mastrorilli, M. and Rana, G. (2008). Water use efficiency of crops cultivated in the Mediterranean region: Review and analysis. *European Journal of Agronomy* **28**(4): 493-507.
- Kaur, R. and Rajni (2010). Impact of increasing CO₂ on crop productivity. *Indian Farming*. June issue. 23-7.
- Keeling, J.W. and Abernathy, J.R. (1989). Pre-emergence weed control in a conservation tillage cotton (*Gossypium hirsutum* L.) cropping system on sandy soils. *Weed Technology* **3**:182-185.
- Kelley, K.W., Long, J.H. and Todd, T.C. (2003). Long-term crop rotations affect soybean yield, seed weight, and soil chemical properties. *Field Crops Research* **83**: 41-50.
- Kennedy A.C. (1999). Soil microorganisms for weed management. *Journal of Crop Production* **2**:123-138.
- Ketring, D.L. and Wheless, T.G. (1989). Thermal requirement for phenological development of peanut. *Agronomy Journal* **8** (16): 910-917.
- Khan A., Jan, M.T., Marwat, K.B. and Arif, M. (2009). Organic and inorganic nitrogen treatments effects on plant and yield attributes of maize in a different tillage systems. *Pakistani Journal of Botany* **41**(1):99-108.
- Khan, A., Jan, M.T., Arif, M., Marwat, K.B. and Jan, A. (2008). Phenology and crop stand of wheat as affected by nitrogen sources and tillage systems. *Pakistan Journal of Botany* **40**(3): 1103-1112.
- Khan, M.A.H. and Parvej M.R. (2010). Impact of conservation tillage under organic mulches on the reproductive efficacy and yield of quality protein maize. *The Journal of Agricultural Sciences* **5**(2): 52-63.
- Kholova, J., Hash, C.T., Kumar, L.K., Yadav, R.S, Koova, M. And Vadez, V. (2010b). Terminal drought tolerant pearl millet (*Pennisetum glaucum* L.) have high leaf ABA and limit transpiration at high vapor pressure deficit. *Journal of Experimental Botany***61**: 1431-1440.
- Khurshid, K.,Iqbal, M., Arif, M.S. and Nawaz, A. (2006). Effects of tillage and mulch on soil physical properties and growth of maize. *Integrated Journal of Agricultural Biology* **8**: 593-596.

- Kipkorir, E.C., Raes, D. and Massawe, B. (2002). Seasonal water production functions and yield response factors for maize and onion in Perkerra, Kenya. *Agricultural Water Management* **56**: 229-240.
- Kjaersgaard, J.H., Plauborg, F., Mollerup, M., Petersen, C.T. and Hansen, S. (2008). Crop coefficients for winter wheat in a sub-humid climate regime. *Agric. Water Management* **95**:918-924.
- Kramer, P.J. and Boyer, J.S. (1995). Water relations of plants and soils. San Diego, Academic Press, p. 495.
- Kredl, Z., Streda, T., Pokorny, R., Kmoch, M. and Brotan, J. (2012). Microclimate in the vertical profile of wheat, rape and maize canopies. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis***1**: 79-90.
- Kumar, D. and Tieszen, L.D. (1980). Photosynthesis in *Coffea arabica* L. Part 1. Effects of light and temperature. *Experimental Agriculture* **16**: 13-19.
- Kumar, K. and Goh, K.M. (2000). Crop residues and management practices: effects on soil quality, soil nitrogen dynamics, crop yield and nitrogen recovery. *Adv. Agronomy* **68**:198-279.
- Kumar, R., Ramesh, K., Singh, R.D. and Prasad, R. (2010). Modulation of wild marigold (*Tagetes minuta* L.) phenophases towards the varying temperature regimes - a field study. *Journal Agrometeorology* **12**: 234-40.
- Kumar, R., Shankar, V. and Kumar, M. (2012). Development of Crop Coefficients for Precise Estimation of Evapotranspiration for Mustard in Mid Hill Zone. *Universal Journal of Environmental Research and Technology* **1**(4): 531-538.
- Kuo, C.G., Shen, B.J., Chen, H.M., Chen, H.C. and Opena, R.T. (1988). Associations between heat tolerance, water consumption, and morphological characters in Chinese cabbage. *Euphytica* **39**: 65-73.
- Lafond, G. P., Loepky, H. and Derksen, D.A. (1991). The effects of tillage systems and crop rotations on soil water conservation, seedling establishment and crop yield. *Canadian Journal of Plant Science* **72**: 103-115.
- Lafond, G.P., W.E. May, F.C. Stevenson, and D.A. Derksen. (2006). Effects of tillage systems and rotations on crop production for a thin Black Chernozem in the Canadian Prairies. *Soil Tillage Research* **89**: 232-245.

