MODELING RICE PRODUCTION IN KOLE LANDS AND ITS VULNERABILITY TO CLIMATE CHANGE

By

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(2013-20-121)

THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Modeling rice production in Kole lands and its vulnerability to climate change"** is a bona fide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me any degree, diploma, fellowship or other similar title, of any other University or Society.

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Certified that this thesis entitled **"Modeling rice production in Kole lands and its vulnerability to climate change"** is a record of research work done independently by **Ms. Surabhi S. R (2013-20-121)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship with any other person.

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EXTERNAL EXAMINER

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Surabhi S. R

Dedicated to my
Family

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SYMBOLS AND ABBREVIATIONS

% - Percentage
AET - Actual Evapotranspiration
AEU - Agro Ecological Unit
AR5 - Assessment Report Five
CERES-Rice model - Crop Estimation through Resource and Environment Synthesis-Rice model
CH_4 - Methane
cm - Centimetres
CO_2 - Carbon dioxide
CRIDA - Central Research Institute for Dry land Agriculture
DSSAT - Decision Support System for Agro - technology Transfer
DT - Total Moisture Detention
FAO - Food and Agriculture Organisation
g - Grams
GCM - General Circulation Models
GDD - Growing Degree Days
GHG - Green House Gases
GIS - Geographic Information System
H_2SO_4 - Sulphuric acid
Ha - Hector
Hrs. - Hours
IBSNAT - International Benchmark Site Network for Agro -

Technology Transfer

IPCC - Inter Governmental Panel on Climate Change

IRRI - International Rice Research Institute

K - Potassium

K_2Cr_2O - Potassium dichromate

Kg - Kilograms

ml - Millilitres

mm - Millimetres

N - Nitrogen

N_2O - Nitrogen dioxide

OC - Organic Carbon

°C - Degree Celsius

P - Phosphorus

PET - Potential Evapotranspiration

ppm - parts per million

R^2 - Coefficient of determination

RCP - Recommended Concentration Pathways

RMSE - Root Mean Square Error

RO - Run Off

UNFCC - United Nations Framework Convention on Climate

WASP 2.0 - Web Agri Stat Package

WD - Water Deficit

WS - Water Surplus

INTRODUCTION

CHAPTER 1

INTRODUCTION

Rice is one of the most important staple food crops of India for more than 2/3rd of its population, and it is the primary source of food for more than three billion people. Rice production plays a significant role in food security under a changing climate. Asia is the major producer of rice in the world with China and India being the major producers - India is the second largest producer and consumer of rice among the countries (IRRI, 2008). The cultivation of rice extends from dried and hot deserts of Egypt to cool mountains of Nepal. However, most of the annual rice production comes from are with tropical climate.

Changes in global atmospheric concentration and observed natural climatic variability are due to climate change, which attributed directly or indirectly by the human activities that observed over a comparable time periods. Climate change is an important issue that will seriously affect agriculture industry by making uncertainties in the availability of natural resources like water and soil. Crop production and food security have serious direct and indirect consequences associated with rising temperature and changes in rainfall patterns. Climate changes have projected effects on agriculture and the net result could be harmful or beneficial and is highly region specific.

Climate change influences rice crop mainly through increased atmospheric CO_2, temperature and change in rainfall. Growth as well as the growth pattern and productivity of rice crops are influenced by the changes in temperature regimes. According to the studies on crop productivity, when the global temperature increases the productivity of rice crop and other tropical crops will decrease (Mohandrass *et al.*, 1995). Rice is sensitive to different abiotic stresses that will be extracted with more climate extremes like high temperatures coinciding with critical developmental stages, Floods causes complete or partial submergence, and salinity, which is often associated with sea-water inundation under changing

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climate scenarios, there may also occur frequent drought spells that are highly deleterious to rainfed systems.

Wetlands are often located between dry terrestrial systems and permanent deep water systems like rivers, lakes, or oceans. So the wetland ecosystem carries a unique feature. The wetlands are the most productive ecosystem among the others and they have key role to exports or imports the organic and inorganic nutrients throughout the ecosystems. Hydrological, chemical, biological and socio-economic balances are maintained by the wetlands neutrally. Wetlands are faces several manmade and other threats which beneficial to sustaining the life on earth.

The Kole wetlands is a multiple use wetland ecosystem covering an area of 13,632 ha spread over Thrissur and Malappuram districts, which is also subjected to seasonal alterations. The Kole lands are a part of the unique Vembanad- wetland ecosystem, which form one of the rice granaries of Kerala. Kole lands supporting the livelihood of a large number of populations by undertaking various types of activities. Rice cultivation, fish farming and other provisioning activities are most important here.

The name Kole in the local language Malayalam refers to a typical type of cultivation practice carried out and resulted in a bumper yield or high returns, in which monsoon rainfall did not damage the crop. Kole lands located below mean sea level of 0.5 to 1 m. The Kole lands situated in between Bharathapuzha River and Chalakudy River in north and south. The Kole lands providing several goods and services they are beneficial for human beings and have been generally classified into on-site and off-site practices.

Rice cultivation is the major cultivation practice in Kole lands. The changes in weather parameters during the growing season is the main reason for getting varied gap between potential yield and actual yield of paddy cultivation in Kole lands. Optimum weather condition in every growing stage is necessary for attaining better yield.

Various models are used in farm decision making, production management, strategic planning, policy decisions and research needs. Among these models, Crop growth models integrate soil, weather and genetic factors to attain yield variability. For crop modelling, Decision Support System for Agro technology Transfer (DSSAT) is most widely used. The model is used to stimulate the growth, development and yield of different crops and predict the future yield under the different scenarios (Hoogenboom *et al.*, 2017).

Considering all these factors, the present study has been taken up with the following objectives,

1. Development of crop weather relationship for the predominant rice varieties and assessment of possible changes in yield due to climate change

2. Study the impact of abiotic factors on rice production using simulation model

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

Climate change is considered as a major critical issue facing the planet earth. It is a hard reality and making huge uncertainties already being experienced by us. Changes in temperature and precipitation will alter the distribution of agro-ecological zones and make consequences in production also. Rice is the most important staple food in Asia. Climate change alters the weather variables which are favourable for the production of rice. Simulation models are very helpful tool in predicting climate change and to estimate the impact of future climate change conditions in the production of rice. The previous studies that are relevant to the objectives of this research are reviewed in this chapter.

2.1 Climate Change

The long wave radiation from the earth surface is trapped by the atmosphere performed as a green house. The trapped rays by the atmosphere can cause changes in temperature seasonally and annually. The most important absorber of reflected radiation is Water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide etc. (Tyndall, 1872).

Climate also varies naturally across all time scales. There have also been periods with little ice and shorter period of wide spread ice. Changes in solar radiation and earth's orbit, continental drift, polar wandering, mountain building, volcanic eruptions etc. causing variations in the climate (Venkata Raman *et al.*, 2011).

The changes in the human activities have a direct effect on all components of the earth and take quick changes in the global climate. By changing the climate, the composition of the atmosphere has changed ominously and the concentrations of atmospheric elements are fluctuating very fast (Kumar, 2015).

The United Nations Framework Convention on Climate Change (UNFCC) reported that increasing the amount of greenhouse gases in the Earth's atmosphere is due to burning of fossil fuels and land use changes. These greenhouse gases like carbon dioxide (CO_2), methane (CH_4) and nitrogen dioxide (N_2O) act as a barrier against the rays from the ground and cause increasing temperature in the earth's atmosphere. The net result of the increasing temperature is climate change. Increases in average global temperature (global warming); changes in cloud cover and precipitation particularly over land; melting of ice caps and glaciers and reduced snow cover; and increases in ocean temperatures and ocean acidity are the foremost indicators of climate change.

The fifth assessment report of the United Nations Intergovernmental Panel on Climate Change (IPCC) reported that the global average temperature is likely to be increased from 0.3 – 4.8°C because future greenhouse gas emission will keep on rising, based on various scenarios (Stocker *et al.*, 2013).

Considering the northern hemisphere, over the last 1400 years, 1983- 2012 was the warmest 30 year period. In addition to that multi-decadal warming, global mean surface temperature exhibits substantial decadal and inter annual variability. Due to natural variability, trends based on short records are very sensitive to the beginning and end dates and do not in general reflect long-term climate trends. As one example, the rate of warming over the past 15 years 1998–2012 is about –0.05 to 0.15°C per decade, which begins with a strong El Nino, is smaller than the rate calculated since 1951 that is1951–2012 is about0.08 to 0.14 °C per decade (IPCC, 2013).

By compiling the past meteorological data and observed that the earth is warming and the study was reported that during the period 1901–2007 the mean annual temperature displays an important tend in warming of 0.51 degree Celsius per 100 years (Kothawale *et al.*, 2010).

Climate change is predicted to cause an increase in the concentration of atmospheric CO_2, average global air temperature of between 1.4°C and 5.8°C and shows some significant changes in rainfall pattern (Houghton *et al.*, 2001). Several studies were done to realize the effects of climate change on various sectors like agriculture, socio-economy, health etc.

The effect of climate change in the 21st century is on the basic necessity of existence of human beings on earth. Four pillars that sustaining the life includes Poverty, population growth, ineffective civil government and environmental crises (Kumar, 2007).

The impacts of climate change will be highly different from one continent to another, and the effect will be different in agriculture, economy, environment and in society. Food insecurity is the serious threat faced by the society. Improvement of technological side is not a precaution but take a global attention against climate change is a better thing (Devereux and Edwards, 2004).

The increasing level of GHGs in the atmosphere has severe impacts on food production, natural ecosystem and human health (Singh, 2012).Climate change affects the world's food production and supply system, and it is expected to positively affect the yield at higher latitudes and negatively affect the yield at lower latitudes (IPCC, 2007).

2.2 Climate Change and Agriculture

Indian agriculture is facing several challenges due to land and water scarcity, labour from non-agricultural sectors and climatic variability. Global warming is the main concern of climate variability and causing seasonal or annual fluctuations in food production (Naresh *et al.*, 2011).

Climate change has both negative as well as positive control on crop growth and yield. The increased temperature would be harmful to the crop growth and yield but the increased concentration of CO_2 is beneficial for the growth and yield. However the rice in the temperature is due to the increased concentration of CO_2 in the atmosphere (Bhattacharya *et al.*, 2013).

Change in climate factors like temperature and precipitation that would affect the agricultural production through physiological changes in crop plants (Chakraborty *et al.*, 1990).

Increases in temperature of 1-3°C along with CO_2 increase and rainfall changes shows a lesser effects on crop yields in mid and high latitude regions. In low-latitude regions cereal crop have negative yield impacts by every increase of temperature of 1-2°C. In tropical regions, suitable cereal production is carried out with the high level of temperature. In addition to that the increases in temperature can lead to greater evaporative demand and water stress on crops in tropical regions (IPCC, 2007).

The lack of rainfall or less rainfall is a lesser problem in many areas than excess rainfall. In high or excess rainfall areas the yields are commonly affected by pests and diseases due to high humidity, low radiation and light intensity and excess water use (Lenka, 2006).

During the growing season, weather is the important external parameter to determine the growth and development of a crop. Even with slight variation from the normal weather conditions can seriously affect the food production. The concentration of carbon dioxide has demanded effect on yield. The carbon dioxide (CO_2) concentration was in the steady state at 280 ppm till the preindustrial period (1850). It is rising since then at the rate of 1.5 to 1.8 ppm per year. The concentration of CO_2 is likely to be doubled by the end of 21st century (Keeling *et al.*, 1995).

Agriculture sector have higher impact of climate change compared to any other sector in the country. The study revealed that occurrence of drought has significant impact on the production of rain fed crops (Latha *et al.*, 2012).

In Kerala, there is a possible increase in rice yields by the middle of the next century under the projected climate change scenario. And also revealed that there is a reduction in crop duration because of increase in temperature and associated with the accumulation of greenhouse gases in the atmosphere (Saseendran *et al.,* 2000).

In India, wheat is grown in 24.2 m ha area and about 50 – 70 per cent wheat is rotated with rice – wheat pattern. About 25 per cent of the rice area is grown in rotation with wheat and it is the major sponsor of the country's food security with yield potential of 8.12 t/ha/year (singh and singh, 1996).

However, these studies have specified that the direct effect of climate changes would be small on kharif crops. In Kharif cropping season, the incidence of extreme weather events like effect of monsoon, drought and floods and disease and pests attack can affect the crop. Production of 'rabi' crop is rather more risky due to projection of larger increase in temperature and higher uncertainties in rainfall pattern (Joshi *et al.*, 2003).

After green revolution the yield of wheat after rice in the area has declined by about 20 – 30 per cent. The lack of winter rains and increased temperature cause reduction in yields by 10- 15 per cent in timely and late sown wheat crop. Due to early withdrawal of monsoon and decrease in air temperature in the month of October induces the reduction in yields by10 – 20 per cent in early and late planted rice (Bisht *et al.*, 2012).

In the eastern slopes and southern plains, growing season rainfall and consecutive dry days were major factors causing yield variation. But in the northern plains, pre-growing season rainfall was included as one of the most important factors. Overall, wheat yield variability in the study area was mainly caused by frequent water shortage, while extreme wetness within growing season had a small effect as it occurred less frequently (Feng *et al.*, 2018).

Many regions throughout the world are projected to experience climate change induced reductions in crop yields due to pests and diseases, water scarcity, and soil degradation. Although some high latitude regions may become more climatically workable for crops (Rosenzweig *et al.*, 2014).

Impact of climate change on agriculture will be one of the major deciding factors influencing the future food security on earth. Agriculture and climate change are inter linked to each other. In tropics, majority of the population is based on agriculture and these people's main livelihood is agriculture activities. Rice, wheat, maize, sorghum, soybean and barley are the six major crops in the world grown in 40 per cent cropped area, and contribute to 55 per cent of non-meat calories and over 70 per cent of animal feed, any effect on these crops would adversely affect the food security (FAO, 2006).

