REPUBLIQUE DU MALI

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MINISTERE DE L'ENSEIGNEMENT SUPERIEUR

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ASSESSING THE EFFECTS OF MANAGEMENT PRACTICES AND CLIMATE CHANGE ON LOWLAND RICE PRODUCTION USING THE DSSAT CROP MODEL IN THE GAMBIA AND MALI.

FATOU BOJANG

(MASTER DEGREE ON CLIMATE CHANGE AND EDUCATION)

A DISSERTATION

IN THE RURAL POLYTECHNIC INSTITUTE OF TRAINING AND APPLIED RESEARCH IN PARTNERSHIP WITH THE WEST AFRICAN SCIENCE SERVICE CENTRE ON CLIMATE CHANGE AND ADAPTED LAND USE (WASCAL), SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN CLIMATE CHANGE AND AGRICULTURE OF THE UNIVERSITY OF SCIENCES TECHNIQUES AND TECHNOLOGIES OF BAMAKO (USTTB), BAMAKO, MALI

JANUARY 2020

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a) By the Student

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Dedication

This work is first and foremost dedicated to my Dear parents, Yusupha Bojang my Father and my mother Mariama Darboe, for their guidance and tireless support from birth to date.

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I first submit my sincere thanks and gratitude to the Almighty Allah for giving me the good health and the ability to complete this program. May Allah bless all of us in this world and in the hereafter.

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List of Acronyms

AgMIP…………………… Agricultural Model Intercomparison and Improvement Project

ANR………………………. Agricultural and Natural Resources

CGIAR…………………… Consultative Group on International Agricultural Research

CO_2……………………….. Carbon dioxide

CRR……………………… Central River Region

DSSAT…………………… Decision Support System for Agro technology Transfer

EC………………………... Electric Conductivity

FACE……………………… Free-air carbondioxide enrichment

GCM………………………. General Circulation model

GNAIP……………………. Gambia National Agricultural Investment Plan

IPCC………………………. Intergovernmental Panel on Climate Change

LAI………………………… Leaf Area Index

NASS……………………… National Agricultural Sample Survey

NERICA…………………... New Rice for Africa

NPK………………………. Nitrogen Phosphorus and Potassium

RCP………………………. Representative Concentration Pathways

RMSE…………………… Root Mean Square error

RMSEn……………………Normalized Root Mean Square Error

WARDA…………………. West Africa Rice Development Association

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Résumé

La production agricole, en particulier la production de riz, est l'un des domaines prioritaires du document de politique agricole et des ressources naturelles de la vision 2020 pour la Gambie. Un essai agronomique a été mené en 2017 et 2018 dans les stations expérimentales de l'Institut national de recherche agricole de Sapu et Kuntaur en Gambie. L'objectif principal de cette étude était d'évaluer les impacts réels et perçus du changement climatique sous différents niveaux d'engrais et dates de transplantation pour le rendement des variétés de riz Sahel 134, IET 3137 et Gambiaka, à travers des expériences, des modèles de simulation et des méthodes participatives pour un mécanisme d'adaptation efficace parmi les petits agriculteurs de Gambie et du Mali. Des données ont été collectées sur la hauteur des plants, la longueur des panicules, le nombre de talles fertiles par plant, le rendement en grains, les jours jusqu'à 50% de floraison et les jours jusqu'à maturité physiologique à différentes dates de repiquage sur les variétés de riz sélectionnées. Les résultats ont montré une différence significative aux niveaux variétaux et aux taux d'engrais azotés sur les paramètres de la culture à (p <0,05. L'ensemble de données expérimentales de 2017 et 2018 a été utilisé pour adapter le modèle de culture de riz Ceres du système d'aide à la décision pour le transfert agrotechnologique (DSSAT) version 4.7).

Les résultats du modèle ont indiqué que les rendements de grains de riz mesurés et simulés, les dates d'anthèse ont une relation très étroite. La différence relative pour toutes les dates de repiquage, à différents niveaux d'engrais et entre les variétés varie de -0,5 à + 14,6%. pour le rendement en grains.Les données climatiques quotidiennes quotidiennes ainsi que les données climatiques projetées à court terme (1980 à 2039) et au milieu du siècle (2040 à 2069) avec un scénario d'émission de RCP 4.5 et RCP 8.5 pour Ségou, Mali et Kuntaur, Gambie. Les résultats indiquent une baisse de rendement pour toutes les dates de repiquage pour les deux scénarios d'émissions lorsque la fertilisation au CO2 n'a pas été prise en compte, mais la fertilisation au CO2 a compensé les baisses de rendement causées par l'augmentation des températures lorsque les valeurs de CO2 projetées ont été incorporées dans le DSSAT. Un gain de rendement de 1 à 50% a été observé sous GCM frais (GFDL-ESM2G) et 1 à 35% a été observé sur GCM chaud (HadGEM2-ES) pour les périodes de RCP 4.5 et 8.5, pour toutes les variétés et à différents niveaux d'engrais et dates de transplantation. Plus de gains sur le rendement ont été notés à Kuntaur, en particulier sur les variétés améliorées (Sahel 134 et IET 3137) et au repiquage de juillet. Une discussion de groupe a eu lieu avec vingt producteurs de riz à Sapu et Kuntaur, ils se sont divisés en cinq groupes. L'entretien personnel et l'informateur clé impliquent les deux chefs de village, deux présidents chargés du développement des jeunes (VDC) et l'agent de vulgarisation supervisant les deux villages. Cela a été fait pour acquérir des connaissances

approfondies sur le sujet. Les résultats de l'analyse ont indiqué que les agriculteurs dépendent fortement de leur propre perception ou de leurs connaissances qui ont été principalement obtenues auprès des familles ou des services de vulgarisation.
Mots-clés: Riz, Pratique de gestion, Changement climatique, Modélisation de la simulation des cultures, Perception des agriculteurs

Abstract

Agricultural production particularly rice production is one of the priority areas for vision 2020 agricultural and natural resources policy document for the Gambia. An agronomic trial was conducted in 2017 and 2018 at the National Agricultural Research Institute experimental stations of Sapu and Kuntaur in The Gambia. The main objective of this study was to assess the actual and perceived impacts of Climate change under different fertilizer levels and transplanting dates for the yield of Sahel 134, IET 3137 and Gambiaka rice varieties, through experiments, simulation modelling and participatory methods for effective coping mechanism among small scale farmers in The Gambia and Mali. Data were collected on plant height, panicle length, number of fertile tillers per plant, grain yield, days to 50% flowering and days to physiological maturity at different transplanting dates on the selected rice varieties. The results showed significant difference at both varietal levels and nitrogen fertilizer rates on the crop parameters at ($p<0.05$.The experimental data set of 2017 and 2018 were used to adapt the Ceres- rice crop model of Decision Support System for Agrotechnology Transfer (DSSAT version 4.7). Outputs of the model indicated that the measured and simulated rice grain yields, anthesis dates have very close relationship. The relative difference for all the transplanting dates, at different fertilizer levels, and across varieties ranges from -0.5 to +14.6% for the grain yield. The historical daily climate data alongside with the projected near term (1980 to 2039) and midcentury (2040 to 2069) climate data with emission scenario of RCP 4.5 and RCP 8.5 for Segou, Mali and Kuntaur, The Gambia. The results indicate a yield decline for all the transplanting dates for both emissions scenarios when CO_2 fertilization was not considered, but CO_2 fertilization did compensate for yield declines caused by increasing temperatures when projected CO_2 values were incorporated into the DSSAT. A yield gain of 1 to 50% was noticed with cool GCM (GFDL-ESM2G) and 1 to 35% was observed with hot GCM (HadGEM2-ES) for both RCP 4.5 and 8.5 time periods, across varieties and at different fertilizer level and transplanting dates. More gains on the yield was noticed at Kuntaur location especially on the improved varieties (Sahel 134 and IET 3137) and at July transplanting. Focus group discussion was held with twenty rice growing farmers at Sapu and Kuntaur, they divided into five groups. Personal interview and key informant involves the heads of the two village, two youth development chairpersons (VDC) and the extension worker overseeing both village. This was done to gain in-depth knowledge on the subject matter. The analysis results indicated that farmers rely heavily on their own perception or knowledge that were mainly obtained from families or extension service.

Keywords: Rice, Management practice, Climate change, Crop Simulation Modelling, Farmers Perception

Chapter 1 General introduction

1.1 Problem statement

The Gambia is situated on the West Coast of Africa and the land area consist of 480km length and 48km width. It is located at latitude between 13° and 14°N and longitude between 13.7° and 17°W. Agriculture employs around 75% of the population of The Gambia, ANR (2009), and rice remains the main staple food. As indicated by Ceesay, (2004), The Gambia meets most of its rice demand through importation, and around 80 percent of rice consumed in the Gambia were mainly from rice exporting countries because the indigenous production cannot meet rice demand in the country. It was estimated that in The Gambia an individual consumes around 117.33 kg of rice per year (Ceesay, 2004). The Gambia is on top in terms of rice consumption among the west African countries due to high dependence as the mojor source of carbohydrates (WARDA, 1993; Marong et al., 2001). The high demand in rice is said to continue to rise because of consumer preference, population growth and immigration of foreign nationalities into The Gambia (Ceesay, 2004). There should be planned efforts in placed to tackle such a situation in order to safeguard the lives and livelihood of the general population in The Gambia. These might include developing policy programs in the rice production sector that would cater for the situation in the future.

Agricultural production systems in developing countries faced a lot of extreme events because of climate change such as floods, drought, and extreme temperatures (IPCC, 2007). Rice production is highly influenced by climatic conditions such as rainfall and temperature for proper growth and development. Balasubramanian *et al.*, (2007),indicated that the production of rice would decline due to rise in temperature, as well as the distribution and marketing which might arise as a result of flood. In CGIAR, (2009), it is mentioned that the recent climate situation in Africa have already affected the lives and the livelihood of its citizens and issue of climate change will worsen the current situation.

These require quick responses to solve the issue by increasing irrigated land areas, coupled with suitable transplanting dates, because it was estimated that only 17% of land area in Africa is under irrigation as compared to 57% land area in China (WARDA)/FAO/SAA, 2008). It is of high demanding to introduce more irrigation systems in West Africa to ensure food security (Cassman and Grassini, 2013). In The Gambia the total arable land for is around 320,000 ha and 22.5% is currently allocated to rice production under rain fed condition(GNAIP, 2011).