- Lal, R., Follett, R.F. and Kimble, J.M. (2002). Achieving soil carbon sequestration in the United States: a challenge to the policy makers. *Soil Science* **168**: 827-845.
- Lampurlanes, J., Angas, P. and Cantero-Martinez, C. (2001). Root growth, soil water content and yield of barley under different tillage systems on two soils in semiarid conditions. *Field Crop Research* **69**: 27-40
- Larcher, W. (2003): *Physiological Plant Ecology – Ecophysiology and Stress Physiology of Functional Groups*. Springer (4th edition). ISBN 3-54043516-6
- Lawlor, D.W. and Cornic, G. (2002). Photosynthetic carbon assimilation and associated metabolism in relation to water deficits in higher plants. *Plant Cell Environment* **25**: 275-294.
- Leake A.R. (2003). Integrated pest management for conservation agriculture. In: Garcia-Torres, L., Benites, J., Martinez-Vilela, A. and Holgado-Cabrera, A. (Eds). *Conservation agriculture: environment, farmers experiences, innovations, socio-economy, policy*. Dordrecht/The Netherlands/ Boston/ Germany/ London/ UK: Kluwer Academia Publishers. pp. 271–279.
- Lecoeur, J. and Ney, B. (2003). Change with time in potential radiation-use efficiency in field pea. *European Journal of Agronomy* **19**: 91–105.
- Li, F.M., Guo, A.H. and Wei, H. (1999). Effects of plastic film mulch on yield of spring wheat. *Field Crops Research* **63**: 79-86.
- Li, Y.J., Wu, J.Z., Huang, M., Yao, Y.Q., Zhang, C.J., Cai, D.X. and Jin, K. (2006). Effects of different tillage systems on photosynthesis characteristics of flag leaf and water use efficiency in winter wheat. *Transactions of the CSAE* **22**: 44-48.
- Limon-Ortega, A., Sayre, K. D., Drijber, R. A. and Francis, C. A. (2002). Soil attributes in a furrow-irrigated bed planting system in northwest Mexico. *Soil Tillage Research* **63**: 123-132.
- Lindquist, J.L., Arkebauer, T.J., Walters, D.T., Cassman, K.G. and Dobermann, A. (2005). Maize radiation use efficiency under optimal growth conditions. *Agronomy Journal* **97**: 72-78.
- Liu Hongyi, Ma Pengli, Yang Xingguo, Yang Qiguo (2005). Temporal and Spatial Analysis of the Water Requirements of Major Crops in Gansu Province (in

- Chinese with English Abstract). *Agricultural Research in the Arid Areas* **23**: 39-44
- Liu, F., Andersen, M.N. and Jensen, C.R. (2003). Loss of pod set caused by drought stress is associated with water status and ABA content of reproductive structures in soybean. *Functional Plant Biology* **30**: 271-280.
- Lodhi, M.A.K. and Malik, K.A. (1987). Allelopathy in agro-ecosystems, wheat phytotoxicity and its possible role in crop rotation. *Journal of Chemical Ecology* **13**: 1881-1891.
- Long, S.P., Zhu, X., Naidu, S.L. and Ort, D.R. (2006). Can improvement in photosynthesis increase crop yields? *Plant, Cell and Environment* **29**: 315-330.
- López-Urrea, R., de Santa, M., Olalla, F., Montoro, A. and López-Fuster, P. (2009). Single and dual crop coefficients and water requirements for onion (*Allium cepa* L.) under semiarid conditions. *Agricultural Water Management* **96**:1031-1036.
- Loss, S.P. and Siddique, K.H.M. (1994). Morphological and Physiological Traits Associated with Wheat Yield Increases in Mediterranean Environments. *Advance Agronomy* **52**:229-276.
- Madari, B., Machado, P.L., Torres, O.A., de Andrade E. and Valencia, A.L. (2005). No tillage and crop rotation effects on soil aggregation and organic carbon in a Rhodic Ferralsol from southern Brazil. *Soil Tillage Research* **80**: 185-200.
- Maduakor, H.O., Lal, R. and Opara-Nadi, O.A. (1984). Effects of methods of seedbed preparation and mulch on the growth and yield of white yam (*Dioscorea rotundata* L.) on an ultisol in south -east Nigeria. *Field Crop Research* **9**: 119-130.
- Mahboubi, A.A. and Lal, R. (1998). Long-term tillage effects on changes in structural properties of two soils in central Ohio. *Soil Tillage Research* **45**: 107-118.
- Major, D.J., Johnson, D.R., Tanner, J.W. and Anderson, I.C. (1975). Effect of day length and temperature on soybean development. *Crop Science* **15**:174-179.
- Mannering, J.V. and Griffith, D.P. (1998). Value of crop rotation under various tillage system. *Agronomy Guide* (Accessed on 15th May 2015).

- Manyatsi, A.M., Mhazo, N., Mkhathshwa, M. and Masarirambi, M.T. (2011). The effect of different in-situ water conservation tillage methods on growth and development of Taro (*Colocasia esculenta* L.). *Asian Journal of Agricultural Sciences* **3**(1): 11-18.
- Martinez, E., Fuentes, J.P., Silva, P., Valle, S. and Acevedo, E. (2008). Soil physical properties and wheat root growth as affected by no-tillage and conventional tillage systems in a Mediterranean environment of Chile. *Soil Tillage Research* **99**: 232-244.
- Mascagni, H.J. and Sabbe, W.E. (1990). Nitrogen fertilization of wheat grown on raised, wide beds. Ark. Agric. Expt. Stn. Report Series 317, 16.
- Masle, J., Doussinault, G., Farquhar, G.D. and Sun, B. (1989). Foliar stage in wheat correlates better to photothermal time than to thermal time. *Plant Cell Environ.* **12**:235-247.
- McGregor, K.C., Bengtson, R.L. and Mutchler, C.K. (1990). Surface and incorporated wheat straw effects on inter rill runoff and soil erosion. *Transaction American Society of Agricultural Engineers* **33**: 469-474.
- Mesfine, T., Abebe, G., and Al-Tawaha, A. M. (2005). Effect of reduced tillage and crop residue ground cover on yield and water use efficiency of sorghum (*Sorghum bicolor* L.) under semi-arid conditions of Ethiopia. *World Journal of Agricultural Sciences* **1**(2): 152-160.
- Michels, K., Sivakumar, M.V.K. and Allison, B.E. (1995). Wind erosion control using crop residue and effects on soil flux and soil properties. *Field Crops Research* **40**: 101-110.
- Miranda, F.R. de Oliveira, J.J.G., Souza, F. and De (2004). Evapotranspiração máxima e coeficientes de cultivo para a cultura da melancia irrigada por gotejamento. *Revista Ciência Agronômica* **35**:36-43.
- Miranda, F.R., Gondim, R.S. and Costa, C.A.G. (2006). Evapotranspiration and crop coefficients for Tabasco pepper (*Capsicum frutescens* L.). *Agricultural Water Management* **82**:237-246.