2.3 Rice Cultivation in Kole Lands

The Kole wetlands, covering an area of about13, 632 ha, are a unique rice production ecosystem appeared over Thrissur and Malappuram districts of Kerala. The Vembanad-Kole wetland was declared as one of the Ramsar sites of India. The term 'Kole' means to a particular type of paddy cultivation during the late Mundakan cropping season. They are known for the bumper yields, but now days it is one of the most endangered wetlands in the State. Geologically, Kole lands situated below mean sea level and the area was rich in alluvium deposits from rivers surrounded by the Kole area.

Kole Wetlands of Kerala

Wet lands of Kerala include estuaries, deltas, mangroves, coastal lagoons, freshwater lakes, swamp forests, rivers, streams, ponds and non-managed systems such as rice fields and reservoirs. Kole wetland is one of the largest and most important wetlands of Kerala, located between 10°20' and 10°40'N latitude and between 75°58' to 76°11'E longitude. Kole wetland is of substantial economic and cultural value and is regarded as the 'rice bowl' of central Kerala (Nikhil Raj and Azeez, 2009).

Karuvannur and Kechery rivers irrigate the Kole lands and finally discharge into the Arabian Sea. The Kole land is a flat bowl shaped low-lying area, filled by alluvium deposits from the eastern and western margins. The Kole land found parallel to the sea and are low-lying areas located below the mean sea level. The water from the rivers brings nutrient rich alluvium, which gets credited in the Kole lands. Kole lands are separated into two divisions namely the Thrissur Kole and the Ponnani Kole. The Karuvannur River splits the Thrissur Kole land into North and South Kole. Some portion of Kole area exhibits a lacustrine environment and contains black carbonaceous clay with many plant parts and in some places shrunken tree trunks. Also, the subsurface study of Kole land displays fine sandy deposits. Mining is the main reason for sand deposits in Kole lands (Johnkutty and Venugopal, 1993).

Kole lands soils are rich in nutrients among other types of soils in Kerala. The nutrient cycling during the monsoon season makes the soil as more fertile. Based on the textural analysis, Kole land soil has been classified into clay, sandy loam, sandy clay loam and clay loam (Sheela, 1975).

The fields are geographically distributed in Mukundapuram, Chavakkad and Thrissur taluks of Thrissur district and Ponnani Taluk of Malappuram district. The area from Velukkara in the south on the Chalakudy river bank in Mukundapuram Taluk to Mullassery of Chavakkad Taluk and Tholur-Kaiparama areas of Thrissur taluk is selected as 'Thrissur Kole' and the contiguous area from Chavakkad and Choondal to Thavannur, covering Chavakkad and Thalapally taluks of Thrissur district and Ponnani Taluk of Malappuram district form the 'Ponnani Kole'. The Kole lands remains submerged under flood water for about six months in a year and this seasonal alteration gives it both terrestrial and water related properties which determine the ecosystem structure and process which in turn give rise to various provisioning services (Srinivasan, 2011).

Virippu is usually cultivated in higher rice fields around the Kole land. Here, sowing is carried out with the onset of monsoon. In Virippu season, the varieties which can withstand flood water is normally cultivated. Mundakan is cultivated on medium elevation fields around the Kole land where flood water recedes by August. Kadumkrishi in Kole land coincides with Mundakan across normal lands, but usually it starts by September. When flood waters in the Kole field start subsiding by the end of South west monsoon season. Dewatering is carried out using petti and Para which is an indigenous axial flow pumping device developed for dewatering the Kole field.

In Kadumkrishi, water management is very important as it requires continuous pumping out of water and towards the end of the crop season and there is a need for supplying irrigation water as well. Punja is a crop raised across the entire Kole area. Water requirements for Punja in the early stages of crop are met with summer flow in the rivers and storage canals and in later stages, water from dams is used for irrigation. Nearly ninety five per cent of the farmers are cultivating rice in a single crop season. Farmers in the Kole are arranged under an institutional arrangement called Padasekharams which is a cluster of farms (Srinivasan, 2011).

A number of local varieties of rice used to be cultivated on the Kole fields. Over the last few decades, Jyothi, Uma and Jaya varieties of rice have come to be cultivated. This includes subsidies for dewatering, purchase of seeds, fertilisers, and pesticides. The Kole rice farms are either marginal or small in nature and pose several challenges in cultivation (Srinivasan, 2011).

The major part of Kole wetland is paddy field. It forms the 'rice granary' of Thrissur and Malappuram districts. The whole Kole paddy fields were reclaimed from the lake by putting up temporary earthen bunds and cultivation of rice was done during summer period from December to May. Due to profitability factor farmers stick to single crop cultivation in the wetland though two dams were constructed to support irrigation facilities in the summer months.

Fishing is one of the main livelihood options available in Kole wetland particularly during monsoon months. Many varieties of indigenous fish species are available in Kole wetland. Inland fishing community namely "Dheevara" is engaged in this activity together with some local community members. Recently, aquaculture was also started in the wetlands particularly during monsoon months when the paddy fields were flooded with water. Kole wetland is endowed with the natural beauty with a long stretch of backwater zone which has opening to the Arabian Sea. Its paddy fields also attract tourists with its dense greenery and water filled canals interspersed through the paddy fields. There are many areas in the wetland with high potential for development as recreational sites. The canals constructed through the paddy fields can be modified to enable inland water transportation (Binilkumar *et al.*, 2010).

Kole wetlands in Kerala, is an area where nature is preserved, spared of usual urbanisation, its flora compliments the environment, and holds a diversity of unexploited endemic plants. Aquatic plants in wetlands are unique and consist of very important resources of food and medicine for the rural population. Aquatic plants are also widely used in the ornamental aquatic plant trade, including both aquarium plant and the water garden. The abundance of the plants in the Kole wetlands indicates the diversity among fauna and flora in that area (Jyothy and Sureshkumar, 2016).

2.4 Rice Crop and Cultivation

Rice (*Oryza sativa*) is a member of the grass family. It has been cultivated in china and then, it was introduced into India. Now, rice cultivation has been carried into all regions with favourable conditions. After wheat, rice is the second most important crop of the world. At world level the rice cultivation area stretches from 39°S latitude to 50°N latitude. In India, rice cultivation area extends from 8 to 34°S latitude that is extending almost throughout the country. It is estimated that the rice demand in 2025 will be 140 million tons in India. The occurrence rice as a crop in freely drained uplands is restricted to zones with sufficient water supply from rain (Chandrasekharan *et al.*, 2008).

Humid, tropical and subtropical regions are more favourable for the rice production. The indica varieties of rice are grown mainly in the tropical countries and these are more photosensitive and making the growing period as more variable (Roy, 1985).

Rice is grown in all the tropical countries of the world. It can grow under submerged water because rice plant is able to transport oxygen to the submerged roots from the leaves. Thus it can live in an aquatic environment. There are two general types of rice – the low land and the upland rice. Irrigation water, precipitation, temperature and soil are the important factors that affect the production of low land rice. The production of rice is also depend upon the availability of water as depth of 6 inches for a period of less than 75 days (Wolfe and Kipps, 2004).

Rice cultivation is recommended for recuperation of highly sodic soils, but because of their poor absorptivity and relatively low motion of exchangeable sodium, the alkaline soils does not progress under low land rice culture (De Datta, 1933).

Rice growing countries shows an average yield range from less than 1 to 6 t/ha. There are a number of biological, environmental and socioeconomic explanations for the large variances in rice yield. Low yield are linked with the upland rice where as high yield is associated with lowland rice. Temperature, solar radiation and rainfall are affecting the crop yield by directly affecting the plant physiological processes involved in grain production (Yoshida, 1981).

Rice has been grown-up on wetlands where soils are submerged under water of 5- 10 cm depth of water during the growing season. Rice demand has grown at an annual rate of approximately 3 per cent for the last 20 year, and is expected to continue at that rate until the end of the century. In some environments, production has been increased by growing two or three rice crops per year or an upland crop before or after one or two rice crops. Most of rice cultivation in Asia show terraced fields with standing water and transplanted rice.

The rice lands divided into pluvial, phreatic, and fluxial. Most rice is grown on phreatic lands in monsoon areas where the water table is close to or above the soil surface throughout wet season, and where bunding retains surface water. There are 85 million ha of phreatic rice land, about 35 million ha of fluxial land and about 20 million ha of pluvial land used for rice-based cropping systems (IRRI, 1985).

Maintaining the field with accurate levelled surface and optimal ponding water depth is necessary to get higher yields. Maximum crop production occurred around 9 cm ponding water depth in all the water regimes and the excess ponding can inversely affect the production. The rice plant has capacity to persist under surface water depth than deep ponding water depths (Anbumozhi *et al.*, 1998).

2.5 Climate Change and Rice Production

Threat of climate change approaching large on crop productivity, the most exposed regions of the world is the tropics. In semi-arid regions differences in temperatures and rainfall could also ominously affect agricultural production with large inferences on food security. By increase in temperatures is likely to affect crop production by 10–40 % in India by 2080–2100 and cause a global impact on food production (IPCC, 2007).

The rise in atmospheric temperature causes harmful effects on growth, development and yield of the rice crop by disturbing its phenology, physiology, and yield components (Sheehy *et al.,* 2005). Any further increase in temperature or high temperature incidents during the sensitive stages of the crop can adversely affect the yield (Krishnan *et al.*, 2011).

Rice yield is decreased by about 5-10 per cent for the period of 1996-2002 periods due to changes in climatic conditions. The monsoon rainfall is not only the weather variable to affect the kharif rice in India, but also nocturnal temperature at the end of growing season has a larger influence on rice yield (Surajit and Datta, 1933). During the period of 1971-2009, there was a drop in rice yield by 411-859 Kg/ha due to increasing temperature (Rao *et al.,* 2014). Drought is one of the major problems to reduce rice yield and increases the production risk (Wang *et al.*, 2017).

Temperature systems seriously influence not only the growth duration, but also the growth pattern and the productivity of rice crops. There is a decrease of 15 per cent yield of dry season rice crops in Philippines for increasing every 1 °C temperature during the growing stages (Peng *et al.*, 2004).

In Kerala, by the middle of the next century an increase in rice yields (under rainfed conditions) is possible under the projected climate change scenario. Also, decline in crop duration was detected at all the sites in the state due to increase in temperature associated with the accumulation of greenhouse gases in the atmosphere (Saseendran *et al.*, 2000).

Studies also revealed that increase in temperature alone would cause decrease in crop yield by affecting the necessary of co_2 in photosynthesis. Insufficient amount of co_2 in the atmosphere led to decrease in the rate of photosynthesis (Zhiqing *et al.*, 1994).

Increased CO_2 concentrations result in higher rice and wheat yields and suppressed evapotranspiration rates which are marginal in case of rice. CO_2 increase would contribute positively to rice production in NW India. The maximum yield for both rice and wheat are obtained at surface temperatures I°C below the pre- sent day climate at current CO_2 levels. The yields decline more sharply for a rise in temperature. A 3°C rise in air temperature almost cancels out the positive effect of elevated CO_2 on rice yields (Lal *et al.*, 1998).

The decrease in diurnal temperature range is harmful for rice, due to the asymmetric effects of maximum and minimum temperatures in rice production areas. The study simulates the yield with optimal management. The spatial variations of the climate effects on yield suggest in northern rice production areas with low growing-season temperatures, adaptations such as adopting crop varieties with more heat requirements should be recommended, whereas in south parts of China, where the rice growing-season temperature is high, the yield damage caused by warmer climate can be reduced through the alteration of the sowing date, and the development of crop varieties with heat-resistance and increased photosynthesis ratio (Jie *et al.,* 2014).

Projected 18 per cent decline in rice by 2020s will be caused because of alterations in temperature, rainfall cycle, soil quality, pests invasions and disease infestations attributable to negative impacts of climate change (Agarwal, 2008).

The higher night temperature reduced yield, with larger contribution than other climatic parameters (Peng *et al*., 2004).

However, regressions between national rice yield and weather specified rising of maximum temperature was more harmful to rice than minimum temperature in most countries (Lobell and Filed, 2007).

Reduction in grain yield is due to in ease of temperature without any increase in CO_2 in the atmosphere. In general, increase in temperature is sternly affecting the southern India compared to other parts. The control rice crop in the eastern region (5.7 t/ ha) less affected than the southern region (7.3 t/ ha) (Aggarwal and Mall, 2002).

There is an increase of one per cent of world rice production annually to meet the growing demand for the food that will result from the population (Rosegrant *et al*., 1995).

Weather parameters have an important role in achieving better yield from a crop throughout the year. Among all the parameters, temperature has the highest influence compared to others. Increases in maximum temperature during the ripening phase contribute to an increase in rice yield up to a critical threshold of 29.9°C. The rice yield becomes reduced, when the maximum temperature goes away from the required level. Apart from that the rice yield was negatively affected by every increase of day time temperature. There is a drop in rice production by 4.2 per cent compared to present level by 2100 in Nepal (Karan, 2014).

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High temperature is a stress during the vegetative and reproductive phases in rice and led to more decline in biomass and grain yield, as compared to the ripening phase. High temperature stress affect the panicle initiation and grain production (Sunil, 2000).

2.6 Crop Simulation Models

The crop simulation model DSSAT (Decision Support System for Agro technology Transfer) was developed by International Benchmark Site Network for Agro technology Transfer (IBSNAT) In 1989 (Tsuji *et al.*, 1998).

The DSSAT crop simulation model calculates growth, development, yield, water requirement and fertilizer application of a growing crop on a uniform area of land. Model requires information on soil, crop and weather parameters that are essential for crop growth. Model efficiency is evaluated by comparing the model output with the experimental data (Jones *et al.,* 2003).

The DSSAT is an advanced physiologically-based crop growth simulation model and has been broadly applied to identify the relationship among the crops with its environment. The model evaluates the yield of irrigated and non-irrigated rice, determine duration of growth stages, dry matter production, root system dynamics, effect of soil water and soil nitrogen contents on photosynthesis, carbon balance and water balance (Kumar *et al.*, 2010).

It is a non-linear dynamic model that stimulates the output with observed data and gives the simulation on the stability of the correlation between the input parameters or crop management factors and the output parameters (Corbeels *et al.*, 2016).

Crop models are the simplified form of complex relationship between crop performance and crop growth factors, it is an efficient tool to assess the impact of climate change, environment, crop management, breeding practices and genetics on crop growth and yield (Craufurd *et al.*, 2013).

