CLIMATE CHANGE ADAPTATION THROUGH IMPROVED WATER USE EFFICIENCY IN RICE (*Oryza sativa* L.)

ANJALY C BOSE

2011-20-111

THESIS

Submitted in partial fulfillment of the

the requirement for the degree of

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Certified that the thesis entitled "**CLIMATE CHANGE ADAPTATION THROUGH IMPROVED WATER USE EFFICIENCY IN RICE (*Oryza sativa* L.)**" is a record of research work done independently by **Ms. ANJALY C BOSE (2011-20-111)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Place: Vellanikkara
Date: 25/3/17

Dr. A. V. SANTHOSHKUMAR
Professor and Head,
Department of Tree physiology and breeding,
College of Forestry, KAU,
Vellanikara

CERTIFICATE

We, the undersigned members of the advisory committee of **Ms. ANJALY C BOSE (2011-20-111),** a candidate for the degree of BSc- MSc (Integrated) Climate Change Adaptation agree that the thesis entitled "**CLIMATE CHANGE ADAPTATION THROUGH IMPROVED WATER USE EFFICIENCY IN RICE (*Oryza sativa* L.)**" may be submitted by **Ms. ANJALY C BOSE (2011-20-111),** in partial fulfillment of the requirement for the degree.

24/3/17

Dr. A. V. Santhoshkumar
(Chairman, Advisory Committee)
Professor and Head
Department of Tree physiology and Breeding
College of Forestry, KAU,
Vellanikkara

Dr. P. Indira Devi
(Member, Advisory Committee)
Professor (Agricultural Economics)
Special Officer and head
ACCER, KAU,
Vellanikara

2017

Dr. K. M. Sunil
(Member, Advisory Committee)
Assistant Professor
(Agricultural Meteorology)
KVK, Pattambi

25/3/17

Dr. Beena V. I.
(Member, Advisory Committee)
Assistant Professor
AICRP on STCR
College of Horticulture,
KAU, Vellanikkara

25-3-17

EXTERNAL EXAMINER

Dr. Jos T. Puthur.
Assoc. Professor
Dept. of Botany
Univ. of Calicut 67363

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SYMBOLS AND ABBREVIATIONS

ABA	Abscisic Acid
CAM	Crassulacean Acid Metabolism
CO_2	Carbon dioxide
CPE	Cumulative Pan Evaporation
DSSAT	Decision Support System for Agrotechnology Transfer
E	East
GDP	Gross National Product
IRRI	International Rice Research Institute
IW	Irrigation water
KAU	Kerala Agricultural University
kg ha^{-1}	Kilogram per hectare
LAI	Leaf Area Index
LEA	Late Embryogenesis Abundant
MSL	Mean Sea Level
N	North
PAR	Photosynthetically Active Radiation
PWP	Permanent Wilting Point
RARS	Regional Agricultural Research Station
RCP	Representative Concentration Pathways
SPSS	Statistical Package for the Social Sciences
W m^{-2}	Watts per square metre

CHAPTER 1

INTRODUCTION

Global climate change is the long term change in the patterns of weather over a region which may be naturally induced or anthropogenic. The effect of climate change on crop and terrestrial food are evident in several region of the world. For major crops like rice, wheat and maize, climate change without adapataion will negatively impact production in the tropical and temperate regions. Climate models predict that warmer temperatures and increase in the frequency of the drought during the 21st century will have net negative effects on agricultural productivity. As for India, where agricultural sector represent 17 per cent of India's Gross National Product (GDP), it is one of the most vulnerable countries due to climate change.

Rice (*Oryza sativa* L.) is the most important cereal crop in the world and it is the primary source of food and calories for about half of mankind. Rice is more sensitive to water deficit than other crop plants. It affects plant growth and development and ultimately leads to a considerable yield reduction or crop failure. With decreasing water availability, rice production needs to switch towards water saving production systems. It is estimated that 48 percent of the world's 141 million hectares of rice is cultivated in rain-fed fields where inadequate water at one growth stage or another limits yield. Since irrigation water is becoming scarce, the world is looking for water-efficient agriculture. Increasing food demand and declining water resources are challenges for food security (Kreye *et al.*, 2009). Drought stress is a serious limiting factor to rice production and yield stability in rainfed rice areas. In rice, the effect of drought varies with the variety, degree and duration of stress and its coincidence with different growth stages (Kato, 2004). It is estimated that drought affects rice growth in about 50 percent of the world production area. More than 50 percent of the 40 million ha of rainfed lowland rice area in South and Southeast Asia are affected by drought annually, which has contributed to significant yield losses. Rice is more susceptible to drought than other cereals because it is unable to regulate its transpirational water loss as effectively as other cereals (Austin, 1989). As a result, drought affected rice rapidly becomes damaged by the effects of low tissue water potential (Kato, 2004). Decreased leaf water potential leads to stomatal closure and ultimately results in low transpiration which in turn increases leaf temperature (Fukai *et al.*, 1999). The degree of drought tolerance differs in cultivars (Zeigler *et al.*, 1994). With increasing water scarcity in agriculture, there is a need to increase water-use efficiency in rice by adopting scientific strategies like new varieties and growing techniques.

Environmental stress reduce yield by more than 50 per cent (Boyer, 1982). In order to avoid the stress or increase their tolerance against it, plants modify their response at morphological, anatomical and cellular levels (Bray, 1997). In that case, crop management practices that improve water stress resistance can benefit plant growth and improve water use efficiency (Abdul-Baki *et al.*, 1992).

Hydrogel is a synthetic polymer, which is able to absorb and hold 80–180 times its volume of water for a long time (Wang and Gregg, 1990). Hydrogel acts as a reservoir to store and release a steady stream of water and nutrients which plants need to grow. Plant roots are able to absorb water from the crystal bead of hydrogel. Several previous studies showed that these are very useful under limited water conditions to cope with plant water needs (Henderson and Hensley, 1985; Ingram and Yeager, 1987; Wang and Gregg, 1990). Johnson (1984) reported that addition of hydrogel at the rate of 2 g/kg improved the water holding capacity of sand from 171 percent to 402 percent. Application of hydrogel decreases the irrigation requirements of several crops by improving water holding capacity resulting in delay and onset of permanent wilting percentages under intense evaporation. An increase in water holding capacity due to hydrogel amendment significantly reduced the irrigation requirement of many plants (Taylor and Halfacre, 1986). Due to the considerable volume reduction of the hydrogel as water is released to the crop, hydrogel creates within the soil, free pore volume offering additional space for air and water infiltration, storage and root growth (Kumar, 2015). The large quantities of water retained by the polymer provide extra available water to crops which facilitates better crop growth. More available water in the soil also means less frequent irrigation. Hydrogel reduces irrigation frequency of field crops. It also reduces irrigation amount from 100 to 85 percent of the crop water requirements and increase crop yield (El-Hady *et al.*, 1982). The excellent water absorbency and water retention by hydrogel may prove especially practical in agriculture. It performs its wetting/drying cycles over a longer period of time, maintaining its very high water swelling and releasing capacity against soil pressure. Consequently evaporation, deep water percolation and nutrient leaching can be avoided (Kumar, 2015).

Thus a better understanding of the abiotic stress and plant responses, along with the application of hydrogel as a super absorbent polymer will help us to devise a management strategy. The present study attempts to understand the effect of water stress on rice growth and yield and the effect of hydrogel in overcoming the stress.

The study aims to:

1. Elucidate the influence of varying soil moisture status on rice productivity and,

2. Evaluate the increased water use efficiency in a climate change adaptation strategy

CHAPTER 2

REVIEW OF LITERATURE

World population is growing at an alarming rate and is anticipated to reach about six billion by the end of the year 2050. On the other hand, agricultural productivity is not increasing at a required rate to keep up with the food demand. The reasons for this are various abiotic stresses. Stress is defined as any environmental variable, which can induce a potentially injurious strain in plants. Since, living organisms cannot control environmental conditions, they have evolved two major strategies for surviving adverse environmental conditions *viz.*, stress avoidance or stress tolerance. The avoidance mechanism is most obvious in warm blooded animals that simply move away from the region of stressful stimuli. Plants lack the response mechanism, of mobility; hence they have evolved intricate biochemical, molecular and genetic mechanisms to avoid stress.

Tolerance mechanisms mainly involve biochemical and metabolic means which are in turn regulated by genes. All the abiotic stresses have profound influence on ecological and agricultural systems. Water stress is the predominant stress among all the abiotic stresses which causes enormous loss in production of crops, more so because water stress is usually accompanied by other stresses like salinity, high temperature and nutrient deficiencies. In addition, the impact of global climate change on crop production has emerged as a major research priority during the past decade. Several forecasts for coming decades project increase in atmospheric CO_2 and temperature, changes in precipitation resulting in more frequent droughts and floods, widespread runoff leading to leaching of soil nutrients and reduction in fresh-water availability.

Any non-living factors that affect living organisms negatively are collectively put under the general term "abiotic stress" and its effects can be and are mitigated by a variety of defense mechanisms developed by the different biological systems in existence. Examples of abiotic stress are desiccation, salinity, high and low temperature etc. There are two general mechanisms used to counteract abiotic stress: avoidance and adaptation. In the case of avoidance, organisms migrate to deeper soil layers where temperatures are within tolerable range (Roelofs *et al.*, 2008). Adaptation to stress is based on activation of stress defense gene pathways, which results in the production of heat shock proteins, LEA proteins, redox regulating proteins, different compatible solutes and cytochrome P450s (Roelofs *et al.*, 2008). Abiotic stresses such as salinity, drought, heavy metal toxicity and extreme temperatures are critical factors that reduce crop yields by more than 50 percent worldwide (Wang *et al.*, 2003).

Water is one of the most important substances for the survival of both plants and animals. Plants require water for photosynthesis, nutrient uptake and transportation as well as for cooling (Farooq *et al.*, 2009). Since water is essential for plant survival, the ability to tolerate water stress is crucial.

Plants need to take up water from the soil and CO_2 from the atmosphere and use it in photosynthesis for its growth. This is done by CO_2 uptake through the stomatal pore, where water is simultaneously transpired. Water transpiration drives the water uptake by the roots and transport through the xylem. When the stomata are open CO_2 is taken up while water is transpired. When the stomata are closed little CO_2 is taken up and the transpiration is lowered. By opening and closing the stomata plants can regulate the amount of water lost, by sacrificing CO_2 uptake, when the environmental conditions are unfavorable. Water stress can be defined as reduced water availability; either by water scarcity (drought) or osmotic stress (high salt concentrations) or water logging. Water stress may reduce photosynthesis, respiration and ion uptake, change the metabolic and growth patterns in the plant and in severe cases result in plant death (Jaleel *et al.*, 2009).

In agriculture and horticulture drought stress is one of the major problems, causing major crop losses every year as well as loss of aesthetic value in ornamentals. In agriculture crop loss is due to reduced numbers of tillers, spikes and grains per plant and reduced grain weight (Farooq *et al.*, 2009). With simultaneous increase of global human population and water scarcity, the loss of crop will be even more serious than before.

2.1. ABIOTIC STRESS AND PLANTS RESPONSE

The major abiotic stresses (drought, high salinity, cold, and heat) negatively influence the survival, biomass production and yields of staple food crops up to 70 percent (Kaur *et al.*, 2008; Thakur *et al.*, 2010). Dehydration stress imparted by drought, salinity and temperature severity is the most prevalent abiotic stress that limits plant growth and productivity (Jaleel *et al.*, 2009; Thakur *et al.*, 2010). Plant responses to abiotic stresses comprises morphological, physiological and biochemical changes that either decrease plant's stress exposure or limit damage and facilitate recovery of impaired systems (Potters *et al.*, 2007). Survival in hostile environments involves developing mechanisms of tolerance, resistance, or avoidance. Plants that develop tolerance to a given factor can, over time, overcome the effects of stress without injury.

Plants avoid dehydration by accumulation of osmolytes and changes in metabolism (Bouchabke *et al.*, 2008). Acceleration of the plant life cycle to allow flowering before a drought period is a good example of plants showing resistance as a response mechanism. Many arid-land grain crops have been improved through breeding programs that allow the crop to avoid seasonal dry periods (Des Marais and Juenger, 2010). Avoidance prevents exposure to the stress (Madlung and Comai, 2004). Stomatal regulation is a strategy to avoid dehydration (Buckley *et al.*, 2003). However, by this conservative strategy, reductions of photosynthesis and growth can occur. Plants are often unable to adjust to a certain condition and become sensitive to it. Depending on the degree of plasticity that a plant possesses to deal with a new environmental situation, morphological, anatomical, and physiological changes may occur. These changes can affect plant growth, productivity in agriculture, metabolic profile and plant nutritional potential (Altman, 2003). Therefore, plant abiotic stress has been a matter of concern for the maintenance of human life on earth and especially for the world economy.

Plants growing in deserts or high salinity habitats are all exposed to more or less constant water stress. To survive such conditions plants have developed growth strategies such as increased water use efficiency with CAM metabolism (Keeley and Rundel, 2003) or succulent growth and extensive root systems (Henry *et al.*, 2011). These strategies are good in a dry environment, but in more favourable conditions at least some of these plants may, due to lower growth rates, more easily be outcompeted by other less drought tolerant plants. Even if they do not live in particularly dry places, most plants will occasionally encounter water stress for shorter or longer periods of time. Most of these plants do not have many of the adaptations of desert plants and must respond to the water stress in other ways. When these plants are exposed to water stress, such as drought or saline conditions, to survive they must be able to retain as much water as possible. If the plants are not able to cope with the water stress, they will not be able to survive.

The sensitivity and response time to drought differs between different species and slow growing species have been found to be more sensitive (Assmann *et al.*, 2000). During water stress, the water content of the plant decreases, which causes the cells to lose turgor pressure and shrink. The loss of turgor pressure in the cells inhibits turgor dependent activities such as cell expansion, which affects the growth of the whole plant. Some studies show that abscisic acid (ABA) can function as a signal to reduce leaf growth rate, both when ABA is applied exogenously or generated by water stress (Wilkinson and Davies, 2010). Reduced cell growth during water stress has been found to decrease the stem length in soybean, potato and parsley (Heuer and Nadler, 1995; Specht *et al.*, 2001; Park *et al.*, 2007; Sankar *et al.*, 2008). Similarly reduced cell enlargement reduces the leaf expansion (Ren et al., 2007). By reducing the leaf expansion the leaves become smaller and therefore transpire less. In some cases water stress can even lead to leaf abscission, as seen in *Populus* and paper birch (Giovannelli *et al.*, 2007; Gu *et al.*, 2007).

To increase water uptake and maintain a minimum osmotic pressure during drought many plants increase their root growth, either deeper or laterally. By increasing the root growth the area for water uptake becomes larger and water further away and deeper in the soil may be reached. This growth response has been found in madagaskar periwinkle (*Catharanthus roseus)* and date palm (*Phoenix dactylifera)* (Djibril *et al.*, 2005; Jaleel *et al.*, 2008; Trachsel *et al.*, 2010).

Under mild to moderate water deficits, stomatal closure is one of the earliest plant responses, with the reduced water potential and turgor associated with even a small decrease in relative water content (Chaves *et al.*, 2003; Lawlor and Tezara 2009). Reduced stomatal conductance limits water loss and CO_2 diffusion, and hence photosynthetic assimilation. Ultimately, reduced photosynthetic assimilation rates result in reduced vegetative growth, and for many crops even mild drought stress results in reduced yield. Nonetheless, in some crops both stomatal conductance and carbon assimilation can be maintained until water potential falls to relatively low levels (Flexas and Medrano, 2002). Both hydraulic and chemical signals sent from drying roots to the shoot are involved in the regulation of stomatal closure and decreased growth during soil drying (Tardieu *et al.*, 2010).

The importance of abscisic acid (ABA) as a root-sourced signal, transported through the xylem and involved in stomatal regulation during drought has been highlighted in several studies (Dodd *et al.*, 2006). Other compounds such as the precursors of ABA or cytokinins also play a role, as do changes in mineral composition or pH of the xylem (Wilkinson and Davies, 2008). The main cause of reduced photosynthetic rate under mild to moderate water deficits is reduction in the diffusion of atmospheric CO_2 to the site of carboxylation (Chaves *et al.*, 2009). This is as a result of both stomatal closure and a reduction in mesophyll conductance, although the extent of the influence of mesophyll conductance is still debated (Pinheiro and Chaves, 2011). Water stress also directly impacts on internal transport of CO_2 and on enzyme activity and hence photosynthetic capacity (Lawlor and Tezara, 2009), and these metabolic and diffusive limitations become predominant relative to stomatal limitation as water stress becomes more severe (Flexas and Medrano, 2002). Despite the importance of reduced photosynthetic assimilation rates on growth and yield, slowly developing water deficit can result in a small leaf area index. This will impact on productivity even though assimilation rates may be close to those of well-watered plants (Lawlor and Tezara, 2009).

2.2. EFFECT OF DROUGHT STRESS IN RICE

Rice (*Oryza sativa* L.) is the most important cereal crop in the world and it is the primary source of food and calories for about half of mankind. Rice is particularly susceptible to soil water deficit, which causes large yield losses in many Asian countries. Drought affects its growth in about 50 percent of the world production area. More than 50 percent of the 40 million ha of rainfed lowland rice area in South and Southeast Asia are affected by drought annually, which has contributed to significant yield losses.

In China, rice is one of the main irrigated crops with high water consumption, approximately account to 65 percent water consumption.

With the occurrence of water deficits, many of the physiological processes associated with growth are affected and under severe deficits, death of plants may result. The effect of water stress may vary with the variety, degree and duration of water stress and the growth stage of the rice crop. Water stress during vegetative stage reduces plant height, tiller number and leaf area. However, the effect during this stage varies with the severity of stress and age of the crop. Long duration varieties cause less yield damage than short duration varieties as long vegetative period could help the plant to recover when water stress is relieved. Leaf expansion during vegetative stage is very sensitive to water stress. Cell enlargement requires turgor to extend the cell wall and a gradient in water potential to bring water into the enlarging cell. Thus water stress decreases leaf area which reduces the intercepted solar radiation.

Rice leaves in general have a very high transpiration rate thus under high radiation levels rice plant may suffer due to mid day wilting. Rice plant can transpire its potential rate even when soil moisture was around field capacity. The effect of water stress on decrease in yield is very pronounced during certain period of growth, called the moisture sensitive periods. The most sensitive periods to water deficits are flowering and head development. In an experiment conducted in the Philippines (IRRI, 1973), it has been shown that moisture stress early in the growth of the rice resulted in reduced tillering, thereby reduced yield. When moisture stress was extended into reproductive phase, yield loss was significant.

Jana and Ghildyal (1971) examined the effect of varying soil water regime during different growth phases on rice yield. They reported that the soil water stress applied at any of the growth phases reduced rice grain yield, compared to the continuous flooding irrigation. In rice, the effect of drought varies with the variety, degree and duration of stress and its coincidence with different growth stages (Kato, 2004). The ripening phase appeared to be most sensitive compared to the other phases. Soil water stress during the earlier growth phases (vegetative) reduced the production of effective tillers resulting in the reduction of grain yield, while stress during the later growth phases (reproductive) appeared to affect the reproductive physiology by interfering with pollination, fertilization and grain filling and thus resulting in the reduction of grain yield.

Rice is particularly susceptible to water deficit at the reproductive stage (Fukai and Lilley, 1994; Zeigler, 1994; Pirdashti *et al.*, 2004). The booting stage and anthesis are the most sensitive stages (McKersie and Ya'acov, 1994). Yield reduction related to water deficit after anthesis occurs due to reduced panicle numbers and increased sterility (Zeigler *et al.*, 1994). Timing, intensity and occurrence of water deficit have been associated with the delay of heading or flowering (Fukai *et al.*, 1999). In a study conducted by Sikuku *et* al. (2010), the well watered plants had higher filled grain ratio percentage and higher yields as compared to those subjected to water deficit. Similar results were reported by

Yeo *et al.* (1996) who observed that water deficit reduced yield in rice. Bouman and Toung (2001) also had similar results and concluded that rice crops are susceptible to drought which causes large yield losses in many countries. Yield depends on accumulation of dry matter and on its partitioning (Baruah *et a.l,* 2006). Grain yield of rice may be limited by the supply of assimilates to the developing grain or by the capacity of the reproductive organ to accept assimilates.