- Miranda, F.R., Souza, F. and Ribeiro, R.S.F. (1999). Estimativa da evapotranspiração e do coeficiente de cultivo para a cultura do melão plantado na região litorânea do Ceará. *Engenharia Agrícola* **18**:63-70.
- Monteith, J.L. (1972). Solar radiation and productivity in tropical ecosystems. *Journal of Applied Ecology* **9**: 747-766.
- Monteith, J.L. (1994). Validity of the correlation between intercepted radiation and biomass. *Agricultural and Forest Meteorology* **68**: 213-220.
- Moreno, F., Pelegrin, F., Fernandez, J.E. and Murillo, J.M. (1997). Soil physical properties, water depletion and crop development under traditional and conservation tillage in southern Spain. *Soil and Tillage Research* **41**: 25-42.
- Morote, C.G.B. *et al.* (1990). Alterações na temperatura do solo pela cobertura morta e irrigação. *Revista Brasileira de Ciência do Solo* **14**, 81-84.
- Mosaddeghi, M.R., Mahboubi, A.A. and Safadoust, A. (2009). Short term effects of tillage and manure on some soil physical properties and maize root growth in a sandy loam soil in western Iran. *Soil and Tillage Research* **104**: 173-179.
- Muchow, R.C., Robertson, M.J. and Pengelly, B.C. (1993). Radiation-use efficiency of soybean, mungbean and cowpea under different environmental conditions. *Field Crops Research* **32**: 1-16.
- Mulumba, L. N. and Lal, R. (2007). Mulching effects on selected soil physical properties. *Soil & Tillage Research* **98**: 106-111.
- Munkholm, L.J., Hansen, E.M. and Olesen, J.E. (2008). The effect of tillage intensity on soil structure and winter wheat root/shoot growth. *Soil Use Management* **24**: 392-400.
- Munoz-Romero, V., Benitez-Vega, J., Lopez-Bellido, L. and Lopez-Bellido, R.J. (2010). Monitoring wheat root development in a rainfed vertisol: tillage effect. *European Journal of Agronomy* **33**: 182-187.
- Nakamoto, T., Yamagishi, J. and Miura, F. (2006). Effect of reduced tillage on weeds and soil organisms in winter wheat and summer maize cropping on Humic Andosols in Central Japan. *Soil & Tillage Research* **85**: 94-106.

- Natarajan, M. and Willey, R.W. (1980). Sorghum-Pigeonpea intercropping and the effects of plant population density and resource use. *Journal of Agricultural Sciences Cambridge* **95**: 59-65.
- Nil, D. and Nil, E. (1993). The efficient use of mulch layers to reduce runoff and soil loss. In: K. Mulongoy and R. Merckx (Eds.) Soil organic matter dynamics and sustainability of tropical agriculture. John Wiley & Sons, Chichester - New York - Brisbane - Toronto - Singapore, pp. 331-339.
- Norwood, C.A. and Dumler, T.J. (2002). Transition to dry land agriculture. Limited irrigation vs. dry land corn. *Agronomy Journal* **94**: 310-320.
- Ogola, J.B.O., Wheeler, T.R. and Harris, P.M. (2002). Effects of nitrogen and irrigation on water use of maize crops. *Field Crop Research* **78**:105-17.
- Okoh, C.A. (2004). The effect of mulching on soil physico-chemical properties and the yield of white yam. *Tropical Journal of Root Tuber Crops* **4**(2): 24-31.
- Olanya, O.M., Ojiambo, P.S. and Nyankanga, R.O. (2006). Dynamics of development of late blight in potato and comparative resistance to cultivar in highland tropics. *Canadian Journal of Plant Pathology* **28**:84-94.
- Omae, H., Kumar, A., Kashiwaba K. and Shono, M. (2007). Assessing drought tolerance of snap bean (*Phaseolus vulgaris* L.) from genotypic differences in leaf water relations, shoot growth and photosynthetic parameters. *Plant Production Science* **10**: 28-35.
- Orkwor, G.C. and Ekanayake, I.J. (1998). Growth and Development. In: Orkwor, G.C., Asiedu, R. and Ekanayake, I.J. (Eds). *The progress in yam Research*. Ibadan, Nigeria: IITA. pp. 39-62.
- Osei-Bonsu, P., Buckles, D., Soza, F.R. and Asibuo, J.Y. (1996). Edible cover crops. ILEIA Newslett. 12, 30.
- Pal, S.K., Verma, V.N., Singh, M.K. and Thakur, R. (1996). Heat unit requirement for phenological development of wheat (*Triticum aestivum* L.) under different levels of irrigation, seeding date and fertilizer. *Indian Journal of Agricultural Sciences* **66**: 397-400.