The trend of rice productivity is declining on annual basis due to lack of appropriate farming technology, poor yielding varieties, and no subsides on fertilizer cost in The Gambia (Ceesay, 2004). The poor conditions of the West African soils and continuous cultivation of the same area of land without applying enough fertilizer to refill the lost nutrient has also contributed to the decline of productivity (Pieri, 1989; Bationo and Buerkert, 2001; Giller et al., 2011; Vanlauwe et al., 2011). It was calculated by researchers that the yearly decrease of NPK fertilizer per hectare in 30 years from African soils were 22: 2.5: 15 percent (Sanchez *et al.,* 1997). This situation will automatically decrease the yields. If the soil conservation methods are not applied by farmers, leaching, infiltration and percolation would also contribute to the nutrient decline, particularly in the lowland ecology. The selection of the appropriate cultivar is very important for the attainment of maximum yield. Late maturing varieties are mostly high yielding due to the sufficient time available for tillering and grain filling (Bello et al., 2012). Whilst short duration varieties are generally low in yield because they need optimum temperature to quickly reach flowering (Akbar et al., 2008).

The Fifth Assessment Reports of Intergovernmental Panel on Climate Change which was published in 2013 has indicated that the world climate is changing in faster pace as compared to the past 400,000 years. These situations will be accompanied by the increase of mean temperature of 1.5-2.0 °C with higher occurrences of extreme events (IPCC, 2013).

West African countries will be greatly impacted by climate change for example the extreme climate events (droughts) that happened in 1972 and 1984 had severe impacts on the lives and livelihood of small scale farmers(Cook et al., 2004; IPCC, 2001; Segele and Lamb, 2005; Washington and Preston, 2006).

Projections of the future climate in west Africa indicates a drier western Sahel and wetter eastern Sahel due to extreme events (Adiku and Stone, 1995). There have been adequate research on the simulation of the impacts of climate change on rice productivity in Asia (Aggarwal and Mall, 2002), whilst in Africa little research is done in this domain . The results of those simulations indicated that rice productivity would be affected negatively due to heat stress that will cause spikelet sterility and decrease the length of productive periods (Aggarwal and Mall, 2002). There were many studies that shows co2 effects in plants but however the effects of CO2 might not be shown in severe environmental conditions (Long, 1991).

The consistent approach to these simulations is the use of global climate models (GCM), that provide reliable climate data in the subject area, and for any scenario GCM models can provide reliable projections (Lobell, 2008).

Farmers On farm adaptation strategies such as change of transplanting dates are significant for the realization of high crop yields(Egharevba, 1979). The gender disparities in the agricultural workforce has also contributed to the decline of productivity. In The Gambia, women contribute to about 67% of the production force, indicating that rice production activities are majorly done by women(Ceesay, 2004). Although some adaptation efforts have been done through the expansion of cultivated land area and the introduction of improved varieties such as the NERICA (New Rice for Africa), though more planning are also on the expansion of the rice irrigation system (Africa Rice Center (WARDA), 2007).

1.2 State of the knowledge

1.2.1 The impacts of nitrogen fertilizer levels and transplanting dates on rice yield

Over the years, farmers in the Gambia have been growing some intraspecific varieties of *Oryza sativa* which was released by Africa rice center some years ago, namely (Sahel 134, Sahel 202, Sahel 201, WAB 105, Sahel 108), these varieties are high yielding of 6-7tons/ha (Ceesay, 2004). Rice is ranked as the fourth most staple food after maize, sorghum and millet in Africa (DeVries and Toenniessen, 2001). In the Gambia, rice is the most important source of carbohydrates (Ceesay, 2004).It was also estimated that around 75 percent of world rice production is under irrigation (Fischer *et al.*, 1996)and Africa comprised about 17% of the growing area as compared to Asia which was around 57%.

Rice production is highly influenced by mineral fertilizer application which is one of the main limiting factors in lowland rice production. Agricultural production particularly rice production is one of the priority areas for vision 2020 agricultural and natural resources policy document for the Gambia (ANR, 2009). Analysis conducted by NASS, (2013a) shows that agricultural production in Gambia has been decreased from 2008 to 2013.

Nitrogen fertilizer been the most important elements for rice production is limited in supply in the Gambia, just as in most developing countries as compared to China, where the average nitrogen application can reach 180 kg ha^{-1}, about 75% higher than the world average (Peng *et al.,* 2004). In order to attain maximum productivity, farmers usually increased the nitrogen application than minimum required to obtain maximum yield (Lemaire *et al.,* 2008). Studies conducted by Peng *et al.*, (2006), shows that only 20 to 30% of nitrogen is utilized by the crop for maximum productivity and the remaining is lost to the environment. Therefore, it is very necessary to improve nitrogen use efficiency in crop which can be achieved through the adjustment of crops nitrogen application (Dawe *et al.,* 2003; Dobermann, 2002).

1.2.2: Adapt the DSSAT crop simulation model for the selected irrigated rice varieties in The Gambia.

Crop simulation modelling was adopted to assess the impacts of climate and soil conditions on crops (Easterling *et al.*,1993). These tools are used to examine the impacts of climate change on crops adopted for simulation at the field level. Crop simulation models are necessary for establishing the relationships between the crop and its environment and the results can be extrapolated to other regions, thereby serving as an important tool for agricultural research and predictions of productivity of crops *(*Jones *et al.*, 2003). Crop simulation considers the dynamic relationship between the crop, weather, soil, water and nitrogen applications for efficient productivity. Recent improvements in crop models enables simulations at the field scale that undergoes calibration and validation for the effective running of the model (Tubiello and Ewert, 2002).

Ritchie *et al.,* (1987),the developer of CERES-Rice model was incorporated into the DSSAT group models Version 4.2 (Jones *et al.,* 2003).The CERES-Rice model is used to analysed rice yield and the biophysical interaction that exist between rice and its environment (Cheyglinted, 2001). Ceres rice model has the capacity to evaluate rice yields, nitrogen levels and water regime, but it has a weakness in evaluating pest and diseases on crops (Boutraa, 2010). Ceres-rice model has been used in most tropical and subtropical environments and other continents (Timsina, 2006;Vilayvong *et al.,* 2012; Ahmad *et al.,* 2012).

1.2.3 Assessing the potential impact of the projected climate change on rice crop yields.

Climate change has been projected for impacting agricultural production in the developing countries (Lobell *et al.,* 2008). Studies conducted by previous authors (Dai *et al.,* 2004;Hicholson, 2001), had all confirm increase rainfall in West Africa together with an increase in temperature that has contributed to decline in yields (Barrios *et al.,* 2008; Traore *et al.,* 2013). Temperature has been projected to be around 2.0 °C to 4.8°C by the end of the 21st century in the Sahelian countries (IPCC, 2013). Climate change as a results of temperature rise has been predicted in Sahel region and other parts of the globe (IPCC, 2007a).

The agricultural production sector worldwide has been undergoing tremendous times in terms of food production that is expected to feed a projected 9 billion people in the future, considering the limited resources, environmental situation, which has prompted the need for adaptation to reduce the impact on the future agriculture (Rosenzweig *et al.* 2013).

Efficient climate change impact assessment can be achieved through the considerartion of soil, crop atmosphere relationship as well as the economic component (Hillel and Rosenweig, 2010). The components of climate impacts assessment which is the soil, crop and economics can be determined through the use of statistical models (Schlenker et al., 2006; Lobell and Burke, 2010) and through process-based crop models (Keating *et al.* 2003; Brisson *et al.*, 2003; Jones *et al*., 2003; van lttersum and Donatelli, 2003; Challinor *et al.*, 2004).

Most of the current reviews on climate change impacts assessments, all highlight the need for the improvement of model for effective projections (Boote *et al.* 2010; White *et al.,* 2011; Rotter *et al.,* 2011). This would reduce the error that eventually arise at the end of the simulation, to enable accurate policy formulations. Agricultural intercomparison improvement project (AgMIP) is the tools formulated to tackle the issues of uncertainity in agricultural model that help researchers and policy making body to get accurate date for current and future climate projection, particularly the CO_2 elevation (Kimball, 1984; Tubiello and Ewert, 2002; Long *et al.*, 2006; Ainsworth *et al.,* 2008). AgMIP protocol has the ability to accurately simulate Co2, due to the incorporation of FACE (free-air carbondioxide enrichment), that will reduce the errors on CO_2 simulations, also the error on the issues of simulating yield gaps on crops such as the potential and actual yields which occurs as a results of pest and disease occurrence would be minimized (Rosenzweig *et al.* 2013).

Global circulation models are created from "well-establish physics of climate component" to assist in climate projection depending on emission of greenhouse gases into the atmosphere (Stocker *et al.,* 2013). Lowland rice production in the Gambia are highly influenced by climate variabilities such as sea level rise, extreme temperature, long period of inundation or flood during raining season. All the General Circulation Model projects temperature increase of 3.3°C in the Sahelian countries in Africa by the end of 21 century and if proper adaptation process are not taking into account, there will be high decline of crop yields. Although, there were large disagreement between the models as to whether the changes in rainfall would be negative or positive in sub-saharan africa (Cooper *etal.,* 2008).

Rice crop will be highly impacted by threats of climate change, an increased in carbon dioxide concentration in the atmosphere has high correlation with biomass production, but its translation to the yields depends on the temperature. As stated by Sheehy *et al.,* (2004), a rise of 75ppm of CO_2 concentration will result into 0.5 t/ha increment in rice yield and a rise of 1° temperature will lead to reduction of yield by 0.6 t/ha. This decrease in yield is mainly because of sink formation, reduction in growth periods, and a rise in maintenance respiration (Wassmann *et al.,* 2009). Numerous studies on Co_2 enrichment have indicated high biomass increment of 25 to 40% and yields 15 to 39% under optimum temperature conditions but yield reduction will occur when Co_2 increases alongside with the temperature (Ziska *et al.,* 1996; Moya *et al.,* 1998). Yield reduction because of both increase in temperature and Co_2 normally leads to spikelet sterility due to rise in temperature (Matsui *et al.,* 1997a), however there is a limited research on temperature x Co_2 correlation curve. Maintenance respiration at night is reduced when night temperature is more than 21°C in rice (Baker *et al.,* 2000). It should also be noted that rice yield is increased when Co_2 increased alongside with nitrogen supply, when there is enough Co_2 enrichment and nitrogen supply is limited will result into limited photosynthesis and growth supply (Ziska *et al.*, 1996b).