Water stress at tillering resulted in significant reduction in plant height and reduction in plant height (Sokoto and Muhammad, 2014). This is because imposing water stress resulted in low leaf water potentials and reductions in photosynthesis. Similarly, during tillering plant produces leaves and due to reduced growth as a result of water stress, the leaf initiation gets decreased and thus, tends to reduce tillering (Sokoto and Muhammad (2014). Similar results were reported by De Datta *et al.* (1973).

Water stress during vegetative stage reduced tiller number, while stress at the reproductive and grain-filling stage reduced grain number and weight. Bouman and Tuong (2001) found that drought before or during tillering reduces the number of tillers and panicle per hill. Total grain number per panicle of genotypes drastically reduced when drought stress occurred at flowering stage. It has been argued that under severe drought stress, when yields are reduced to below 50 percent of those under favorable conditions the relationship between yield under favorable and stress conditions break down (Ceccarelli and Grando, 1991). Plants that were stressed took longer time to flower and to mature as compared to plants that were well watered.

2.3. IMPORTANCE OF HYDROGEL IN MITIGATING STRESS

Hydrogels are synthetic polymers in the form of crystals or tiny beads available under several trade names such as super absorbent polymers, root watering crystals and drought crystals. They have enormous capacity to absorb water when it comes by and make it available to plants over time. Thus hydrogels or Super Absorbent Materials are hydrophilic polymer complexes which have capacity to absorb large volume of aqueous fluids within short period of time and desorb the absorbed water under stress condition. Super absorbent polymer holds 400-1500 g of water per dry gram of hydrogel (Bowman and Evans, 1991; Woodhouse and Johnson, 1991). Johnson and Veltkamo (1985) have suggested that when these hydrogel are used correctly, 95 percent of their stored water is available for plant absorption. They are capable of cyclical absorption and desorption for a long period of time. Hence these absorbents act as a slow-release source of water and dissolved nutrients in the soil. The survival of seedlings is extended by increasing the time of wilting between intervals of rainfall and may lead to increased yields in certain conditions. The drought stress effects can be reduced by the application of super absorbent polymer and improves plant yield and agriculture production stability (Khadem *et al.*, 2010; Ali *et al.*, 2014).

Water scarcity for agricultural production has been on the rise and development of new water resources increasingly costly. Increased efficiency in the use of water is essential for future food security in Asia where rice production has to be increased by 70 percent of the present amount by the year 2025. An increase in water holding capacity due to hydrogel significantly reduced the irrigation requirement of many plants (Taylor and Halfacre, 1986). Seed germination and establishment are critical phases in plant growth and development. The establishment of crop cover is often restricted due to low moisture available in coarse textured soils, particularly in arid environments. The application of hydrogels is an important practice to assist plant growth by increased water retention by sandy soils and its availability to plants in dry regions. The amendment with hydrogel is known to improve seed germination and seedling growth in several species. Ahmed and Verplancke (1994) reported an improvement in germination and biomass production of trifolium, lettuce and ryegrass in dune sand with gel amendment compared to control. Woodhouse and Johnson (1991) have shown varying degrees of improvement in the germination and establishment of different plant species.

Despite various beneficial effects of hydrogel addition, some studies have shown little or no benefit with hydrogel addition (Conover and Poole 1976; James and Richards 1986; Ingram and Yeager 1987). While the amount of plant available water is increased by hydrogel amendment, the period of its availability is also important for plants and is determined by the rate of evaporation from the soil. The evaporation losses from untreated soils were rapid compared with soil amended with hydrogel. The reduction in evaporation losses with hydrogel addition were more pronounced in sandy loam soil compared with loam soil. As a result, the onset of a permanent wilting point was delayed by 4 to 5 days (Akhter *et al.*, 2004). Such an increase in time to wilt reduced the water requirements of plants (Ghering and Lewis 1980; Taylor and Halfcare 1986).

Significant increase in plant height and number of branches per plant were noticed due to soil application of hydrophilic polymer. With an increase in concentration of hydrophilic polymer, there was increase in plant height and number of branches per plant (Kumar, 2015). Similar results have been reported by Sendur *et al.* (2001) in tomato. High polymer content with water supply caused opening of stomata for long time, subsequently good fixation of CO_2 resulted in increase of dry matter in crop (Khadem *et al.*, 2010). Hydrophilic polymer significantly reduced the number of irrigation frequency in tomato by increasing water holding capacity of soil which is in accordance with the results observed by Abedi-Koupai *et al.* (2004). Hydrophilic polymer increases the turgor pressure inside the cells by maintaining sufficient amount of water as per crop requirement and thus causing increase in leaf area and other related growth parameters (Al-Harbi *et al.*, 1999; Yazdani *et al.*, 2007). An increase in yield and yield related attributes could be because of sufficient availability of water and indirectly nutrients supplied by the super absorbent polymer to the plants under water stress condition, which in turn lead to better translocation of water, nutrients and photosynthates and finally better plant yield.

Use of hydrogel increased the amount of available moisture in the root zone resulting in longer intervals between irrigations (Abedi-Koupai *et al.*, 2004;

Allahdadi *et al.*, 2005). In arid and semi-arid regions of world, intensive research on water management is being carried out and use of superabsorbent polymers may effectively increase water use efficiency in crops. Soil conditioning with superabsorbent polymers could be an innovative facet in the field of agriculture, which works as miniature water storage reservoirs. Research evidences suggested that problems associated with traditional micro irrigation and the factors which are catalyst in practicing efficient irrigation techniques can be taken care of by conditioning the soil with superabsorbent polymer.

In term of water conservation and optimize water use efficiency where water scarcity is a common problem, superabsorbent polymer can be used as a water conservator in agriculture. The permanent wilting point (PWP) is reached more easily when no hydrogel is applied. Therefore, the use of hydrogel as a retainer soil water and delayer of the PWP, may explain the better growth and development of the crop. This result is consistent with the findings of a study by Akhter *et al.* (2004) in which the addition of hydrogel to the soil improved the availability of soil moisture and promoted the growth and development of plants.

2.4. ROLE OF CLIMATE MODELS

Climate change and agriculture processes are interrelated on the earth. Global warming, which includes increasing temperature and upcoming water deficit are going to be greatly exacerbating and will have significant impact on agriculture. The effect in crop production is projected at 10-40 percent loss by 2100. So, we are in great necessity to adapt the future climate change for food security and socio- economic development. Agriculture is strongly dependent on water resources and climatic conditions, particularly in the regions of the world that are particularly sensitive to climatic hazards, such as Africa, South and Central America, and Asia. It is now well recognized that crop production is very sensitive to climate change (McCarthy *et al.*, 2001), with different effects according to region.

Modeling climate and Earth system processes on a regional scale is essential for projecting the impacts of climate change on society and our natural resources. A crop model needs a season-long daily weather dataset to simulate the crop productivity. A skillful seasonal forecast in a monthly or seasonal average sense is recommended (Pal *et al.,* 2007). Several researchers have used rainfall forecasts from different global circulation models (GCMs) for its application in crop simulation models with promising results. Grain productivity prediction using a crop simulation model requires weather input for entire growing season. When the availability of weather information is limited for certain period only, it becomes necessary to generate 'synthetic weather' for the remaining part of the season. This deficiency can be fulfilled by use of stochastic weather generator (Hansen and Ines, 2005).

DSSAT is a software application program that contains crop simulation models for over twenty eight crops which is being used for more than 20 years in over 100 countries over the world. This package incorporates models of 16 different crops with software that facilitates the evaluation and application of the crop models for different purposes. The models simulate the effects of weather, soil water, genotype, soil and crop N dynamics on crop growth and yield (Jones *et al.*, 2003). It is one of the best systems research tool for modeling crop, soil, weather and management or husbandry interactions and to assess the climate change impacts (Jones *et al.*, 2003). It also standardizes the input format and brings lot of individual models in one platform which contributes major to its popularity. It has to be functional and it can be used for processing the database management programs for weather, climate, soil, experimental data, utilities, crop management date and other application programs. The crop simulation models can simulate growth, development and productivity as a function of the soil, crop and atmospheric dynamics. DSSAT and its crop simulation models have been utilized for various applications ranging from on-farm and precision management to regional assessments of the impact of climate variability and climate change. The inputs for these crop models include daily weather data, soil surface and profile information and detailed crop management. Along with these some additional information about the crop genetics and information about the cultivar or variety should also be provided. DSSAT also help users to compare simulated outcomes with observed results thus evaluating the results of the model.

CHAPTER 3

MATERIALS AND METHODS

3.1. DETAILS OF THE FIELD EXPERIMENT

3.1.1. Location

The research experiment titled "Climate change adaptation through improved water use efficiency in rice, *Oryza sativa*" was conducted at the Regional Agricultural Research Station (RARS), Pattambi situated at 10.82° N latitude and 76.19° E longitude and about 63m above MSL.

3.1.2. Climate

The study site had a tropical climate in which most months of the year are marked by significant rainfall. The climatic parameters collected during the study period are given in the table 1.

Table 1. Climate parameters of the study site (source: Agro meteorological observatory situated in RARS campus)

Year	**Month**	**Temperature (°C) (Max)**	**Temperature (°C) (Min)**	**Rainfall (mm)**	**Relative Humidity**	**Evaporation (mm)**
2016	**May**	34.2	25.2	6.2	78	4.3
	June	30.0	23.9	16.0	89	2.3
	July	29.8	23.8	11.1	82	2.9
	August	30.5	23.9	3.9	81	3.3
	September	30.3	23.6	3.1	79	3.4

3.1.3. Variety

Jyothy (PTB 39) which is a semi dwarf variety having 105-125 days duration of growth period was used for the study.

3.2. EXPERIMENTAL LAYOUT

A pot size of 0.1 m^2 surface area was used for the experiment and it was laid out in a completely randomized design with two factors in a poly house at RARS, Pattambi. As first factor, irrigation levels at IW/CPE=2, IW/CPE=1.5, IW/CPE=1 and IW/CPE=0.5 were maintained. Irrigation was fixed on the basis of ratio between irrigation water (IW) and cumulative evaporation from class A pan evaporimeter minus the precipitation since the previous irrigation (CPE) (Prihar *et al.*, 1974). This ratio is assumed to be close and direct relationship of crop evapotranspiration with pan evaporation. For calculating pan evaporation, the pan is filled with a known quantity of water. Water is allowed to evaporate for 24 hours. After 24 hours, the remaining quantity of water is determined. The amount of evaporation per unit time is calculated. The pan evaporation values were added up each day till it is equal to the amount of water applied as irrigation. When an irrigation of 3 cm depth would be applied to rice, the CPE value at which the irrigation to be applied would be 1.5 cm when the IW/CPE ratio is 2. The CPE value is calculated each time starting from the date of irrigation to the subsequent one. Hydrogel at two intervals (with hydrogel and no hydrogel) were maintained as the second factor. There were a total of 8 treatment combinations and the whole experiment was replicated three times (Table 3). Each replication had 10 pots.

3.2.1. Cultural operations

3.2.1.1. Nursery management

The rice nursery was raised in trays. Beds were prepared in tray using soil, cowdung and bran at the ratio of 3:1:1. The pre-germinated seeds were evenly spread on the tray and watered daily. Seedlings were transplanted to the experimental site at 20 days of sowing.

3.2.1.2. Preparation of pots and transplanting

The experiment was laid out in poly house after clearing weeds in the poly house. Environmental conditions in polyhouse are given in table 2. Each pot of

0.1 m² area was filled with 23 kg of soil and were kept at a spacing of 60 cm×60 cm. Cowdung (2 kg/pot) and lime (500 g/pot) were applied to the soil and the 20 day healthy seedlings were transplanted in to it. Hydrogel at the rate of 2-2.5 mg/kg of soil was applied to half of the pots. Irrigation was given immediately after transplanting.

3.2.1.3. Fertilizer application

The pots were fertilized at a dose of 90:45:45 kg/ha as per KAU package of practices (KAU, 2011). Urea, Rock phosphate and Muriate of Potash were the source material for supplying nitrogen, phosphorous and potassium respectively.

3.2.1.4. Irrigation scheduling

The IW/CPE approach is based on the relationship of crop evapotranspiration and pan evaporation. The cumulative pan evaporation (CPE) values for three days was estimated and water was applied to each pot under the ratio of IW/CPE=2, IW/CPE=1.5, IW/CPE=1 and IW/CPE=0.5 at 4 day interval.

3.2.1.5. After cultivation

The pots were kept free of weeds throughout the crop growth period by hand weeding.

3.2.1.6. Harvesting

The crop was harvested at physiological maturity.

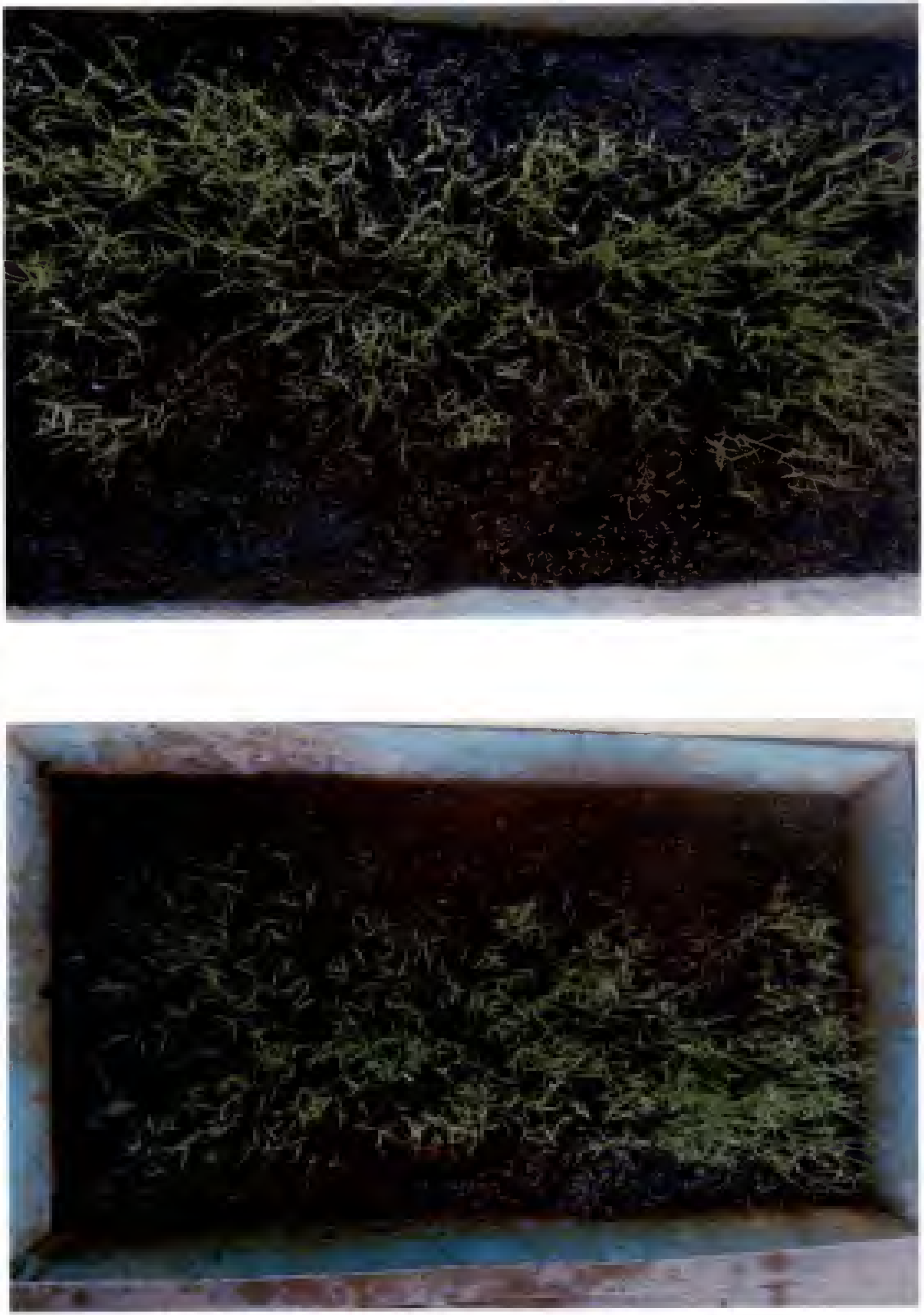

Plate 1. Rice seedlings in nursery bed

Plate 2. Preparation of pots for transplanting the seedlings

Plate 3. Rice seedlings transplanted in pots

Plate 4. Rice plants at the vegetative stage

Table 2. Environmental conditions in poly house (weekly)

Week No.	MAX AT	MIN AT	Soil temp min	Soil temp max	Relative humidity (%)		Sun-shine (hrs)
					I	II	
1	48.9	26.4	33.2	43.3	97	57	73.3
2	47.7	26.5	32.8	40.7	97	65	67.0
3	47.3	25.1	32.9	38.8	95	66	66.9
4	44.8	24.6	33.0	39.5	97	70	54.1
5	45.1	24.8	33.7	40.1	97	73	73.4
6	44.7	25.0	33.7	40.6	97	70	90.8
7	42.1	24.5	33.5	40.4	98	75	57.3
8	43.8	25.6	33.6	40.8	98	76	55.6
9	44.3	26.7	33.9	41.7	98	67	57.5
10	43.2	25.6	33.4	41.3	98	69	53.3
11	41.6	25.0	33.2	41.4	98	77	42.1
12	38.2	24.6	33.3	41.5	99	79	30.3
13	36.0	25.4	33.3	32.7	98	98	33.3
14	40.4	24.7	32.5	28.8	99	99	48.4
15	33.3	25.7	30.5	38.0	93	74	28.1
16	34.1	25.1	30.7	39.4	94	76	28.0
17	31.3	25.0	30.6	31.4	95	88	25.9
18	36.1	24.9	30.9	29.6	95	75	27.4
19	34.6	25.2	31.7	30.4	94	72	27.8
20	32.1	25.1	30.8	29.9	90	79	27.4
21	34.3	25.9	32.2	30.5	94.6	76.6	28.1

Plate 5. Rice plants at the reproductive stage

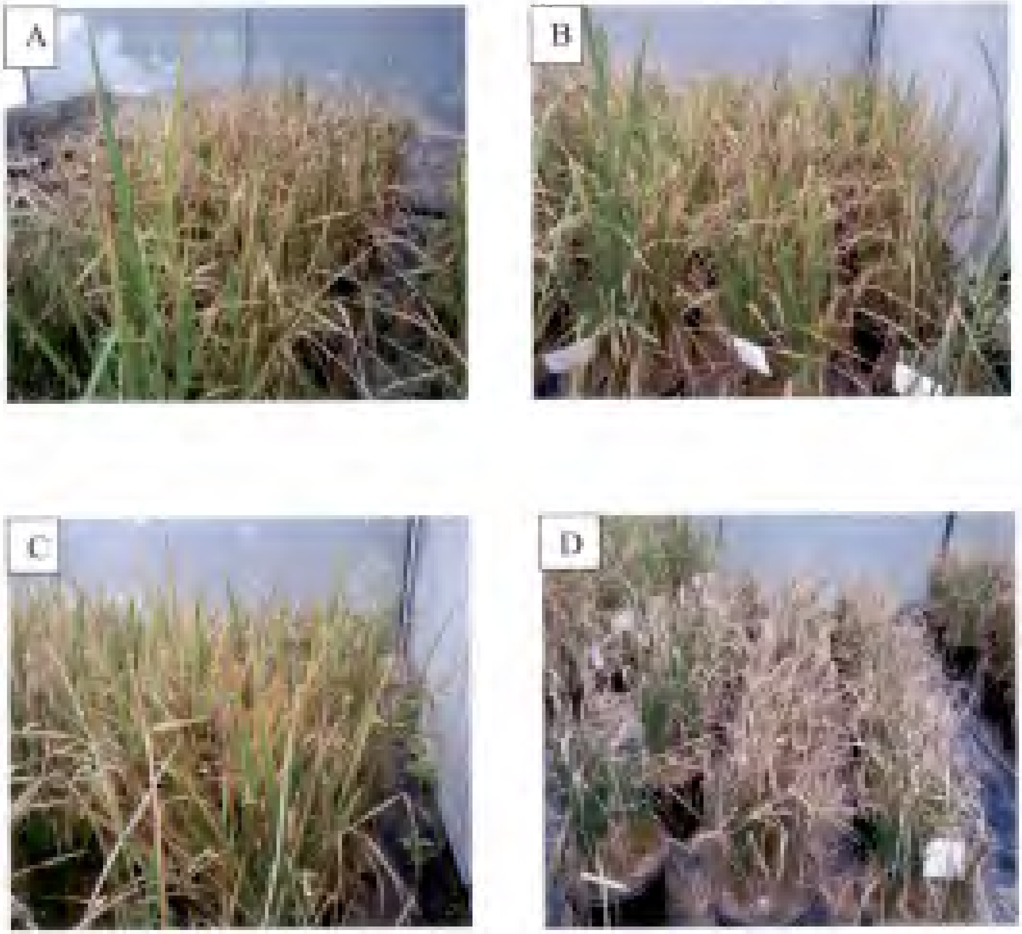

Plate 6. Rice plants with hydrogel at the mature stage in different irrigation levels (A=IW/CPE=2, B=IW/CPE=1.5, C=IW/CPE=1 and D=IW/CPE=0.5)