- Pearson, G.J., Mann, I.G. and Zhang, Z. (1991). Changes in root growth within successive wheat crops in a cropping cycle using minimum and conventional tillage. *Field Crops Research* **28**: 117-133.
- Peixi, S., Mingwu, D., Aifen, Z. And Xiaojun, Z. (2002). Study on Water Requirement Law of Some Crops and Different Planting Mode in Oasis (in Chinese with English Abstract). *Agricultural Research in Arid Areas*. **20**: 79-85.
- Pervez, M.A., Iqbal, M., Shahzad, K. and Hassan, A. U. (2009). Effect of mulch on soil physical properties and N, P, K concentration in maize (*Zea mays* L.) shoots under two tillage systems. *International Journal of Agriculture and Biology* **11**(2): 119-124.
- Phadnawis, N.B. and Saini, A.D. (1992). Yield models in wheat based on sowing time and phenological development. *Annals of Plant Physiology* **6**: 52-59.
- Plenet, D., Mollier, A. and Pellerin, S. (2000). Growth analysis of maize field crops under phosphorus deficiency. II. Radiation-use efficiency, biomass accumulation and yield components. *Plant and Soil* **224** (2): 259-272.
- Poulovassilis, A., Anadranistakis, M., Liakatas, A., Alexandris, S. and Kerkides, P. (2001). Semi-empirical approach for estimating actual evapotranspiration in Greece. *Agricultural Water Management* **51**: 143–152.
- Power, J.F. (1983). Soil Management for Efficient Water use: Soil Fertility. pp. 461-470 In: H.M. Taylor *et al.* (ed.) Limitations to efficient water use in crop production. ASA, Madison, WI.
- Prihar, S.S. and Sandhu, B.S. (1987). Irrigation of Field Crops—Principles and Practices. ICAR, New Delhi, India. 142pp.
- Radke, J.K. (1982). Managing early season soil temperatures in the northern Corn Belt using configured soil surfaces and mulches. *Soil Science Society of American Journal* **46**: 1067-1071.
- Raeini-Sarjaz, M. and Barthakur, N.N. (1997). Water use efficiency and total dry matter production of bush bean under plastic straw mulchs. *Agricultural Forest Meteorology* **87**: 75-84.

- Rajput, R.P. (1980). Response of soybean crop to climate and soil environments. Ph D thesis. Indian Agricultural Research Institute, Pusa, New Delhi.
- Raki, E., Chehbouni, A., Guemouria, N., Duchemin, B. And Ezzahar, J. (2007). Combining FAO-56 model and ground-based remote sensing to estimate water consumptions of wheat crops in a semi-arid region. *Agricultural Water Management* **87**:41-54.
- Ramig, R.E., Allmaras, R.R. and Papendick, R.I. (1983). Water conservation: Pacific Northwest. In. Dregne, H.E and Willis, W.O. (Ed.). *Dryland agriculture*. Madison, WI: ASA, CSSA, and SSSA: pp. 105–124.
- Rao, V.U.M., Singh, D. and Singh, R. (1999). Heat use efficiency of winter crops in Haryana. *Journal of Agrometeorology* **1**(2): 143-8.
- Rashid, A. and Akhtar, M.E. (2006). Soil Fertility Research and Balanced Nutrient Management in Pakistan. Proc. Symp. *Balanced Fertilizer Use Impact on Crop Production*, NFDC, Islamabad: pp. 90-113.
- Rasmussen, K.J. (1999). Impact of ploughless soil tillage on yield and soil quality: a Scandinavian review. *Soil Tillage Research* **53**(1):3-14.
- Reddy, G.R., Malewar, G.U. and Karle, B.G. (2002). Effect of crop residue incorporation and tillage operations on soil properties of Vertisol under rainfed agriculture. *Indian Journal of Dryland Agricultural Research and Development* **17**:55-58.
- Reddy, M.S. and Willey, R.W. (1981). Growth and resource use studies in an intercrop of pearl millet/groundnut. *Field Crops Research* **4**: 13-24.
- Ribeiro, H.M., Romero, A.M., Pereira, H., Borges, P., Cabral, F. and Vasconcelos, E. (2007). Evaluation of a compost obtained from forestry wastes and solid phase of pig slurry as a substrate for seedlings production. *Bioresource Technology* **98**: 3294- 3297.
- Riley, H.C.F, Bleken, M.A, Abrahamsen, S, Bergjord, A.K.and Bakken, A.K. (2005). Effects of alternative tillage systems on soil quality and yield of spring cereals on silty clay loam and sandy loam soils in cool, wet climate of central Norway. *Soil Tillage Research* **80**: 79-93.

- Robertson, M.J., Fukai, S., Ludlow, M.M. and Hammer, G.L. (1993). Water extraction by grain sorghum in a sub-humid environment: II. Extraction in relation to root growth. *Field Crop Research* **33**: 99-112.
- Roca-Pérez, L., Martínez, C., Marcilla, P. and Boluda, R. (2009). Composting rice straw with sewage sludge and compost effects on the soil-plant system. *Chemosphere* **75**: 781-787.
- Rockstrom, J., Hatibuu, N., Oweis, T. and Wani, S.P. (2007). Managing Water in Rainfed Agriculture. In: Molden, D. and Earthscan (Ed.). “*Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*”, London, UK and International Water Management Institute (IWMI), Colombo, Srilanka: pp. 315-348.
- Roder, W., Mason, S.C., Clegg, M.D. and Kniefp, K.R. (1989). Yield-soil relationships in sorghum-soybean cropping systems with different fertilizer regimes. *Agronomy Journal* **81**(3): 470-75.
- Roldan, A., Caravaca, F., Hernandez, M., Garcia, C., Sanchez, B.C., Velasquez, M. and Tiscaren, M. (2003). No-tillage, crop residue additions, legume cover cropping effects on soil quality characteristics under maize in Patzcuaro watershed (Mexico). *Soil Tillage Research*. **72**: 65-73.
- Ros, M., Pascual, J.A., Garcia, C., Hernandez, M.T. and Insam, H. (2006). Hydrolase activities, microbial biomass and bacterial community in a soil after long-term amendment with different composts. *Soil Biology and Biochemistry* **38**: 3443-3452.
- Rosner J., Zwarts, E., Klik, A. and Gyuricza, C. (2008). Conservation tillage systems- soil-nutrient and herbicide loss in lower Austria and the mycotoxin problem, 15th International Congress of ISCO 18- 23 May 2008, Budapest, Published by the Geographical Research Institute, Hungary, ISBN 978 963 9545 205.
- Roth, G.W. (1996). Crop rotation and conservation tillage. *Conservation tillage series* **1**: 1-2.
- Roy, S., Meena, R.L., Sharma, K.C., Kumar, V., Chattopadhyay, C., Khan, S.A. and Chakravarthy, N.V.K. (2005). Thermal requirement of oilseed Brassica