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

The research was carried out during the period of 2017-2018 with the objective to study “Modelling rice production in Kole lands and its vulnerability to climate change”. The details of the study area, climate and soil conditions of the experimental site and methodology of estimation of various parameters and model procedure are described in this chapter. The materials used and methods followed are described below:

3.1 Study area

Kole wetland is one of the major and most important wetlands of Kerala, covering an area of 13,632 ha and blow-out over Thrissur and Malappuram district, extending from the northern bank of Chalakkudy river in the south to the southern bank of Bharathapuzha river in the north located between 10°20’ and 10°40’N latitude and between 75°58’ to 76°11’E longitude (Fig. 1).

3.2 Climate

The climate is humid tropical with both South-West and North-East monsoons. The area receives around 2600 mm rainfall, within that about 60-70 per cent of which is contributed by South-West monsoon and the rest is received during the North-East monsoon.

3.3 Soil

The soil of Kole area is mainly the product of weathering of river alluvial deposits and colluviums. The deposits occupy the flood plain and have mostly clayey texture.

3.4 Varieties

The most widely cultivated variety of Kole lands are Jyothi, Uma and Rudra, among these most popular variety Jyothi was selected for this study.

Kole lands (AEU 6)

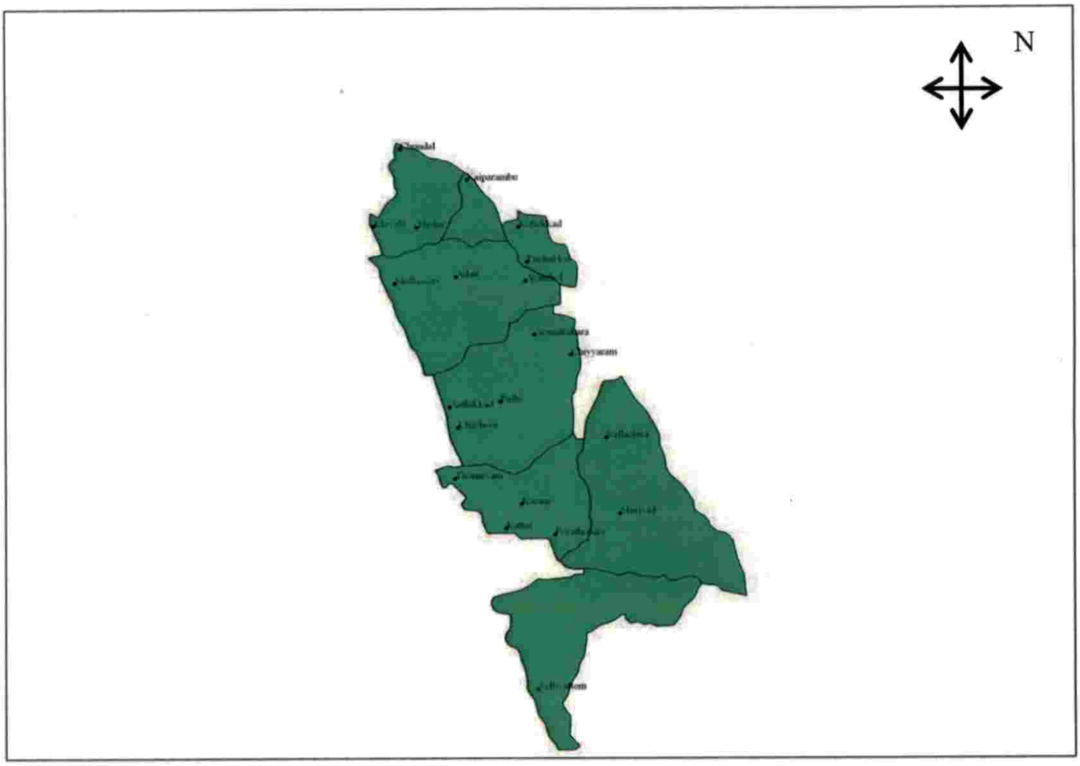

Fig 1. Map of Kole lands (AEU 6)

3.5 Soil sample collection

The Kole lands have eight administrative blocks of which 5 blocks were selected at random. From each of the selected blocks three locations were randomly selected for collecting soil samples. Composite soil samples were collected using soil cores in from all the 15 plots (5 blocks x 3 sites per block). Surface soil samples (0 - 20 cm) were taken in each of the selected sites and used for the study. For determining the bulk density, soil samples were collected by using PVC pipe of 20 cm length and 5 cm diameter. Geographical coordinates of the sampling sites were marked during the sample collection. Soil samples were packed in plastic bags, properly labelled and brought to the laboratory. The samples that were collected for determining bulk density were directly placed into the oven after determining its fresh weight. Samples for nutrient analysis were dried and sieved 2 mm sieve. A separate set of subsamples were sieved through 0.5 mm sieve for organic carbon estimation.

Table 1. Sample site description

Sl.no	Site Name	Latitude	Longitude
1	Mullassery 1	10°31’51” N	76°57’52” E
2	Mullassery 2	10°31’52” N	76°55’46” E
3	Mullassery 3	10°32’53” N	76°58’42” E
4	Puzhakkal 1	10°32’45” N	76°10’58” E
5	Puzhakkal 2	10°31’32” N	76°11’16” E
6	Puzhakkal 3	10°33’38” N	76°10’55” E
7	Anthikkad1	10°27’28” N	76°11’47” E
8	Anthikkad 2	10°26’56” N	76°11’22” E
9	Anthikkad 3	10°28’41” N	76°10’48” E
10	Irinjalakkuda 1	10°19’12” N	76°14’20” E
11	Irinjalakkuda 2	10°26’56” N	76°13’51” E
12	Irinjalakkuda 3	10°19’27” N	76°12’46” E
13	Cherpu 1	10°18’27”N	76°12’28”E
14	Cherpu 2	10°19’36”N	76°10’21”E
15	Cherpu 3	10°18’32”N	76°10’12”E

3.6 Analysis of basic soil properties

Analytical methods for estimation of soil properties like soil pH, bulk density, texture, soil organic carbon and soil available nitrogen, phosphorous and potassium are described below:

3.6.1 pH

The pH of the soil was determined in 1:2.5 soil water suspension. 5g sample of soil was transferred into a 50 ml beaker through 2 mm sieve. 25 ml of distilled water was added, stirred well for about 5 minutes and kept for half an hour. Stirred well again and took the reading using pH meter (Jackson, 1958).

3.6.2 Soil texture

The texture of the soil was determined by using the Bouycous hydrometer method.

$$\text{Clay (\%)} = \frac{\text{Corrector reading at 2 hrs}}{\text{Weight of the soil}} \times 100$$

$$\text{Slit (\%)} = \frac{\text{Reading at 4min} - \text{Corrector reading at 2hrs}}{\text{Weight of the soil}} \times 100$$

$$\text{Sand (\%)} = 100 - (\%\ \text{slit} + \%\ \text{clay})$$

3.6.3 Bulk density

The bulk density of the soil was determined by using international core method. The core was taken out without pressing the cylinder too hard on the soil so that the natural bulk density of the soil may not get disturbed. The collected soil was oven dried and weight was determined. The volume of the soil was calculated by measuring the volume of the cylinder ($\pi r^2 h$). The bulk density was calculated by dividing the oven dry weight of soil samples (g) by volume of the soil.

3.6.4 Soil organic carbon

Organic fraction of the soil was oxidised by treatment with a mixture of potassium dichromate ($K_2Cr_2O_7$) and sulphuric acid (H_2SO_4) and titrating the solution with 0.5N ferrous ammonium sulphate in the presence of phenolphthalein indicator Make a blank determination in the same manner, but without soil for the calculation (Walkely and Black , 1947).

$$\text{Organic carbon (\%)} = \frac{(\text{Blank value} - \text{Titre value}) \times 0.5 \times 0.003 \times 100}{\text{Weight of soil}}$$

3.6.5 Soil nutrient analysis

3.6.5.1 Available nitrogen

Available nitrogen in the soil was determined by alkaline permanganate method (Subbiah and Asija, 1956).

3.6.5.2 Available phosphorus

Available phosphorus was extracted using Bray-1 extractant (Bray and Kurtz, 1945) and the P content was colorimetrically assayed (Chloromolybdic acid blue colour method). The reducing agent used was ascorbic acid (Jackson, 1958).

Phosphorus (kg/ha) = Reading× (25/5) × (25/2.5) × 2.24

3.6.5.3 Available potassium

Available potassium was determined by flame photometry using 1N neutral normal ammonium acetate solution as the extractant (Jackson, 1973).

Potassium (kg/ha) = Reading × (25/5) × 2.24

3.7 Collection of data

3.7.1 Meteorological data

Daily weather data for the period 1998-2016 was collected from the India Meteorological Department, Thiruvananthapurm Table 1 shows the name, latitude and longitude of the weather stations considered for weather data collections

Table 2. Weather stations taken for the study

Sl.No	District	Station / Location	Latitude	Longitude
1	Thrissur	Chalakkudy	10°18’N	76°20’E
2		Enamackel	10°50’N	76°06’E
3		Irinjalakkuda	10°22’N	76°14’E
4		Kodungallur	10°03’N	76°22’E
5		Kunnamkulam	10°38’N	76°00’E
6		Thrissur	10°31’N	76°13’E
7		Vadakkancherry	10°35’N	76°10’E
8		Vellanikkara	10°31’N	76°13’E

3.7.2 Crop data

The block wise information on area, production and productivity of rice was collected fiom Agricultural Statistics, Department of Economics and Statistics, Kerala.

3.8 Methodology

The daily weather data were analysed on weekly, monthly, seasonal and annual basis. Mean values for the above periods were computed for maximum temperature and minimum temperature, while totals were computed for rainfall for all the years.

3.8.1 Rainfall

Mean weekly, monthly, seasonal and annual rainfall were worked from the totals obtained as above. Coefficient of variation for the above periods were also woked out. Spatial variation in mean rainfall and coefficient of variation during the different seasons over the entire state has been presented.

In rainfed agriculture, it is important to know the amount of rainfall that can be expected at least in 3 out of 4 years rather than simple mean rainfall. This is known as the dependable rainfall i.e., rainfall received at 75 per cent probability level. A simple ranking method as described by Doorenbos and Pruitt (1977) was used for the computation of dependable rainfall for the stations. The method is as follows:

The monthly rainfall records were arranged in decreasing order and each record was assigned a ranking number 'm'. Every ranking number has a 1 Probability level Fa (m) which is expressed as, = 100 m.

$$Fa\,(m) = {}^{100\,m}/_{n\,+\,1}$$

Where, n = Number of records. The rank number which has a probability level of 75 per cent and 90 per cent was calculated. The rainfall record corresponding to this rank number gave the rainfall having the corresponding probability. Weekly dependable rainfall at 75 per cent and 90 per cent were calculated using the above mentioned ranking method. As month is too long a period for agricultural operational planning, analysis on weekly rainfall was carried out. Both the initial and conditional probabilities of receiving 30 mm or more rainfall per week were worked out, following the methodology given by Virmani *et al.* (1978) which is as follows:

If the rainfall in a particular week is more than the specified amount, it is called a Wet week (W) otherwise designated as a Dry week (D).

$$\mathrm{P(Wj)} = \frac{\mathrm{N(Wj)}}{\mathrm{N}}$$

Where

P (Wj) is the probability of receiving a certain amount of rainfall during the j^{th} week

N (Wj) is the Number of occurrence of W during the j^{th} week

N is Number of observation

Hence, P (Dj) = 1- P (Wj)

Similarly probability of next week being wet, given the current week is wet P (w/w) was also worked out. Initial and conditional probabilities of receiving 30mm or more rainfall was worked out for all the stations.

3.8.2. Potential Evapotranspiration (PET)

The potential evapotranspiration has been computed on a weekly basis for the station where data on temperature, humidity, wind and sunshine duration was available. The method suggested by Doorenbos and Pruitt (1977) is widely accepted for such estimations and the method is as follows:

$$ET_o = c\ [W.Rn + (1-w).\ flu).\ (ea-ed)]$$

Where

ETo = Reference crop evapotranspiration in mm/day

W = Temperature - related weighting factor

Rn = Net radiation in equivalent evaporation in mm/day

f(u) = Wind related function

(ea-ed) = Difference between the saturation vapour pressure at mean air temperature and the mean actual vapour pressure of the air both in millibar.

C = adjustment factor to compensate for the effect of day and night weather conditions.

PET for all the rain gauge stations has been interpolated based on Agro Ecological Units.

3.8.3. Water Balance Studies

Water balances were computed following the book-keeping method of Thornthwaite and Mather (1955). The field capacity of the soil to hold moisture was determined by taking the type of soil and vegetation into consideration. Weekly water balances for all the stations have been computed by taking the dependable rainfall and the interpolated PET. The spatial variation of actual evapotranspiration, water surplus and water deficit is as follows.

Thornthwaite's Method of Water-Balance Computation

To facilitate the use of this method step by step description to estimate the various components and book – keeping procedures follows:

The requirements are the data of mean monthly temperature, the latitude of the station, the monthly precipitation and tables and charts prepared by the author (Thornthwaite and Mather, 1957).

Step 1. Unadjusted potential evapotranspiration (Unadj PE) to be ascertained from the monogram and the tables given by Thornthwaite (Thornthwaite and Mather, 1957).

Step 2. Adjusted potential evapotranspiration (PE). Correct the unadjusted PE values according to the latitude of the stations and to the month of the year (Thornthwaite and Mather, 1957).

Step 3. P is the rainfall and can be snowfall.

Step 4. $P - PE$.

This is the difference between precipitation and the adjusted potential evapotranspiration.

If P is less than PE, the value is negative.

If P is more than PE the value is positive.

Step 5. Accumulated Potential Water Loss (Acc Pot WL).

In wet climate

Where $P > PE$ (annual values)

Start with 0 in the month just before the one where negative value of $P - PE$ has started.

In dry climate where $P < PE$ (annual values)

Find the potential value of water deficiency with which to start accumulating negative value of PE.