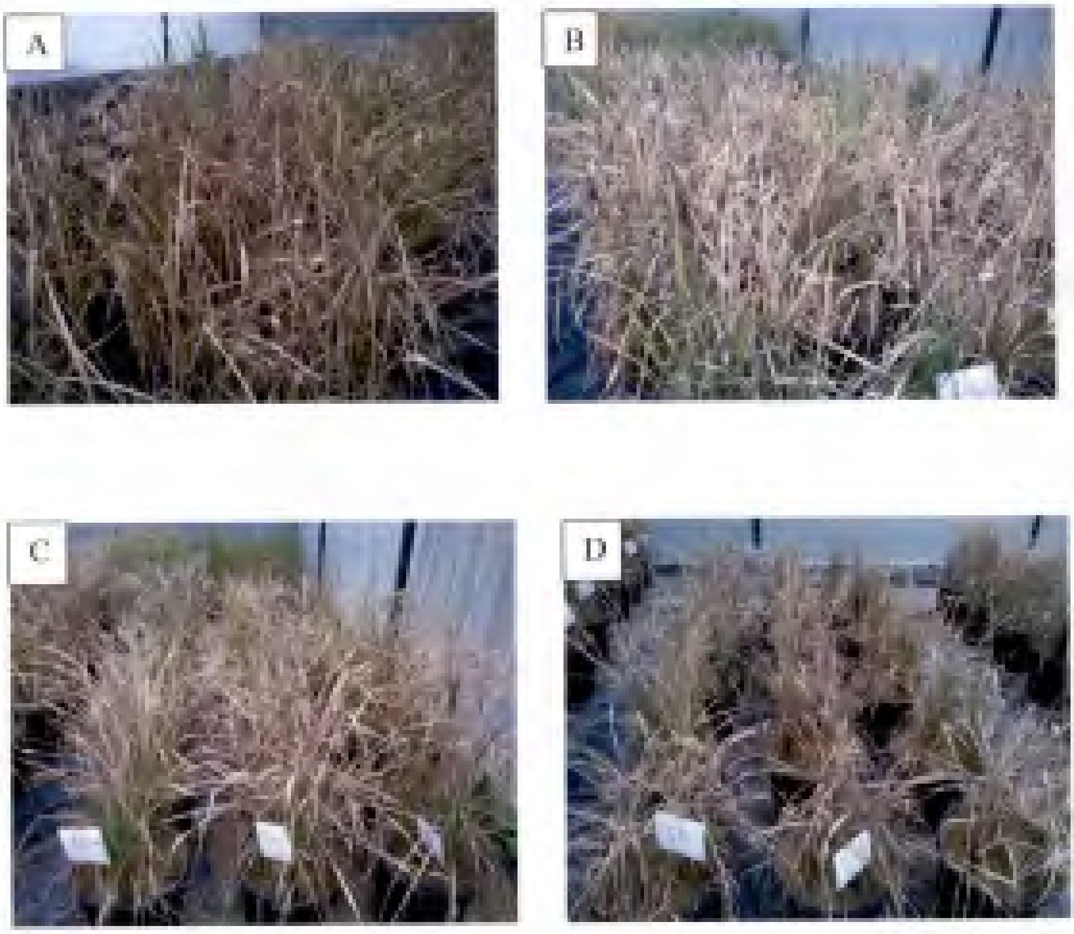

Plate 7. Rice plants without hydrogel at the mature stage in different irrigation levels (A=IW/CPE=2, B=IW/CPE=1.5, C=IW/CPE=1 and D=IW/CPE=0.5)

3.3. OBSERVATIONS

3.3.1. Biometric observations

3.3.1.1. Plant height

The plant height was measured as the distance from the base to the highest point of the plant for each replication at weekly interval and the mean was calculated. It was expressed in cm.

3.3.1.2. Leaf area index (LAI)

Leaf area index is measure of the total one-sided area of leaf tissue per unit ground surface area (Watson, 1947). It was measured using a Plant Canopy Analyser, LAI-2000 at weekly intervals for each replication and the mean was calculated.

3.3.1.3. Dry matter accumulation

The total dry matter accumulated in kg/plant for each replication was noted at the harvest and the mean was calculated. It was converted into kg/ha.

3.3.1.4. Number of tillers

The tiller number was determined by observing and counting all the emerging shoots in the hill from the time of transplanting to the harvest. The number of tillers in each replication was counted at weekly intervals and the mean was calculated.

3.3.1.5. Number of panicles per hill

The number of panicles per hill includes all the unfilled and filled panicles of a plant. The number of panicles per hill for each replication was counted and the mean was calculated.

3.3.1.6. Number of primary branches per panicle

The primary branches refer to the first differentiation of a panicle which contains large number of other rachis-secondary branches. The number of primary branches per panicle was counted for each replication and the mean was calculated.

3.3.1.7. Number of filled grains per panicle

Number of filled grains per panicle was counted for each replication and the mean was calculated.

3.3.1.8. 1000 grain weight

1000 grain weight for each replication was measured and the mean was calculated. It was measured in gram.

3.3.1.9. Straw yield

Straw yield refers to the total dry weight of all the leafy parts of the plant excluding the grains. The straw yield in kilogram was measured for each replication at the harvest and the mean was calculated. This was converted in to kg/ha.

3.3.1.10. Grain yield

Grain yield is the total weight of all the filled grains in a plant. The grain yield in kilogram was measured for each replication at the harvest and the mean was calculated. This was then converted in to kg/ha.

3.3.2. Physiological observations

3.3.2.1. Days taken for active tillering

The number of days taken from transplanting to active tillering was recorded for each replication and the mean was worked out.

3.3.2.2. Days taken for panicle emergence

The number of days taken from transplanting to panicle emergence was recorded for each replication and mean was worked out.

3.3.2.3. Days taken for 50 percent flowering

50 percent flowering refers to the stage at which the 50 percent of plants in a replication had entered the stage of flowering. The number of days taken from transplanting to 50 percent flowering was recorded for each replication and mean was worked out.

3.3.2.4. Days taken for booting

The booting stage refers to the bulging of the leaf stem, which conceals the developing panicle. The number of days taken from transplanting to booting stage was recorded for each replication and mean was worked out.

3.3.2.5. Days taken for heading

The rice is said to be in its heading stage when the panicle is fully visible outside the leaf stem. The number of days taken from transplanting to heading stage was recorded for each replication and mean was worked out.

3.3.2.6. Days taken for physiological maturity

Physiological maturity is when 80 percent of the grain turns yellow. The number of days taken from transplanting to physiological maturity was recorded for each replication and mean was worked out.

3.3.2.7. Transpiration

The transpiration was recorded for each replication using infra-red gas analyser (LI-6400 XT, LI-COR-USA) and the mean was calculated. It was expressed in mmol H_2O m^{-2} sec^{-1}.

3.3.2.8. Photosynthesis

The photosynthesis was recorded for each replication using infra-red gas analyser (LI-6400 XT, LI-COR-USA) and the mean was calculated. It was expressed in µmol CO_2 m^{-2} s^{-1}.

3.3.3. Analysis and projections

The data recorded from the experiment was analysed using the statistical software SPSS and it was interpreted.

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) had introduced a new way of developing scenarios for projecting the future. These scenarios span the range of plausible radiative forcing scenarios, and are called representative concentration pathways (RCPs). In this study RCP 4.5 was used for future projection of the climate. Using MarSim weather generator, climate projections of rainfall, maximum temperature, minimum temperature and solar radiations was projected. Using DSSATv4.5 model, the yield was predicted for the years 2030, 2050 and 2080. The weather parametrs like rainfall, solar radiation, maximum and minimum temperature for the year 2016, 2030, 2050 and 2080 was parametrised in this model. Under the management practices, the date of planting, harvesting and the total amount of irrigated water was given. No change in the fertilizer application and residue placement was made. No change in soil dynamics was also made. As hydrogel application is not a parameter in DSSAT, the yields of plants with different irrigation treatments only was inputed to it and its results were calculated.

Table 3. The treatment combination used in the study

Hydrogel	**Irrigation**	**Replication**
1	1	1
1	1	2
1	1	3
1	2	1
1	2	2
1	2	3
1	3	1
1	3	2
1	3	3
1	4	1
1	4	2
1	4	3
2	1	1
2	1	2
2	1	3
2	2	1
2	2	2
2	2	3
2	3	1
2	3	2
2	3	3
2	4	1
2	4	2
2	4	3

Plate 8. Infrared gas analyser for measuring transpiration and photosynthesis

Plate 9. Plant canopy analyser LAI-2000, for measuring LAI

CHAPTER 4

RESULTS

The results of the experiment entitled "Climate change adaptation through improved water use efficiency in rice, *Oryza sativa*" are presented in this chapter. The effect of different irrigation levels and the use of hydrogel on the different morpho-physiological parameter and the yield of rice were studied.

4.1 BIOMETRIC OBSERVATIONS

4.1.1 Plant height at weekly interval (cm)

Hydrogel didn't have any significant impact on plant height for the first two weeks after transplanting (Table 4). From the 3rd week onwards to the 9th week, the effect of hydrogel on plant height was significant. The higher values of plant height were observed for the plants with hydrogel (45.18, 58.54, 74.73, 81.05, 83.90, 85.68 and 86.38 cm for the weeks 3, 4, 5, 6, 7, 8 and 9 respectively) and lower values for the plants without hydrogel (38.12, 50.92, 64.50, 71.15, 74.98, 77.95 and 80.78 for the weeks 3, 4, 5, 6, 7, 8 and 9 respectively). From week 10 to 14 the hydrogel impact on plant height was nonsignificant.

While considering the irrigation regimes, it was found that, there was no significant impact on plant height for the first three weeks. From 4th week to the harvest, different irrigation treatments had a significant impact on plant height. For week 4, 5, 6 and 7, the higher values was for the treatment IW/CPE=2 (58.87, 77.22, 83.40 and 85.82 cm for the weeks 4, 5, 6 and 7 respectively) and lower values for the treatment IW/CPE=0.5 (51.10.59.32, 64.33 and 67.73 cm for the weeks 4, 5, 6 and 7 respectively). At weeks 8, 9, and 10, the treatment IW/CPE=2, IW/CPE=1.5 and IW/CPE=1 were on par while, lowest value was observed for the treatment IW/CPE=0.5. At weeks 11, 12, 13 and 14, the treatment IW/CPE=2 again recorded highest value (96.92, 100.05, 100.45 and 100.9 cm for the weeks 11, 12, 13 and 14 respectively) and lower values for the treatment IW/CPE=0.5 (78.88, 79.50, 80.02 and 80.50 cm for the weeks 11, 12, 13 and 14 respectively).

The effect of interaction was found to be significant only after the booting stage of the rice plant. From week 1st to 10th, there was no significant effect of interaction on plant height. From week 11 to 14, the higher value (100.46, 104.67, 105.07 and 105.30 cm for the weeks 11, 12, 13 and 14 respectively) was recorded for the treatment IW/CPE=2 without hydrogel and lower values (77.63, 78.00, 78.63 and 78.63 cm for the weeks 11, 12, 13, and 14 respectively) was observed for the treatment IW/CPE=0.5 without hydrogel. These differences were significant.

4.1.2 Leaf area index (LAI) at weekly interval

Hydrogel alone and the interaction of hydrogel and irrigation treatments did not have any significant impact on LAI (Table 5).

While considering the irrigation regimes, it was found that, the difference between the irrigation treatments were nonsignificant for the weeks 1, 2, 3, 5, 6, 7, 9, 10, 11 and 13. At 4th week, irrigation had a significant impact on LAI. The treatment IW/CPE=2 and IW/CPE=1.5 had higher values (1.37 and 1.35) while, IW/CPE=1 and IW/CPE=0.5 had lower values (1.24 and 1.22). At 8th week, the highest value was for the treatment IW/CPE=2 and IW/CPE=1.5 (2.72 and 2.61) while, IW/CPE=1 and IW/CPE=0.5 had the lowest values (2.45 and 2.31) which was found to be significant. At 12th week the treatment IW/CPE=2 and IW/CPE=1.5 had the higher values (1.67 and 1.45) and IW/CPE=0.5 had the lowest value (1.31). At 14th week, the higher values was for the treatment IW/CPE=2 (1.60) and lower value for the treatment IW/CPE=0.5 (1.40).

Table 4. Plant height (cm) in rice as influenced by hydrogel and irrigation treatments

Factors	Treatments	Plant height (cm)													
		WEEKS													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Irrigation	IW/CPE=2	9.40	23.55	43.63	58.87^{a}	77.22^{a}	83.40^{a}	85.82^{a}	88.03^{a}	91.00^{a}	93.77^{a}	96.92^{a}	100.05^{a}	100.45^{a}	100.9^{a}
	IW/CPE=1.5	8.50	20.23	42.10	55.30^{ab}	70.82^{b}	76.33^{b}	80.40^{b}	83.57^{a}	84.80^{a}	85.93^{a}	87.73^{b}	89.52^{b}	89.85^{b}	89.95^{b}
	IW/CPE=1	8.85	21.22	40.50	53.65^{ab}	71.08^{b}	80.43^{a}	83.82^{ab}	86.07^{a}	87.22^{a}	88.32^{a}	91.10^{ab}	93.32^{b}	93.97^{b}	94.55^{b}
	IW/CPE=0.5	9.00	19.60	40.37	51.10^{b}	59.32^{c}	64.23^{c}	67.73^{c}	69.60^{b}	71.30^{b}	77.08^{b}	78.88^{c}	79.50^{c}	80.02^{c}	80.50^{c}
	F value	**0.24^{ns}**	**2.10^{ns}**	**0.79^{ns}**	**3.24***	**41.65***	**43.02***	**31.80***	**22.60***	**11.42***	**6.05***	**10.86***	**17.29***	**18.04***	**17.34**
Hydrogel	Hydrogel	9.26	21.80	45.18^{x}	58.54^{x}	74.73^{x}	81.05^{x}	83.90^{x}	85.68^{x}	86.38^{x}	88.14	90.48	92.10	92.44	93.07
	No hydrogel	8.60	20.48	38.12^{y}	50.92^{y}	64.50^{y}	71.15^{y}	74.98^{y}	77.95^{y}	80.78^{y}	84.41	86.83	89.10	89.70	89.88
	F value	**0.76^{ns}**	**1.19^{ns}**	**16.57***	**17.78***	**78.40***	**59.40***	**38.34***	**19.40***	**4.88***	**1.75^{ns}**	**2.54^{ns}**	**2.12^{ns}**	**1.85^{ns}**	**2.38^{ns}**
Interaction	**F value**	**0.26^{ns}**	**0.40^{ns}**	**1.16^{ns}**	**1.27^{ns}**	**0.28^{ns}**	**0.91^{ns}**	**2.38^{ns}**	**2.78^{ns}**	**2.11^{ns}**	**1.93^{ns}**	**3.07***	**4.39***	**4.40***	**4.10***

*Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with the same superscript along the column do not differ significantly

Table 5. Leaf area index (LAI) in rice as influenced by hydrogel and irrigation treatments

Factors	Treatments	Leaf area index (LAI)													
		WEEKS													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Irrigation	IW/CPE=2	0.46	0.49	1.02	1.37^{a}	1.60	1.70	2.50	2.72^{a}	2.43	1.76	1.56	1.67^{a}	1.64	1.60^{a}
	IW/CPE=1.5	0.44	0.49	0.96	1.35^{ab}	1.57	1.76	2.55	2.61^{ab}	2.22	1.40	1.46	1.45^{ab}	1.57	1.53^{ab}
	IW/CPE=1	0.44	0.48	0.70	1.24^{bc}	1.54	1.54	2.27	2.45^{bc}	2.11	1.34	1.35	1.37^{b}	1.50	1.52^{ab}
	IW/CPE=0.5	0.37	0.45	0.60	1.22^{c}	1.51	1.60	2.22	2.31^{c}	2.00	1.29	1.32	1.31^{b}	1.48	1.40^{b}
	F value	**1.38^{ns}**	**0.18^{ns}**	**1.32^{ns}**	**3.62***	**0.41^{ns}**	**0.50^{ns}**	**1.66^{ns}**	**5.55***	**1.41^{ns}**	**2.06^{ns}**	**2.86^{ns}**	**4.28***	**1.15^{ns}**	**3.96***
Hydrogel	Hydrogel	0.45	0.48	0.88	1.31	1.57	1.70	2.47	2.56	2.26	1.45	1.47	1.42	1.55	1.51
	No hydrogel	0.41	0.48	0.76	1.28	1.54	1.60	2.29	2.50	2.12	1.44	1.40	1.48	1.54	1.51
	F value	**0.97^{ns}**	**0.02^{ns}**	**0.46^{ns}**	**0.48^{ns}**	**0.32^{ns}**	**0.43^{ns}**	**2.02^{ns}**	**0.90^{ns}**	**0.75^{ns}**	-	**1.65^{ns}**	**0.64^{ns}**	**0.01^{ns}**	-
Interaction	**F value**	**0.1^{ns}**	**0.11^{ns}**	**0.04^{ns}**	**0.04^{ns}**	**0.03^{ns}**	**0.15^{ns}**	**0.15^{ns}**	**0.26^{ns}**	**0.38^{ns}**	**0.12^{ns}**	**1.07^{ns}**	**0.58^{ns}**	**0.07^{ns}**	**0.30^{ns}**

*Significant at 0.05 level; ns- non significant at 0.05 level. Values with the same superscript along the column do not differ significantly

4.1.3 Dry matter accumulation at harvest (kg ha^{-1})

Hydrogel did not have significant impact on dry matter accumulation of rice at harvest (Table 6).

The different irrigation regimes had a significant impact on dry matter accumulation. The highest value is observed for the treatment IW/CPE=2 (14318.39 kg ha^{-1}) and lowest value is for the treatment IW/CPE=0.5 (850.11 kg ha^{-1}).

The effect of interaction was significant in the dry matter accumulated at harvest. Except at IW/CPE=2, the higher values were observed in the plants grown with hydrogel (12794.71, 9894.25 and 1165.73 kg ha^{-1} for the treatments IW/CPE=1.5, IW/CPE=1 and IW/CPE=0.5 respectively) and lower values for plants without hydrogel (10531.91, 8679.29 and 534.60 kg ha^{-1} for the treatments IW/CPE=1.5, IW/CPE=1 and IW/CPE=0.5 respectively). For IW/CPE=2, the highest value is recorded for the plants without hydrogel (15473.35 kg ha^{-1}) and lowest value is with hydrogel (13163.42 kg ha^{-1}).

4.1.4 Number of tillers

Except at week 5, hydrogel did not influence the number of tillers in rice (Table 8). At week 5, plants with hydrogel had the higher number of tillers (10.42) than without hydrogel (8.50).