- cultivars at different phenological stages under varying environmental conditions. *Indian journal of Agricultural Science* **75**(11): 717-21.
- Saad, A.A., Das, T.K., Rana, D.S., Sharma A.R., Bhattacharyya, R. and Lal, K. (2016). Energy auditing of a maize-wheat-green gram cropping system under conventional and conservation agriculture in irrigated north-western Indo-Gangetic Plains. *Energy* **116**: 293-305.
- Sahrawat, K.L., Wani, S.P., Rego, T.J., Pardhasaradhi, G. and Murthy, K.V.S. (2007). Widespread Deficiencies of Sulphur, Boron and Zinc in Dryland Soils of the Indian Semi-arid Tropics. *Current Science* **93**(10):1-6.
- Saini, H.S. and Aspinall, D. (1982). Sterility in wheat (*Triticum aestivum* L.) induced by water deficit or high temperature: possible mediation by abscisic acid. *Australian Journal of Plant Physiology* **9**: 529-537.
- Salton, J. C.; *et al.* (1995). Relações entre sistemas de preparo, temperatura e umidade de um podzólico vermelho-escuro de Eldorado do Sul (RS). *Revista Brasileira de Ciência do Solo* **19**: 313-319.
- Sangakkara, U.R., Attanayake, K.B., Gajanayake, J.N. and Bandaranayake, P.S.D.R. (2004). Impact of mulches on growth and yields of cassava and sweet potato in tropical Asia. 4th International Crop Science Congress.
- Sarkar, S. and Singh, S.R. (2007). Interactive effect of tillage depth and mulch on soil temperature, productivity and water use pattern of rainfed barley (*Hordium vulgare* L.). *Soil Tillage Research* **92**: 79-86.
- Sayre, K.D. and Hobbs, P.R. (2004). The raised-bed system of cultivation for irrigated production conditions. In: Columbus, Lal, R., Hobbs, P., Uphoff, N and Hansen (Eds) '*Sustainable agriculture and the rice-wheat system*'. Ohio State University. pp. 20: 337-355.
- Schillinger, W.F. and Bolton, F.E. (1993). Yield components and crop characteristics of no-tillage winter wheat grown in wheat fallow rotation. In: "*Columbia Basin Agricultural Research Center*" Annual Report. Spec. Rep. 909. Agric. Exp. Stn. Oregon State Univ., Corvallis: pp. 50-54.
- Scholander, P.F., Hammel, H.T., Hemmingsen, E.A. and Bradstreet, E.D. (1964). Hydrostatic pressure and osmotic potential in leaves of mangroves and some

- other plants. *Proceedings of the National Academy of Sciences, USA*. **52**:119-125.
- Scopel, E., Fernando, A., Da Silva, M., Corbeels, M., François, A. And Maraux, F. (2004). Modelling crop residue mulching effects on water use and production of maize under semi-arid and humid tropical conditions. *Agronomie* **24**: 383-395.
- Scopel, E., Muller, B., Arreola Tostado, J.M., Chavez Guerra, E. and Maraux, F. (1998). Quantifying and modeling the effects of light crop residue mulch on water balance: An application to rain-fed maize in western Mexico. Paper presented at the 16th International Congress of Soil Science, Montpellier, France, Aug. 20-26, 1998.
- Sepat, S., Bana, R.S., Kumar D. and Rana, K.S. (2013). A practical manual on principles and practices of managing soil and field crops. New Delhi, India: Division of Agronomy, IARI: p. 10.
- Shah, Z., Shah, S.H., Peoples, M.B., Schwenke, G.D., and Herridge, D.F. (2003). Crop residue and fertiliser N effects on nitrogen fixation and yields of legume–cereal rotations and soil organic fertility. *Field Crops Research* **83**:1-11.
- Sharma, A.R., Jat, M.L., Saharawat, Y.S., Singh, V.P. and Singh, R. (2012). Conservation agriculture for improving productivity and resource-use efficiency: prospects and research needs in Indian context. *Indian Journal of Agronomy* **57**: 131-140.
- Shinners, K.J., Nelson, W.S. and Wang, R. (1993). Effects of residue-free band width on soil temperature and water content. *Trans. ASAE*. **37**: 39-49.
- Shirani H., Hajabbasi, M.A., Afyun, M. and Hemmat, A. (2002). Effects of farmyard manure and tillage systems on soil physical properties and corn yield in Central Iran. *Soil Tillage Research* **68**:101-108.
- Shoubo, H. (1989). Meteorology of the tea plant in China: a review. *Agriculture and Forest Meteorology* **47**: 19-30.
- Shuttleworth, W.J., Gash, J.H.C., Lloyd, C.J., Moore, C.J., Roberts, J., Marques Filho, A.O., Fish, G., Silva Filho, V.P., Ribeiro, M.N.G., Molion, L.C.B.,