The climate change impacts assessments for this research involves the use of AgMIP protocol (Agricultural Model Intercomparison and Improvement Project, the protocol from AgMIP has capacity to inform the decision and policy making bodies with appropriate information on future impacts of climate change on crops for effective adaptation. It has also enable researchers the practices, improvement and adoption of agricultural models and scenarios that are suitable in the region of sub-Saharan Africa (Rosenzweig *et al.*, 2013). Studies conducted by White *et al.,* (2011), mentioned that, climate change impact studies generally are prone to bias in selecting climate models and this cause misunderstanding among decision makers. He shows a number of differences in crop modelling outputs with regards to the type of global climate model used in many studies.

1.2.4 Brief Decription of CO_2 and temperature impacts in rice growth process

There were many studies that confirms the impacts of high CO_2 concentration in plants, CO_2 supply or fertilization as reality (see Kimball, 1983; Acock and Allen, 1985; Cure and Acock, 1986; Allen, 1990; Rozema *et al.*, 1993; Allen, 1994; Allen and Amthor, 1995). Although there should be suitable environmental and soil conditions for the plant to effectively benefit from CO_2 fertilization (Long, 1991).

Rice crop that undergoes C_3 photosynthetic pathways benefits from high CO_2 supply under favourable condition unlike the C_4 plants (Baker and Allen, 1993a). Photosynthesis rate of plant goes along with the availability of sunlight intensity until the plant reaches asymptotic maximum. High CO_2 have impacts on plant phenology as well temperature levels, time and photoperiod. Suitable dates for transplanting of grains is important since phenological stages are influence by temperature levels(Baker and Allen, 1993a). Both rice and wheat grain yields have been increased by CO_2 enrichments (Gifford, 1977; Sionit et al., 1980, 1981a,b; Imai and Murata, 1976, 1979a,b; Imai et al., 1985; Baker et al., 1990a). tillering rate and spikes formations were high in wheat and panicle formation was also high in rice (Gifford 1977; Sionit et al., 1980, 1981a,b; Imai et al., 1985; Baker et al., 1990a).

The Projections of climate change scenarios indicated that high temperatures goes along with rise of CO_2 and other greenhouse-effect gases. The interation of Carbon dioxide x temperature increases vegetative growth (i.e., the CO_2 fertilization effect is greater at warmer temperatures than at cooler temperatures (Baker and Allen, 1993a). Rice grain yield is negatively correlated with air temperature during the reproductive phase of growth (Yoshida and Parao, 1976). At high tem- peratures, spikelet sterility is induced almost exclusively on the day of anthesis (Satake and Yoshida, 1978). Temperatures greater than 35°C for more than 1 hour induce a high percentage of spikelet sterility (Yoshida, 1981).

1.2.5 Rice Farmers perceptions about climate change, management practice and the on farm coping strategies at rice fields.

Small scale farming in Africa will be greatly affected by climate change due to low adaptation strategy (Sivakumar et al., 2005), these impacts will vary from one region to the other. Small scale farmers in West Africa have effectively utilized their scarce resources in order to cope with climate change (Mortimore and Adams, 2001), and the problems now lies on sustainability. One of the pillar in response to climate change impacts is the adaptive capacity of small scale farmers, farming sector will be greatly impacted without adaptation but the question is whether they will be able to continue to do this under a changing climate (Adger et al., 2003; Rosenzweig and Parry, 1994;). Waha et al., (2013a), indicated that adaptation greatly helps in climate change response. The farmer's perceptions about climate highly determines the kind of adaptation strategy to be adopted (Roncoli et al., 2001; Thomas et al., 2007). Many research on perception has supported inclusion of farmer's perception or indigenous knowledge into scientific knowledge (Mutiso, 1997; Sillitoe, 1998). Little research was conducted on farmer's perception on climate and how it impacts their adaptation options (Vedwan, 2006), the knowledge of past and recent adaptation strategies would greatly help in the fight against climate change (Kitinya et al., 2012).

1.3 Research hypothesis

The hypothesis for the study was that rice productivity would be impacted by climate change depending on management practices and that there are coping options existing among farmers to boost their yields.

1.4 Objectives

14.1 Overall objective

To assess the actual and perceived impacts of Climate change under different fertilizer levels and transplanting dates for the yield of Sahel 134, IET 3137 and Gambiaka rice varieties, through experiments, simulation modelling and participatory methods for effective coping among small scale farmers in the Gambia.

1.4.2 Specific objectives

1. Determine the impacts of nitrogen fertilizer levels and transplanting dates on selected irrigated rice varieties in The Gambia
2. Adapt the DSSAT crop simulation model for the selected irrigated rice varieties in The Gambia.
3. Determine the potential impact of the projected climate change on the yield of those rice varieties in The Gambia and Mali.
4. Determine farmers perceptions about climate change, management practice and the on farm coping strategies at rice fields in The Gambia.

Chapter 2: Impact of Nitrogen Fertilizer levels and Transplanting Dates on Irrigated Lowland Rice Yield in The Gambia.

2.1 Material and Methods

The experiment was conducted at National Agricultural Research Institute of the Gambia (NARI) experimental fields in Sapu and Kuntaur on plot number 8 and 9 at Central River Region South and North of the Gambia. The trials were conducted to fulfil the objectives of the research, it consisted of six transplanting dates of different rice cultivars at different fertilizer levels in the year 2017 and 2018.

2.2.1 Study site

The field experiment was conducted at Central River Region (CRR) on latitude 13.56 and longitude -15.93. it belongs to humid savannah vegetation type with the mean annual rainfall varying from 900 to 1200mm. The study sites have unimodal rainfall distribution with the peak of the rain in August, the rainfall begins from mid-July and ends at early October. Based on studies and local experiences rains begins about 15 days in the study area before the rest of the country(Ceesay, 2004)

The soil types are silty loam and clayed loam for Sapu and Kuntaur experimental fields after soil profile analysis. These soils were originally derived from the soils formed through alluvial material deposition by river Gambia and its tributaries, which is highly influenced by temporal or enduring wet conditions. Alluvial soils in the area comprised of 80 percent silt and some clay deposits.

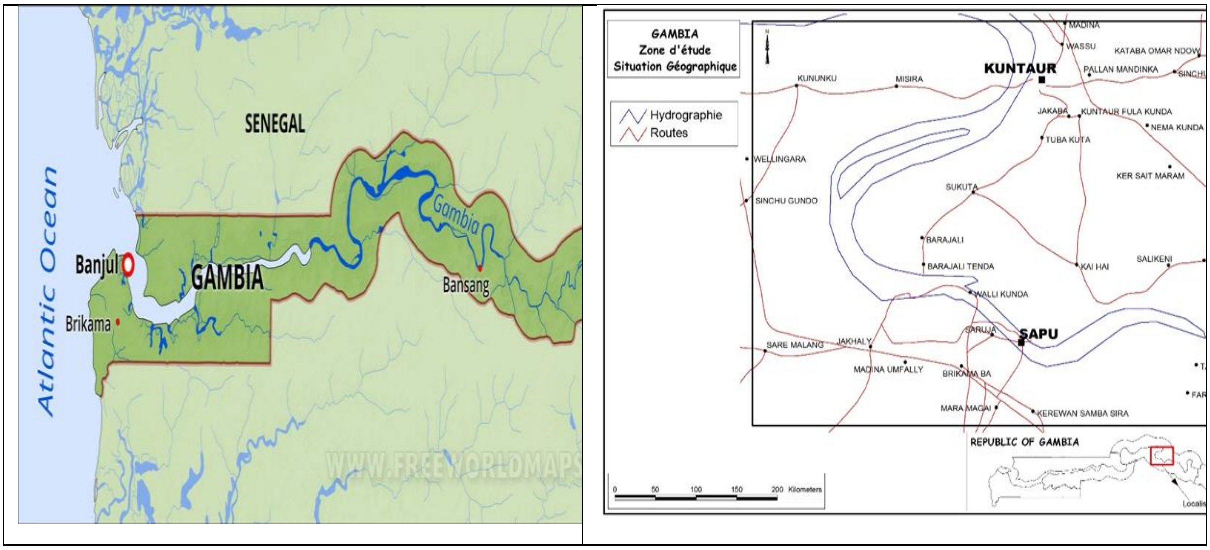


Figure 1: Map of Sapu and Kuntaur site

2.2.2 Treatment details

The experiment was a split-split plot design in three replications. It was repeated at different periods of the year at three transplanting dates (July, August and September in 2017) and the experiment was repetted in March, April and May in 2018).Three rice varieties (Sahel 134, IET 3137 and the Gambiaka) were used for the experiments with different nitrogen fertilizer application rates (90,120 and 150kgN/ha). The plot size was 6mx3m, with main plot treatment as transplanting dates, sub plot treatments as varieties and sub-sub plot treatment fertilizer levels. The field was cleared before the transplanting of the seedlings, the experimental field was puddled using 2-wheel power tiller and the levelling was done using levelling board which was mounted on the power tiller. Making of bunds was done to separate treatments and create foot paths at both study locations. Transplanting was done with thirty-five days old seedlings for all the treatments for both years. The rice seedlings were transplanted at two seedlings /hill with a spacing of 20x20cm.The experimental field was irrigated when necessary to maintain a water depth of 10cm for all the treatments. Weeding was done manually two times during the experimental periods and it was done on the specific dates. The inorganic fertilizers that were applied on the experimental fields included nitrogen, phosphorus and potassium at the levels of 90-60-60 kg, 120-60-60kg and 150-60-60kg (NPK), this was divided as basal application and top dressing during the experiments periods. The NPK level of 90-60-60, 45-60-60kg was applied as basal, 22kg nitrogen was applied at tillering and 23kg nitrogen was applied at heading. The NPK level of 120-60-60, 60-60-60 for the basal application and 30kg nitrogen during tillering and 30kg nitrogen at heading. The NPK level of 150-60-60, 75-60-60 for the basal treatments and 37.5kg nitrogen was applied at tillering and 37.5kg nitrogen at heading. The NPK were applied at these levels and at those specific periods to provide sufficient nutrients during the critical stages of rice production.