The starting value can be found as follows:

a) Sum up all the negative $P - PE$ values
b) Sum up all the positive $P - PE$ values
c) Locate the value arrived in '*a*' (Thornthwaite and Mather, 1957) and locate corresponding value of actual retention
d) Locate the value arrived in step c on the vertical scale on the left side of the figure 1.2 (Thornthwaite and Mather, 1957).
e) Follow horizontally across on this line until it intersects the sloping line whose value equals the sum of the positive P – PE (step b). Read the value of the potential deficiency with which start accumulation.

Step 6. Storage (*St*)

For the negative values of $P - PE$, locate the storage figures using table 1.3 (Thornthwaite and Mather, 1957)

For the positive $P - PE$ values proceed as

a) Locate the last negative value in the column $P - PE$
b) Note the storage value of '*a*'
c) Add to the value of (b) the first positive integer (That is the positive value next to the negative value).
d) Complete the procedure for the rest of the months.

***Step** 7*. Change in soil moisture (ΔSt)

It is the difference in the storage value of two consecutive months. No difference is recorded when the values are above 300.

Step 8. Actual Evapotranspiration (*AE*)

When $P > PE$

Then $PE = AE$

When $P < PE$

then $AE = P + St$* (Soil moisture storage)

*The negative sign of S is not considered.

It means that AE is the sum of P and St without considering the sign of St.

Step 9. Moisture deficit (D)

It is the difference between $PE - AE$ or $D = PE - AE$

Step 10. Moisture surplus (S)

1) Surplus exist when storage (St) is 300 and more and $P - PE$ is positive.
2) When the storage values are moving up towards 300, the first surplus will be $(P - PE) - St$.

Step 11. Water Run-off (RO)

RO is the one half of the surplus (S), the rest half goes to the next month. This should be added to the surplus of that month. Again, one-half of that month will be the run-off Add the remaining one-half to the next month and the procedure continues.

Step 12. Snow-Melt Run Off ($SMRO$)

It is computed in areas of snow fall.

Step 13. Total Run-Off (*Tot. RO*)

It is the sum of the water surplus run-off and the snow-melt run-off.

Step 14. Total Moisture Detention (DT)

It is the sum of storage St and total run-off.

3.9. Software

Weather cock v1.5 developed by Central Research Institute for Dry land Agriculture (CRIDA) has been used to convert the daily weather data into standard week, month and seasonal formats. It is also used to compute initial and conditional probabilities of rainfall, PET and Thornthwaite water balances.

QGIS, which is a cross-platform free and open-source desktop geographic information system (GIS) application that provides data viewing, editing, and analysis was used for spatial representation and to create maps.

3.10. Climate change scenarios

Impacts of climate change will depend not only on the response of the Earth system but also on how humankind responds. These responses are uncertain, so future scenarios are used to explore the consequences of different options. The scenarios provide a range of options for the world's governments and other institutions for decision making. Policy decisions based on risk and values will help determine the pathway to be followed.

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) has introduced a new way of developing scenarios. These scenarios span the range of plausible radioactive forcing scenarios and are called representative concentration pathways (RCPs).

RCPs are concentration pathways used in the IPCC Assessment Report 5 (AR5). They are prescribed pathways for greenhouse gas and aerosol concentrations, together with land use change, that are consistent with a set of broad climate outcomes used by the climate modeling community. The pathways are characterized by the radiative forcing produced by the end of the 21st century. Radiative forcing is the extra heat the lower atmosphere will retain as a result of additional greenhouse gases, measured in Watts per square meter. The RCPs considered in the present study and their descriptions are given in Table 3.

Table 3. Description of Representative Concentration Pathway (RCP) scenarios

RCP	Description
RCP2.6	Its radiative forcing level first reaches a value around 3.1 Wm^{-2} mid-century, returning to 2.6 Wm^{-2} by 2100. Under this scenario greenhouse gas (GHG) emissions and emissions of air pollutants are reduced substantially over time.
RCP4.5	It is a stabilization scenario where total radiative forcing is stabilized before 2100 by employing a range of technologies and strategies for reducing GHG emissions.
RCP6.0	It is a stabilization scenario where total radiative forcing is stabilized after 2100 without overshoot by employing a range of technologies and strategies for reducing GHG emissions.
RCP8.5	It is characterized by increasing GHG emissions over time representative of scenarios in the literature leading to high GHG concentration levels.

Climate change data projected by GCM's on daily basis was used for the present study. Daily data of following variables were considered for modeling purposes.

1. Rainfall
2. Maximum Temperature
3. Minimum Temperature
4. Solar radiation

The regional climate scenarios including radiation, Maximum temperature (T_{max}), Minimum temperature (T_{min}) and precipitation as inputs of the Thornthwaite water balance was used to simulate the impacts of climate change on water balance in Kole Wetlands.

3.11 Crop weather model

CERES-Rice has been used in this study to model the effect of weather parameters on crop growth and yield. The CERES models have been extensively

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used for assessment of the impact of climatic change on agricultural crop production. CERES-Rice model is physiologically oriented and simulates rice response to climate variables.

The simulation of rice growth was performed with the CERES-Rice. Model developed by the International Benchmark Sites Network for Agro technology Transfer (IBSNAT). The IBSNAT models were employed for the simulation of crop response to climate change because they have been already validated for a wide range of climates all over the world and are independent of location or soil type encountered.

The CERES-Rice (Crop Estimation through Resource and Environment Synthesis) model was adopted as the basis to simulate the effects of cultivar, planting density, weather, soil water and nitrogen on crop growth, development and yield. CERES- Rice model shared a common input and output data format, which had been developed and embodied in a software package called Decision Support System for Agro-technology Transfer (DSSAT) (Tsuji *et al.*, 1994).

Validation of CERES-Rice requires to develop genetic co-efficient based on the varietal characters of the variety and the details are as follows (Table 4):

Table 4. Genetic Coefficients for the CERES Rice model

P1	Time period (expressed as growing degree days [GDD] in °C above a base temperature of 9°C) from seedling emergence to end of juvenile phase during which the rice plant is not responsive to changes in photoperiod. This period is also referred to as the basic vegetative phase of the plant.
P2R	Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in °C) for each hour increase in photoperiod above P2O.
P2O	Critical photoperiod or longest day length (in hours) at which the development occurs at maximum rate. At values higher than P2O the development rate is slowed (depending on P2R), there is delay due to longer day length.
P5	Time period in GDD in °C from beginning of grain-filling (3-4 days after flowering) to physiological maturity with base temperature of 9.0°C

G1	Potential spikelet number coefficient as estimated from number of spikelet per g of main culm dry weight (less leaf blades and sheaths plus spikes at anthesis. A typical value is 55.
G2	Single dry grain weight (g) under ideal growing conditions. i.e., non-limiting light, water, nutrients, and absence of pests and diseases.
G3	Tillering coefficient (scalar value) relative to IR64 cultivars under ideal conditions. A higher tillering cultivar would have coefficient greater than 1.
G4	Temperature tolerance coefficient. Usually 1.0 for cultivars grown in normal environment. G4 for japonica type rice grown in warmer environments would be ≥ 1.0. Tropical rice grown in cooler environments or season will have G4 < 1.0

The minimum data set required for the operation and calibration of the CERES -Rice is (Hoogenboom, *et al.,* 2017) given below,

3.11.1. Data required

3.11.1.1 Level 1 Data

Weather Data Required (Daily)

1. Minimum and maximum temperature
2. Rainfall
3. Total solar radiation or sunshine hours
4. Dew point temperature or relative humidity

Soil Data

1. General site information
2. Soil surface information
3. Soil profile data, for each soil horizon in which roots are likely to grow

Initial Conditions

1. Previous field history
2. Initial soil profiles conditions
3. Surface residues at the start of simulation or at planting

Management Data

1. Planting

2. Input information

3.11.1.2 Level 2 Data

Crop and Soil Response Measurements

1. Treatments
2. Yield and yield components

3.11.1.3 Level 3 Data

1. Growth analysis measurements
2. Soil water content versus depth
3. Soil fertility versus depth

3.11.2 Calibration of CERES-Rice Model

The genetic coefficients that influence the occurrence of development stages in the model were derived iteratively, by manipulating the relevant coefficients to achieve the best possible match between the simulated and observed events as well as the model was calibrated for yield parameter.

3.11.3 Validation of CERES-Rice Model

Validation is the comparison of the results of model simulations with observations that were not used for calibration. The experimental data collected were used for independent model validation. Statistical index used for model validation is

RMSE (Root Mean Square Error) = $\sqrt{\frac{\sum_{i=1}^{n}\left(P_i - O_i\right)^2}{n}}$

Where Pi and Oi refer to the predicted and observed value for the studied variables respectively and n is the mean of the observed variables.

3.11.4 Model Efficiency

The efficiency of the model was calculated by using the given equation:

$$= 1 - \frac{\sum (A - S)^2}{\sum (A - M)^2}$$

Where A and S refers to the actual and predicted value of the studied variables respectively and M is the mean of the actual variable.

3.12 Statistical analysis

The recorded data was analysed statistically using regression technique. The regression analysis was done between the predicted yield of rice with predicted maximum temperature, minimum temperature and rainfall. Microsoft – excel and WASP 2.0 (Web Agri Stat Package) was used for statistical analysis in the study.

3.13 General Circulation Models (GCMs) used

The ensembled mean data of seventeen models has been used for 2030 and 2050.

Table 5. General Circulation Models used for the study

No	Model	Institution
1	BCC-CSM 1.1	Beijing Climate Centre, China Meteorological Administration
2	BCC-CSM 1.1 (m)	Beijing Climate Centre, China Meteorological Administration
3	CSIRO-MK3.6.0	Commonwealth Scientific and Industrial Research Organisation and the Queensland Climate change Centre of Excellence
4	FIO-ESM	The First Institute of Oceanography, SOA, China
5	GFDL-CM3	Geophysical Fluid Dynamics Laboratory
6	GFDL-ESM2G	Geophysical Fluid Dynamics Laboratory

7	GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory
8	GISS-E2-H	NASA Goddard institute for Space Studies
9	GISS-E2-R	NASA Goddard institute for Space Studies
10	HadGEM2-ES	Met Office Hadley Centre
11	IPSL-CM5A-LR	Institute Pierre-Simon Laplace
12	IPSL-CM5A-LR	Institute Pierre-Simon Laplace
13	MICROC-ESM	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
14	MICROC-ESM-CHEM	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
15	MICROC5	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies
16	MRI-CGCM3	Meteorological Research Institute
17	NorESM1-M	Norwegian Climate Centre

RESULTS AND DISCUSSION

CHAPTER 4

RESULTS AND DISCUSSION

The results and discussion of the study entitled "Modelling rice production in Kole lands and its vulnerability to climate change" is presented in this chapter. The changes in rainfall pattern, temperature and solar radiation due to changes in climate and its impact on rice production and abiotic parameters on growth and yield of different varieties were studied. The crop simulation model DSSAT – developed by IBSNAT was used for studying the effect of climate change based on IPCC projections for the year 2030 and 2050 under different Representative Concentration Pathways.

4.1 Rainfall analysis of Kole lands (AEU - 6)

The Kole lands is a multiple use wetland ecosystem covering an area of 13,632 ha spread over Thrissur and Malappuram districts, extending from the northern bank of Chalakkudy river in the south to the southern bank of Bharathapuzha river in the north located between 10°20' and 10°40'N latitude and between 75°58' to 76°11'E longitude. The data collected from India Meteorological Department, Thiruvananthapuram from 1998 to 2016 and the data from General Circulation Models based on RCP 4.5 and 8.5 were analyzed. The rainfall parameters or indices like seasonal rainfall, monthly rainfall, rainy days and high rainfall events were calculated for the Kole lands (AEU - 6).

4.1.1 Rainfall analysis of Kole lands (AEU - 6) and impact of projected climate change in Kole lands

The Kole Lands agro-ecological unit (AEU - 6), spread over the coastal part of Thrissur district and extending to southern coastal parts of Malappuram district covers 40 panchayats. This land is, for most part, below sea level. Seawater ingress into these lands is controlled through barrages and weirs to facilitate rice cultivation. This unit covers 13, 632 ha (1.83 %) in the state.

4.1.1.1 Rainfall and Rainy days of Kole lands (AEU - 6)

The monthly rainfall distribution of Kole lands (AEU - 6) for the present and projected climate (RCP 4.5 and 8.5) presented in Table 6.

Table 6. Monthly rainfall distribution under projected climate of Kole lands (AEU - 6)

Rainfall (mm)		RCP 4.5		RCP 8.5	
Month	Present	2030	2050	2030	2050
January	3.1	7.8	9.8	7.7	7.9
February	11.9	7.6	0.7	0	0
March	21.1	6.4	15.9	15.4	12
April	98	42.2	15.8	44.1	58.9
May	244.6	283.7	317.5	276.5	387.4
June	768.5	1144.5	1472.2	1286.9	849.5
July	630.8	1388.4	1182.9	1200.7	1156.7
August	398.2	406.4	447.7	451.7	460.1
September	294.8	7.2	10.7	9.1	109
October	351.7	384.8	435.8	375.1	241.1
November	110.1	38.5	63.7	58.4	60
December	12.3	42	48.2	45.6	47.3
Total	**2945.1**	**3759.5**	**4020.9**	**3771.2**	**3389.9**

At present, June and July are the wettest months, having a rainfall of 768.5 mm and 630.8 mm. December, January and February are the months having lowest rainfall. Projections based on RCP 4.5 and 8.5, indicate that though the probability of getting maximum rainfall remain same during June and July months the actual quantity of rainfall during these months in 2030 and 2050 will be almost double than that of the present. The projections show lowest rainfall in the months of January and February. In February there will be no rainfall based on RCP 8.5. Compared to the present condition, the rainfall will decrease during April, September and November

The projections by RCP 4.5 and RCP 8.5 gave contrasting results for annual rainfalls of 2030 and 2050. As for RCP 4.5 the total rainfall shows an increasing trend from 2030 to 2050. But RCP 8.5 indicates a decrease in yearly rainfall from 2030 to 2050.