The irrigation levels did not differ for number of tillers for the weeks 1, 2, 8, 9, 10, 11 and 12. The treatment IW/CPE=2 had higher values (6.50, 9.00, 13.50 and 15.67 for the weeks 3, 4, 5 and 6 respectively) and treatments IW/CPE=1.5, IW/CPE=1 and IW/CPE=0.5 had the lower values. At week 7, IW/PE=2, IW/CPE=1.5 and IW/CPE=1 had the higher value (17.17, 16.00 and 14.50) and IW/CPE=0.5 had the lowest value (10.83). At week 13 and 14, the number of tillers was maximum (17.17 and 18.33) for the treatment IW/CPE=2. The treatments IW/CPE=1.5, IW/CPE=1 and IW/CPE=0.5 had the lower values (13.50, 13.00 and 13.22 for the week 13 and 13.50, 13.33 and 13.17 for the week 14).

While considering the interaction, it was found that, the interaction was nonsignificant for the weeks 1, 2, 3, 5, 6, 8, 9, 10 and 12. For the weeks 4, 11, 13 and 14, the higher values were recorded for the treatment IW/CPE=2 with hydrogel (9.33, 17.00, 16.33 and 15.46) and lower values for the treatment IW/CPE=0.5 without hydrogel (4.33, 10.67, 12.00 and 12.67). At week 7, the treatment IW/CPE=1.5 with hydrogel had the highest value (19.67) and IW/CPE=0.5 without hydrogel had the lowest value (10.67).

4.1.5 Number of panicles per hill

Hydrogel did not influence the number of panicles produced per hill (Table 7).

The irrigation treatments had a significant impact on the number of panicles per hill. The highest value was for the treatment IW/CPE=1.5 (9.16) and lowest value for the treatment IW/CPE=0.5 (1.72).

The interaction also had a significant impact on the number of panicles per hill in rice. Plants with hydrogel showed higher (3.00) number of panicles per plant for the treatment IW/CPE=0.5 than plants without hydrogel (0.44). For the treatments IW/CPE=2, IW/CPE=1.5 and IW/CPE=1, plants without hydrogel had the higher values (9.00, 9.20 and 7.50) and plants with hydrogel had the lower values (7.66, 9.11 and 7.35).

Table 6. Dry matter accumulation at harvest (kg ha^{-1}) in rice as influenced by hydrogel and irrigation treatments.

Factors	Treatments	Dry matter (kg ha^{-1})
Irrigation	IW/CPE=2	14318.39^{a}
	IW/CPE=1.5	11663.31^{b}
	IW/CPE=1	9286.77^{c}
	IW/CPE=0.5	850.11^{d}
	F value	**420.94***
Hydrogel	With hydrogel	9254.50
	No hydrogel	8804.79
	F value	**2.51^{ns}**
Interaction	**F value**	**11.90***

*Significant at 0.05 level; ns- non significant at 0.05 level. Values with the same superscript along the column do not differ significantly.

Table 7. Number of panicles per hill in rice as influenced by hydrogel and irrigation treatments

Factors	Treatments	Number of panicles per hill
Irrigation	IW/CPE=2	8.33^{b}
	IW/CPE=1.5	9.16^{a}
	IW/CPE=1	7.43^{c}
	IW/CPE=0.5	1.72^{d}
	F value	**233.00***
Hydrogel	With hydrogel	6.78
	No hydrogel	6.54
	F value	**1.24^{ns}**
Interaction	**F value**	**13.90***

*Significant at 0.05 level; ns- non significant at 0.05 level. Values with the same superscript along the column do not differ significantly

Table 8. Number of tillers in rice as influenced by hydrogel and irrigation treatments

Factors	Treatments	Number of tillers													
		WEEKS													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Irrigation	IW/CPE=2	3.00	3.67	6.50^{a}	9.00^{a}	13.50^{a}	15.67^{a}	17.17^{a}	15.17	14.00	13.33	15.17	16.00	17.17^{a}	18.33^{a}
	IW/CPE=1.5	3.00	3.00	4.17^{b}	6.67^{b}	8.83^{b}	10.33^{b}	16.00^{a}	12.17	11.67	12.50	13.67	13.17	13.50^{b}	13.50^{b}
	IW/CPE=1	3.00	3.33	3.83^{b}	5.00^{b}	7.50^{b}	9.33^{b}	14.50^{a}	14.00	14.67	13.83	13.83	12.50	13.00^{b}	13.33^{b}
	IW/CPE=0.5	3.00	3.67	4.67^{b}	6.67^{b}	8.00^{b}	8.00^{b}	10.83^{b}	11.17	12.67	14.67	13.83	13.83	13.22^{b}	13.17^{b}
	F value	-	**0.67**^{ns}	**3.91***	**7.79***	**9.81***	**12.81***	**8.27***	**2.42**^{ns}	**1.24**^{ns}	**0.70**^{ns}	**0.74**^{ns}	**1.78**^{ns}	**4.73***	**3.61***
Hydrogel	Hydrogel	3.00	3.24	5.17	6.67	10.42^{x}	11.50	15.67^{x}	13.25	13.83	13.58	13.67	13.17	15.83	16.08
	No hydrogel	3.00	3.42	4.42	7.00	8.50^{y}	10.17	13.58^{y}	13.00	12.67	13.58	14.58	14.58	15.08	16.58
	F value	-	**0.00**^{ns}	**1.56**^{ns}	**0.32**^{ns}	**4.77***	**2.02**^{ns}	**4.73***	**0.05**^{ns}	**0.93**^{ns}	**0.00**^{ns}	**1.27**^{ns}	**1.55**^{ns}	**0.62**^{ns}	**0.18**^{ns}
Interaction	**F value**	-	**0.50**^{ns}	**2.22**^{ns}	**5.23***	**2.43**^{ns}	**1.43**^{ns}	**3.34***	**0.92**^{ns}	**1.60**^{ns}	**2.29**^{ns}	**9.39***	**2.89**^{ns}	**5.24***	**3.38***

*Significant at 0.05 level; ns- non significant at 0.05 level. Values with the same superscript along the column do not differ significantly

4.1.6 Number of primary branches per panicle

Hydrogel had a significant impact on number of primary branches per panicle (Table 9). The higher value is recorded for the plants with hydrogel (10.25) compared to plants without hydrogel (8.25).

The irrigation regimes had a significant impact on number of primary branches per panicle. The highest value was for the treatment IW/CPE=2 (11.67) and lowest value for the treatment IW/PE=0.5 (6.17).

While considering the interaction, it was found that, interaction was non significant for the number of primary branches produced per panicle.

4.1.7 Number of filled grains per panicle

Hydrogel had a significant impact on number of filled grains per panicle (Table 10). The higher number of filled grains per panicle (86.00) was for the plants grown with hydrogel and lower value (72.25) was for the plants without hydrogel.

The irrigation significantly influenced the number of filled grains produced per panicle. The highest value (119.67) was for the treatment IW/CPE=2 and lowest value (7.17) was for the treatment IW/CPE=0.5.

The interaction effect of hydrogel and irrigation was non signficant for the number of filled grains per panicle produced.

Table 9. Number of primary branches per panicle in rice as influenced by hydrogel and irrigation treatments

Factors	Treatments	Number of primary branches per panicle
Irrigation	IW/CPE=2	11.67^{a}
	IW/CPE=1.5	9.33^{b}
	IW/CPE=1	9.83^{b}
	IW/CPE=0.5	6.17^{c}
	F value	**31.39***
Hydrogel	With hydrogel	10.25^{x}
	No hydrogel	8.25^{y}
	F value	**24.00***
Interaction	**F value**	**2.11^{ns}**

*Significant at 0.05 level; ns- non significant at 0.05 level. Values with the same superscript along the column do not differ significantly

Table 10. Number of filled grains per panicle in rice as influenced by hydrogel and irrigation treatments

Factors	Treatments	Number of filled grains per panicle
Irrigation	IW/CPE=2	119.67^{a}
	IW/CPE=1.5	92.33^{b}
	IW/CPE=1	97.33^{b}
	IW/CPE=0.5	7.17^{c}
	F value	**230.80***
Hydrogel	With hydrogel	86.00^{x}
	No hydrogel	72.25^{y}
	F value	**17.86***
Interaction	**F value**	**2.97^{ns}**

*Significant at 0.05 level; ns- non significant at 0.05 level. Values with the same superscript along the column do not differ significantly

4.1.8 Thousand grain weight (g)

Hydrogel application and different irrigation treatment had a significant impact on the 1000 grain weight (g) (Table 11). The higher value (23.43 g) for 1000 grain weight was for the plants with hydrogel and the lower value (18.48 g) was for the plants without hydrogel.

While considering the irrigation treatments, IW/CPE=2 had the highest value (26.95 g) and IWE/CPE=0.5 had the lowest value (9.50 g). 1000 grain weight decreased from IW/CPE=2 to IW/CPE=0.5 (26.95, 24.37, 23.02 and 9.50 g for IW/CPE=2, IW/CPE=1.5, IW/CPE=1 and IW/CPE=0.5 respectively).

While considering the interaction, at IW/CPE=2, plants without hydrogel had the higher value (27.23 g) and plants with hydrogel had the lower value (26.67). For the treatments IW/CPE=1.5, IW/CPE=1 and IW/CPE=0.5, plants with hydrogel had the higher values (24.40, 23.67 and 19.00 g) than plants without hydrogel (24.33, 22.7 and 0.00 g).

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

Hydrogel did not influence the straw yield of rice at harvest (Table 12).

The irrigation treatment had a significant effect on straw yield produced at harvest. The treatment IW/CPE=2 had the highest value (7555.77 kg ha^{-1}) and treatment IW/CPE=0.5 had the lower value (742.49 kg ha^{-1}). The straw yield decreased from IW/CPE=2 to IW/CPE=0.5 (7555.77, 6183.44, 4823.26 and742.49 kg ha^{-1} for the treatments IW/CPE=2, IW/CPE=1.5, IW/CPE=1 and IW/CPE=0.5 respectively).

Table 11. 1000 grain weight (g) in rice as influenced by hydrogel and irrigation treatments

Factors	Treatments	1000 grain weight (g)
Irrigation	IW/CPE=2	26.95^{a}
	IW/CPE=1.5	24.37^{b}
	IW/CPE=1	23.02^{b}
	IW/CPE=0.5	9.50^{c}
	F value	**217.48***
Hydrogel	With hydrogel	23.43^{x}
	No hydrogel	18.48^{y}
	F value	**87.34***
Interaction	**F value**	**78.72***

*Significant at 0.05 level; ns- non significant at 0.05 level. Values with the same superscript along the column do not differ significantly

Table 12. Straw yield (kg ha^{-1}) in rice as influenced by hydrogel and irrigation treatments

Factors	Treatments	Straw yield (kg ha^{-1})
Irrigation	IW/CPE=2	7555.77^{a}
	IW/CPE=1.5	6183.44^{b}
	IW/CPE=1	4823.26^{c}
	IW/CPE=0.5	742.49^{d}
	F value	**284.50***
Hydrogel	With hydrogel	4799.50
	No hydrogel	4853.00
	F value	**0.09^{ns}**
Interaction	**F value**	**11.31***

*Significant at 0.05 level; ns- non significant at 0.05 level. Values with the same superscript along the column do not differ significantly

The interaction did have a significant impact on the straw yield. Except for IW/CPE=2, plants with hydrogel had higher straw yield (6522.00, 5072.81 and 950.37 kg/ha for the treatments IW/CPE=1.5, IW/CPE=1 and IW/CPE=0.5) and plants without hydrogel had the lower values (5844.90, 4573.71 and 534.60 kg/ha for the treatments IW/CPE=1.5, IW/CPE=1 and IW/CPE=0.5 respectively). For IW/CPE=2, plants without hydrogel had the higher value (8458.70 kg/ha) and plants with hydrogel had the lowest value (6652.84 kg/ha).

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

Hydrogel application and different irrigation treatment had a significant impact on the grain yield (Table 13). The higher grain yield (4455.03 kg ha^{-1}) was observed for the plants grown with hydrogel and lower value (3951.77 kg ha^{-1}) was for the plants without hydrogel.

While considering the irrigation treatments, IW/CPE=2 had the higher grain yield (6762.68 kg ha^{-1}) and IW/CPE=0.5 had the lowest value (107.67 kg ha^{-1}). Grain yield decreased from IW/CPE=2 to IW/CPE=0.5 (6762.68, 5479.85, 4463.38 and 107.67 kg ha^{-1} for the treatments IW/CPE=2, IW/CPE=1.5, IW/CPE=1 and IW/CPE=0.5).

The interaction of hydrogel and irrigation was also found to have significant impact on grain yield. The highest value (7014.63 kg ha^{-1}) for grain yield was noted for the plants without hydrogel and lowest value (6510.73 kg ha^{-1}) for plants with hydrogel at IW/CPE=2. For irrigation levels IW/CPE=1.5, IW/CPE=1 and IW/CPE=0.5, the higher values of grain yield (6272.60, 4821.43 and 215.33 kg ha^{-1}) was observed for plants with hydrogel and lower values (4687.10, 4105.33 and 0.00 kg ha^{-1}) for plants without hydrogel.

4.2 PHYSIOLOGICAL OBSERVATIONS

4.2.1 Days taken for active tillering

It was found that the application of hydrogel and different irrigation treatments alone and their interaction did not have any significant impact on the number of days taken for active tillering (Table 14).

4.2.2 Days taken for panicle emergence

It was found that the application of hydrogel and interaction did not had any significant impact on the number of days taken for panicle emergence (Table 15).

Irrigation treatments had a significant impact on panicle emergence. The treatment which took the minimum number of days for panicle emergence was IW/CPE=2 (38.00) and the treatment which took the maximum number was IW/CPE=0.5 (50.33).

4.2.3 Days taken for 50 percent flowering

It was found that the application of hydrogel and interaction did not have any significant impact on the number of days taken for 50 percent flowering (Table 16).

For the irrigation levels, the treatments which took the minimum number of days for 50 percent flowering was IW/CPE=2 (71.00). IW/CPEC=1.5 and IW/CPE=1, almost took the same number of days (75.50 and 77.00). For the treatment IW/CPCE=0.5, there occurred no flowering.

Table 13. Grain yield (kg ha^{-1}) in rice as influenced by hydrogel and irrigation treatments

Factors	Treatments	Grain yield (kg ha^{-1})
Irrigation	IW/CPE=2	6762.68^a
	IW/CPE=1.5	5479.85^b
	IW/CPE=1	463.38^c
	IW/CPE=0.5	107.67^d
	F value	**300.70***
Hydrogel	With hydrogel	4455.03^x
	No hydrogel	3951.77^y
	F value	**9.13***
Interaction	**F value**	**7.00***

*Significant at 0.05 level; ns- non significant at 0.05 level. Values with the same superscript along the column do not differ significantly

Table 14. Number of days taken for active tillering in rice as influenced by hydrogel and irrigation treatments

Factors	Treatments	Active tillering (Days)
Irrigation	IW/CPE=2	34.67
	IW/CPE=1.5	44.00
	IW/CPE=1	41.33
	IW/CPE=0.5	54.83
	F value	**2.30^{ns}**
Hydrogel	With hydrogel	43.33
	No hydrogel	44.08
	F value	**0.18^{ns}**
Interaction	**F value**	**0.16^{ns}**

*Significant at 0.05 level; ns- non significant at 0.05 level. Values with the same superscript along the column do not differ significantly

Table 15. Number of days taken for panicle emergence in rice as influenced by hydrogel and irrigation treatments

Factors	Treatments	Panicle emergence (Days)
Irrigation	IW/CPE=2	38.00^{c}
	IW/CPE=1.5	41.83^{b}
	IW/CPE=1	42.67^{b}
	IW/CPE=0.5	50.33^{a}
	F value	**54.14***
Hydrogel	With hydrogel	42.25
	No hydrogel	44.17
	F value	**7.45^{ns}**
Interaction	**F value**	**1.60^{ns}**

*Significant at 0.05 level; ns- non significant at 0.05 level. Values with the same superscript along the column do not differ significantly

Table 16. Number of days taken for 50 percent flowering in rice as influenced by hydrogel and irrigation treatments

Factors	Treatments	50 percent flowering (Days)
Irrigation	IW/CPE=2	71.00^{b}
	IW/CPE=1.5	75.50^{a}
	IW/CPE=1	77.00^{a}
	F value	**7.58***
Hydrogel	With hydrogel	73.67
	No hydrogel	75.33
	F value	**1.62^{ns}**
Interaction	**F value**	**2.61^{ns}**

*Significant at 0.05 level; ns- non significant at 0.05 level. Values with the same superscript along the column do not differ significantly

4.2.4 Days taken for booting

It was found that the application of hydrogel and interaction didn't have any significant impact on the number of days taken for booting (Table 17).

While considering the irrigation levels, it was found that the irrigation treatments had a significant impact on booting. The treatments which took the minimum number of days for booting was IW/CPE=2, and IW/CPE=1.5 (56.67 and 59.33). The treatment which took the maximum number was IW/CPE=0.5 (80.17).

4.2.5 Days taken for heading

It was found that the application of hydrogel and interaction did not have any significant impact on the number of days taken for heading (Table 18).

It was found that the irrigation had a significant impact on heading. The treatments which took the minimum number of days for heading was IW/CPE=2 (63.00) and maximum number was IW/CPE=0.5 (83.00).

4.2.6 Days taken for physiological maturity

It was found that the application of hydrogel and different irrigation treatments alone and their interaction did not had any significant impact on the number of days taken for physiological maturity (Table 19). The treatment IW/CPE=0.5 did not even reached the stage of physiological maturity.

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Table 17. Number of days taken for booting in rice as influenced by hydrogel and irrigation treatments

Factors	Treatments	Booting (Days)
Irrigation	IW/CPE=2	56.67^{c}
	IW/CPE=1.5	59.33^{bc}
	IW/CPE=1	62.50^{b}
	IW/CPE=0.5	80.17^{a}
	F value	**40.70***
Hydrogel	With hydrogel	63.83
	No hydrogel	65.50
	F value	$\mathbf{1.00}^{ns}$
Interaction	**F value**	$\mathbf{2.92}^{ns}$

*Significant at 0.05 level; ns- non significant at 0.05 level. Values with the same superscript along the column do not differ significantly

Table 18. Number of days taken for heading in rice as influenced by hydrogel and irrigation treatments

Factors	Treatments	Heading (Days)
Irrigation	IW/CPE=2	63.00^{c}
	IW/CPE=1.5	66.50^{b}
	IW/CPE=1	67.67^{b}
	IW/CPE=0.5	83.00^{a}
	F value	**146.92***
Hydrogel	With hydrogel	69.33
	No hydrogel	70.75
	F value	$\mathbf{3.75}^{ns}$
Interaction	**F value**	$\mathbf{1.00}^{ns}$

*Significant at 0.05 level; ns- non significant at 0.05 level. Values with the same superscript along the column do not differ significantly

4.2.7 Transpiration (mmol H_2O m^{-2} s^{-1})

It was found that the application of hydrogel alone and the interaction of hydrogel and irrigation treatments did not have any significant impact on transpiration (Table 20).

While considering the irrigation levels, it was found that, the higher value of transpiration rate was recorded for the treatment IW/CPE=2 (4.17 mmol H_2O m^{-2} s^{-1}) and lower values was for the treatments IW/CPE=1 and IW/CPE=0.5 (3.13 and 2.75 mmol H_2O m^{-2} s^{-1}).

4.2.8 Photosynthesis (µmol CO_2 m^{-2} s^{-1})

It was found that the application of hydrogel alone and the interaction of hydrogel and irrigation treatments did not have any significant impact on photosynthesis (Table 21).

While considering the irrigation levels, it was found that, the highest value of photosynthesis rate was recorded for the treatment IW/CPE=2 and IW/CPE=1.5 (8.74 and 8.48 µmol CO_2 m^{-2} s^{-1}) and the lowest value was recorded for the treatment IW/CPE=0.5 (6.63 µmol CO_2 m^{-2} s^{-1}).

4.3 CLIMATE PROJECTIONS FOR 2030, 2050 and 2080

Using MarSim weather generator with RCP 4.5, climate projections of rainfall, maximum temperature, minimum temperature and solar radiations was projected. The climate data for the year 2016 is given in table. 21.