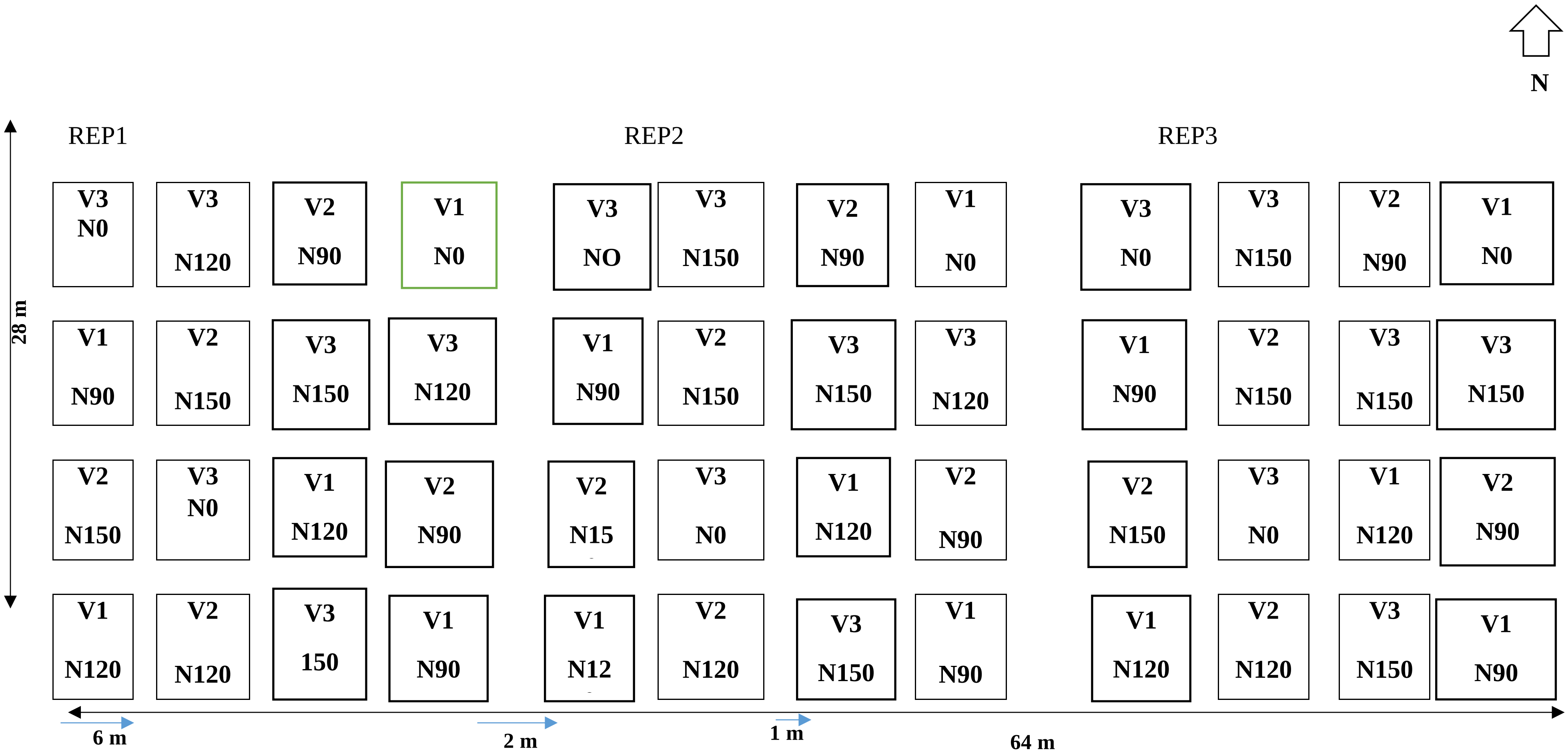


Figure 2: Field layout of the experimental field

Table 1 Nitrogen treatment

Treatment	Code	N	P	K
N1 Sahel 134	N1 SL134	0	0	0
N1 IET 3137	N1 IT 3137	0	0	0
N1 Gambiaka	N1 GMBK	0	0	0
N2 Sahel 134	N2 SL 134	90	60	60
N2 IET 3137	N2 IT 3137	90	60	60
N2 Gambiaka	N2 GMBK	90	60	60
N3 Sahel 134	N3 SL 134	120	60	60
N3 IET 3137	N3 IT 3137	120	60	60
N3 Gambiaka	N3 GMBK	120	60	60
N4 Sahel 134	N4 SL 134	150	60	60
N4 IET 3137	N4 IT 3137	150	60	60
N4 Gambiaka	N4 GMBK	150	60	60

2.2.3 Data collection details

- Tillering Rate

At 55 DAT(days after transplanting) six plants were selected from each plot, the number of tillers from each plant were counted and recorded.

- Days to 50% Flowering

A 3x3m within the plot were calculated and the plant population were recorded, the vigorous plant per plot were selected and marked. The number of plants that flower on daily basis were recorded and when half of the marked plants have flowered within the 3x3m plot, the date was recorded to calculate days from planting to that date.

- Plant Height at Maturity

Plant height was recorded from each plot before biomass sampling. The initial measurements for plant height and biomass sampling was obtained before N application to determine the N responses.

- Days to Physiological Maturity

Within the 3x3m plot, the number of days to physiological maturity were recorded. That is when the panicle turns brown. When the plants within the 3x3m are physiologically mature, the date were recorded and the number of days from planting to that date were also recorded.

- Harvesting and threshing

The rice crop was harvested when the grains reached physiological maturity with a moisture content of 20-25%. The crops were harvested in the middle thereby leaving 3 border rows at both side of each plot. The harvested grains were threshed and sun dried for several days to reach (14%) moisture content before weighing.

- Grain Yield

Within the 3x3m that was used for yield parameter calculations, all the grains were weight and the yield were recorded in ton or kg per ha, the 1000 grain weight was determined.

2.2.4 Data analysis

The data collected were analyzed using Genstat version 12 edition. The analysis of variance was conducted on the collected data to determine the difference between the treatments. The Newman Student-kleus method was used to test the significance of the difference between treatments means at the 0.05% probability threshold.

2.3 Results

2.3.1 plant height

- Effects of Transplanting Dates on plant Height

Transplanting dates for this experiments have not significantly influenced plant height. The results show an average plant height of 94.9, 94.9, 94.9, 94.1, 94.6 and 94.4cm for all transplanting dates. More details are shown in **Table** 2 and 3.

- Effects of Genotype on Plant height

The average plant height of 115.88cm was recorded for the Gambiaka rice variety, followed by IET 3137 with 98.5cm, and the lowest average plant height was recorded for Sahel 134 with 70.44cm at both study locations. Those differences were significant at the 5% probability level.

- Effects of Nitrogen Levels on plant height

The highest average plant height was recorded from the fertilizer application level of 150kg/ha with 96.8cm, followed by nitrogen level 120kg/ha with 94.2cm and 94.17cm, then 94.0cm and 94.0cm, the lowest average plant height was recorded from the control treatments 93.75cm and 94.1cm at both Sapu and Kuntaur study locations. However, those difference were not significant at the 5% probability level, **Table** 2 and 3.

- Interaction between varietis, fertilizer levels and transplanting dates

The interactions effects between varieties have indicated influence on plant height in **Table** 3 and 4. However, the interaction effects on location, fertilizer levels, transplanting date, genotypes, varieties did not show influence on this study.

2.3.2 Number of tiller

- Effects of transplanting dates on tiller numbers

The greatest tiller number was obtained for transplanting 3 (24.1), followed by transplanting 2 (22), then transplanting 5 and 1, the least tiller was recorded from transplanting 4 (21) at Sapu study location.

On the Kuntaur study site, transplanting 1 had the maximum tiller number (24), followed by transplanting 2 (22) then transplanting 4,5 and 6, the lowest was recorded from transplanting 3 (21),**(Table** 2 and 3).

- Effects of Genotypes on tiller numbers

The Gambiaka rice variety produced more tillers per hill (29 and 28), while a low tillering rate was recorded from Sahel 134 (19 and 19) at the study location of Sapu and Kuntaur, respectively. There were significant differences between the cultivars on the tiller numbers as indicated in **(Table** 2 and 3).

- Effects of Nitrogen Levels on tiller numbers

The highest tillering rate was achieved at the nitrogen fertilizer level of 150kg N/ha at Sapu and Kuntaur study sites (30 and 29), while from the control treatment of fertilizer level zero, the average tiller number was (13 and 12) **(Table** 2 and 3).

- Effects of interaction on tiller numbers

The interaction between the fertilizer levels and the genotype was highly significant (pvalue<0.001) but the interaction between the transplanting dates, genotypes and nitrogen levels was not significant at both study locations.

2.3.3 Weight of 1000 grains

- Effects of transplanting dates on 1000 grain weight

The maximum 1000grain weight was obtained from transplanting 2 (27.11g and 27.31g), and the lowest was obtained from transplanting 4 (25.13g and 25.11g) at Sapu and Kuntaur, respectively, **(Table** 2 and 3).

- Effects of varieties or Genotypes on 1000 grain weight

Genotype influence on 1000 grain weight was highly significant at both study locations. Gambiaka had a 1000 grain weight of (33.52 and 30.32 g), IET 3137 (27.35g and 27.36g) and the lowest weight was observed in Sahel 134 rice variety which score (26.7g and 23.44g) **(Table** 2 and 3).

- Effects of Nitrogen Levels on 1000 grain weight

The highest record of 1000 grain weight was noticed from the application of 150kg nitrogen per hectare (30.25g and 28.51g), then 120kg nitrogen level (26.83g and 26.85g), followed by 90kg (26.21 and 26.12) nitrogen level and the lowest record was observed from the control plots which did not receive any nitrogen fertilizer application (24.35g and 24.45g) nitrogen levels at Sapu and Kuntaur respectively, details in **(Table** 2 and 3).

- Effects of interaction on 1000 grain weight

The interaction between varieties and fertilizer levels was significant at 0.005 probability threshold. But the interactions between the fertilizer rates, varieties, and transplanting dates was not significant at both study sites.

3.7.4 Grain yield

- Effects of Transplanting dates on grain yield

Transplanting dates are highly significant on grain yield in lowland rice production. The analysis data of this experiment pertaining to the effects of transplanting dates on grain yield showed that the maximum grain yield was obtained at transplanting 3 (4.9 tons/ha and 4.7 tons/ha), this is followed by transplanting date 6 (4.1 and 3.9 tons /ha) and the least was recorded from transplanting 4 (3.4 and 3.3 tons/ha) (**Tabl**e 2 and 3)

- Effects of Genotypes on grain yield

The Gambiaka rice cultivar scored the maximum grain yield of (5.8 and 5.6 tons/ha), then IET 3137 (3.9 and 3.7 tons/ha) and the lowest was recorded from Sahel 134 (3.4 and 3.3 tons/ha) at the study locations of Sapu and Kuntaur, respectively.