- de,S.A.L., Nobre, D.A., Cabral, O.M.R., Patel, S.R. and Moraes, J.C. (1985). Daily variations of the temperature and humidity within and above Amazonian forest. *Weather* **40** (4): 102-108.
- Sikder, S. (2009). Accumulated heat unit and phenology of wheat cultivars as influenced by late sowing heat stress condition. *Journal of Agriculture & Rural Development* **7**(1&2):57-64.
- Sikuku, P.A., Netondo, G.W., Onyango, J.C. and Musyimi, D.M. (2010). Chlorophyll fluorescence, protein and chlorophyll content of three nerica rainfed rice varieties under varying irrigation regimes. *Journal of Agricultural and Biological Science* **5**: 19-25.
- Sinclair, T.R. (1986). Water and nitrogen limitations in soybean grain production. I. Model development. *Field Crops Research* **15**: 125-141.
- Sinclair, T.R. and Ludlow, M.M. (1985). Who taught plants thermodynamics? The unfulfilled potential of plant water potential. *Australian Journal of Plant Physiology* **12**: 213-217.
- Singh, B. and Malhi, S.S. (2006). Response of soil physical properties to tillage and residue management on two soils in a cool temperate environment. *Soil & Tillage Research* **85**: 143-153.
- Singh, B., Humphreys, E., Eberbach, P.L., Katupitiya, A., Singh, Y. and Kukal, S.S. (2011). Growth, yield and water productivity of zero till wheat as affected by rice straw mulch and irrigation schedule. *Field Crops Research* **121**: 209-225.
- Singh, G. and Bhushan, L.S. (1980). Water use, Water use efficiency, and yield of dryland chickpea as influenced by P fertilization, stored soil water, and crop season rainfall. *Agricultural Water Management* **2**:299-305.
- Singh, K., Verma, H.D., Singh, P.P. and Jasmini, D.K. (1985). Effect of sowing dates and nitrogen on growth and yield of some new wheat varieties. *Indian Journal of Agronomy* **30**: 72-74.
- Singh, M., Srivastava, J.P. and Kumar, A. (1990). Effect of water on water potential components in wheat genotypes. *Indian Journal of Plant Physiology* **33**: 312-317.

- Singh, S. (1996). Growth and yield response of different crop species to low light and high temperature-humidity stress. *Indian Journal of Plant Physiology* **2**:151-155.
- Sinsinwar, T., Peterson, G. and Sherrod, L. (2003). Cropping intensification in dryland systems improves soil physical properties: regression relations. *Geoderma* **116**(1-2): 149-164.
- Sivakumar, M. V. K. and Virmani, S.M. (1984). Crop Productivity in Relation to Interception of Photosynthetically Active Radiation. *Agricultural and Forest Meteorology* **31**:131-141.
- Slafer, G.A. and Rawson, H.M. (1994). Sensitivity of wheat phasic development to major environmental factors: A re-examination of some assumptions made by physiologists and modellers. *Australian Journal of Plant Physiology* **21**: 393-426.
- Slatyer, R.O. and Taylor, S.A. (1960). Terminology in plant-soil-water relations. *Nature* **187**: 922-924.
- Smart, J.R. and Bradford, J.M. (1999). Conservation tillage corn production for a semi-arid, subtropical environment. *Agronomy Journal* **91**: 116-121.
- Smith, W.N., Desjardins, R.L. and Patty, E. (2009). The net flux of carbon from agricultural soils in soil properties root growth grain yield and water use efficiency of winter wheat in Canada 1970-2010. *Global Change Biology* **6**: 557-568.
- Somasundaram, E., Jauhar Ali, A., Manoharan, M. L. and Arokiaraj, A. (2000). Response of crops to different land management practices under sodic soil conditions. *Indian Journal of Agronomy* **45**: 92-96.
- Spaner, D., Todd, A.G., Navabi, A., McKenzie, D.B. and Goonewardene, L.A. (2005). Can leaf chlorophyll measures at differing growth stages be used as an indicator of winter wheat and spring barley nitrogen requirements in eastern Canada? *Journal of Agronomy and Crop Science* **191**: 393-399.
- Stanghellini, C., Bosma, A.H., Gabriels, P.C.J. and Werkoven, C. (1990). The water consumption of agricultural crops: how crop coefficient are affected by crop geometry and microclimate. *Acta Horticulturae* **278**: 509-516.

- Steiner, J.L., Schomberg, H.H., Unger, P.W. and Cresap, J. (1999). Crop residue decomposition in no-tillage small-grain fields. *Soil Science Society of American Journal* **63**: 1817-1824.
- Steinsiek, J.W., Oliver, L.R. and Collins, F. (1982). Allelopathic potential of wheat (*Triticum aestivum* L.) straw on selected weed species. *Weed Science* **30**: 495-497.
- Stone, P.J., Sorensen, I.B. and Jamieson, P.D. (1999). Effect of soil temperature on phenology, canopy development, biomass and yield of maize in a cool temperate climate. *Field Crop Research* **63**: 169-78.
- Streck, N.A., Lago, I., Gabriel, L.F. and Samboranza, F.K. (2008). Simulating maize phenology as a function of air temperature with a linear and a nonlinear model. *Pesquisa Agropecuária Brasileira* **43**: 449-55.
- Su Peixi, Du Mingwu, Zhao Aifen, Zhang Xiaojun (2002). Study on Water Requirement Law of Some Crops and Different Planting Mode in Oasis (in Chinese with English Abstract). *Agricultural Resources in Arid Areas* **20**: 79-85.
- Tanner, C.B. and Sinclair, T.R. (1983). Efficient water use in crop production: research or re-search? In *Limitations to Efficient Water Use in Crop Production*. Eds. Taylor, H.M., Jordan, W.R. and Sinclair, T.R. pp 1-27. American Society of Agronomy, Wisconsin, USA.
- Tarantino, E. and Onofrii, M. (1991). Determinazione dei coefficienti culturali mediante lisimetri. *Bonifica* **7**: 119-136 (in Italian)
- Tarantino, E. and Spano, D. (2001). La valutazione dei fabbisogni irrigui. *Rivista di Irrigazione e Drenaggio* **48**(4): 21-35 (in Italian).
- Tejada, M. and Gonzalez, J.L. (2006). Crushed cotton gin compost effect on soil biological properties and rice yield. *European Journal of Agronomy* **25**: 22-29.
- Tewari, S.K. and Singh, M. (1993). Yielding ability of wheat at different dates of sowing: a temperature development performance. *Indian Journal of Agronomy* **38**: 204-209.