Table 19. Number of days taken for physiological maturity in rice as influenced by hydrogel and irrigation treatments

Factors	Treatments	Physiological maturity (Days)
Irrigation	IW/CPE=2	101.00
	IW/CPE=1.5	105.00
	IW/CPE=1	107.00
	F value	-
Hydrogel	With hydrogel	104.33
	No hydrogel	104.33
	F value	-
Interaction	**F value**	-

*Significant at 0.05 level; ns- non significant at 0.05 level. Values with the same superscript along the column do not differ significantly

Table 20. Transpiration (mmol H_2O m^{-2} s^{-1}) in rice as influenced by hydrogel and irrigation treatments

Factors	Treatments	Transpiration (mmol H_2O m^{-2} s^{-1})
Irrigation	IW/CPE=2	4.17^{a}
	IW/CPE=1.5	3.20^{b}
	IW/CPE=1	3.13^{bc}
	IW/CPE=0.5	2.75^{c}
	F value	18.70*
Hydrogel	With hydrogel	3.25
	No hydrogel	3.37
	F value	0.75^{ns}
Interaction	F value	0.30^{ns}

*Significant at 0.05 level; ns- non significant at 0.05 level. Values with the same superscript along the column do not differ significantly

Table 21. Photosynthesis (µmol CO_2 m^{-2} s^{-1}) in rice as influenced by hydrogel and irrigation treatments

Factors	Treatments	Photosynthesis (µmol CO_2 m^{-2} s^{-1})
Irrigation	IW/CPE=2	8.74^{a}
	IW/CPE=1.5	8.48^{a}
	IW/CPE=1	8.14^{b}
	IW/CPE=0.5	6.63^{c}
	F value	**86.56***
Hydrogel	With hydrogel	8.06
	No hydrogel	7.94
	F value	**1.25^{ns}**
Interaction	**F value**	**0.04^{ns}**

*Significant at 0.05 level; ns- non significant at 0.05 level. Values with the same superscript along the column do not differ significantly

Table 22. Data of T_{max}, T_{min}, sunshine hours and rainfall for the year 2016

WEEKS	T max(°C)	T min(°C)	Hours	Rainfall(mm)
Week 1	32.8	19.8	8.9	0.0
Week 2	32.3	21.4	7.9	0.0
Week 3	32.7	21.7	5.8	0.0
Week 4	34.1	23.3	7.3	0.0
Week 5	34.4	19.3	7.5	0.0
Week 6	35.1	21.1	7.4	0.0
Week 7	34.1	23.1	8.1	0.0
Week 8	35.2	23.9	8.2	0.0
Week 9	36.4	23.8	8.2	0.0
Week 10	36.6	24.0	7.4	0.0
Week 11	36.8	25.0	7.4	0.0
Week 12	36.8	25.9	6.4	0.0
Week 13	37.8	25.3	7.6	0.0
Week 14	37.2	25.7	8.1	0.0
Week 15	36.3	26.3	6.8	0.0
Week 16	37.1	27.0	6.0	0.0
Week 17	37.2	26.9	8.3	0.0
Week 18	37.4	26.3	8.6	0.0
Week 19	35.9	24.3	7.5	13.3
Week 20	32.4	25.1	3.6	2.5
Week 21	33.6	25.6	7.7	0.0
Week 22	31.6	24.5	4.8	0.0
Week 23	30.5	24.6	4.1	0.0
Week 24	31.3	24.3	3.5	0.0
Week 25	29.6	23.3	3.0	0.0
Week 26	28.9	23.4	0.4	0.0
Week 27	30	23.9	3.3	0.0
Week 28	29.3	23.4	2.2	0.0
Week 29	29.6	23.7	3.2	0.0

WEEKS	T max(°C)	T min(°C)	Hours	Rainfall(mm)
Week 30	30.2	24.2	5.4	0.0
Week 31	30.6	24.0	5.8	0.0
Week 32	30.5	23.5	6.8	0.0
Week 33	30.3	23.9	6.2	0.0
Week 34	31	24.1	7.3	0.0
Week 35	29.8	23.8	3.3	0.0
Week 36	30.2	23.2	4.6	0.0
Week 37	30.4	23.6	7.7	0.0
Week 38	30.4	23.4	7.7	0.1
Week 39	30.2	24.1	4.9	1.9
Week 40	31.5	22.6	8.7	0.0
Week 41	31.2	22.6	5.5	0.2
Week 42	29.4	24.4	3.6	12.2
Week 43	27.1	26.3	4.9	5.8
Week 44	27.3	26.4	5.5	11.8
Week 45	31.7	23.3	5.0	0.2
Week 46	32.6	23.0	6.5	3.4
Week 47	32.5	22.3	6.2	0.3
Week 48	31.1	21.3	3.6	0.0
Week 49	32.4	19.8	6.8	0.0
Week 50	33.3	22.6	6.0	0.0
Week 51	33	22.7	6.6	0.0
Week 52	32.3	21.9	4.9	0.0

4.3.1.Rainfall (mm)

Table. 23 shows the projected rainfall for the year 2030, 2050 and 2080. It was observed that a decrease in rainfall was noted from 2030 to 2080.

4.3.2 Maximum Temperature (°C)

Table. 24 shows the projected maximum temperature for the year 2030, 2050 and 2080. The maximum temperature was found to be increased along the years from 2030 to 2080.

4.3.3 Minimum Temperature (°C)

Table. 25 shows the projected minimum temperature for the year 2030, 2050 and 2080. The minimum temperature was found to be increased along the years from 2030 to 2080.

4.3.4 Solar radiation (W m^{-2})

Table. 26 shows the projected solar radiation for the year 2030, 2050 and 2080. It was found that, along the years 2030, 2050 and 2080, solar radiation did not have any considerable variations.

4.4. PROJECTED YIELD FOR 2030, 2050 and 2080

Using DSSAT 4.5, the yield was projected for the year 2016, 2030, 2050 and 2080 (Table 27). It was observed that the treatments IW/CPE=2 (5869, 6010, 6205 and 6291 kg ha^{-1} for the year 2016, 2030, 2050 and 2080 respectively) and IW/CPE=1.5 (5859, 5997, 5859 and 6148 kg ha^{-1} for the year 2016, 2030, 2050 and 2080 respectively) showed the maximum amount of projected yield, followed by IW/CPE=1 (3765, 3504, 2703, 3608 kg ha^{-1} for the year 2016, 2030, 2050 and 2080 respectively) and nil to IW/CPE=0.5.

Table 23. Projected rainfall (mm) for the year 2030, 2050 and 2080

WEEKS	2030	2050	2080
Week 1	0.0	0.0	0.0
Week 2	0.0	0.0	0.0
Week 3	0.0	0.0	0.0
Week 4	0.0	0.6	1.1
Week 5	0.0	0.0	0.0
Week 6	0.0	0.0	0.0
Week 7	0.0	0.0	0.0
Week 8	0.0	0.0	0.0
Week 9	0.6	0.0	0.4
Week 10	0.0	0.7	0.7
Week 11	0.5	0.2	0.1
Week 12	0.0	0.5	0.1
Week 13	0.0	0.0	0.4
Week 14	0.3	0.1	0.2
Week 15	0.0	0.0	0.0
Week 16	0.0	0.0	0.0
Week 17	1.5	1.7	5.5
Week 18	2.7	4.6	1.3
Week 19	0.0	4.1	0.4
Week 20	7.9	8.1	10.1
Week 21	21.8	21.4	16.4
Week 22	14.1	16.5	9.2
Week 23	41.7	17.1	30.8
Week 24	47.1	71.6	27.5
Week 25	26.0	27.2	34.9
Week 26	67.0	54.8	29.8
Week 27	40.8	48.1	54.3
Week 28	26.4	32.7	34.7
Week 29	32.8	16.9	19.4
Week 30	45.0	37.6	45.9
Week 31	26.5	36.5	44.1
Week 32	20.7	21.1	23.8
Week 33	16.1	12.7	12.7
Week 34	6.7	9.3	8.2
Week 35	3.7	4.0	3.2

WEEKS	2030	2050	2080
Week 36	0.8	0.8	0.7
Week 37	0.0	0.0	0.0
Week 38	0.0	0.0	0.0
Week 39	0.0	0.0	0.0
Week 40	13.3	5.5	6.1
Week 41	11.2	15.8	16.9
Week 42	7.2	11.4	11.5
Week 43	0.2	0.2	0.2
Week 44	1.9	1.9	1.8
Week 45	0.2	0.2	0.2
Week 46	0.0	0.0	0.0
Week 47	0.0	0.0	0.0
Week 48	3.4	1.9	1.6
Week 49	0.4	1.9	0.4
Week 50	0.8	0.9	0.4
Week 51	2.6	2.8	0.3
Week 52	0.0	0.0	0.0

Table 24. Projected maximum temperature (°C) for the year 2030, 2050 and 2080

WEEKS	2030	2050	2080
Week 1	31.6	32.7	33.31
Week 2	32.8	32.84	33.5
Week 3	30.27	31.12	31.8
Week 4	31.6	31.62	32.31
Week 5	30.9	31.7	32.34
Week 6	34.3	34.3	34.9
Week 7	35.2	36.1	36.6
Week 8	35.9	35.7	36.2
Week 9	32.3	33.1	33.7
Week 10	33.71	34.11	34.7
Week 11	38.2	38.01	38.54
Week 12	36.7	37.34	37.83
Week 13	35.3	36	36.34
Week 14	33.64	34.1	34.64
Week 15	35.11	35.31	35.8
Week 16	35.2	35.72	36.2
Week 17	36.1	36.71	37.2
Week 18	34.22	35.12	35.84
Week 19	37.7	37.1	37.74
Week 20	36.4	36.11	36.71
Week 21	37.3	38.3	38.83
Week 22	34.14	34.5	35.1
Week 23	30.74	32	32.7
Week 24	33	32.85	33.3
Week 25	32.12	31.8	32.44
Week 26	30.22	31.4	32.01
Week 27	29.04	29	29.6
Week 28	27.8	28.34	29
Week 29	29.8	30.4	30.9

WEEKS	2030	2050	2080
Week 30	30.2	31.3	31.54
Week 31	31.9	31.62	32.1
Week 32	29.41	29.9	30.4
Week 33	31.6	31.42	31.8
Week 34	34.21	34.8	35.2
Week 35	29.5	31.11	31.6
Week 36	30.15	29.71	30.14
Week 37	30.72	31.71	32.13
Week 38	27.62	28.41	28.9
Week 39	31.7	31.55	32
Week 40	33.6	33.41	33.86
Week 41	33.44	34.04	34.6
Week 42	32	32.12	32.61
Week 43	33	33.23	33.6
Week 44	33.41	33.7	34.04
Week 45	33.74	34.61	35
Week 46	31.7	31.84	32.2
Week 47	28.1	29.03	29.5
Week 48	29.14	28.81	29.35
Week 49	32.64	33.16	33.65
Week 50	31.11	31.63	32.2
Week 51	36.7	36.6	37.13
Week 52	34.9	35	35.5

Table 25. Projected minimum temperature (°C) for the year 2030, 2050 and 2080

WEEKS	2030	2050	2080
Week 1	23.54	24.43	24.9
Week 2	22.53	22.7	23.23
Week 3	21.4	22.11	22.7
Week 4	22.41	22.61	23.2
Week 5	20.5	21.26	22
Week 6	23.1	23	23.54
Week 7	26.1	26.64	27.1
Week 8	24.73	25.55	26.03
Week 9	22.61	23.24	23.8
Week 10	25	25.6	26
Week 11	26.25	26.51	27
Week 12	27	27.3	27.7
Week 13	26.3	27	27.4
Week 14	24.31	25	25.4
Week 15	26.11	26.2	26.71
Week 16	27.03	27.64	28.1
Week 17	27.44	28.16	28.6
Week 18	26.24	26.7	27.2
Week 19	28.61	28.46	28.82
Week 20	28.13	28.61	29
Week 21	29.43	29.7	30.1
Week 22	26.7	27.05	27.41
Week 23	25.51	26.54	27
Week 24	26.1	26.43	26.8
Week 25	26.16	26.3	26.7
Week 26	26	26.4	26.75
Week 27	24.2	24.66	25.1
Week 28	23.3	23.64	24.13
Week 29	25	25.73	26.11

WEEKS	2030	2050	2080
Week 30	23	23.03	23.5
Week 31	25.2	25.3	25.66
Week 32	24.36	24.9	25.3
Week 33	25.5	25.6	26
Week 34	27.26	27.7	28
Week 35	24.45	25.36	25.76
Week 36	24	24.2	24.64
Week 37	24.32	25.04	25.46
Week 38	23.5	23.8	24.23
Week 39	25.41	25.5	25.84
Week 40	26.36	26.8	27.16
Week 41	27.33	28	28.17
Week 42	24.7	25.44	25.83
Week 43	26.16	26.14	26.51
Week 44	26.01	26.54	26.86
Week 45	26	26.44	26.8
Week 46	23.36	24	24.11
Week 47	22.2	23.84	24.3
Week 48	20.53	20.2	20.7
Week 49	22	23	23.31
Week 50	22.5	22.71	23.24
Week 51	25.34	25.23	25.7
Week 52	24.1	25.13	25.6

Table 26. Projected solar radiation (W m^{-2}) for the year 2030, 2050 and 2080

WEEKS	2030	2050	2080
Week 1	19.60	18.24	18.63
Week 2	20.93	21.51	21.70
Week 3	18.91	19.50	19.63
Week 4	19.17	16.47	16.53
Week 5	21.50	21.43	21.54
Week 6	21.69	22.83	23.11
Week 7	23.34	22.90	23.16
Week 8	23.00	23.59	23.71
Week 9	19.93	21.94	21.96
Week 10	25.96	22.84	22.87
Week 11	18.29	21.24	21.36
Week 12	27.13	24.43	24.61
Week 13	28.13	28.23	26.43
Week 14	23.79	24.49	25.07
Week 15	26.24	26.97	27.46
Week 16	27.06	26.09	26.40
Week 17	21.04	20.81	20.76
Week 18	11.21	14.33	16.27
Week 19	28.90	22.83	25.90
Week 20	24.26	22.59	24.34
Week 21	18.91	21.37	22.24
Week 22	20.77	18.59	20.29
Week 23	14.39	13.41	16.74
Week 24	14.37	16.11	14.49
Week 25	8.21	7.11	9.83
Week 26	9.50	7.66	10.36
Week 27	9.50	10.44	12.11
Week 28	7.24	5.93	5.97
Week 29	7.44	11.96	11.34
Week 30	11.60	13.54	11.86
Week 31	15.94	13.46	12.04
Week 32	16.77	14.79	14.24
Week 33	20.09	22.07	22.29
Week 34	20.93	21.94	22.81

WEEKS	2030	2050	2080
Week 35	23.67	21.60	22.46
Week 36	25.23	25.30	25.74
Week 37	25.09	25.07	25.44
Week 38	17.64	17.39	17.50
Week 39	24.10	25.69	25.70
Week 40	15.50	17.09	17.14
Week 41	9.84	8.67	8.83
Week 42	16.97	15.23	15.51
Week 43	21.51	21.51	21.73
Week 44	23.04	23.06	23.14
Week 45	21.56	22.13	22.16
Week 46	25.30	25.09	25.09
Week 47	19.81	19.60	19.60
Week 48	15.69	18.09	18.27
Week 49	19.26	19.33	19.70
Week 50	17.59	15.64	16.17
Week 51	14.90	15.51	16.19
Week 52	20.70	22.29	22.67

Table 27. Projected yield (kg ha^{-1}) for the year 2030, 2050 and 2080

IRRIGATION LEVELS	2016	2030	2050	2080
IW/CPE=2	5869	6010	6205	6291
IW/CPE=1.5	5859	5997	5859	6148
IW/CPE=1	3765	3504	2703	3608
IW/CPE=0.5	0	0	0	0

CHAPTER 5

DISCUSSION

The results of the experiment on climate change adaptation through improved water use efficiency in rice, *Oryza sativa* are discussed here.

5.1 BIOMETRIC OBSERVATIONS

5.1.1 Plant height (cm)

The plant height in rice was significantly influenced by hydrogel and irrigation treatments. Hydrogel had influence from 3rd week to 9th week which marks the beginning of booting stage (Fig 1). Irrigation had its significance from 4th week, which continues till the harvest. Interaction was significant only during the last four weeks of the harvest. An increase in water stress had caused a reduction in plant height. Drought stress can significantly impact plant height (Yang *et al.*, 2006).

A reduction in water availability will a cause a decrease in cell elongation. From the results it can be seen that the application of hydrogel improved the plant height than for the plants without hydrogel. This is in confirmation with the findings of Baron *et al.* (2007), Rehman *et al.* (2011) and Gales *et al.* (2012). But the effect of hydrogel did last only up to the booting stage of rice. Up to booting stage, hydrogel could be effective because the requirement of water is relatively low and hydrogel was able to provide the short fall of water. Beyond the stage, hydrogel may not be enough to create an impact on plant height, since the water requirement is higher than that supplemented by hydrogel. But its effect is further emphazised when the interaction effect of hydrogel and irrigation is significant from the 11th week onward. Moisture availability is crucial for a plant to germinate and establish in soil.

The application of hydrogel seems to have increased the moisture content in soil and helped the plants to grow more as compared to the plants without hydrogel. This study agrees with the work done by Akhter *et al.* (2004), which confirms that hydrogel improved the soil moisture availability and thus helped plant establishment. But, while considering the interaction, it was observed that the hydrogel application did not increase the plant height for the treatment IW/CPE=2. Except for IW/CPE=2, the hydrogel application had increased the plant height for all the other remaining irrigation treatments, which means that hydrogel had beneficial role in holding and releasing the required amount of moisture to the plant at lower irrigation levels of IW/CPE=1.5, IW/CPE=1 and IW/CPE=0.5. This could be because, at higher irrigation, hydrogel may be limiting the available water to soil, which resulted in the decrease in plant height. This confirms that, despite various beneficial effects of hydrogel addition, some studies have shown little or no benefit with hydrogel (Conover and Poole, 1976; James and Richards, 1986; Ingram and Yeager, 1987).

5.1.2. Leaf area index (LAI)

LAI was significantly influenced by the irrigation treatments while, hydrogel and interaction did not significantly impact the LAI (Fig 2). LAI is the ratio of one-sided leaf tissue to the ground surface. It is an indicator of photosynthetic surface available to the plant. The treatment IW/CPE=2 had the higher value of LAI and IW/CPE=0.5 had the lower value. The higher LAI for the plants may be due to lower solar radiation as the experiment was done in a polyhouse. This is because, Photosynthetically Active Radiation (PAR), inside the polyhouse was reduced to about 50 percent compared to outside (Sam and Regeena, 2015). Lower solar radiation promotes leaf expansion, which is needed for better light interceptions (Watson, 1952; Milthrope, 1959; Takemiya *et al.*, 2005). Often decrease in leaf area is a response to water deficit condition as it enables survival through lower transpiration (Kumar, 2015).

The reduction in number of leaves is mainly due to the death and abscission of leaves at a faster rate before the production of new leaves for which water is an important factor. Thus the reductions are caused both by the decrease in photosynthetic activity of a unit of leaf and in the reduction of leaf surface (Sokoto and Muhammad, 2014). There are studies which shows that superabsorbent polymers increase the turgor pressure inside the cell by providing sufficient amount of water and thus increasing the leaf area (Yazdani *et al.*, 2007), but here the lack of effect of hydrogel may be due to the inadequate quantity of hydrogel applied. In a work done by Kumar (2015), it was clearly emphazised that different doses of hydrogel had effect on the growth, yield and the production processes. Thus, by increasing the dosage of hydrogel applied, a significant change in LAI of the plants could be possible.

5.1.3. Number of tillers

Hydrogel had significant impact on number of tillers at the vegetative stage of the plant (Fig 3). Irrigation had significant impact on mumber of tillers at the vegetative and ripening stage and interaction was significant at the vegetative, reproductive and ripening stages. For the irrigation levels, it was found that, the higher number of tillers was recorded for the treatment IW/CPE=2 and lower value for IW/CPE=1.5, IW/CPE=1 and IW/CPE=0.5. This indicates that water stress at the tillering stage reduced the number of fertile tillers produced per plant which resulted in the reduction of intercepted photosynthetically active radiation, (PAR) (Sokoto and Muhammed, 2014). The water stress probably reduced the leaf initiation and resulted in reduced tillering. Similar results were reported by Somayeh *et al.* (2013).