- Effects of Nitrogen levels on grain yield

The maximum grain yield was recorded from fertilizer level 150kg/ha N (5.0and 5.2 tons/ha). Fertilizer level 120kg/ha N obtained a yield of (4.4 and 4.2 tons /ha), fertilizer level 90kg/ha N scored a yield of (3.8 and 3.9 tons /ha) and the lowest grain yield was obtained from fertilizer level zero kg/ha N (3.1 and 3.0 tons /ha). These differences among between the fertilizer levels were significant at both study locations **(Table** 2 and 3).

- Effects of interaction on grain yield

The interaction between the fertilizer levels and genotype on grain yield were highly significant (<.001). But the interaction between the fertilizer levels, genotype and transplanting dates were not significant at 0.05 probability threshold at both study locations.

3.7.5 Total Biomass

- Effects of Transplanting Dates on biomass weight

Transplanting date 3 has scored the highest biomass yield of (5.24 and 2.22 tons/ha), transplanting 2 has (5.18 and 5.11 tons/ha), the lowest biomass yield was recorded from transplanting 4 (4.98 and 4.50 tons/ha).

- Effects of Genotypes on biomass yield

The highest biomass yield was recorded from the Gambiaka variety (5.58 and 5.60 tons/ha), followed by IET 3137 (5.20 and 5.19 tons/ha). The lowest biomas yield was obtained from Sahel 134 (4.9. and 4.88 tons/ha). The differences among genotypes was highly significant at both study locations, **(Table** 2 and 3).

- Effects of Nitrogen levels on biomass yield

Fertilizer levels has high impacts on biomass weight, the maximum biomass weight was obtained from fertilizer level 150kg/ha (5.8 and 5.7), fertilizer level 120kg has a biomass weight of (5.56 and 5.55), 90kg fertilizer level has a biomass yield score of (5.1 and 5.0) and the least was recorded from fertilizer level zero (4.10 and 4.12),**(Table** 2 and 3).

- Interaction Effects on biomass weight

The interaction between the fertilizer levels and genotypes was highly significant but the interaction between the transplanting dates, genotypes and fertilizer levels was not significant at 95% probability at both study locations.

2.3.6 Panicles per hill

- Effects of Transplanting Dates on panicle number per hill

Transplanting dates have significant impacts on the panicle number per hill in low land rice production. Transplanting 3 has the highest panicle number per hill (23.22 and 24.04), whilst transplanting 2 has a panicle number per hill of (22.81 and 23.44) and least was observe from transplanting 4 (19.17 and 22.96). There were significant differences between the transplanting dates and panicle number per hill **(Table** 2 and 3).

- Effects of Genotype on panicle per hill

Varieties of rice crop has significant influence on panicle number per hill. Gambiaka rice variety scored 27.56 and 27.31, followed by IET 3137 rice cultivar (23.22 and 22.63) and the lowest panicle number per hill was obtained from Sahel 134 rice variety (18.50 and 17.50) at both locations.

- Effects of Nitrogen levels on panicle number per hill

Nitrogen levels has huge influence on panicle number /hill, the maximum panicle number was obtained from fertilizer level 150kg (29.83 and 29.25), then 120kg fertilizer level has score

27.58 and 26.42, then fertilizer level 90kg has obtained 22.08 and 21.72 and the least was recorded from fertilizer level zero (13.17 and 12.53).

- Effects of interaction on panicle per hill

The interaction between the fertilizer levels and varieties was highly significant but the interaction between the transplanting dates, nitrogen levels and the varieties were not significant at 95% probability level and at both study locations.

Table 2: Analysis of fertilizer level and transplanting dates on yield and yield components of rice at Sapu experimental site

	Tillers/hill	Days to 50%flower	Biomass wgt (tons/ha)	Panicle/hill	1000 GWT (g)	Grain yield (Ton/Ha)	Plant hgt (cm)
Varieties							
Sahel 134	19.28 a	60.96 a	4.88 a	17.50 a	23.44 a	3.4 a	70.44 a
Gambiaka	28.74 b	99.67 b	5.58 b	27.31 b	30.36 b	5.8 b	115.88 c
IET 3137	23.86 c	74.75 c	5.19 a	22.62 c	27.35 c	3.8 a	98.50 b
Grand mean	22.79	74.60	5.13	22.48	26.15	4.4	94.94
Fertilizer levels							
0-0-0	13.24 a	73.44 a	4.12 a	12.53 a	24.35 a	3.1 a	93.80 a
90-60-60	21.26 b	73.83 a	5.06 b	21.72 b	26.83 b	3.9 b	94.00 b
120-60-60	26.26 c	74.36 b	5.55 c	26.42 c	26.21 c	4.4 c	94.20 b
150-60-60	30.40 d	74.63 b	5.80 d	29.25 d	27.20 d	5.0 d	96.80 c
Grand mean	22.79	74.09	5.13	22.48	29.53	4.4	94.9
Transplanting dates							
Date 1	24.22 a	74.07 a	4.80 a	22.96 a	25.13 a	4.9 a	94.63 a
Date 2	22.62 b	74.12 a	5.18 b	23.44 b	27.11 b	3.9 b	94.63 a
Date 3	21.53 c	74.09 a	5.22 c	24.04 c	26.20 c	3.3 c	94.63 a
Grand mean	22.79	74.09	5.13	22.61	26.15	4.1	88.63
Probability V	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Probability F	0.001	NS	0.004	0.001	0.002	0.003	0.004
Probability T	NS	NS	0.032	0.004	0.001	0.001	NS
Interaction V*F	0.001	0.001	0.002	0.001	0.001	0.001	0.001
Interaction V*T	NS	NS	NS	NS	NS	NS	NS
Interaction F*T	NS	NS	NS	NS	NS	NS	NS
Interaction T*V*F	NS	NS	NS	NS	NS	NS	NS

Source: *Student-Newman-Keuls test on yield and yield component Sahel 134, Gambiaka and IET 3137 rice varieties (GenStat 12ed).*

NB: a> b> c> d: *the averages assigned to the same letter in the same column are not statistically different at the 5% probability threshold.*

V*: Probability variety,* ***F****: Probability fertilizer,* ***T:*** *Probability transplanting dates:*

Table 3: Analysis of fertilizer level and transplanting dates on yield and yield components of rice at Kuntaur experimental site

	Tillers/hill	Days to 50%flower	Biomass wgt	Panicle/hill	1000 GWT	Grain/Ton/Ha	Plant hgt
Varieties							
Sahel 134	19.17 a	60.96 a	4.88 a	17.50 a	23.44 a	3.3 a	70.44 a
Gambiaka	28.22 b	99.67 b	6.58 b	27.31 b	30.32 b	5.6 b	115.88 c
IET 3137	23.53 c	74.75 c	5.19 a	22.62 c	27.36 c	3.7 a	98.50 b
Grand mean	22.79	78.60	5.20	22.48	29.53	4.4	94.94
Fertilizer levels							
0-0-0	12.97 a	73.44 a	4.12 a	12.53 a	24.45 a	3.1 a	93.80 a
90-60-60	20.94 b	73.83 a	5.06 b	21.72 b	26.12 b	3.9 b	94.00 b
120-60-60	26.19 c	74.36 b	5.55 c	26.42 c	26.85 c	4.4 c	94.20 b
150-60-60	29.97d	74.67 b	5.79 d	29.25 d	27.20 d	5.2 d	96.80 c
Grand mean	24.28	74.09	5.20	22.48	29.53	4.4	94.9
Transplanting dates							
Date 1	24.22 a	74.07 a	4.50 a	22.96 a	25.13 a	4.7 a	94.63 a
Date 2	22.62 b	74.12 a	5.18 b	23.44 b	27.11 b	3.9 b	94.63 a
Date 3	21.53 c	74.09 a	5.22 a	24.04 c	26.20 c	3.3 c	94.63 a
Grand mean	22.79	74.09	5.13	23.61	26.15	4.1	88.63
Probability V	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Probability F	0.001	NS	0.001	0.001	0.002	0.001	0.001
Probability T	0.004	NS	0.002	0.004	0.004	0.011	NS
Interaction V*F	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Interaction F*T	NS	NS	NS	NS	NS	NS	NS
Interaction V*T	NS	NS	NS	NS	NS	NS	NS
Interaction F*T *V	NS	NS	NS	NS	NS	NS	NS

Source: *Student-Newman-Keuls test on yield and yield component Sahel 134, Gambiaka and IET 3137 rice varieties (GenStat 12ed).*
NB: a> b> c> d: *the averages assigned to the same letter in the same column are not statistically different at the 5% probability threshold.*

Chapter 3: Adapting the DSSAT crop simulation model for most commonly used rice varieties at different fertilizer levels and transplanting dates in The Gambia.

3.1 Materials and Methods.

The experiment was conducted at the National Agricultural Research Institute of the Gambia (NARI) experimental fields in Sapu and Kuntaur.The trials were conducted to fulfil the objectives of the research, it focuses on six transplanting dates with different cultivars and different fertilizer levels in the year 2017 and 2018 respectively.

3.2 Treatment Details

Three rice varieties were used for the experiments (Sahel 134, IET 3137 and the Gambiaka) with different nitrogen fertilizer application rates (0, 90,120 and 150kg) and a control at six transplanting dates (July, August and September 2017 and March, April and May 2018). Other details of the experiments and results were described in Chapter 2 above.

3.2.1 Inputs data of the Model

- Weather directory file

The file WTH.DIR contains a list of weather data for several years. Weather files created for the years 2017 and 2018 experiments for the study location of Sapu and Kuntaur were included in the list of historical weather files. The historical data from 1980 to 2018 includes the daily solar radiation, minimum and maximum temperature and rainfall.

- Soil properties directory file

The file SOIL.SOL contains the list of different soils with their physical and chemical properties. The soil conditions of Sapu and Kuntaur were included in soil file.

- Soil profile initial conditions

The soil profile initial condition file contained the initial values of soil water, soil reaction and soil nitrogen data depending on the local situation, the appropriate data were inputted.

- Irrigation management

The irrigation management window has the provision of date and amount of water (mm) applied depth (cm). For the purpose of this research water was applied when required at 10 cm depth. No recording of dates and irrigation amount was conducted.

- Fertilizer management file

The fertilizer management file contained the date, form and amount of nitrogen application. For this particular research 4 fertilizer levels were used and their information were entered as required.