The monthly rainy days of Kole lands (AEU - 6) for the present and projected climate (RCP 4.5 and 8.5) represented in table 7.

Table 7. Monthly rainy days of Kole lands (AEU6) and the projected climate

Rainy days		RCP 4.5		RCP 8.5	
Month	Present	2030	2050	2030	2050
January	1	1	1	1	1
February	1	1	0	0	0
March	1	2	3	3	2
April	5	3	2	3	1
May	10	11	14	13	14
June	24	26	26	25	26
July	24	28	24	27	29
August	18	14	14	15	13
September	13	1	1	1	6
October	14	11	12	10	11
November	5	3	4	4	4
December	1	3	3	3	3
Total	**117**	**104**	**104**	**105**	**110**

In the current condition, June and July have the extreme number of rainy days with about 24 days. The lowest numbers of rainy days are expected in January, February and March. The maximum rainy days will be 29 days in July (RCP 8.5) followed by 26 days in June and the minimum will be 0 to 1 day in (both RCP 4.5 and RCP 8.5) February. Both RCP 4.5 and RCP 8.5 predict that the Kole regions will have less number of rainy days than the present during the monsoon seasons. However the summer rainy days will be slightly higher. Though the number of rainy days are relatively less, the quantity of rains received during each of these days are predicted to be much higher than the present conditions (Table 7).

Table 8. Seasonal rainy days of Kole lands (AEU - 6) and the projected climate

RCP	Season	Winter		Summer		South West monsoon		North East monsoon	
	Year	Rainy Days	Rain (mm)	Rainy Days	Rain (mm)	Rainy Days	Rain (mm)	Rainy Days	Rain (mm)
	Present	1	14.95	16	363.63	80	2092.2	21	474.13
4.5	2030	2	15.4	16	332.3	69	2946.5	17	465.3
	2050	1	10.5	19	349.2	65	3113.5	19	547.7
8.5	2030	1	7.7	19	336	68	2948.4	17	479.1
	2050	1	7.9	17	458.3	74	2575.3	18	348.4

Presently, the maximum number of rainy days occurs during south west monsoon season (80 days) followed by North East (21 days), summer season (16 days) and winter season (1 day). According to projected climate the highest number of rainy days will be during South West monsoon followed by North east, both of which will have lesser number of rainy days than the present conditions. In the case of summer and north east monsoon time there will be a noticeable change in the amount of rainfall as predicted by the RCPs.

4.1.2 High rainfall events of Kole lands (AEU - 6)

The heavy rainfall events of Kole lands (AEU - 6) for the present condition and projected climate based on RCP 4.5 and 8.5 presented in Table 9.

Table 9. Heavy rainfall events of Kole lands (AEU - 6) and the projected climate

		RCP 4.5					RCP 8.5				
	Rainfall (mm)	10 <25	25 <50	50 <75	75 <100	>= 100	10 <25	25 <50	50 <75	75 <100	>= 100
Year	Season	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days
Present	Winter	0	0	0	0	0	0	0	0	0	0
	Summer	0	2	1	0	1	0	2	1	0	1
	Southwest monsoon	32	20	5	3	1	32	20	5	3	1
	Northeast monsoon	10	5	1	0	0	10	5	1	0	0
	Total	**42**	**27**	**7**	**3**	**2**	**42**	**27**	**7**	**3**	**2**
2030	Winter	0	0	0	0	0	0	0	0	0	0
	Summer	3	5	1	0	0	3	3	2	0	0
	Southwest monsoon	20	21	12	4	5	17	23	12	2	6
	Northeast monsoon	8	2	1	0	1	8	1	2	0	1
	Total	**31**	**28**	**14**	**4**	**6**	**28**	**27**	**16**	**2**	**7**
2050	Winter	0	0	0	0	0	0	0	0	0	0
	Summer	4	3	1	1	0	4	4	2	0	1
	Southwest monsoon	18	24	8	2	7	23	25	12	2	3
	Northeast monsoon	7	5	0	2	0	7	3	1	0	0
	Total	**29**	**32**	**9**	**5**	**7**	**34**	**32**	**15**	**2**	**4**

Currently the number of rainfall events occur is more in the range of 10 to 25 mm and 25 to 50 mm. But in the case of heavy rainfall which is in the range 50 to more than 100 mm the number of rainfall events is less. Contrasting the present with the projected climate there will be a decreasing trend in the number of rainfall events during low rainfall. In the case of heavy rainfall the number of rainfall events shows an increasing trend.

4.2 Water Balance

4.2.1. Computed water balance of Kole lands (AEU - 6)

4.2.1.1 Monthly Potential Evapotranspiration, Deficit and Surplus of Kole lands (AEU - 6)

The monthly potential evapotranspiration of Kole lands (AEU - 6) for the present and projected climate (RCP 4.5 and 8.5) given in Table 10.

Table 10. Monthly Potential Evapotranspiration of Kole lands (AEU - 6) and the projected climate

PET (mm)		RCP 4.5		RCP 8.5	
Months	Present	2030	2050	2030	2050
January	150.4	170	152.4	149.2	153.6
February	170.8	150	152.8	150.4	157.6
March	231.6	225	196.5	193.5	200
April	184.1	163.6	164	161.2	165.6
May	202.1	238	213	209.5	214
June	140	162.4	172.8	170.4	175.2
July	177.3	236.5	206	202.5	218
August	149.5	165.6	165.2	162.8	166.8
September	182.2	222.5	206.5	203.5	206.5
October	135.6	156.4	154.8	152	162.8
November	134.8	177.2	156.4	154.4	154.4
December	134.8	152.4	156.8	154.4	157.2
Total	**1993.2**	**2219.8**	**2096.5**	**2062.9**	**2131.4**

At present condition, the maximum potential evapotranspiration is 231.6 mm during March and the minimum is 134.8 mm during November/ December. In projected climates based on RCP 4.5 and 8.5 the yearly potential evapotranspiration will be relatively higher than the present condition. In the projected climate scenarios the maximum values will occur in March, May, July and September and the minimum will be in February.

The monthly Moisture Deficit of Kole lands (AEU - 6) for the current and projected climate (RCP 4.5 and 8.5) were computed and shown in Table 11.

Table 11. Monthly Moisture Deficit of Kole lands (AEU - 6) and the projected climate

Deficit (mm)		RCP 4.5		RCP 8.5	
Months	Present	2030	2050	2030	2050
January	150.4	161.2	141.6	140.5	144.7
February	170.8	142.4	152.1	150.4	157.6
March	231.6	218.6	180.6	178.1	188
April	135.5	121.6	148.4	117.3	121.3
May	88.4	87.6	35.1	77.4	54.6
June	0	0	0	0	0
July	1.7	0	0	0	0
August	21.9	5.8	3.7	5.3	5.8
September	50.9	170.2	155	154.8	111
October	8.8	43.4	0.3	40.3	52.2
November	89	131	104.7	109.6	110.2
December	113.6	118.1	113.6	115.1	110
Total	**1062.6**	**1200.3**	**1034.7**	**1088.4**	**1055.3**

At present, the maximum moisture deficit occurs in March (231.6 mm) and the deficit is zero in June. July has a moisture deficit below 10 mm. In the projected climates (RCP 4.5 and 8.5). The maximum March will continue to have the maximum deficit but will be lower than the present condition. Both the projected scenarios indicate a higher total annual deficit by 2030 than the present which will reach below the present deficit values by 2050.

The monthly Surplus of Kole lands (AEU - 6) for the present and projected climate (RCP 4.5 and 8.5) given in Table 12.

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Table 12. Monthly Surplus of Kole lands (AEU - 6) and the projected climate

Surplus (mm)		RCP 4.5		RCP 8.5	
Months	Present	2030	2050	2030	2050
January	0	0	0	0	0
February	0	0	0	0	0
March	0	0	0	0	0
April	0	0	0	0	7.1
May	147.5	236	172.4	209.4	260.1
June	463.1	1040.4	1304.9	1083.5	664.4
July	576.2	1081.6	1056.3	1084.1	1068.9
August	486.4	155.5	169.2	177.6	178.8
September	52	131.7	95.1	129	29
October	190.2	95.6	152.2	113.7	106.7
November	53.6	0	9.6	0	0
December	0	0	0	0	0
Total	**1969**	**2741**	**2960.1**	**2797.6**	**2314.9**

In the present condition the surplus during January, February, March, April and December is zero and the maximum amount of surplus is occurs in July (576.2 mm.). As per RCP 4.5 and 8.5 in projected climate, during the months January, February, March, April, November and December the amount of surplus will be zero. The maximum amount of surplus will occur in July and the yearly value shows an increase from the current condition.

4.3 Soil fertility status of Kole lands (AEU - 6)

The soil fertility status of major rice growing areas of Kole lands (AEU - 6) is shown in Table 12. The soil test results of pH, bulk density, texture, soil organic carbon and soil available nitrogen, phosphorous and potassium given in below Table 13.

Table 13. The soil test results of Kole lands (AEU - 6)

Soil parameters	Range
pH	4.2 – 5.2
Bulk density	1.4 – 1.7 g/cm3
Organic carbon	1.9 – 2.4 %
Available Nitrogen	133 – 279 kg/ha
Available Phosphorus	11.8 – 25.5 kg/ha
Available Potassium	66 - 221kg/ha
Sand	57 – 83 %
Slit	2 – 12 %
Clay	12 – 32 %

As per the soil test results the soils of Kole lands (AEU - 6) are acidic in nature with the pH ranging from 4.2 – 5.2. The low productivity of laterite and allied soils can be generally attributed to low pH (Rani, 2014). Low to moderate acidity in Kole lands has serious problems in rice yield. The observations are in conformity with the studies of Patnaik (1971). The bulk density of the soil was 1.56%. The availability of nitrogen in Kole lands is low, available phosphorous medium to high and available potassium low to medium.

4.4 Blok wise area, production and productivity of Rice in Kole lands (AEU - 6)

The area, production and productivity of the rice cultivation in Kole lands are analyzed and described in table 14 – 19.

4.4.1 Area under rice cultivation in Kole lands (AEU - 6)

The area under rice cultivation in Kole lands are given in table 14 to 15 and from the results it can be clearly seen that the area under rice cultivation is declining at an alarming rate.

4.4.1.1 Area (ha) under rice cultivation during the Mundakan cropping season in Kole lands (AEU - 6)

The area under rice cultivation during the Mundakan cropping season in Kole lands is analyzed and described in below table 14

Table 14. Area (ha) under rice during the Mundakan cropping season in Kole lands (AEU - 6)

Block	Year								
	2008	2009	2010	2011	2012	2013	2014	2015	2016
Puzhakkal	2103	1291	1066	749.8	1475.2	1104	1619.	1662.5	1543.6
Mullassery	330.5	830.7	228.2	223.2	979.01	840.3	791.9	851.67	990.6
Anthikkad	450.7	319.4	212	234.0	874.45	868.4	770.1	812.29	899.4
Chowannur	1796	1415	1092	906.3	1671.9	1920	1863	2019.1	1720.1
Cherp	655.8	227.1	552.9	150.6	345.73	220.0	162.5	60.99	380.04
Irinjalakuda	154.1	7.50	36.10	325.5	90.16	100	135.4	163.5	165.79
Vellangallur	339.6	272.2	377.7	269.2	325.74	395.9	390.6	417.39	354.81
Chavakkad	101	25	29.21	30.93	55.38	37.23	42.26	47.95	50

As per the latest statistics, It can be seen that, the highest area under rice cultivation during the Mundakan cropping season was 2103.4 hectares in Puzhakkal block during 2008. The lowest area of 7.50 hectares was in Irinjalakkuda block during 2009. From the above table it can be surmised that the lowest area under rice cultivation during 2008 – 2016 was in Chavakkad block.

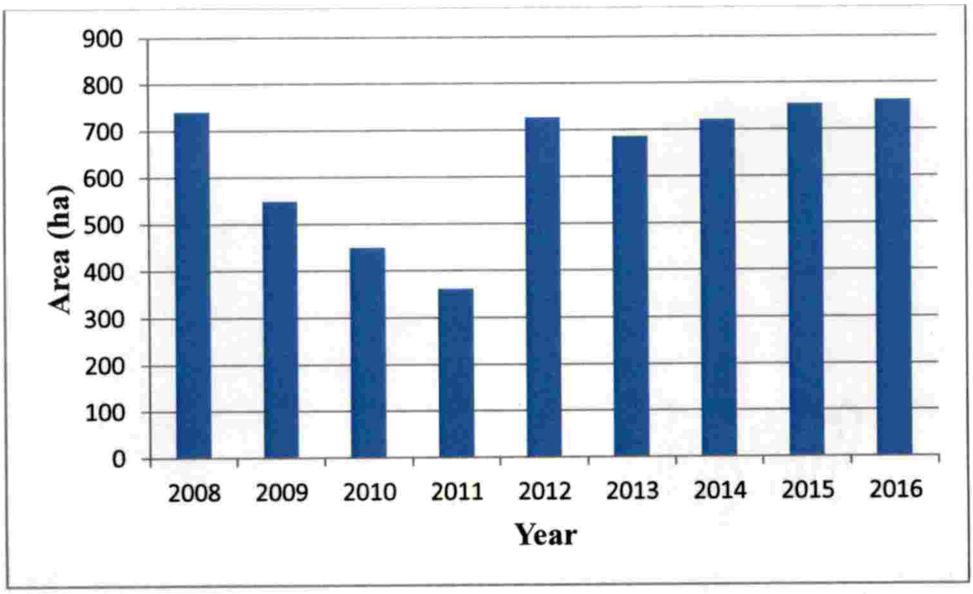

Fig 2. Area (ha) under rice cultivation during the Mundakan cropping season

Fig. 2 represents the changes in area under rice cultivation during the second crop season in Kole lands over 2008 – 2016. The area under rice production has shown a decline from 2008 – 2011, but showed an abrupt increase in area during 2012 – 2016 by 707.53 ha. The least area under rice cultivation was 361.19 ha in 2011.

4.1.1.2 Area (ha) under rice during the Puncha cropping season in Kole lands (AEU - 6)

The area under rice cultivation during the Puncha cropping season in Kole lands was analyzed and shown in Fig. 3.