Hydrogel probably increased the water availability since plants with hydrogel had more tillers than for the plants without hydrogel. Similar trend was observed for the experiment conducted by Rehman *et al.* (2011). The results of the interaction showed the effect of hydrogel in increasing the soil moisture and reducing water stress. At the reproductive and vegetative stage also the highest value was for the treatment IW/CPE=2 with hydrogel. This indicates that, hydrogel application decreased the irrigation requirements by increasing the moisture availability resulting lesser damages to crop (Taylor and Halfacre, 1986).

4. Number of primary branches per panicle

From the results it was observed that irrigation and hydrogel had a significant impact on the number of primary branches produced per panicle (Fig

4). The highest value was recorded for the treatment IW/CPE=2 and lowest value for the treatment IW/CPE=0.5. The reduction in primary branches caused due to the increase in water stress indicate that when drought affects the plants at their anthesis and filling stages, it affects the overall yield in rice. The water stress at the flowering stage caused more reduction in yield (Sarvestani *et al.*, 2008), in which the number of primary branches per panicle play an important role. Poor moisture content is one of the factors which reduces the plant establishment and reduction in yield.

The hydrogel applied plants recorded more primary branches per panicle, probably due to the increase in water availability than for the plants without hydrogel. Hydrogel application evidently increased the soil moisture availability and thus helped in plant establishment (Akhter *et al.*, 2004). The interaction did not show a significant impact on the number of primary branches per panicle.

5.1.5. Yield components

The yield components includes a number of factors like the number of panicles produced per plant, number of filled grains per panicle, 1000 grain weight, straw yield, grain yield and dry matter accumulation at harvest. Hydrogel and irrigation treatments had a significant impact on the yield components of rice (Fig 5 to Fig 10). The rate of accumulation of dry matter in the economically valuable part of a plant is the major factor affecting the yield. When the water stress increases, it is reflected in the yield components of rice. The higher values were recorded for the treatments IW/CPE=2 and IW/CPE=1.5 and lower values for the treatment IW/CPE=0.5. When water stress occur at the anthesis and flowering stages of rice, it cause spikelet degeneration, reduction in grain number, increase in unfilled grains, reduction in 1000 grain weight and reduction in yield. In an experiment conducted in Philippines (IRRI, 1973), it was found that, moisture stress at the early stages will reduce tillering and thereby reduce yield and at the later stages affect the grain filling. Similar to this, in the present study it was found that lower irrigation levels resulted in poor yield. The number of panicles per hill is determined by the effect of water stress at or before the tillering stage. Thus, at maximum water stress the number of panicle per hill decreased compared to well irrigated condition.

The moisture stress at the booting, flowering and grain filling stages decreased the number of filled grains produced per panicle (Rahman *et al.*, 2002). This is mainly because, the water stress at different stages hinders the translocation of assimilates to the grains, lowering its weight and increasing the emptiness in grain. Under these conditions, the genetypes has no capability in expressing their genetic yield potential (Sarvestani *et al.*, 2008). The biomass of the plant is mainly concentrated on the straw yield produced and the dry matter accumulated at the harvest which in turn depends on the number of tillers produced per plant, plant height and number of leaves. When water stress affects all these factors, it will in turn affect the total biomass.

Water stress at the tillering stage resulted in lower photosynthesis, translocation rate and dry matter accumulation which in turn affect the total biomass (Sokoto and Muhammad, 2014). Thus the reduction in leaf expansion and photosynthetic rate will result in low dry matter and grain yield. Water deficit at the vegetative, flowering and grain filling stages reduced the mean grain yield by 21 percent, 50 percent and 21 percent in rice (Sarvestani *et al.*, 2008) and the reduction in yield mainly comes from the reduction in fertile panicle number and filled grain percentage. At IW/CPE=0.5, the yield obtained was very low, which indicates that water stress at the booting stage hindered the translocation of assimilates severly and thus resulted in low yield.

The hydrogel application could reduce water deficit and result in an increase of yield. Even though, the hydrogel application did not have a significant impact on the number of panicles per hill, straw yield and dry matter accumulated at harvest, it had a significant effect on number of filled grains per panicle, 1000 grain weight and grain yield. Since hydrogel application did not impact number of panicle, straw yield and dry matter it indicates that, most of the moisture supplied by hydrogel was mainly used for the translocation of assimilates to the grains and increased the number of filled grains per panicle which further increased the 1000 grain weight and inturn the grain yield. Thus, hydrogel helped in retention of water and increased the water availability of plant and released it when the plants need the most.

The increase in soil moisture and delay in permanent wilting point of the plant which resulted in increased yield parameters consequently to hydrogel application is already reported (Rehman *et al.*, 2011). While considering the interaction, it can be seen that at higher irrigation levels, plants with hydrogel did not show any increase in yield, while at lower irrigation treatments plants with hydrogel increased the yield. For number of panicles per hill, plant with hydrogel had the higher value for the treatment IW/CPE=0.5. The beneficial effect was restricted to lower irrigation levels (IW/PE=1.5, IW/CPE=1 and IW/CPE=0.5). The results mainly indicate that at higher irrigation levels, hydrogel limits the available water to the plant and it in turn reduce the plant establishment and growth compared to plant without hydrogel. Thus, the application of hydrogel seem to have significant role in increasing the water availability to plants and increasing the yield at water stressed conditions.

5.2. PHYSIOLOGICAL OBSERVATIONS

From the results, it was found that application of hydrogel alone and interaction did not have any significant impact on the physiological observations like days taken for active tillering, panicle emergence, 50 percent flowering, booting and heading. (Fig 11 to Fig 15). Irrigation significantly influenced these traits. But for active tillering and physiological maturity there was no significance of any of these treatments. The results showed that, the highest water stressed plants (IW/CPE=0.5) took the maximum number of days for panicle emergence, booting, heading and flowering stages and the treatments IW/CPE=2 took the minimum. This indicates that the water stressed plants took more number of days to mature as observed by Sikuku *et al.* (2010) and Fukai *et a.l* (1999). But, for the treatment IW/CPE=2, it was found that the moisture stress was not severe and they had early booting, heading, flowering and panicle emergence as compared to others. In this case, the effect of hydrogel was non-significant, which indicates that, the amount of hydrogel was not enough to produce any considerable changes on the physiological observations of the plant, which maybe because, the plants had enough moisture for their growth and survival at that stages.

From the observations, it was apparent that the increasing levels of water stress decreased the rate of photosynthesis in rice (Fig 16). The treatment IW/CPE=2 and IW/CPE=1.5 showed higher rates of photosynthesis, while IW/CPE=0.5 showed lowest rates. However, the effect of hydrogel and interaction was non significant. Among the various physiological, biochemical and molecular processes that controls plant growth, photosynthesis is the fundamental process that provides the organic blocks that contributes substantially to the plant growth and development. According to Taiz and Zeiger (2010), the chemical energy consumed in various metabolic processes is derived from the conversion of light energy into chemical energy. Water stress can hinder that process by changing the ultrastructure of the organelles. Abiotic stress can reduce the photosynthetic rate by stress-induced stomatal or non stomatal limitations (Rahnama *et al.*, 2010). When leaves remain green during grain filling, photosynthesis will be high, which result in more yield (Fu and *Lee.*, 2009). Presence of hydrogel in the present experiment did not seem to have any influence on soil moisture to change the photosynthesis rate significantly. Different doses of hydrogel has its own significant impact on the growth, yield, water productivity and economic production (Kumar, 2015).

The increasing levels of water stress had a significant impact on the transpiration of rice (Fig 17). In the present study, treatment IW/CPE=2 had the higher values of transpiration rate, while IW/CPE=1.5, IW/CPE=1 and IW/CPE=0.5 had lower values. Hydrogel application and interaction had no significant impact on the transpiration rate of rice. More than the CO_2 diffusion into leaf tissues, stomatal closure is known to have more inhibitory effect on transpiration of water (Chaves *et al.*, 2009). Its already known that water shortage reduces assimilation and transpiration in plants (Fini *et al.*, 2011). The main driving force of transpiration is the water potential gradient between the inner space of stomata and the atmospheric air and it was low in the case of IW/CPE=0.5. It is likely that closure of stomata results from water stress (Nurul *et al.*, 2016). But at IW/CPE=2, the plants had enough water to increase their yield and keep transpiring, which gave them highest value of transpiration than the other treatments. The hydrogel application at the prescribed rate seem to have created no beneficial role. Increased amount of hydrogel could result in high transpiration as observed by Kumar (2015).

5.3. Climate projections and yield for the year 2030, 2050 and 2080

The climate projections for the year 2030, 2050 and 2080 indicates that, there would be a shortfall of rainfall during 2030, 2050 and 2080 and a marked increase in the maximum and minimum temperatures (Fig 18 to Fig 21). From the yield we can see that the treatments IW/CPE=2 and IW/CPE=1.5 showed a significant increase in yield over the years. Further, the addition of hydrogel can increase the yield in a considerable manner. As the projections here was without hydrogel, we can say that, with the addition of hydrogel to the treatment IW/CPE=1, we can possibly match the yield to that of IW/CPE=1.5. Thus, the addition of hydrogel to plants growing in drought conditions may increase the overall plant establishment and yield.

Figure 1. Plant height (cm) in rice at reproductive stage as influenced by hydrogel and irrigation treatments

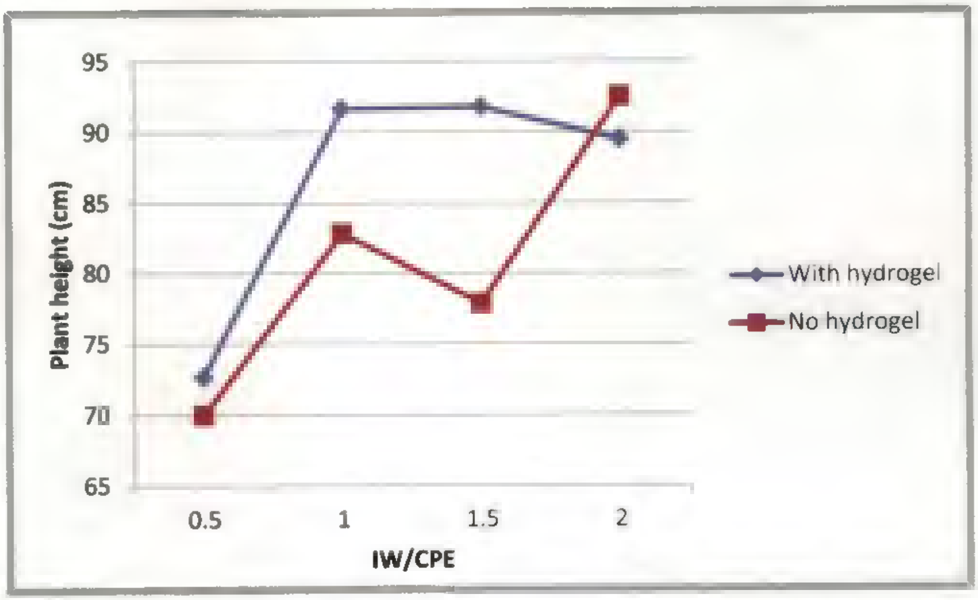


Figure 2. Leaf area index (LAI) in rice at reproductive stage as influenced by hydrogel and irrigation treatments

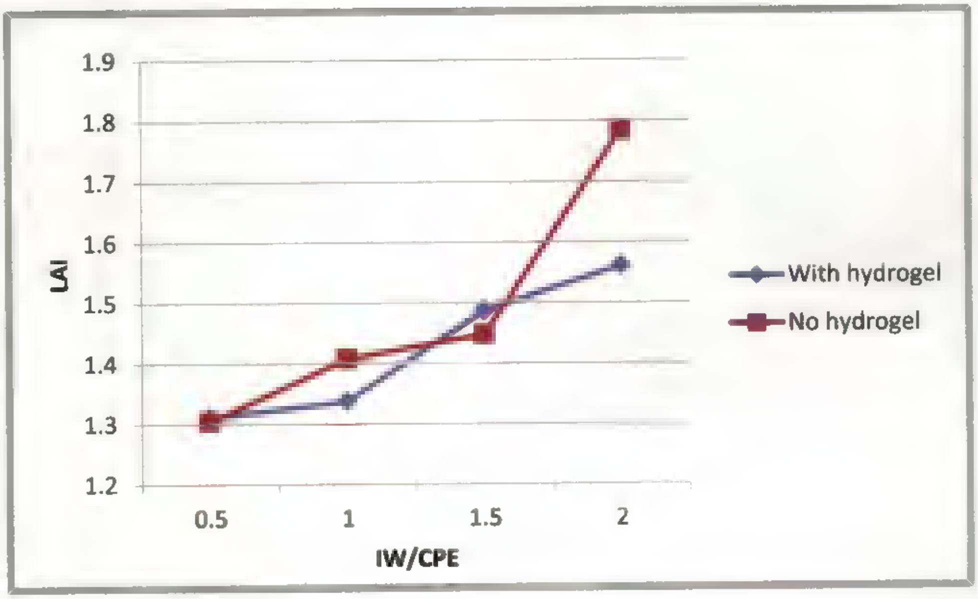


Figure 3. Number of tillers in rice at vegetative stage as influenced by hydrogel and irrigation treatments

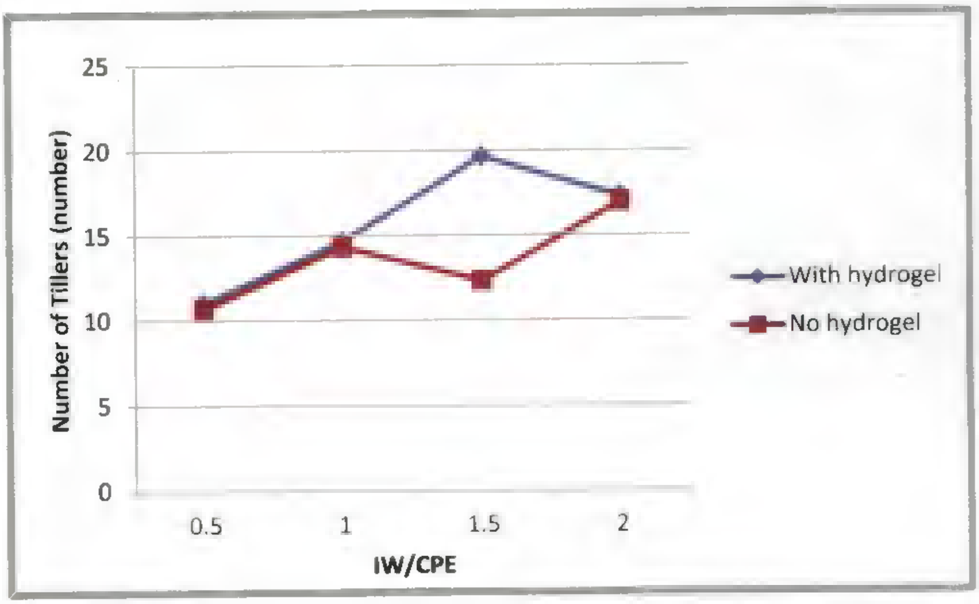


Figure 4. Number of primary branches per panicle in rice as influenced by hydrogel and irrigation treatments

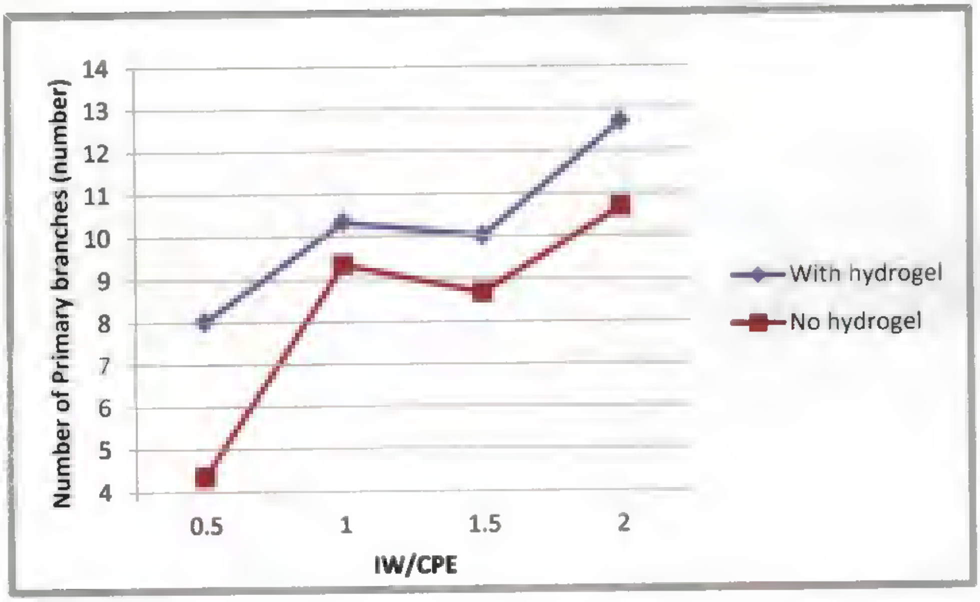


Figure 5. Number of panicles per hill in rice as influenced by hydrogel and irrigation treatments

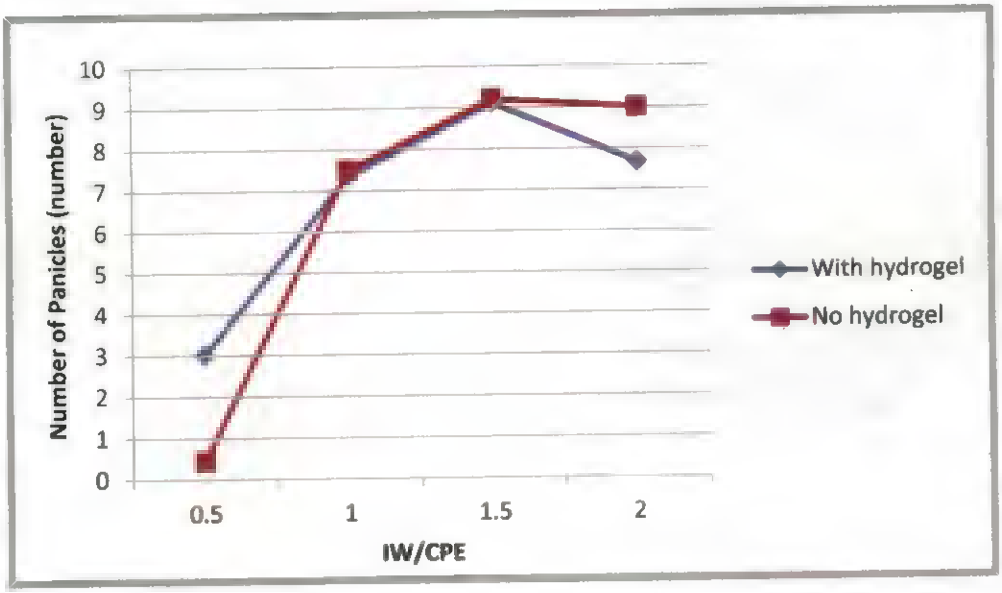


Figure 6. Number of filled grains per panicle in rice as influenced by hydrogel and irrigation treatments