- Treatments

For each transplanting date 12 treatment were involved which include the 3 rice varieties and the 4 nitrogen fertilizer levels. All the treatments were incorporated into the DSSAT treatment window.

- Genotype file

The file RICER047.SPE contained the list of different rice cultivars with their genetic coefficients (see **Table** 5). Those for our varieties were obtained by adapting existing ones determined by the Africa Rice Centre Saint Louis (Senegal). The genetic coefficients viz., P1, P2R, P2O, P5, G1, G2, G3 and G4 (described in adaptation part of this chapter) were modified for the selected varieties of this research.

- Field observed data

The field observed data window is meant for entry of observed data on crop performance at the field. It enables the model to compare the simulated and the observed data. As needed the observed data on yield and yield components were incorporated into this window.

Table 4 Cultivar parameters of Ceres-rice model

S. No	Description of the coefficients
1	P1: time period (expressed as growing degree days (GDD) in oc above a base temperature of 90^{o}C) from seedling emergence during which the rice plant is not responsive to changes in photoperiod. This period is also referred as the basic vegetative phase of the plant.
2	P20: Critical photoperiod or the longest day length (in hours) at which the development occurs at a maximum rate. At values higher than P20 developmental rate is slowed, hence there is delay due to longer day lengths
3	P2R: Extent to which phasic development leading to panicle initiation is delayed (expressed as 0°C) for each hour increase in photoperiod above P20.

4	P5: Time period in GDD (oC) from beginning of grain filling (3 to 4 days after flowering) to physiological maturity with a base temperature of 9°C.
5	G1: Potential spikelet number co-efficient as estimated from the number of spikelet's per g of main culm dry weight (less leaf blades and sheaths plus spikes) at anthesis. A typical value is 55.
6	G2: Single grain weight (g) under ideal growing conditions, i.e. non-limiting light, water, nutrients and absence of pests and diseases.
7	G3: Tillering co-efficient (scalar value) relative to IR64 cultivar under ideal conditions. A higher tillering cultivar would have co-efficient greater than 1.0.
8	G4: Temperature tolerance co-efficient. Usually 1.0 for varieties grown in normal environments. G4 for japonica type rice growing in a warmer environment would be 1.0 or greater. Likewise, the G4 value for indica type rice in very cool environments or season would be less than 1.0

Source: (Hoogenboom *et al.,* 2010)

3.2.4 Adaptation of the CERES Rice model

The CERES- Rice component of DSSAT model v 4.6 (Hoogenboom et al., 2010), was the tool used for this research work. Adaptation is the process of adjusting some model parameters to local conditions which is geared towards enabling closeness between the observed and the simulated values. The model was adapted with the data collected during experimental periods of July, September 2017 and April 2018. There were six transplanting dates in total at each study location. Then August 2017, March and May 2018 was used for model evaluation.

To check the accuracy of the model simulation, the data obtained from the experimental fields such as the available data on grain yield, anthesis dates were compared with simulated values.

3.2.5 Evaluation of the model

Evaluation of the model is the comparison of the results of model simulations with observations from crops that were not used for the adaptation. The experimental data sets of August 2017, March and May 2018, was used for the evaluation of the model. Different statistical measures such as RMSE, RMSEn and r-Square (Willmott et al., 1985; Wallach and Goffinet 1987)were used to compare observed and simulated results and they are as follows.

RMSE (root mean square error)

$$\boldsymbol{RMSE} = \left[\frac{\mathbf{1}}{\boldsymbol{n}} \sum (\boldsymbol{P_i} - \boldsymbol{O_i})^2\right]^{\mathbf{1/2}}$$

Where

pi is the simulated values

Oi is the observed values

n is the number of observation

In addition to this, the overall performance of model was estimated using Normalized RMSE (RMSEn), which gives a measure (%) of the relative difference of simulated against observed data. The simulation is considered excellent with a normalized RMSE less than 10 %, good if the normalized RMSE is greater than 10 and less than 20%, fair if the normalized RMSE is greater than 20% and less than 30%, and poor if the normalized RMSE is greater than 30% (Loague and Green, 1991).

Normalized root mean square error

$$\boldsymbol{RMSEn} = \left[\frac{\boldsymbol{RMSE}}{\overline{\boldsymbol{O_i}}}\right] \boldsymbol{x100}$$

Where

Oi is the observed values

3.3 Results

3.3.1 Model adaptations

The model was adapted using experimental data of July, September and April, the genetic coefficient of the selected rice varieties are presented in table 5 below.

Table 5: Estimated genetic coefficient of Sahel 134, IET 3137 and Gambiaka rice varieties

Varieties	**Parameters**							
	P1	**P20**	**P2R**	**P5**	**G1**	**G2**	**G3**	**G4**
Sahel 134	600	13	100	150	58	0.0250	1.00	1.00
Gambiaka	700	11	200	180	60	0.0300	1.00	1.00
IET 3137	650	12.4	150	160	60	0.0270	1.10	1.00

3.3.2 Grain Yield for Kuntaur Location

The results of the simulation on the grain yield showed that the model satisfactorily estimated Sahel 134 at 90kg/ha N fertilizer level at the August 20 transplanting date 2.8%, this is followed by 120kg 8.5% and then 150kg 10.9%. Similar condition was observed with Gambiaka rice variety, where close estimation was noticed at 150kg 1.1% fertilizer level followed by 90kg -8.4% and then 120kg fertilizer level 11.5%. As for IET 3137, good estimation was observed on 120kg fertilizer level 0.2%, then followed by 90kg 1.2% and then 150kg fertilizer level 4.5%.

At March 20 transplanting, a good agreement was again obtained between the simulated and the observed grain yield for Sahel 134 at 150kg nitrogen fertilizer level -1.1%, followed by 90kg 1.9% and then 120kg 5.9% nitrogen fertilizer level. Similar close estimation was noticed for Gambiaka rice variety at 90kg nitrogen fertilizer level 0.13%, then 120kg 2.7% and then 150kg nitrogen fertilizer level 4.7%. Also a good agreement was observed for IET 3137 rice variety at 90kg nitrogen fertilizer level -0.5%, then 120kg 2.4% and finally 150kg nitrogen fertilizer level -8.6%.

At May 20 transplanting a good agreement was also noticed between the observed and the simulated values for Sahel 134 at 90kg nitrogen fertilizer level 0%, followed by 150kg -4.1% and 120kg nitrogen fertilizer level -10.4%. As for cultivar Gambiaka, a good estimation was obtained at 90kg nitrogen fertilizer level 0.9%, followed by 150kg nitrogen fertilizer level -3.0% and then 120kg 14.6% nitrogen fertilizer level. The IET 3137 variety also had similar closeness of he observed and simulated grain yields at 150kg nitrogen fertilizer level -2.1%, followed by 120kg 3.5% and then 90kg 4.3%.

The model at some instances overestimated the values and at some it underestimated the values at all transplanting dates across fertilizer levels and varieties. At both first and second transplanting dates closeness between the observed and the simulated values was noticed on Sahel 134 at 150kg and 90kg nitrogen level as compared to Gambiaka and IET 3137 varieties. Whilst for third transplanting date more closeness was observed on IET 3137 as compared to other varieties.

The model has satisfactorily simulated rice grain yield at all transplanting dates for Sahel 134, more closeness was shown at 90kg nitrogen fertilizer level for Sahel 134 rice variety with the RMSE, RMSEn and r-Square of (56), (2.4) (and 0.99) respectively, this is followed by 120kg nitrogen level (238), (9.2) and (0.96), then 150kg nitrogen level (531) (9.8) and (0.99).

The RMSE, RMSEn and r-Square for Gambiaka rice variety at different transplanting dates and at 150kg nitrogen fertilizer levels were (189.6), (3.0) and (0.97), which was followed by 90kg nitrogen fertilizer level (269), (5.2) and (0.93), then at 120kg nitrogen fertilizer level (532), (9.7) and (0.98).

The simulated and observed grain yield for IET 3137 was found good agreements with the RMSE, RMSEn and r-Square values of (75), (1.9) and (1) for 150kg fertilizer level at different transplanting dates, then 120kg nitrogen fertilizer level (85), (2.4) and (0.99), then 90kg nitrogen fertilizer level (101), (3.1) and (0.99), (see **Table** 6.)

Table 6 Observed and simulated rice grain yields (kg/ha) at different dates of transplanting and nitrogen levels at Kuntaur location

Varieties	**Transplanting dates**	**Nitrogen Fertilizer levels**					
		90 kg/ha		**120kg/ha**		**150kg/ha**	
Sahel 134		**observed**	**simulated**	**observed**	**simulated**	**observed**	**simulated**
	20/08/2017	3300	3394 (2.8%)	3666	3979 (8.5%)	4233	4693 (10.9%)
	20/03/2018	1599	1629 (1.9%)	1666	1764 (5.9%)	1700	1682 (-1.1%)
	20/05/2018	2152	2152 (0%)	2393	2143 (-10.4%)	2263	2157 (-4.1%)
	RMSE	56		238		531	
	NRMSE	2.4		9.2		9.8	
	r-Square	0.99		0.96		0.99	
Gambiaka	20/08/2017	5534	5071 (-8.4%)	5610	6253 (11.5%)	7166	7247 (1.1%)
	20/03/2018	3800	3805 (0.13%)	4800	4929 (2.7%)	5121	5362 (4.7%)
	20/05/2018	5906	5961 (0.9%)	5823	6671 (14.6%)	6933	6725 (-3.0%)
	RMSE	269		532		189.6	
	RMSEn	5.2		9.7		2.96	
	r- square	0.93		0.98		0.97	
IET 3137	20/08/2017	3806	3762 (1.2%)	4433	4442 (0.2%)	4300	4493 (4.5%)
	20/03/2018	2133	2122 (-0.5%)	2266	2321 (2.4%)	2333	2132 (-8.6%)
	20/05/2018	3900	4069 (4.3%)	3933	4071 (3.5%)	3433	3361 (-2.1%)
	RMSE	101		85		75	
	RMSEn	3.1		2.4		1.9	
	r-Square	0.99		0.99		1	

RMSE: Root Mean Square Error, RMSEn: Normalized Mean Square Error

3.3.3 Anthesis Date at Kuntaur study Location

The August 20 transplanting date for Sahel 134 showed good estimate between the observed and simulated anthesis dates at 120kg nitrogen fertilizer level 5.8%, similar close estimate was noticed for both 150kg 5.8% and 90kg nitrogen fertilizer level 8%. The Gambiaka rice variety also have a fair correlation between the observed and simulated anthesis date at nitrogen level 90kg, 120kg and 150kg -11%. A similar situation was also observed with the IET 3137 rice variety at 90kg, 120kg and 150kg nitrogen fertilizer levels -8.8%.