It can be inferred from that as per the latest statistics, the highest area under rice cultivation ha in Kole lands during the Puncha cropping season was 2309 ha. In general, Puncha season was found to have more area under rice in comparison to Mundakan in the Kole lands.

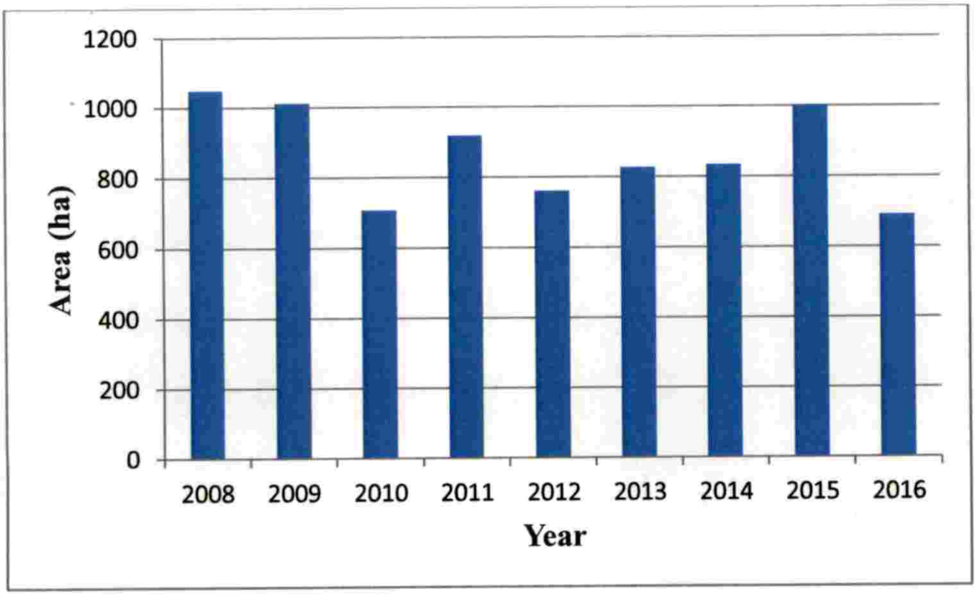

Fig 3. Area (ha) under rice cultivation during the Puncha cropping season

4.4.2 Production under rice cultivation in Kole lands (AEU - 6)

The production under rice in Kole lands (AEU - 6) given in table 15 to 16.

4.4.2.1 Production (kg) under rice during the Mundakan cropping season in Kole lands

The production under rice during the Mundakan cropping season in Kole lands was analyzed and shown in Table 15.

Table 15. Production (kg) under rice during the Mundakan cropping season in Kole lands (AEU - 6)

Block	Year								
	2008	2009	2010	2011	2012	2013	2014	2015	2016
Puzhakkal	6318	3637	3294	2146.5	4800	3529.9	5677	5471.1	4233
Mullassery	1150	3017	794.1	923	4021	3657.6	3196	3875.9	3380.5
Anthikkad	1424	999.9	581.9	767.16	3434	2556.9	2890	2675.1	2522.5
Chowannur	3321	2613	2919	2201.9	4048	4929.2	5620	5925.7	3950.5
Cherp	1886	695.5	1678	454.98	842	535.42	603.2	179.6	992.75
Irinjalakuda	321.3	16.3	73.38	992.29	205	257.01	356.3	385.2	459.44
Vellangallur	751.5	553.6	689	642.86	746	984.51	1011	1026.2	788.84
Chavakkad	0	57.9	40.68	127.82	167	110.9	156.1	122.2	145.52

It can be inferred that as per the latest statistics, highest production under rice in Kole lands during the Mundakan cropping season was 6318.4 kg (2008) in Puzhakkal block and the lowest production under rice during the second crop season was 0 kg in Chavakkad block. By comparing the block wise data the highest production of rice was in 2015.

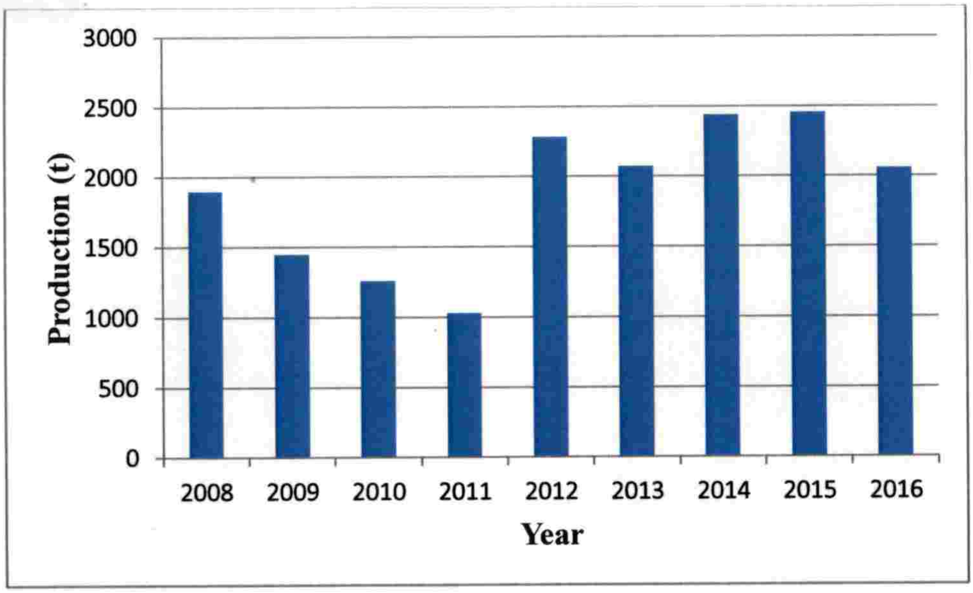

Fig 4. Production (kg) under rice during the Mundakan cropping season

The above figure represents the production under rice cultivation in Mundakan cropping season during 2008 – 2016. The production under rice has shown a drastic reduction during 2008 – 2011. The highest value in production of rice cultivation in Kole lands was 2457 kg in 2015.

4.4.2.2 Production (kg) under rice during the Puncha cropping season in Kole lands (AEU - 6)

The production under rice during the Puncha cropping season in Kole lands is analyzed and described in below Table 16.

Table 16. Production (kg) under rice during the Puncha cropping season in Kole lands (AEU - 6)

Block	Year								
	2008	2009	2010	2011	2012	2013	2014	2015	2016
Puzhakkal	7609	5658	4889	8405	4074	6212	3864	7955	4142.2
Mullassery	3482	2340	3125	5720	3731	2801	3314	3353	1319.4
Anthikkad	2716	5730	4129	4009	5741	5642	6623	5509	5401.7
Chowannur	2815	4585	1884	2501	2484	2028	3264	3782	2834.1
Cherp	9409	5783	2637	4850	4089	4048	3791	4851	2766.0
Irinjalakuda	1136	1427	1242	949.7	1372	1658	2058	2714	2186.7
Vellangallur	218	459	319.8	358.7	442	755	740	813	379.8
Chavakkad	0	206.7	246.4	254.5	468.2	1117	1823	1380	997.07

It can be seen from the table 16 that, highest production under rice during the Puncha cropping season was 9409 kg (2008) in Cherp block and the lowest production was 0 kg (2008) was in Chavakkad block. It was noticed that production under rice during the third crop season has shown a decline in Kole lands over a period from 2009 – 2017.

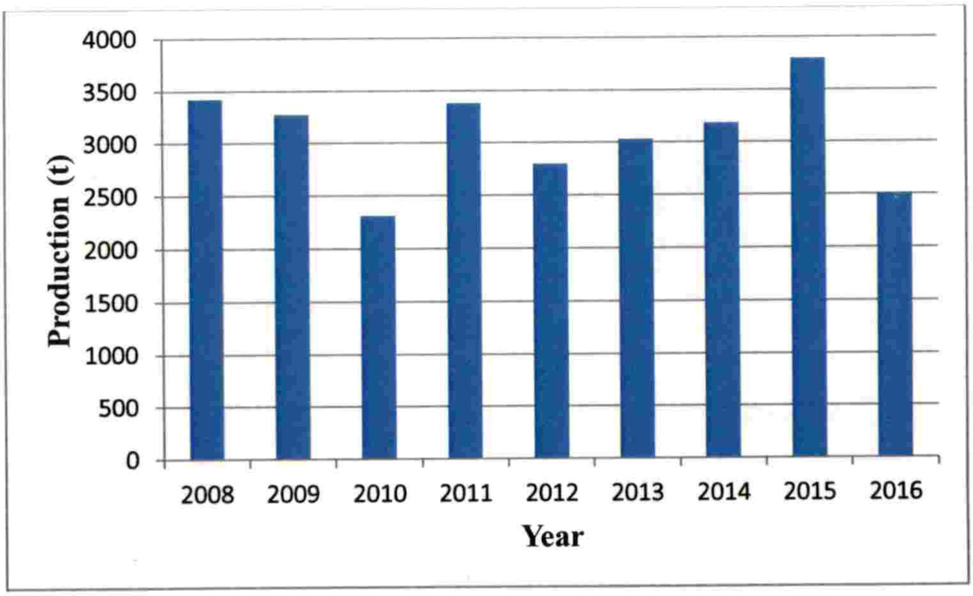

Fig 5. Production (kg) under rice during the Puncha cropping season

The Fig. 5 represents production under rice cultivation in Puncha cropping season during 2008 – 2016. The production under rice which was showing a consistently increase trend during 2011 – 2015. But there has shown drastic in 2016. The highest production of rice cultivation was 3794 kg in 2015 and the lowest production was 2309 kg in 2010.

4.4.3 Productivity under rice in Kole lands (AEU - 6)

The productivity under rice in Kole lands (AEU - 6) given in table 17 to 18.

4.4.3.1 Productivity (t/ha) under rice during the Mundakan cropping season in Kole lands

The productivity under rice during the Mundakan cropping season in Kole lands was analyzed and shown in Table 17.

Table 17. Productivity (t/ha) under rice during the Mundakan cropping season in Kole lands (AEU - 6)

Block	Year								
	2008	2009	2010	2011	2012	2013	2014	2015	2016
Puzhakkal	3.004	2.817	3.089	2.863	3.254	3.196	3.506	3.291	2.742
Mullassery	3.479	3.632	3.478	4.128	4.108	4.353	4.035	4.551	3.412
Anthikkad	3.160	3.130	2.745	3.278	3.928	2.944	3.752	3.293	2.805
Chowannur	1.849	1.847	2.672	2.429	2.421	2.567	3.016	2.935	2.297
Cherp	2.876	3.062	3.035	3.016	2.436	2.433	3.712	2.946	2.612
Irinjalakuda	2.085	2.175	2.033	3.049	2.280	2.570	2.630	2.356	2.771
Vellangallur	2.213	2.029	1.824	2.388	2.291	2.486	2.589	2.459	2.223
Chavakkad	0	2.318	1.393	4.133	3.024	2.981	3.694	2.550	2.911

From the table 17, the highest productivity achieved under rice during the mundakan crop season was 4.5 t/ha in Mullassery block in 2015 and the lowest productivity under rice during the mundakan crop season was 0 t/ha in Chavakkad block..

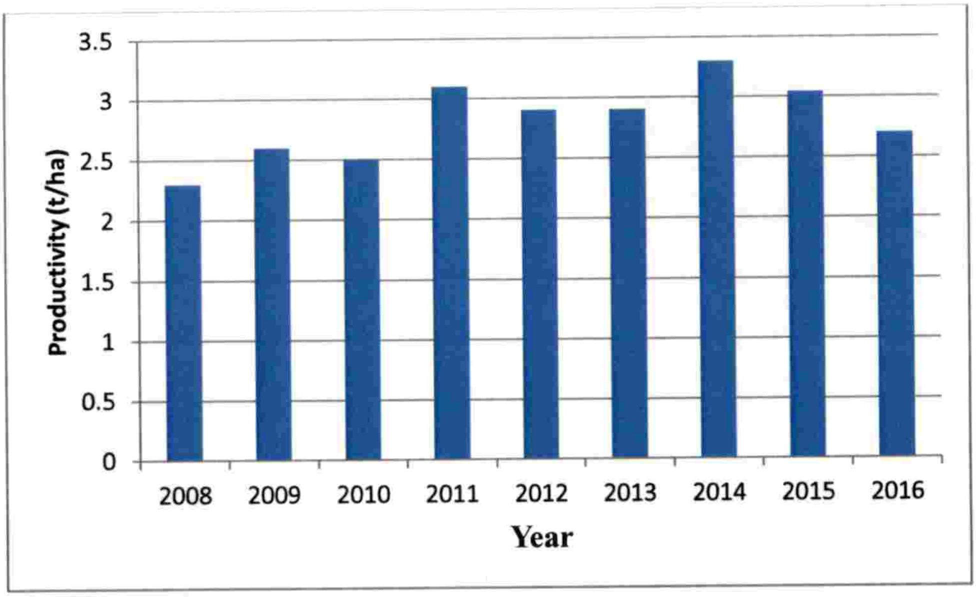

Fig 6. Productivity (t/ha) under rice during the Mundakan cropping season

The above figure represents the productivity under rice cultivation in Mundakan cropping season during 2008 – 2016. From the above figure the productivity under rice has shown an increase during 2012 – 2014 and then gradually fallen during 2015 - 2016. The highest value of productivity (3.3 t/ha) was recorded in 2014.

4.4.3.2 Productivity (t/ha) under rice during the Puncha cropping season in Kole lands (AEU - 6)

The productivity under rice during the Puncha cropping season in Kole lands (AEU - 6) is analyzed and described in Table 18.