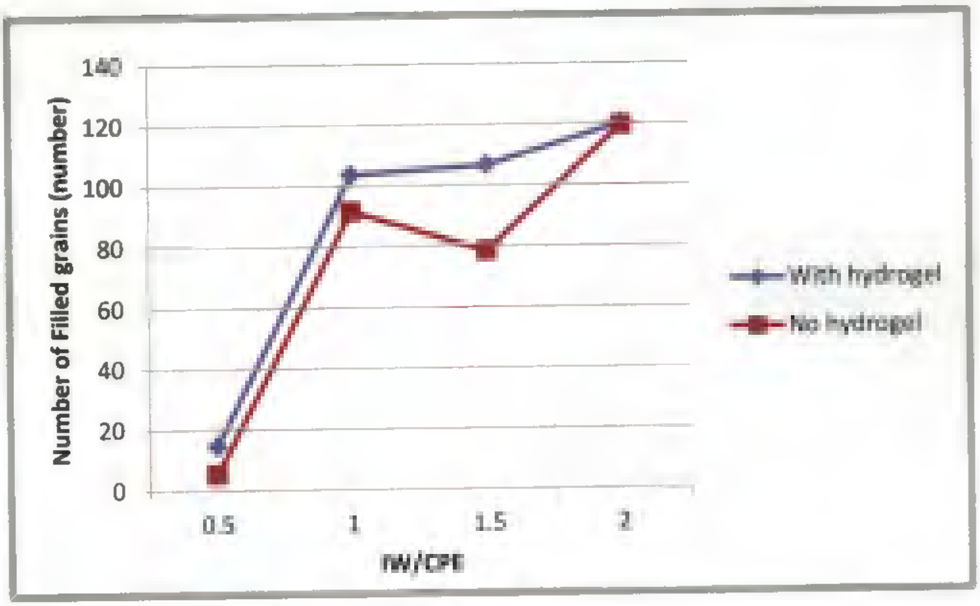


Figure 7. 1000 grain weight (g) in rice as influenced by hydrogel and irrigation treatments

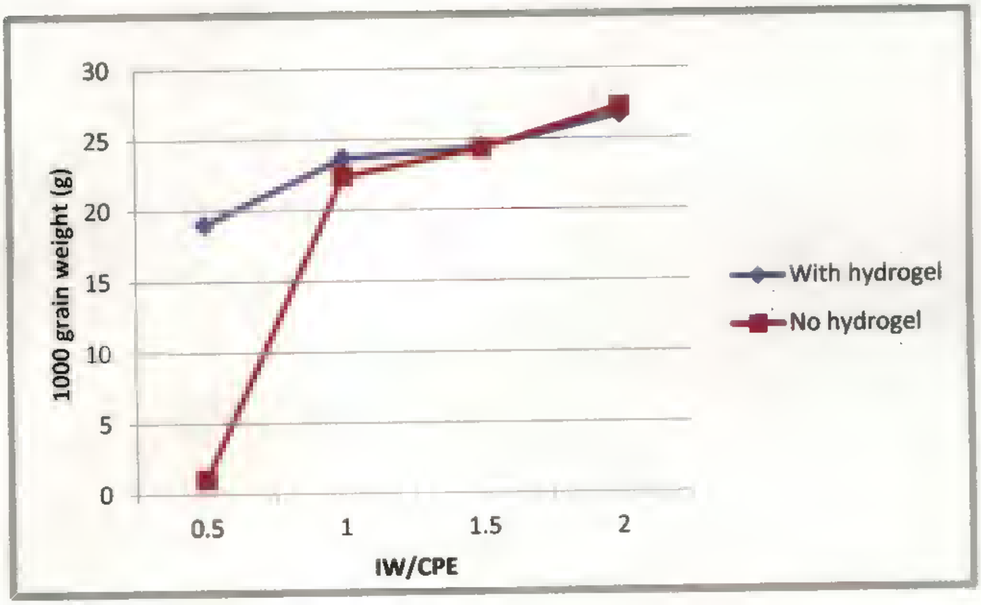


Figure 8. Straw yield (kg ha^{-1}) in rice as influenced by hydrogel and irrigation treatments

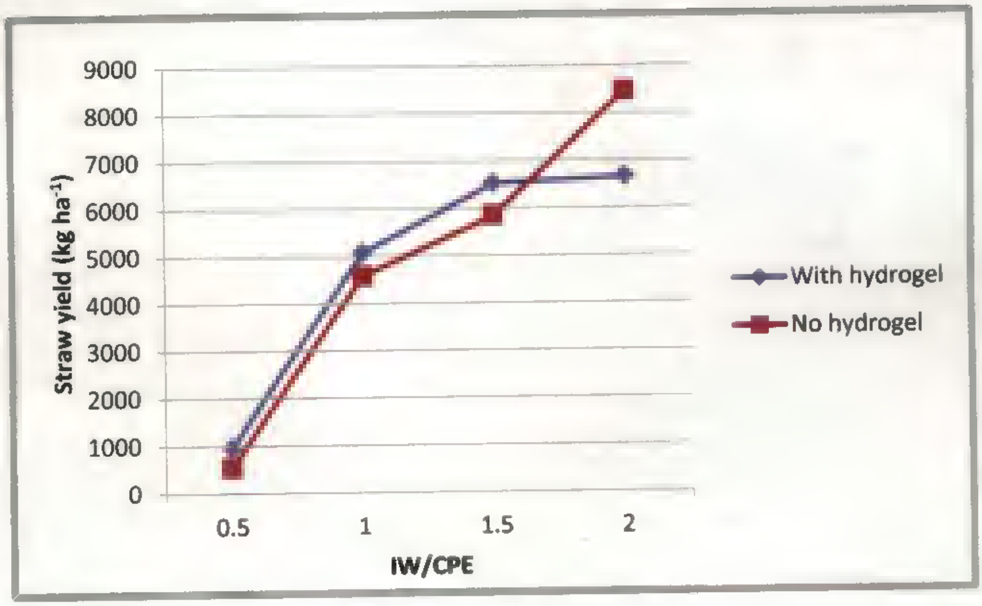


Figure 9. Grain yield (kg ha^{-1}) in rice as influenced by hydrogel and irrigation treatments

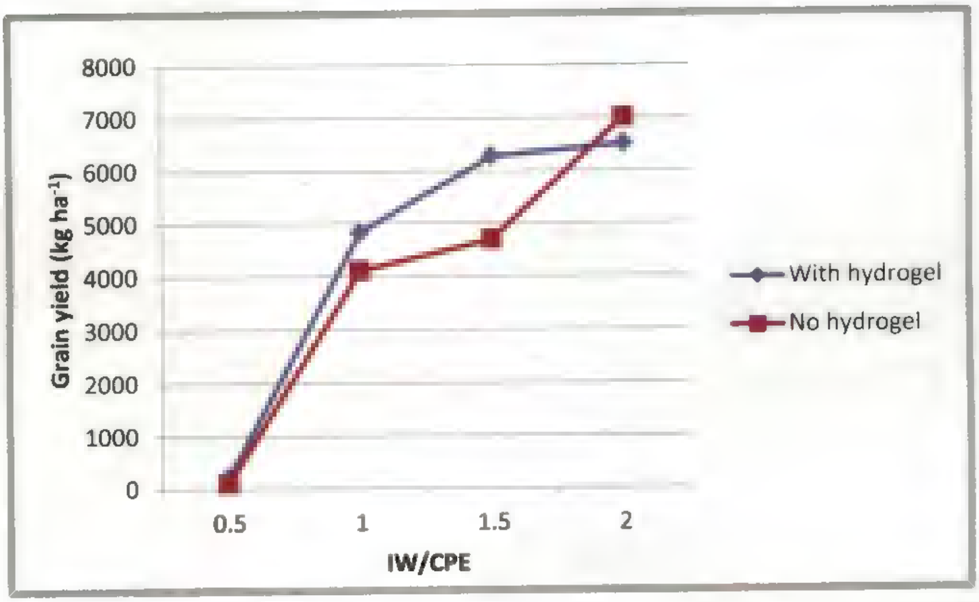


Figure 10. Dry matter accumulation at harvest (kg ha^{-1}) in rice as influenced by hydrogel and irrigation treatments.

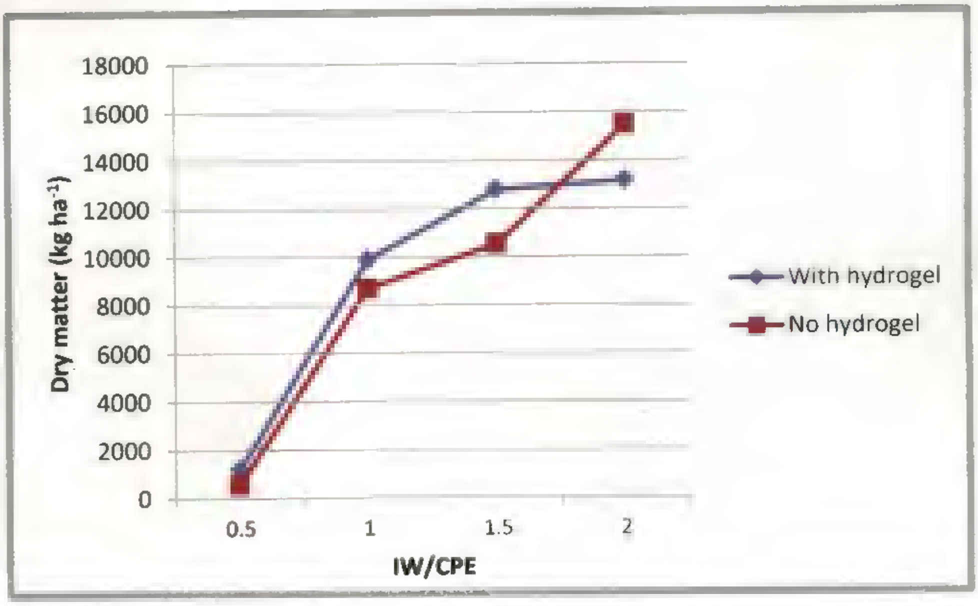


Figure 11. Number of days taken for active tillering in rice as influenced by hydrogel and irrigation treatments

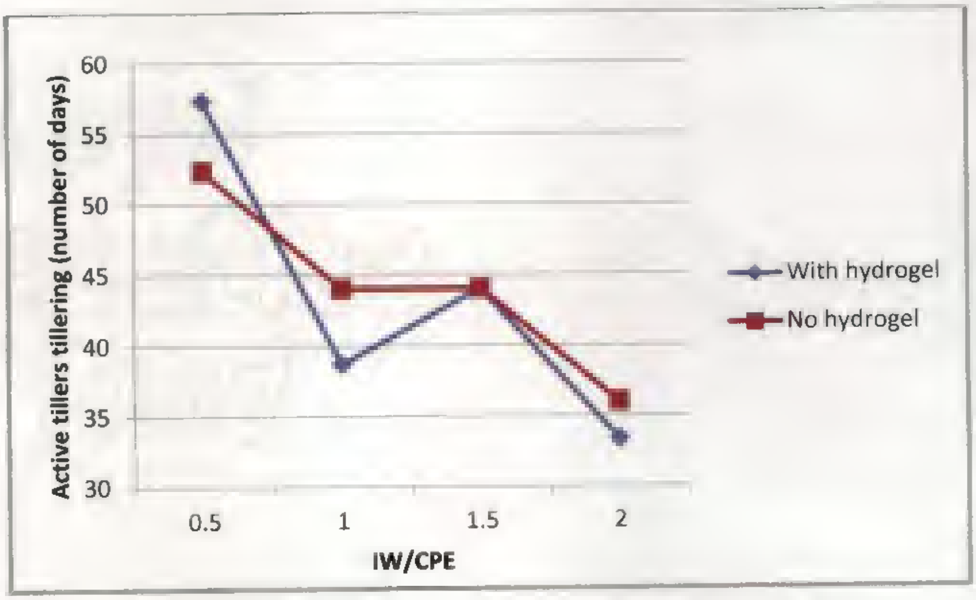


Figure 12. Number of days taken for panicle emergence in rice as influenced by hydrogel and irrigation treatments

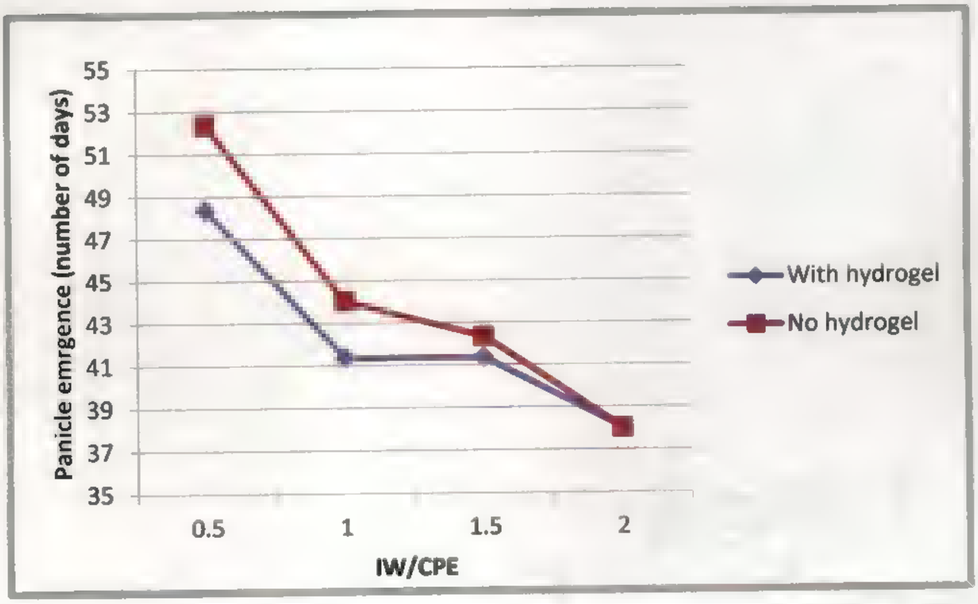


Figure 13. Number of days taken for 50 percent flowering in rice as influenced by hydrogel and irrigation treatments

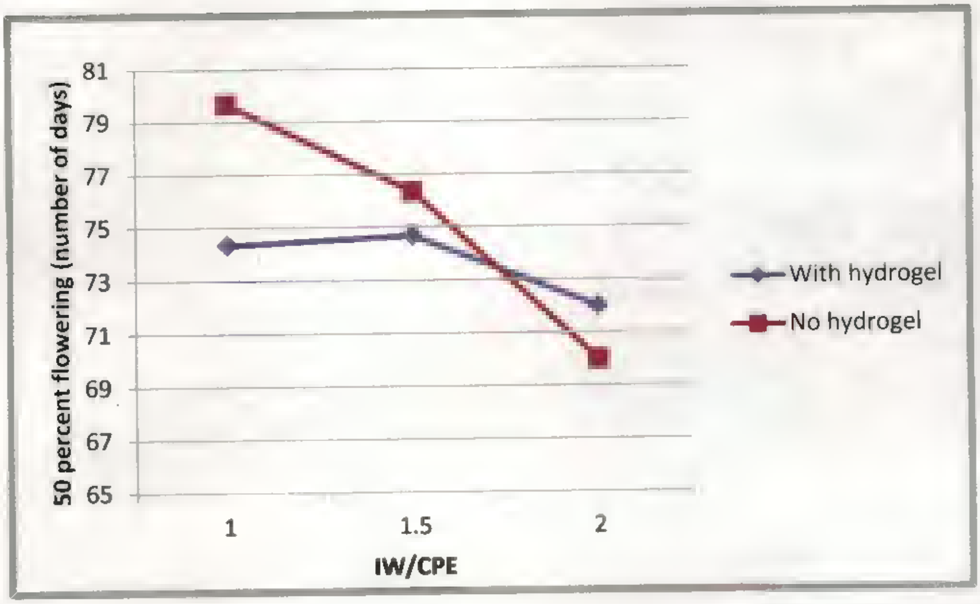


Figure 14. Number of days taken for booting in rice as influenced by hydrogel and irrigation treatments

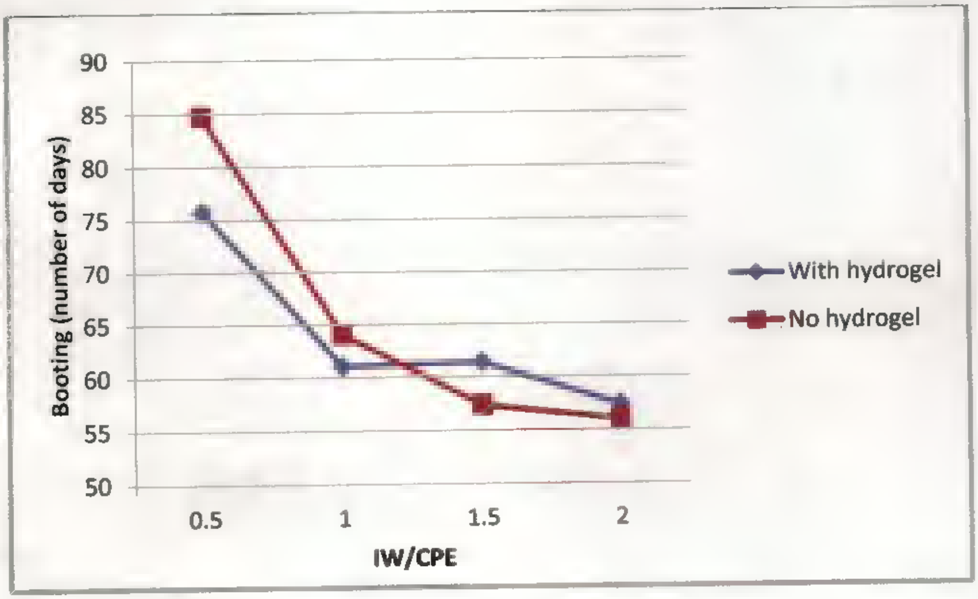


Figure 15. Number of days taken for heading in rice as influenced by hydrogel and irrigation treatments

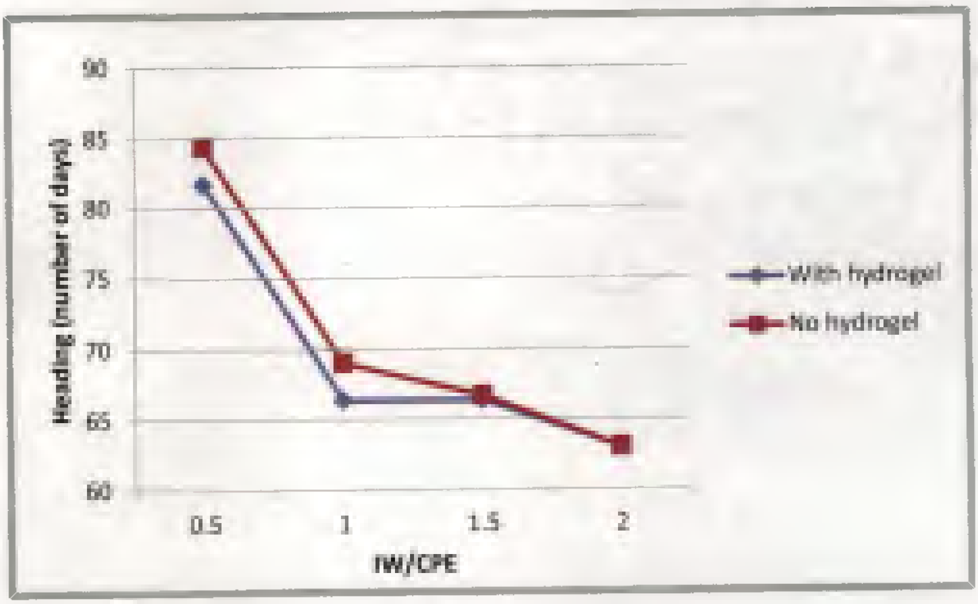


Figure 16. Photosynthesis (µmol CO_2 m^{-2} s^{-1}) in rice as influenced by hydrogel and irrigation treatments

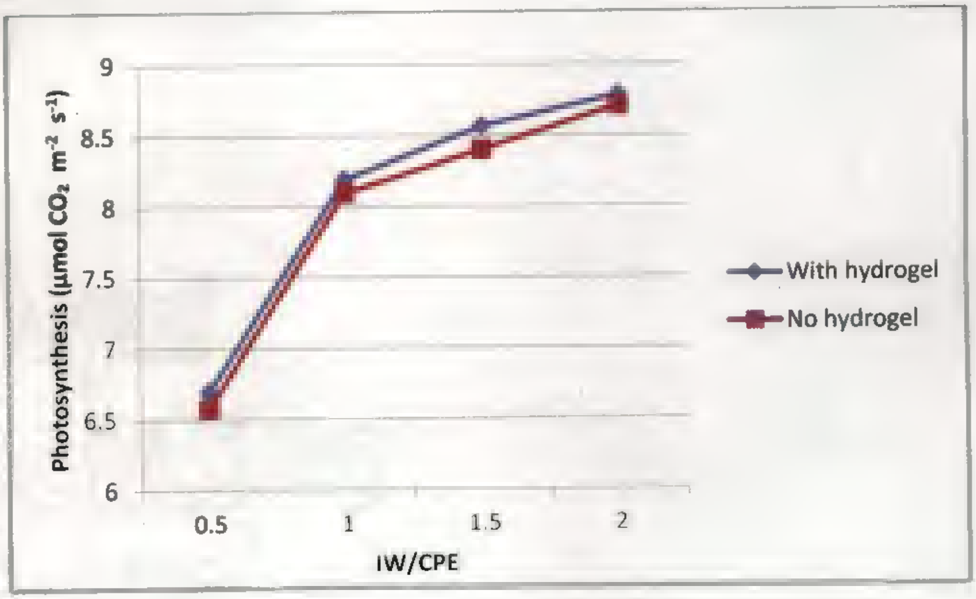


Figure 17. Transpiration (mmol H_20 m^{-2} s^{-1}) in rice as influenced by hydrogel and irrigation treatments