- Tewolde, H., Sistani, K.R., Rowe, D.E., Adeli, A. and Tsegaye, T. (2005). Estimating cotton leaf area index non destructively with a light sensor. *Agronomy Journal* **97**:1158-1163.
- Tezara, W., Mitchel, V., Driscul, S.P. and Lawlor, D.W. (2002). Effects of water deficit and its interaction with CO₂ supply on the biochemistry and physiology of photosynthesis in sunflower. *Journal of Experimental Botany* **53**: 1781-1791.
- Thierfelder, C. and Wall, P.C. (2009). Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. *Soil and Tillage Research* **105** (2): 217–227.
- Thierfelder, C., Amezquita, E. and Stahr, K. (2005). Effects of intensifying organic manuring and tillage practices on penetration resistance and infiltration rate. *Soil Tillage Research* **82**: 211-226.
- Thomas, J.A., Jaffrey, A.C., Atsuko, K. and David, M.K. (2005). Regulating the proton budget of higher plant photosynthesis. *Proc. Natl. Acad. Sci. USA*, **102**: 9709-9713.
- Thurling, N. (1992). Morphological determinate of yield in rapeseed (*Brassica campestris* L. and *Brassica napus* L.). Growth and morphological characters. *Australian Journal of Agricultural Research* **25**: 697-710.
- Tian, Y., Su, D.R., Li, F.M. and Li, X.L. (2003). Effect of rainwater harvesting with ridge and furrow on yield of potato in semiarid areas. *Field Crops Research* **84**: 385-391.
- Tolk, J.A., Howell, T.A. and Evett, S.R. (1999). Effect of mulch, irrigation and soil type on water use and yield of maize. *Soil and Tillage Research* **50** (2): 137-147.
- Tripathi, P., Tomar, S. K. and Singh, A.K. (1999). Crop weather models to predict the growth and yield of mustard and wheat under mustard-wheat cropping system. In: Proceedings of the National Workshop on Dynamic Crop Simulation Modelling for Agro-met Advisory Services, National Center for Medium range Forecasting, New Delhi. pp. 285

- Tsubo, M., Walker, S. and Mukhala, E. (2001). Comparison of radiation use efficiency of mono-/inter-cropping systems with different row orientations. *Field Crop Research* **71**: 17 - 29.
- Tsukaguchi, T., Kawamitsu, Y., Takeda, H., Suzuki, K. and Egawa, Y. (2003). Water status of flower buds and leaves as affected by high temperature in heat-tolerant and heat-sensitive cultivars of snap bean (*Phaseolus vulgaris* L.). *Plant Production Science* **6**: 24-27.
- Turner, N.C. (1987). Crop water deficits: a decade of progress. *Advances in Agronomy* **39**: 1-51.
- Tyagi, N.K., Sharma, D.K. and Luthra, S.K. (2000). Evapotranspiration and crop coefficient of wheat and sorghum. *Journal of Irrigation and Drainage Engineering* **126**: 215-222.
- Unger, P.W. and Parker, J.J. (1976). Evaporation reduction from soil with wheat, sorghum and cotton residues. *Journal of Soil Science Society of America* **40**: 938-942.
- Unger, P.W., and Stewart, B.A. (1983). Soil management for efficient water use: An overview. p. 419–460. In H.M. Taylor *et al.* (ed.). Limitations to efficient water use in crop production. ASA, MadiSauer, WI.
- Urbano, P., Arroyo, J.M., Conde, J.R., Rojo, C. and Gonzalez, F.C. (1992). Sugarbeet irrigation. *Revista Agromecuaría* **61**(718): 380-385.
- Van Beem, J., Smith, M.E. and Zobel, R.W. (1998). Estimating root mass in maize using a portable capacitance meter. *Agronomy Journal* **90**: 566-570.
- Van Wijk, W.R., Larson, W.E. and Burrows, W.C. (1959). Soil temperature and the early growth of corn from mulched and unmulched soil. *Soil Science Society of American Proceedings* **23**: 428-434.
- Varsa, E.C., Chong, S.K., Abolaji, J.O., Farquhar, D.A. and Olsen, F.J. (1997). Effect of deep tillage on soil physical characteristics and corn (*Zea mays* L.) root growth and production. *Soil Tillage Research* **43**: 219-228.
- Vaux, Jr., H.J. and Pruitt, W.O. (1983). Crop–water production functions. In: Hillel, D. (Ed.), *Advances in Irrigation*, Vol. 2. Academic Press, New York, pp. 61-97.

- Verma, M.C. and Acharya, C.L. (1996). Root development, leaf area index, water use and yield in vertisol over 5 years in a semi-arid region of India. *Soil & Tillage Research* **70**: 163-173.
- Vetsch, J.A. and Randall, G.W. (2002). Corn production as affected by tillage systems and starter fertilizer. *Agronomy Journal* **96**: 502-509.
- Vidhana Arachchi, L. P. and Liyanage M de S. (2003). Soil water content under coconut palms in sole and mixed (with nitrogen-fixing trees) stands in Sri Lanka. *Agroforestry Systems* **57**: 1-9.
- Volkmar, K.M. and Irvine, B. (2004). Stubble effects on crop microclimate and crop performance in a subhumid Prairie climate. In: *Soil and crops conference proceedings, USA*.
- Wang, H., Zhang, L., Dawes, W.R. and Liu, C. (2001). Improving water use efficiency of irrigated crops in the North China Plain—measurements and modelling. *Agricultural Water Management* **48**: 151-167.
- Wang, J.Y. (1960). A critique of the heat units approach to plant response studies. *Ecology* **41**: 785-90.
- Wang, S.T. (1987). Water use efficiency of plant and dryland farming production. *Agricultural Resources in Arid Areas*.**2**: 67-80.
- Wang, X. (2006). Conservation tillage and nutrient management in dryland farming in China. PhD. Dissertation, Wageningen University, pp 197.
- Wang, X., Dai, K., Zhang, D., Zhang, X., Wang, Y., Zhao, Q., Cai, D., Hoogmoed, W.B. and Oenema, O. (2011). Dryland maize yields and water use efficiency in response to tillage/crop stubble and nutrient management practices in China. *Field Crops Research* **120**(1): 47-57.
- Wang, X.Q., Li, S.X. and Gao, Y.J. (1998). Effects of film mulch on physi-ecology and yield of spring corn. *Acta Agronomica Sinica* **24**(3): 348-353.
- Wang, Y.J., Xie, Z.K., Malhi, S.S., Vera, C.L., Zhang, Y.B. and Wang, J.N. (2009). Effects of rainfall harvesting and mulching technologies on water use efficiency and crop yield in the semi-arid Loess Plateau, China. *Agricultural Water Management* **96**: 374-382.