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Table 18. Productivity (t/ha) under rice during the Puncha cropping season in Kole lands (AEU - 6)

Block	Year								
	2008	2009	2010	2011	2012	2013	2014	2015	2016
Puzhakkal	3.296	2.887	3.020	3.553	3.403	3.462	3.638	3.911	3.638
Mullassery	3.355	2.678	3.568	4.121	3.401	4.020	4.083	3.941	3.460
Anthikkad	3.135	3.077	3.505	3.692	3.725	3.604	3.635	3.269	3.219
Chowannur	3.470	3.954	3.826	3.888	4.650	4.246	5.028	5.110	5.522
Cherp	3.433	3.756	3.173	3.496	3.857	3.522	3.351	3.435	3.289
Irinjalakuda	2.904	3.284	2.790	3.268	3.396	3.575	3.740	3.744	3.824
Vellangallur	2.631	2.698	2.336	3.252	3.762	4.103	3.208	3.014	2.791
Chavakkad	1.23	2.252	3.036	3.352	3.572	4.027	4.433	4.535	3.573

It can be inferred from table 18 that, highest Productivity under rice during the Puncha crop season was 5.5 t/ha in Chowannur block. It can be also noticed that the overall productivity under rice during the Puncha crop season has shown a decline in Kole lands from 2009 – 2017.

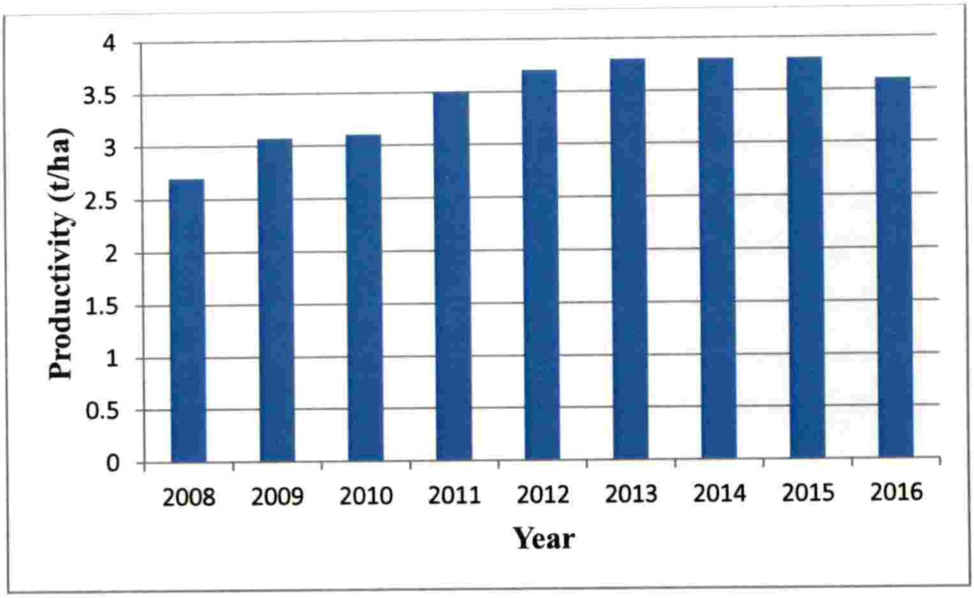

Fig 7. Productivity (t/ha) under rice during the Puncha cropping season

The Fig. 7 represents the productivity under rice cultivation during the Puncha cropping season during 2008 – 2016. From the above figure the productivity under rice has shown an increasing trend during 2010 - 2015 and the productivity gradually decreased during 2015 - 2016. The highest value of productivity was 3.8 t/ha in 2015.

4.5 Modeling of Rice Production Using DSSAT model

Sixteen dates of transplanting in two seasons (Mundakan and Puncha) has been used for validating CERES –Rice model (DSSAT 4.7). The Genetic coefficients of the varieties were developed and presented in the Table 19.

Table 19. Genetic coefficients of major rice varieties

Variety	Genetic coefficients							
	P1	P2R	P5	P20	G1	G2	G3	G4
Jyothi	556.8	29.7	423	10.4	49.8	0.0235	1	1

4.5.1 Observed and predicted yield of rice in Kole lands (AEU - 6)

4.5.1.1 Observed and predicted yield of rice in Kole lands (AEU - 6) during the Mundakan and Puncha cropping seasons

CERES – Rice model results of predicted yield and observed yield of rice in Kole lands over a period of 2008 – 2015 during the Mundakan and Puncha cropping seasons presented in Table 20 - 21.

Table 20. Observed and predicted yield of rice in Kole lands (AEU - 6) during the Mundakan cropping season

Year	Mundakan Cropping Season	
	Observed yield(kg/ha)	Predicted yield(kg/ha)
2008	2616	3285
2009	2700	3625
2010	2687	3423
2011	3254	3450
2012	2911	3404
2013	2802	3452
2014	3300	2675
2015	2924	2971

The observed and predicted yield of rice in Kole lands during cropping seasons using DSSAT 4.7 model showed consistency in results (Fig. 8 to 9).

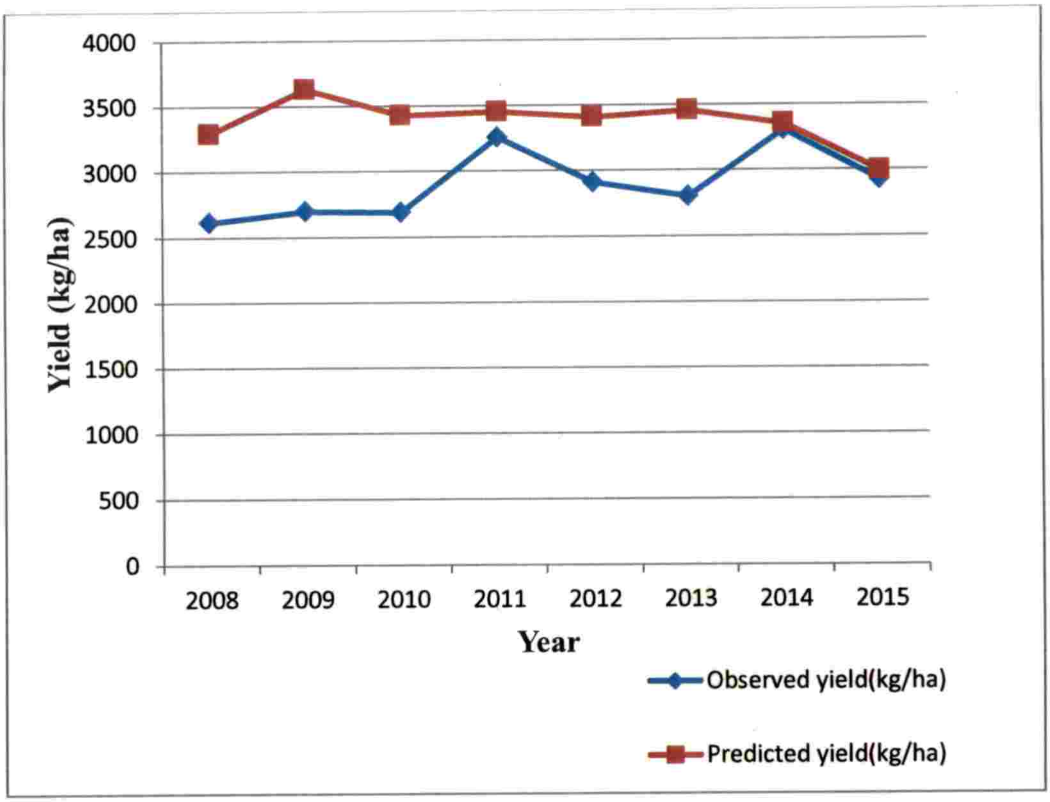

Fig 8. Observed and predicted yield of rice in Kole lands during the Mundakan Cropping Season

Table21. Observed and predicted yield of rice in Kole lands (AEU - 6) during the Puncha cropping season

Year	Puncha cropping season	
	Observed yield(kg/ha)	Predicted yield(kg/ha)
2008	3129	3360
2009	3013	3484
2010	3100	3836
2011	3500	3753
2012	3607	3387
2013	3700	3707
2014	3832	3634
2015	3887	3523

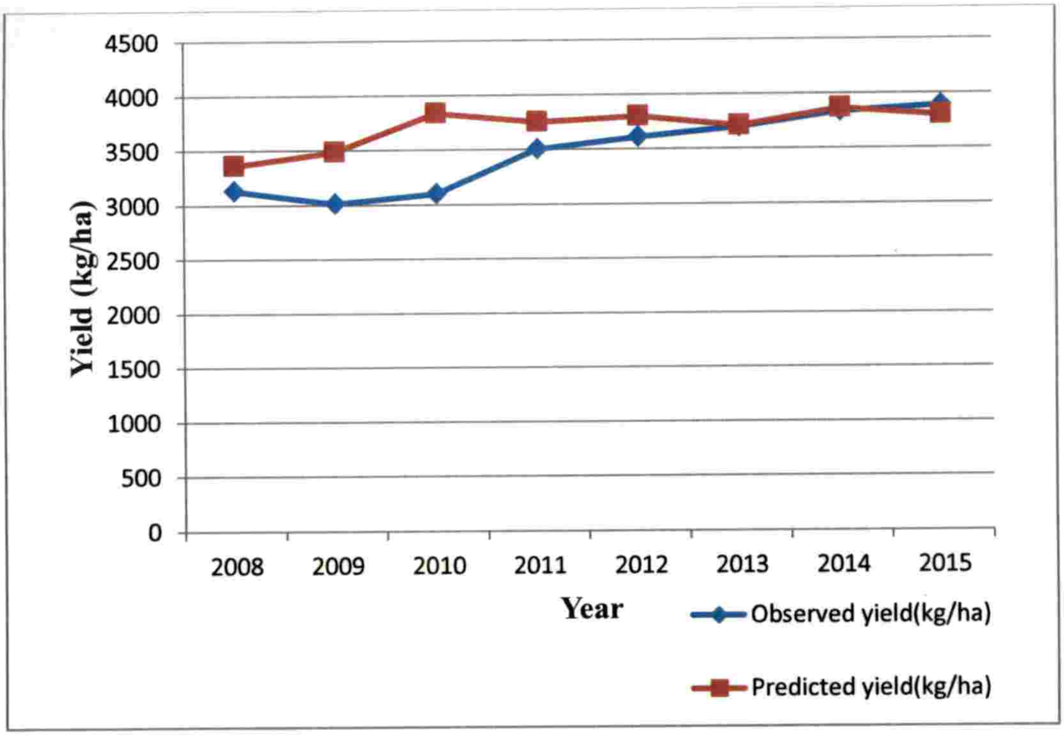

Fig9. Observed and predicted yield of rice in Kole lands during the Puncha cropping season

The observed and model predicted results indicate that the production of rice in Kole lands is more during the Puncha cropping season than Mundakan season.

The major rice cultivation in Kole lands was carried out during the Puncha cropping season, because a period of six months, a major portion of this land lies submerged under water. Kechery and Karuvannur are the two rivers which bring flood water into the area and finally it is emptied into the Arabian Sea. The results were in conformity to the studies by Sivaperuman and Jayson (2000).

The RMSE (Root Mean Square Error) for rice prediction and model efficiency were calculated and presented in Table 22.

Table22. RMSE and Model Efficiency for DSSAT prediction

Model	RMSE	Model Efficiency
CERES – Rice	2.15 (good)	0.64 (> 0.5, very good)

4.6 Regression Analysis

The regression analysis was carried out to determine the critical variables, which contribute to yield.

In rice, heading to maturity stage is the most important phase for grain yield. Among all the weather parameters minimum temperature was to found to have the maximum influence on grain yield.

The influence of the climatic parameters and predicted rice yield in Kole lands are given in Table 23 – 25 and Fig. 10 -12

Table.23. Predicted yield and maximum temperature during Mundakan and Puncha cropping seasons in Kole lands (AEU - 6)

Maximum Temperature (°C)	Predicted Yield (kg/ha)
31	3285
31	3360
32	3484
32	3423
31.8	3836
31.8	3625
31.8	3836
31.8	3753
32.2	3404
32.2	3387
32.04	3452
32.04	3707
32.4	2675
32.4	3634
32.4	2971
32.4	3523

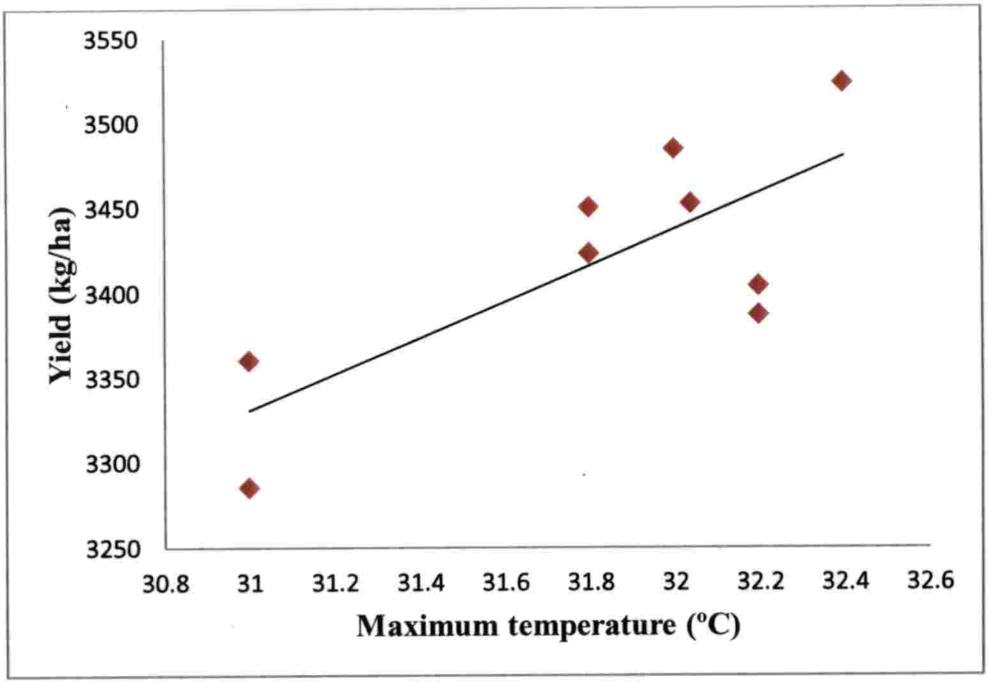

Fig 10. Regression between predicted yield and maximum temperature in Kole lands during the Mundakan and Puncha cropping seasons