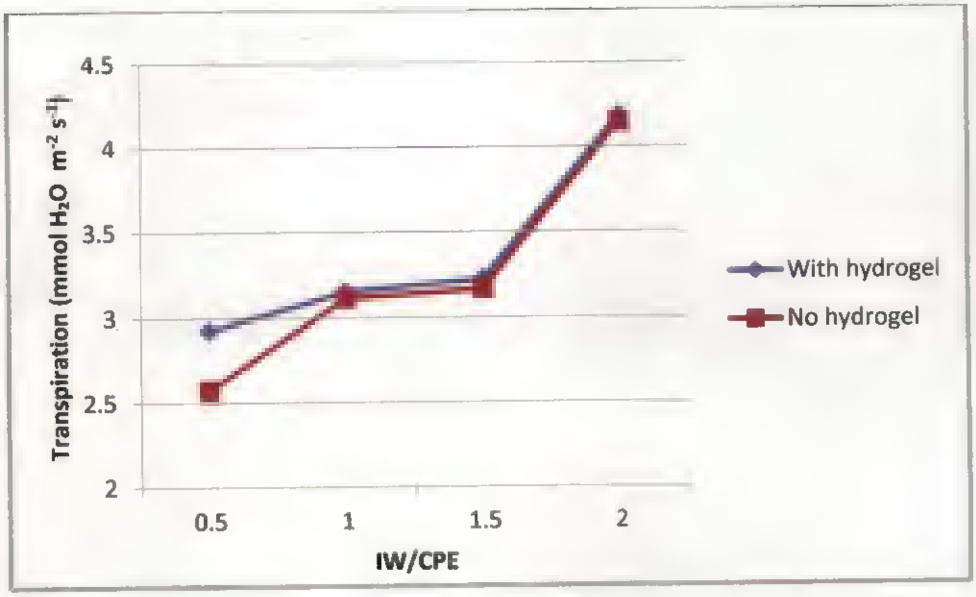


Figure 18. Projected maximum temperature (°C) for the year 2030, 2050 and 2080

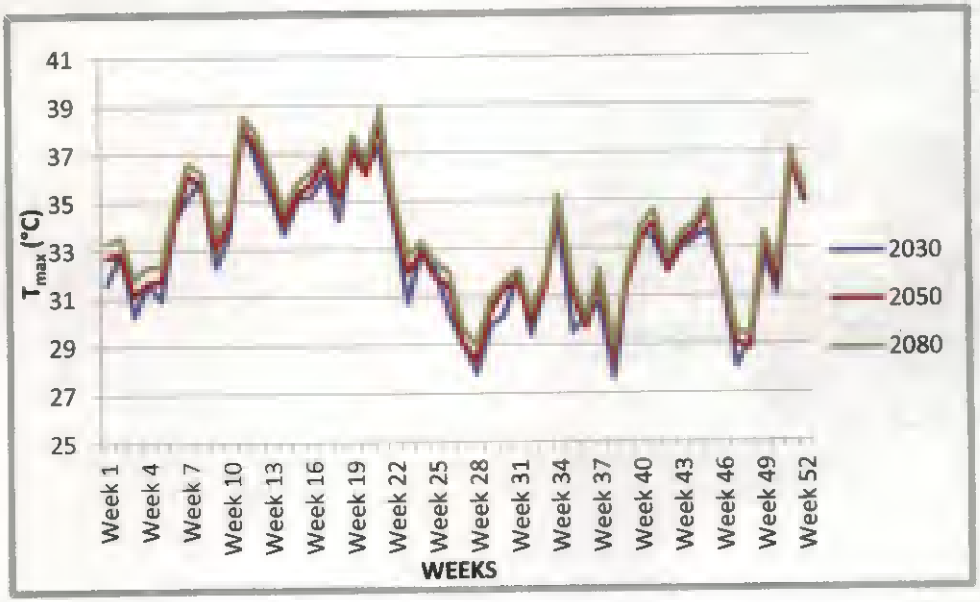


Figure 19. Projected minimum temperature (°C) for the year 2030, 2050 and 2080

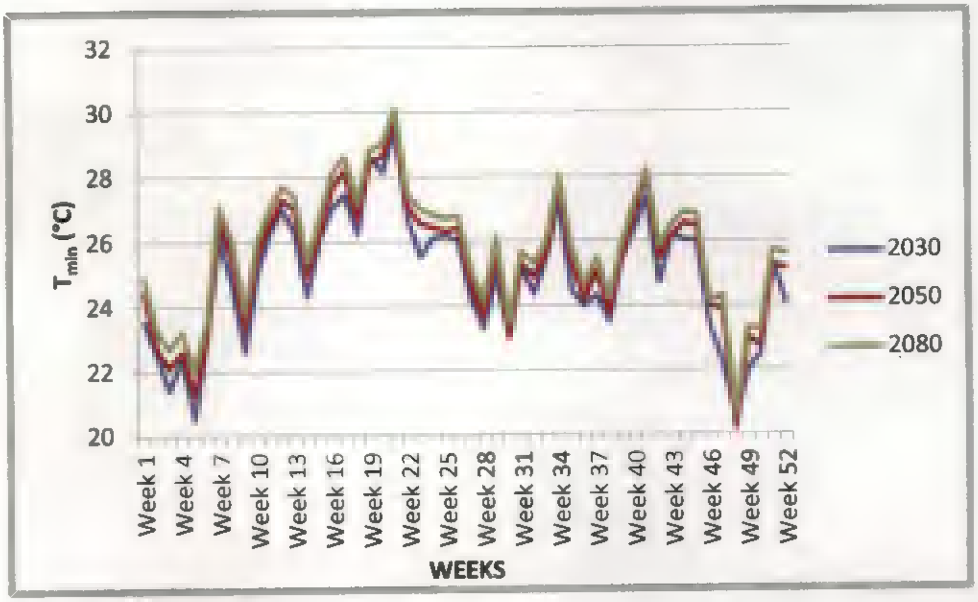


Figure 20. Projected solar radiation (W m^{-2}) for the year 2030, 2050 and 2080

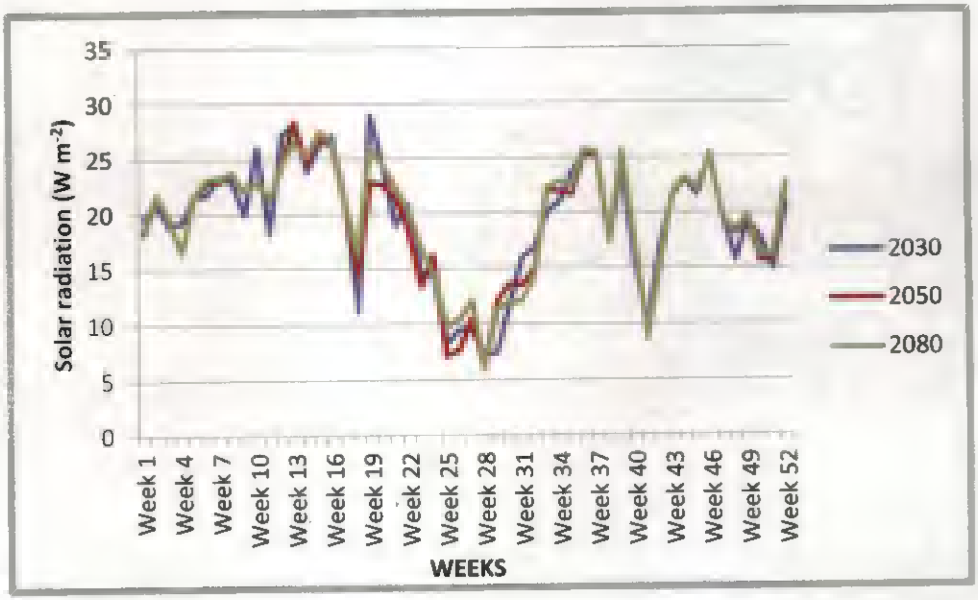


Figure 21. Projected rainfall (mm) for the year 2030, 2050 and 2080

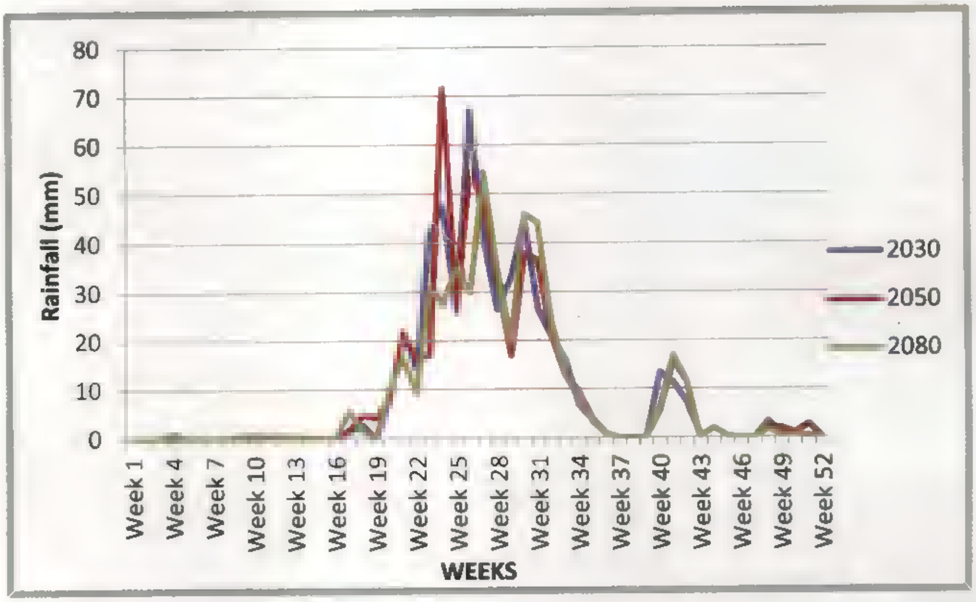
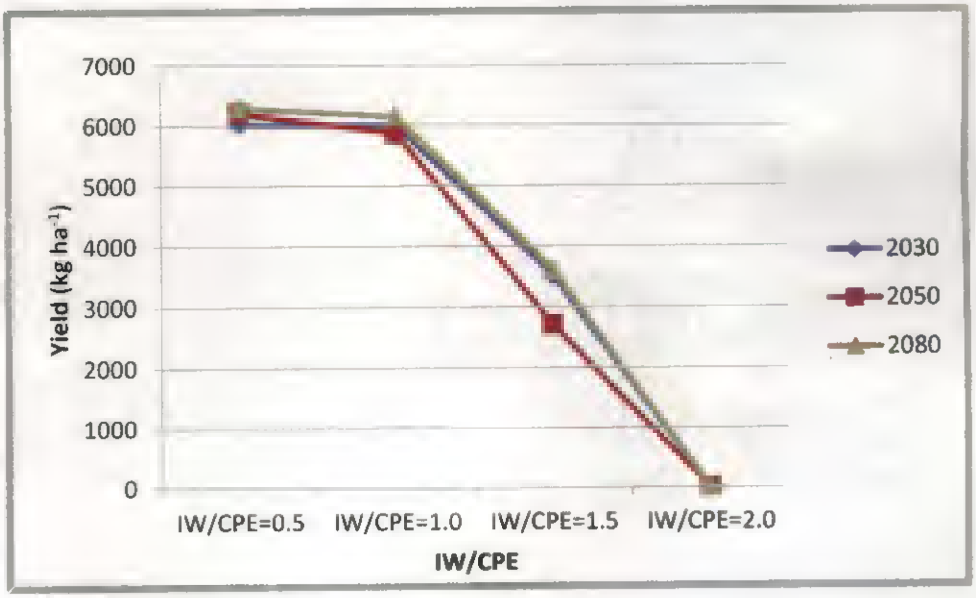


Figure 22. Projected yield (kg ha^{-1}) for the year 2030, 2050 and 2080



CHAPTER 6

SUMMARY AND CONCLUSION

A study entitled "Climate change adaptation through improved water use efficiency in rice (*Oryza sativa* L.)" was conducted at the Regional Agricultural Research Station (RARS), Pattambi. The objective of the study was to elucidate the influence of varying soil moisture status on rice productivity and to evaluate the increased water use efficiency in a climate change adaptation strategy.

The results of the study showed that the different irrigation treatments and the application of hydrogel had a significant impact on the growth and development of rice. The hydrogel application was significantly prominent at lower irrigation levels (IW/CPE=1.5, IW/CPE=1 and IW/CPE=0.5). At higher irrigation (IW/CPE=2), hydrogel failed to exhibit any significant role.

The parameters like plant height, number of tillers, 1000 grain weight and grain yield at harvest was significantly influenced by irrigation treatments, hydrogel application and its interaction. The treatment IW/CPE=2 without hydrogel had the maximum value of plant height, 1000 grain weight and grain yield at harvest. For IW/CPE=1.5, IW/CPE=1 and IW/CPE=0.5, plants with hydrogel was recorded higher values. In the case of number of tillers, the treatments IW/CPE=2 and IW/CPE=1.5 with hydrogel had the maximum number of tillers, while IW/CPE=0.5, without hydrogel recorded the minimum number of tillers.

The different irrigation treatments and hydrogel had its significant effect on the number of primary branches per panicle and number of filled grains per panicle. Even though the interaction was non significant, plants treated with hydrogel was recorded with higher number of primary branches per panicle and higher number of filled grains per panicle. The irrigation also significantly influenced the number of primary branches and filled grains. IW/CPE=2 showed the maximum value and IW/CPE=0.5 had the minimum.

The effect of irrigation alone had its significance for the parameters like LAI, transpiration, photosynthesis, days taken for panicle initiation, 50% flowering, booting and heading. The treatments IW/CPE=2 and IW/CPE=1.5 was recorded with the higher values of LAI and IW/CPE=1 and IW/CPE=0.5 was with the lower values. The highest value of transpiration was observed for the treatment IW/CPE=2 and lowest values was on par with the treatments IW/CPE=1.5, IW/CPE=1 and IW/CPE=0.5. In the case of photosynthesis, IW/CPE=2 and IW/CPE=1.5 were on par while lowest value was observed for the treatment IW/CPE=0.5. Plants with water stressed condition took the maximum number of days for panicle initiation, 50 percent flowering, booting and heading, while IW/CPE=2 recorded the minimum number.

For the parameters like, dry matter accumulation at harvest, number of panicle per hill and straw yield, irrigation and interaction had a significant effect, but hydrogel alone did not show any significanct differences. For the plants with hydrogel, the treatments IW/CPE=1.5, IW/CPE=1 and IW/CPE=0.5 had the higher value of straw yield and dry matter accumulated at harvest. In the case of number of panicles produced per hill, the interaction was noticed at severely stressed condition. Thus, plants with hydrogel had higher number of panicles per hill for the treatment IW/CPE=0.5. For IW/CPE=2, IW/CPE=1.5 and IW/CPE=1, plants without hydrogel showed the maximum number.

There was no significant effect of either hydrogel, irrigation and interaction for the number of days taken for active tillering and physiological maturity.

Thus, hydrogel had its significance only when irrigation level is low (IW/CPE=1.5 and IW/CPE=1). At extreme low water level (IW/CPE=0.5) and high water level (IW/CPE=2), hydrogel failed to exhibit any beneficial role. The climate projections for the year 2030, 2050 and 2080 indicated that, there would be a shortfall of rainfall for the years 2030, 2050 and 2080 and a marked increase in the maximum and minimum temperatures. From the yield we can see that the treatments IW/CPE=2 and IW/CPE=1.5 showed a significant increase in yield over the years. Further, the addition of hydrogel can increase the yield in a considerable manner. As the projections here was without hydrogel, we can say that, with the addition of hydrogel to the treatment IW/CPE=1, we can possibly match the yield to that of IW/CPE=1.5. Thus, the addition of hydrogel to plants growing in drought conditions may increase their overall plant establishment and yield.

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CLIMATE CHANGE ADAPTATION THROUGH IMPROVED WATER USE EFFICIENCY IN RICE (*Oryza sativa* L.)

ANJALY C BOSE

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ABSTRACT OF THE THESIS

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KERALA AGRICULTURAL UNIVERSITY

VELLANIKKARA, THRISSUR - 680 656

KERALA, INDIA

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ABSTRACT

The food security of more than half of the world population depends on rice. Studies suggest that global climate change is going to affect the food production through temperature and water stress and this affect the rice production around the globe. The present study tried to elucidate the influence of varying soil moisture status on rice productivity and evaluate the strategies for increased water use efficiency in a climate change adaptation strategy. The study was conducted during May 2016-September 2016 at RARS, Pattambi in variety Jyothi. The treatment combination included the presence or absence of hydrogel along with 4 different levels of irrigation (IW/CPE=2, IW/CPE=1.5, IW/CPE=1 and IW/CPE=0.5). The results showed that the various irrigation levels and hydrogel application had a significant impact on the physiology of rice. Hydrogel application improved the soil moisture availability and increased plant establishment. The maximum plant height was observed for the treatment IW/CPE=2 (105.30 cm) without hydrogel. The hydrogel effect on plant height was significant only up to the booting stage. Hydrogel had its significance on number of tillers only at the vegetative stage of the plant, while, interaction was significant at the vegetative, reproductive and ripening stages. The higher value (19.67) of tiller number was recorded for the treatment IW/CPE=1.5 with hydrogel. LAI was not affected by the application of hydrogel. Only the irrigation treatments had a significant effect on LAI, of which the treatments IW/CPE=2 (2.72) and IW/CPE=1.5 (2.61) recorded the maximum LAI. Higher number of primary branches per panicle was recorded for plants with hydrogel (10.25). The number of panicle per hill was more for the treatment IW/CPE=1.5 without hydrogel (9.20). The number of filled grains produced per panicle is more for plants with hydrogel (86.00). 1000 grain weight observed was higher for the treatment IW/CPE=2 (27.23 g) without hydrogel. Hydrogel did not have any significant effect on the plants physiological parameters like booting, heading, flowering, number of days taken for active tillering and panicle initiation. The more stressed plants took the maximum number of days to booting, heading, flowering and panicle initiation. For the treatment IW/CPE=0.5, there seen no

sign of 50 percent flowering and consequently, it did not attained physiological maturity. Hydrogel and irrigation had a significant impact on grain yield. Even though the higher yield (7014.63 kg ha^{-1}) was observed for the irrigation level IW/CPE=2 without hydrogel, the mean average value of grain yield of plants treated with hydrogel is higher than plants treated without hydrogel (4455.03 kg ha^{-1} and 3951.80 kg ha^{-1} for with and without hydrogel). It can be concluded that hydrogel had significance only when the irrigation level was low (IW/CPE=1.5 and IW/CPE=1). However, at extreme low water level (IW/CPE=0.5) and high water level (IW/CPE=2), hydrogel failed to exhibit any beneficial role.

Under the projected climate scenario using RCP 4.5, it was found for the year 2030 the maximum yield was observed for the treatment IW/CPE=2 (6010 kg ha^{-1}), followed by comparable yield in the treatment IW/CPE=1.5 (5997 kg ha^{-1}). The production was found to be less in the treatment IW/CPE=1 (3504 kg ha^{-1}) and nil to the treatment IW/CPE=0.5. For the year 2050 and 2080, the maximum yield was for the treatment IW/CPE=2.

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