- Wang, Y.M., Chen, S.Y., Sun, H.Y., and Zhang, X.Y. (2009). Effects of different cultivation practices on soil temperature and wheat spike differentiation. *Cereal Resistant Community* **37**: 575-584.
- Watiki, J.M., Furai, S., Banda, J.A., and Keating, B.A. (1993). Radiation interception and growth of maize/cowpea intercrop as affected by plant density and cowpea cultivar. *Field Crops Research* **35**: 123-133.
- Weatherley, P.E. (1950). Studies in the water relations of the cotton plant. I. The field measurement of water deficits in leaves. *New Phytologist* **49**: 81-87.
- Weaver, M.L. and Timm, H. (1988). Influence of temperature and plant water status on pollen fertility in beans. *Journal of American Society of Horticultural Science* **113**: 31-35.
- Werker, A.R. and Jaggard, K.W. (1998). Dependence of sugar beet yield on light interception and evapotranspiration. *Agricultural Forest Meteorology* **89**: 224-240.
- Whisler, F.D., Acock, B., Baker, D.N., Fye, R.E., Hodges, H.F., Lambert, J.R., Lemmon, H.E., Mckinion, J.M. and Reddy, V.R. (1986). Crop simulation models in agronomic systems. *Advance Agronomy* **40**:141-208.
- Wilhelm, W.W.J., Doran, W. and Power, J.F. (1986). Corn and soybean yield response to crop residue management under no tillage production systems. *Agronomy Journal* **78**: 184-9.
- Williams, D.G., Cable, W., Hultine, K., Hoedjes, J.C.B., Yopez, E.A. and Simonneaux, V. (2004). Evapotranspiration components determined by stable isotope, sap flow and eddy covariance techniques. *Agricultural Forest Meteorology* **125**: 241-258.
- Williams, M.M., Mortensen, D.A. and Doran, J.W. (2000). No-tillage soybean performance in cover crops for weed management in the western Corn Belt. *Journal of Soil Water Conservation* **55**:79-84.
- Wright, J.L. (1982). New evapotranspiration crop coefficients. *Journal of Irrigation and Drainage* **108**: 57-74.

- Wurr, D.C.E., Fellows, J.R. and Phelps, K. (2002). Crop scheduling and prediction – Principles and opportunities with field vegetables. *Advances in Agronomy* **76**: 201-234.
- Yang, H.S., Dobermann, A., Lindquist, J.L., Walters, D.T., Arkebauer, T.J. and Cassman, K.G. (2004). Hybrid-maize: a maize simulation model that combines two crop modeling approaches. *Field Crops Research* **87**: 131-154.
- Yi, Z.X., Zhou, W.X., Tu, N.M., Tu, X.D., Wu, Y.L., Yang, W.L., 2007. Effects of no-tillage and straw mulching on soil nutrient content and drought resistance of maize on dry land. *Research Agriculture Mode*. **28**(4): 490-493.
- Yogev, A., Raviv, M., Kritzman, G., Hadar, Y., Cohen, R., Kirshner, B. and Katan, J. (2009). Suppression of bacterial canker of tomato by composts. *Crop Protection* **28**: 97-103.
- Zapata and Cleemput, V. (1986). Recovery of fertilizer by sugar beet–spring wheat and winter rye–sugar beet cropping sequences. *Fertilizer Research* **8**: 269-278.
- Zayed, G. and Abdel-Motaal, H. (2005). Bio-active composts from rice straw enriched with rock phosphate and their effect on the phosphorous nutrition and microbial community in rhizosphere of cowpea. *Bioresource Technology* **96**: 929-935.
- Zhang X., Chen S., Sun H., Pei D. and Wang Y. (2008). Dry matter, harvest index, grain yield and water use efficiency as affected by water supply in winter wheat. *Irrigation Science* **27**: 1-10.
- Zhang, H., Pala, M., Oweis, T. and Harris, H. (2000). Water use and water-use efficiency of chickpea and lentil in a Mediterranean environment. *Aust. Journal of Agricultural Research* **51**: 295-304.
- Zhang, X., Chen, S., Sun, H., Pei, D. and Wang, Y. (2006). Dry matter, harvest index, grain yield and water use efficiency as affected by water supply in winter wheat. *Irrigation Science* **27**(1): 1-10.
- Zhang, X., Wang, T. and Li, C. (2005). Different responses of two contrasting wheat genotypes to abscisic acid application. *Biologia Plantarum* **49**: 613-616.

Zhang, Y., Yu, Q., Liu, Ch., Jiang, J. and Zhang, X. (2004). Estimation of winter wheat evapotranspiration under water stress with two semi empirical approaches. *Agronomy Journal* **96**: 159-168.