Another good estimate was noticed at the March 20 transplanting for the Sahel 134 variety at 90kg nitrogen fertilizer level -8.9%, followed by 120kg and 150kg nitrogen fertilizer level -10.5%. The Gambiaka rice variety showed a good estimation of yield at 90kg, 120kg and 150kg nitrogen fertilizer level 7.2%. Similar condition was noticed for IET 3137 rice variety at 90kg -7.7%, 120kg nitrogen fertilizer level -9.5% followed by 150kg nitrogen fertilizer level -10.4%. As at the May 20 transplanting date, similar situation was observed for Sahel 134 at 90kg, 120kg and 150kg nitrogen fertilizer level -7.3%. As for the Gambiaka rice variety, the same close estimation was observed at 90kg, 120kg and 150kg nitrogen fertilizer level -5.1%. The IET 3137 variety, showed good estimation at 90kg, 120kg and 150kg nitrogen fertilizer level -6.2%.

The model at some point, it under estimate the values and sometime over estimation was also noticed in all the transplanting at different fertilizer levels and across varieties than over estimation. In all the transplanting dates greater closeness between the observed and the simulated values were noticed on Sahel 134 followed by IET 3137 and then Gambiaka rice varieties.

The results of the simulation on the anthesis dates indicates that the model satisfactorily estimates Sahel 134 at 90kg nitrogen fertilizer level in all the transplanting dates with the RMSE, RMSEn and r-Square of (4.3), (8.0) and (0.97) respectively, followed by 120kg and 150kg nitrogen level (4.5), (8.3) and (0.89).

Near estimation was also noticed with Gambiaka rice variety at different transplanting dates and at 90kg nitrogen levels with RMSE, RMSEn and r-Square of (5.9), (7.8) and (0.07), followed by 120kg nitrogen fertilizer level (5.9), (7.8) and (0.07) and then 150kg fertilizer level (5.6), (7.4) and (0.08).

A closer estimation on observed and simulated anthesis dates for IET 3137, at 90kg nitrogen fertilizer and at different transplanting dates with RMSE, RMSEn and MBE values of (5.0), (7.7) and (0.75), followed by 120kg fertilizer level (5.4) (8.2) and (0.4) and then 150kg fertilizer level (5.8), (8.7) and (0.1).

Table 7 Observed and simulated anthesis dates at different dates of transplanting and nitrogen levels at Kuntaur location

Varieties	**Transplanting dates**	**Nitrogen Fertilizer levels**					
		90 kg/ha		**120kg/ha**		**150kg/ha**	
		observed	**simulated**	**observed**	**simulated**	**observed**	**simulated**
Sahel 134	20/08/2017	50	54 (8%)	51	54 (5.8%)	51	54 (5.8%)
	20/03/2018	56	51 (-8.9%)	57	51 (-10.5%)	57	51 (-10.5%)
	20/05/2018	55	51 (-7.3%)	55	51 (-7.3%)	55	51 (-7.3%)
	RMSE	4.3		4.5		4.5	
	RMSEn	8.0		8.3		8.3	
	r-Square	0.97		0.89		0.89	
Gambiaka	20/08/2017	80	72 (-11%)	80	72 (-11%)	80	72 (-11%)
	20/03/2018	69	74 (7.2%)	69	74 (7.2%)	69	74 (7.2%)
	20/05/2018	79	75 (-5.1%)	79	75 (-5.1%)	79	79 (-5.1%)
	RMSE	5.9		5.9		5.6	
	RMSEn	7.8		7.8		7.4	
	r-Square	0.07		0.07		0.08	
IET 3137	20/08/2017	68	62 (-8.8%)	68	62 (-8.8%)	68	62 (-8.8%)
	20/03/2018	65	60 (-7.7%)	66	60 (-9.5%)	67	60 (-10.4%)
	20/05/2018	65	61 (-6.2%)	65	61 (-6.2%)	65	61 (-6.2%)
	RMSE	5.0		5.4		5.8	
	RMSEn	7.7		8.2		8.7	
	r-Square	0.75		0.4		0.1	

RMSE: Root Mean Square Error, RMSEn: Normalized Root Mean Square Error

3.3.4 Grain Yield for Sapu Location

Simulation values at August 20 transplanting date were in close estimation with observed values for Sahel 134 at 120kg -0.2%, followed by 90kg -1.9% nitrogen fertilizer and then 150kg 2.8% nitrogen fertilizer level. Cultivar Gambiaka also revealed good conformity between the observed and simulated values at 90kg 3.3%, then 120kg nitrogen fertilizer level 5.1% and finally 150kg nitrogen fertilizer level 8.6%. IET 3137 showed close estimation at 90kg 1.6% then 90kg 1.7% and then 150kg nitrogen fertilizer level -2.0%.

Furthermore, simulation effects of Sahel 134 have indicated closer estimate at March 20 transplanting date and at 90kg nitrogen fertilizer level -2.0% then followed by 150kg -4.1% and then 120kg nitrogen fertilizer level -4.2%. Gambiaka rice variety also indicates good correlation at 90kg nitrogen fertilizer level -2.6% then followed by 120kg nitrogen fertilizer level 4.2% and finally 150kg nitrogen fertilizer level 8.6%. As for IET 3137, a close agreement was noticed at 120kg nitrogen fertilizer level -1.6% then followed by 150kg nitrogen fertilizer level 3.5% and then 90kg 7.4% nitrogen fertilizer level.

A closer situation was observed at May 20 transplanting dates for Sahel 134 and at 120kg 0.5% nitrogen fertilizer level followed by 90kg 2.7% and finally 150kg 4.8% nitrogen fertilizer level. Similar close condition was observed for Gambiaka rice variety at 90kg -1.4% then accompanied by and 120kg nitrogen fertilizer level -1.8% then followed by 150kg nitrogen fertilizer level 2.5%. Close estimation was noticed for IET 3137 rice variety at 120kg nitrogen fertilizer level 2.6% then 150kg 3.5% and finally 90kg nitrogen fertilizer level 4.6%.

Similar situation occurred at Sapu study site, the model at times it under estimate the values and sometimes it over estimate the values in all the transplanting dates, at different fertilizer levels and across varieties. In all transplanting dates greater closeness between the observed and the simulated values was noticed on Sahel 134 then followed by IET 3137 and then Gambiaka rice varieties.

The results of the simulation on the grain yield has in shown that the model satisfactorily predict Sahel 134 at 90kg nitrogen fertilizer level in all the transplanting dates with RMSE, RMSEn and r-Square of (70), (2.3) and (0.98) respectively, followed by nitrogen level 120kg (110), (3.3) and (1) and then150kg nitrogen fertilizer level (143), (4.1) and (0.99).

The RMSE, RMSEn and r-Square values for Gambiaka rice variety at different transplanting dates and at 90kg nitrogen levels were (113), (2.6) and (0.99), then 120kg nitrogen fertilizer level (156), (2.5) and (1), and then (218), (4.0) and (0.98) at 150kg nitrogen levels.
The simulated and observed grain yield for IET 3137 was also found good agreements with RMSE, RMSEn and r-Square values of (98), (2.8) and (1) at different transplanting for 90kg fertilizer level, followed by (93), (2.1) and (0.99) for 120kg fertilizer level and finally (118), (2.5) and (0.99) for 150kg nitrogen fertilizer level.

Table 8 Observed and simulated rice grain yield (kg/ha) at different dates of transplanting and nitrogen levels at Sapu location

Varieties	Transplanting dates	Nitrogen Fertilizer levels					
		90 kg/a		120kg/ha		150kg/ha	
		observed	simulated	observed	simulated	observed	simulated
Sahel 134	20/08/2017	3300	3236 (-1.9%)	3866	3858 (-0.20%)	3500	3597 (2.8%)
	20/03/2018	2266	2222 (-2.0%)	3366	3224 (-4.2%)	3080	2954 (-4.1%)
	20/05/2018	3433	3527 (2.7%)	4550	4573 (0.5%)	4003	4194 (4.8%)
	RMSE	70		110		143	
	RMSEn	2.3		3.3		4.1	
	r-Square	0.98		1		0.99	
Gambiaka	20/08/2017	5100	5268 (3.3%)	6433	6761 (5.1%)	7633	7839 (8.6%)
	20/03/2018	2633	2564 (-2.6%)	3500	3648 (4.2%)	3616	3928 (8.6%)
	20/05/2018	5166	5093 (-1.4%)	6431	6313 (-1.8%)	7139	7314 (2.5%)
	RMSE	113		218		156	
	RMSEn	2.6		4.0		2.5	
	r-Square	0.99		0.98		1	
IET 3137	20/08/2017	4000	4064 (1.6%)	4944	5025 (1.7%)	4800	4703 (-2.0%)
	20/03/2018	2300	2470 (7.4%)	3500	3443 (-1.6%)	3420	3541 (3.5%)
	20/05/2018	3000	3137 (4.6%)	4833	4960 (2.6%)	3983	4124 (3.5%)
	RMSE	98		92.9		117.6	
	RMSEn	2.8		2.1		2.5	
	r-Squar	1		0.99		0.99	

RMSE: Root Mean Square Error, RMSEn: Normalized Root Mean Square Error

3.3.5 Anthesis dates at Sapu Location

The simulated anthesis date at Sapu study location at different transplanting dates and nitrogen levels for three rice cultivars are presented below in **Table** 9.

Sahel 134 at August 20 transplanting date have indicated good estimation between the observed and simulated anthesis dates at 90kg nitrogen fertilizer level -1.9%, then followed by 120kg -4% nitrogen fertilizer level and then -5.7%. Gambiaka rice variety have good estimation between the observed and simulated anthesis date at 150kg nitrogen level 1.9% then 120kg nitrogen fertilizer level 2.8% and finally 90kg 4.2%. Similar situation was noticed on IET 3137 rice variety at 90kg nitrogen fertilizer level -7.7% and 120kg -9.1%, and 150kg nitrogen fertilizer level -9.1%.