Table 24. Predicted yield and minimum temperature during Mundakan and Puncha cropping seasons in Kole lands (AEU - 6)

Minimum Temperature (°C)	Predicted Yield (kg/ha)
23.3	3285
23.3	3360
23.5	3625
23.5	3484
23.4	3423
23.4	3325
23.2	3450
23.2	3753
23.4	3404
23.4	3387
23.3	3452
23.3	3707
23.8	2675
23.8	3634
23.8	2971
23.8	3523

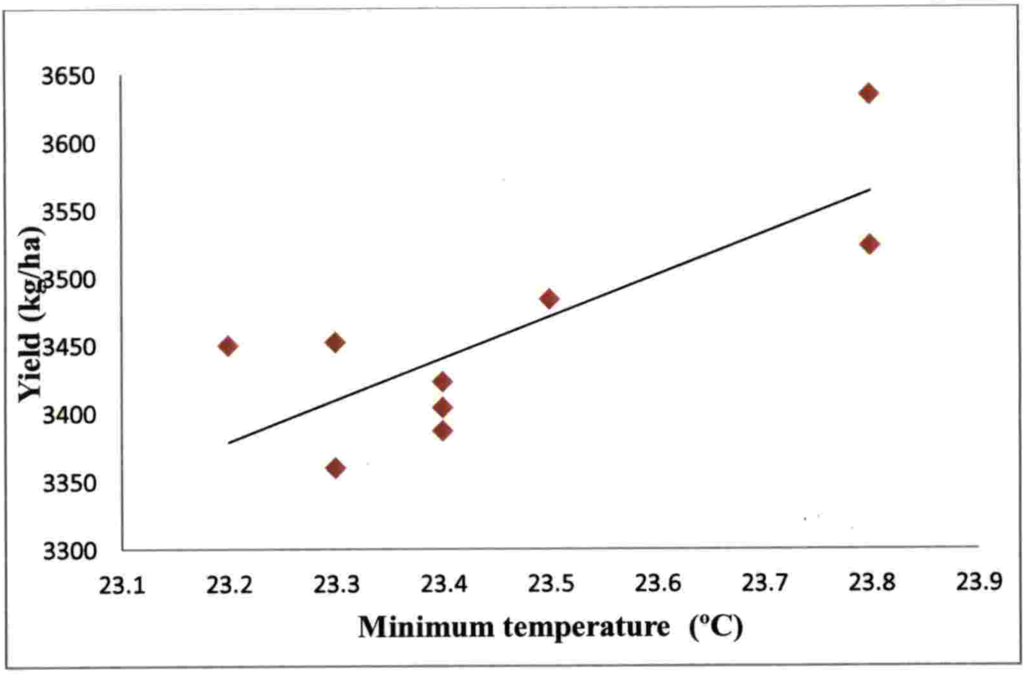

Fig 11. Regression between yield and minimum temperature in Kole lands during the Mundakan and Puncha cropping seasons

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Table 25. Predicted yield and rainfall during Mundakan and Puncha cropping seasons in Kole lands (AEU - 6)

Rainfall (mm)	Predicted Yield (kg/ha)
6.5	3285
6.5	3360
7.8	3625
7.8	3484
8.2	3423
8.2	3325
9.7	3450
9.7	3753
6.02	3404
6.02	3387
8.8	3452
8.8	3707
8.08	2675
8.08	3634
7.04	2971
7.04	3523

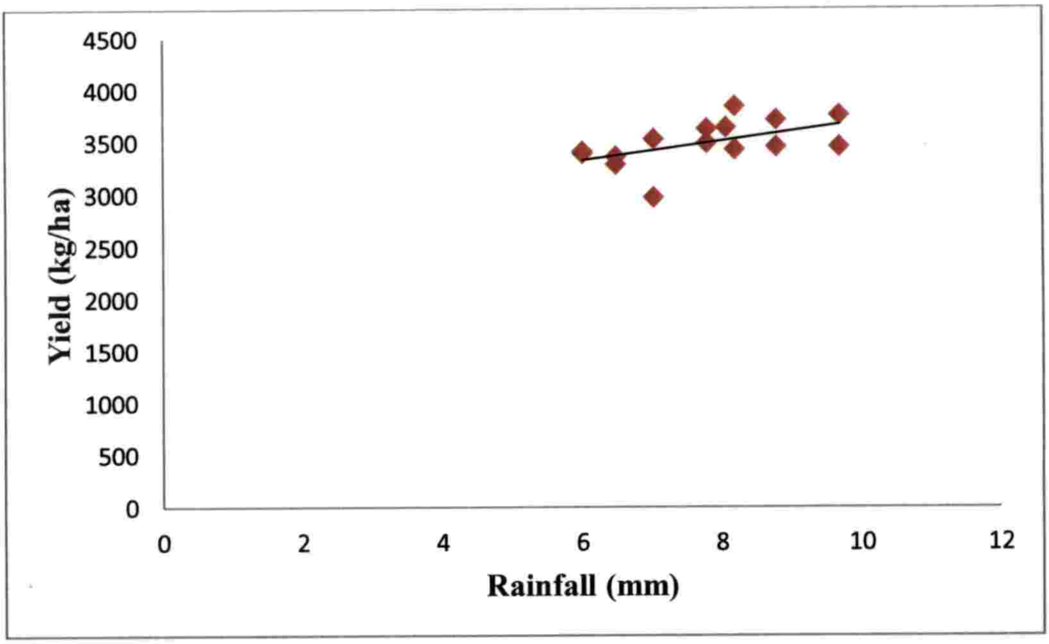

Fig 12. Regression between predicted yield and rainfall in Kole lands during the Mundakan and Puncha cropping seasons

Table 26. Regression between climatic parameters and predicted rice yield in Kole lands (AEU - 6)

Regression equations developed		R^2 Value
Predicted yield and maximum temperature	Y = 106.77 X + 20.636	0.58
Predicted yield and minimum temperature	Y = 307.21X – 3748.3	0.62
Predicted yield and rainfall	Y = 92.573 X + 2769.1	0.28

An increase in daily maximum and minimum temperature during the entire cropping season may decrease the tiller number and yield, also maximum temperature (28-32 °C) and higher relative humidity (80-90 %) may increase plant biomass. Similar observations are made by Sunil (2000).

High temperature at heading induces spikelet sterility and leads poor yield in rice (Satake and Yoshida, 1978). In addition, low minimum temperature during ripening period results in high grain filling. The observation was supported by Boerma (1974).

4.7 Climate change impact on rice production

The future climatic projections were taken from Ensemble of 17 General Circulation Models (GCMs). The future carbon dioxide concentrations and climate data has been incorporated into crop simulation model-DSSAT and predicted the future yield for the years 2030 and 2050.

The observed and predicted yield for the years 2030 and 2050 under RCPs 4.5 and 8.5 has been presented in table 27.

Table 27. Impact of Projected Climate on Rice yield in Kole lands (AEU - 6)

		II Crop	III Crop
Kole Lands (AEU 6)	Present	3285	3360
	2030	3143	3149
	2050	3017	3424

In southern India, the increasing temperatures in atmosphere severely affect the rice yield. But increasing atmospheric CO_2 is likely to have certain positive effect on yield, which will be neutralized by the negative effects of temperature on rice. Increase of 1°C temperature without any increase in CO_2 resulted in 3–7 per cent decrease in grain yield. In general, as the temperatures increased rice yields in eastern and western India were less affected, moderately affected in north whereas severely affected in southern India. Grain yields increased in all regions as the CO_2 concentration increased. A doubling of CO_2 resulted in 12 to 21 per cent increase in yield (Aggarwal and Mall, 2002).

The maximum temperature above 35°C and minimum temperature 23°C at flowering stage increased the pollen sterility in varieties of rice and the effect is more profound in basmati cultivars (Rao and Alexander, 2007). In many tropical and subtropical regions, potential yields are projected to decrease for most projected increases in temperature (Krupa, 2003). The yields of rice increased significantly by 28 per cent for a doubling of CO_2. However, 2 °C rises in temperature cancelled out the positive effect of elevated CO_2 on rice. The combined effect of enhanced CO_2 and imposed thermal stress on the rice crop is 4 per cent increase in yield (Lal *etal.,* 1998).

SUMMARY

CHAPTER 5

SUMMARY

Rice is the most important human food crop in India, directly feeding more people than any other crop. Rice is produced in a wide range of locations and under a variety of climatic conditions, from the wettest areas to the driest deserts. Climate change is a serious issue that will affect the rice yield. The rice cultivation in Kole lands (AEU- 6) constitutes 4.09% of the total rice area in the Kerala state and the Kole area in Thrissur and Malappuram districts signifies 23.2% and 10.9% of the total rice area of the respective districts.

The present study entitled "Modeling rice production in Kole lands and its vulnerability to climate change" was conducted at Kerala Forest Research Institute (KFRI), Peechi with the following objectives:-

1. Development of crop weather relationship for the predominant rice varieties and assessment of possible changes in yield due to climate change.

2. Study the impact of abiotic factors on rice production using simulation model.

Composite surface soil samples of 0 - 20 cm from 15 different sampling areas were collected for the analysis and geographical coordinates of the sampling sites marked during the sample collection. The crop simulation model DSSAT – developed by IBSNAT was used for studying the impact of climate change and influence of abiotic factors on rice production in Kole lands. The climate scenarios for 2030 and 2050 were derived based on IPCC projections under different Representative Concentration Pathways.

CROPWAT model was used for the calculations of crop evapotranspiration, crop water requirements and irrigation requirements for the development of irrigation schedules under various management conditions and scheme water supply. Weather cock v.1.5 was used for converting the daily weather data into standard week, month and seasonal formats. It was also used to compute PET and Thornthwaite water balances.

The salient findings of the study are:

- The monthly rainfall of Kole lands indicates that there is an increase in rainfall during the months of June, July and August in Projected climate as per RCP 4.5 and 8.5
- According to RCP 8.5, there will be a decrease in yearly rainfall from 2030 to 2050
- As per RCP 4.5 and 8.5, the projected climate shows an increasing trend in the annual rainy days of Kole lands from 2030 to 2050
- According to RCP 4.5 and 8.5, there is an increasing trends in number of seasonal rainy days during the monsoon seasons
- As per RCP 4.5, there is no change in the total monthly rainy days during 2030 and 2050
- In projected climate, the number of rainfall events during low rainfall shows a visible decrease from the present condition
- In projected climate, the maximum amount of Potential Evapotranspiration can be observed during the month of May, whereas the minimum will be in, November, December, and January
- Based on the projected climate, the Potential Evapotranspiration will be higher than the present condition
- As per the projections, maximum amount of water deficit will happen during the month of March
- The maximum amount of surplus will occur in July and the yearly value shows an increase from the current condition
- As per RCP 4.5 and 8.5 in projected climate, during the months January, February, March, April, November and December there will be no surplus
- The area under rice production has shown a decline trend in Kole lands over a period of 2008 – 2017

- The observed and model predicted results indicates that the production of rice in Kole lands is more during the third cropping season than second season
- According to the projected results of 2030 and 2050, there is a decreasing trend in rice yield during the second cropping season
- By 2030, the second cropping season is projected to have a yield of 3.124 t/ha
- By 2050, the third cropping season will have a productivity of 3.424 t/ha (at present condition, productivity is about 3.32 t/ha)
- DSSAT model was validated and gave good RMSE values and very good model efficiency. It can also be used for studying the impact of climate change on growth and yield of rice
- Regression analysis was conducted with maximum temperature, minimum temperature and rainfall to predict rice yield. Among these analyses, regression between predicted yield and minimum temperature gave the good result and the R^2 value is above 50%.

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MODELING RICE PRODUCTION IN KOLE LANDS AND ITS VULNERABILITY TO CLIMATE CHANGE

By

Surabhi S. R

(2013-20-121)

ABSTRACT

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Faculty of Agriculture

Kerala Agricultural University, Thrissur

ACADEMY OF CLIMATE CHANGE EDUCATION AND RESEARCH

VELLANIKKARA, THRISSUR – 680 656

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ABSTRACT

Rice is the most important staple food crop for more than 2/3rd of India's population, and is the primary source of food for more than three billion people globally. Hence rice production plays a significant role in food security under a changing climate. The Kole lands is a multiple use wetland ecosystem covering an area of 13,632 ha spread over Thrissur and Malappuram districts, and form one of the rice granaries of Kerala. It is a part of the unique Vembanad-Kole wetland ecosystem. The objectives of the study were to develop crop weather relationship for the predominant rice varieties and assess possible changes in yield due to climate change and to study the impact of abiotic factors and farming practices on rice production using simulation model.

Daily weather data for the period 1998-2016 were collected from the India Meteorological Department, Thiruvananthapuram. Information on area, production and productivity of rice in Kole lands was collected from Agriculture Statistics Report - Department of Economics and Statistics, Kerala. The weather data from General Circulation Models based on RCP 4.5 and 8.5 were used for the analysis and projections were made up to 2050. Weather cock v.1.5 was used for converting the daily weather data into standard week, month and seasonal formats. The rainfall parameters or indices like seasonal and monthly rainfall, rainy days and high rainfall events were calculated. It is also used to compute PET and Thornthwaite water balances. The crop simulation model DSSAT –developed by IBSNAT was used for studying the impact of climate change on these ecosystems.

The monthly rainfall of Kole lands indicates that there was an increase in rainfall during the months of June, July and August as per RCP 4.5 and 8.5. According to RCP 4.5 and 8.5 an increasing trend in number of seasonal rainy days was observed during the monsoon seasons. The maximum amount of potential evapotranspiration was observed during the month of May, whereas the minimum in, November December, and January. The months of January,

February, March, April, November and December were found to have no surplus. Whereas water deficit is projected to happen during the month of march. The maximum amount of surplus was found to occur in July and the yearly value shows an increase from the current condition.

The area under rice production has shown a declining in Kole lands over a period of 2008 – 2017. Results indicates that the productivity of rice in Kole lands during the first cropping season was 2.08 t/ha. By 2030, the second cropping season was projected to have a yield of 3.124 t/ha. By 2050, the third cropping season would surpass the productivity of first two seasons with productivity of 3.424 t/ha.