Another good prediction was noticed on March 20 transplanting for Sahel 134 at 90kg -5.5% then 120kg -5.5% and then 150kg nitrogen fertilizer level -7.1%. Gambiaka rice variety also shows good prediction at 90kg, 120kg and 150kg nitrogen fertilizer levels 8.7% and 8.7% 8.7%. Good prediction was noticed for IET 3137 rice variety at 90kg nitrogen fertilizer level 0%, then followed by 120kg and 150 nitrogen fertilizer level -1.7% and -1.7%.

Good conformity was realized at May 20 transplanting date and at 150kg nitrogen fertilizer level for Sahel 134 0% then followed by 120kg 2% and then 90kg nitrogen fertilizer level 4%. As for Gambiaka rice variety, the same close estimation was notice at 90kg 13% 120kg and 150kg nitrogen fertilizer level 13% and 13%. Cultivar IET 3137, have shown good estimation at 90kg 5%, 120kg and 150kg nitrogen fertilizer level 5% and 5%.

The model underestimated and some instances it overestimated the values in all transplanting dates and at different nitrogen fertilizer levels and across varieties. In all the transplanting dates greater closeness between the observed and the simulated values was noticed on Sahel 134 then followed by IET 3137 and then Gambiaka rice varieties.

The simulated anthesis dates for Sahel 134 rice varieties shows satisfactory conformity between the observe and the simulated values at 90kg fertilizer level at different transplanting dates with an RMSE and RMSEn and r-Square of (2.2), (4.1) and (0.1), then followed by 120kg nitrogen fertilizer level (2.2), (4.1) and (0.08) and finally, 150kg nitrogen fertilizer level (2.9), (5.3) and (0.08).

Gambiaka rice variety has the RMSE, RMSEn and MBE at different transplanting dates and at 120kg fertilizer level of (6.3), (9.1) and (0.64), then 150kg nitrogen fertilizer level, (6.3), (9.0) and (0.64) and then 90kg fertilizer level (6.5), (9.4) and (0.64). These values show good agreement between the simulated and the observe values.

The simulated anthesis dates for IET 3137 also shows good conformity between the simulated and the observed values with RMSE, RMSEn and r-Square values of (3.9), (6.2) and (0.86) for 150kg fertilizer level, followed by 120kg nitrogen fertilizer level (3.9), (8.3) and (0.86) and then 90kg nitrogen fertilizer level (3.4), (9.3) and (0.75).

Table 9 Observed and simulated anthesis dates at different dates of transplanting and nitrogen levels at Sapu location

Varieties	Transplanting dates	Nitrogen Fertilizer levels					
		90 kg/ha		**120kg/ha**		**150kg/ha**	
		observed	**simulated**	**observed**	**simulated**	**observed**	**simulated**
Sahel 134	20/08/2017	51	50 (-1.9%)	52	50 (-4%)	53	50 (-5.7%)
	20/03/2018	55	52 (-5.5%)	55	52 (-5.5%)	56	52 (-7.1)
	20/05/2018	50	52 (4%)	51	52 (2%)	52	52 (0%)
	RMSE	2.2		2.2		2.9	
	NRMSE	4.2		4.1		5.3	
	r-Square	0.1		0.08		0.08	
Gambiaka	20/08/2017	70	73 (4.2%)	71	73 (2.8%)	72	73 (1.9%)
	20/03/2018	69	75 (8.7%)	69	75 (8.7%)	69	75 (8.7%)
	20/05/2018	69	78 (13%)	69	78 (13%)	69	78 (13%)
	RMSE	6.5		6.3		6.3	
	NRMSE	9.4		9.1		9.0	
	r-Square	0.64		0.64		0.64	
IET 3137	20/08/2017	65	60 (-7.7%)	66	60 (-9.1%)	66	60 (-9.1%)
	20/03/2018	61	61 (0%)	62	61 (-1.6%)	62	61 (-1.6%)
	20/05/2018	60	63 (5%)	60	63 (5%)	60	63 (5%)
	RMSE	3.4		3.9		3.9	
	NRMSE	9.3		8.3		6.2	
	r-Square	0.75		0.86		0.86	

RMSE: Root Mean Square Error, RMSEn: Normalized Mean Square Error

Chapter 4: Assessing the potential impact of the projected climate change on yield of selected rice varieties in The Gambia and Mali.

4.1 Materials and Methods

4.2.1 Study site

The field experiment was conducted at Kuntaur, Central River Region (CRR) on latitude 13.56 and longitude -15.93. The study sites have unimodal rainfall distribution with the peak of the rain in August. The mean annual rainfall varies from 1000- 700 mm, the vegetation's are mainly trees, shrubs and seasonal grasses. The main crops grown in the area are rice, vegetables, millet, groundnut, and maize (Ceesay, 2004)

The soil types are silty loam at Kuntaur experimental fields after soil profile analysis. These soils were originally derived from the soils formed through alluvial material deposition by river Gambia and its tributaries, which is highly influenced by temporal or enduring wet conditions. Alluvial soils in the area comprised of 80 percent silt and some clay deposits.

Segou is one of the administrative regions of Mali and it is one of the main rice growing regions of the country, it has sudano-sahelian climate with mean annual rainfall ranging from 900 to 500mm (Traore *et al.*, 2014). It houses the main rice growing centre in west Africa called "Office du Niger", which was established in 1930 (Ceesay, 2004).Segou region which is located in southern Mali occupies around 13.5% of Malian territory (approximately 160.825km^{s}). It has around 50% arable land and provides habitat for more than 40% of the of Malian population (Traore *et al.*, 2014). The southern region of Mali provides more than 45% of the countries income (Deveze, 2006).

The study uses climate data of Segou location of Mali to compare the projected climate change on the selected rice varieties because there was no variation in the results of Sapu and Kuntaur study location. The experimental data, soil data obtained from Kuntaur study site was used for both Segou and Kuntaur in the model.

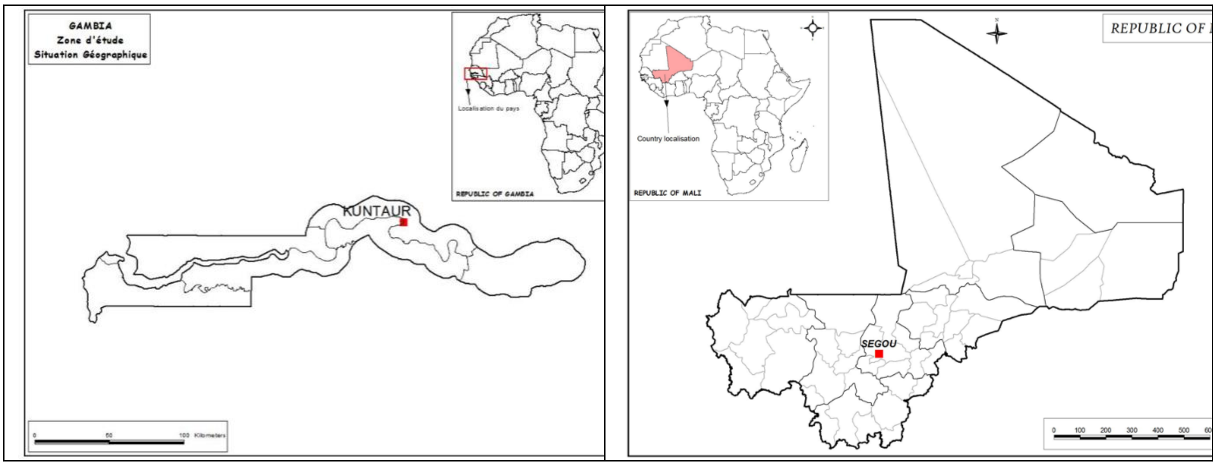


Figure 3 map of Kuntaur and Segou

4.2.2 Data collection methods

4.2.2.1 Future Climate Prediction

The prediction of future climate involves the usage of CMIP5 model output (Couple Model Intercomparison Project Phase 5) (Hempel et al., 2013). Three GCMs were selected (GFDL-ESM2G, HadGEM2-ES and MPI-ESM-LR*)* for efficient prediction as compared to single GCM (Pope et al., 2007). The selected GCMs were bias corrected on daily basis for maximum and minimum temperatures and secondly. (IPCC, 2013), and finally, the selected GCMs were also used in climate impacted assessments in the Sahelian countries (Adiku, et al., 2015a; Traore, 2014).

The greenhouse gas emission scenario Nakicenovic, et al., (2000), as it was described in the emission scenario was used. The emission scenario for rice yield impact assessments were RCP 4.5 and RCP 8.5 for the periods of near term (2010 to 2039), mid-century (2040 to 2069), (IPCC, 2013).

The future climate generation was aided by AgMIP protocol through its climate scenario generation tool to create future daily climate data using R script for this study (Ruane, et al., 2017).

4.2.2.2 Baseline climate data

Historical climate data for this study was obtained from three sources, the Department of water resources in the Gambia, regional weather station of Segou and the NASA Power on maximum temperature, minimum temperature, solar radiation, relative humidity and rainfall (Stackhouse, 2006). To check for the accuracy of the data, some faults were found on the data set, where the minimum temperature was greater than maximum temperature, the data was then plotted using the simple box plot technique to view some of the outliers and errors and datasets with more than 20% missing data were automatically removed from the study. The rejected data were replaced with NASA power data, with mean adjusted according to a comparison between NASA Power and observed station monthly climatology.

4.2.2.3 Experiment data

Three rice varieties were used for the experiments (Sahel 134, IET 3137 and the Gambiaka) with different fertilizer application rates (0, 90,120 and 150kg) at three transplanting dates (July, August and September 2017). The full details of the experiment are found in Chapter 2.

4.2.2.4 Selection of GCMs

About two GCMs was selected per country, the selection of GCMs were based on the AgMIP protocol (Rosenzweig, et al., 2013). A scatter plot of 29 GCMs was done to determine their influence on rainfall and temperature change on the selected stations or baseline, in relations to propensity of the models being warm/dry, warm/wet, cool/wet, cool/dry and or just in the middle for RCP4.5 and the RCP8.5, **Figure** 4 and 5. The GCM closer to the baseline were selected in each quadrant for this study and similar method was done by (Ruane, et al., 2017; Adiku et al 2015). For the purpose of this study, the coolest and hottest GCM were selected to assess their impacts on the yields of selected rice varieties in Kuntaur and Segou.

The list of GCMs selected for Kuntaur (Gambia) and Segou (Mali) are given below in **Table** 10 and 11. Additional analysis such as determining the weight of GCMs in each quadrant was conducted to ensure that the model capture both study area for this study and similar procedure was done by (Ruane, et al., 2017).

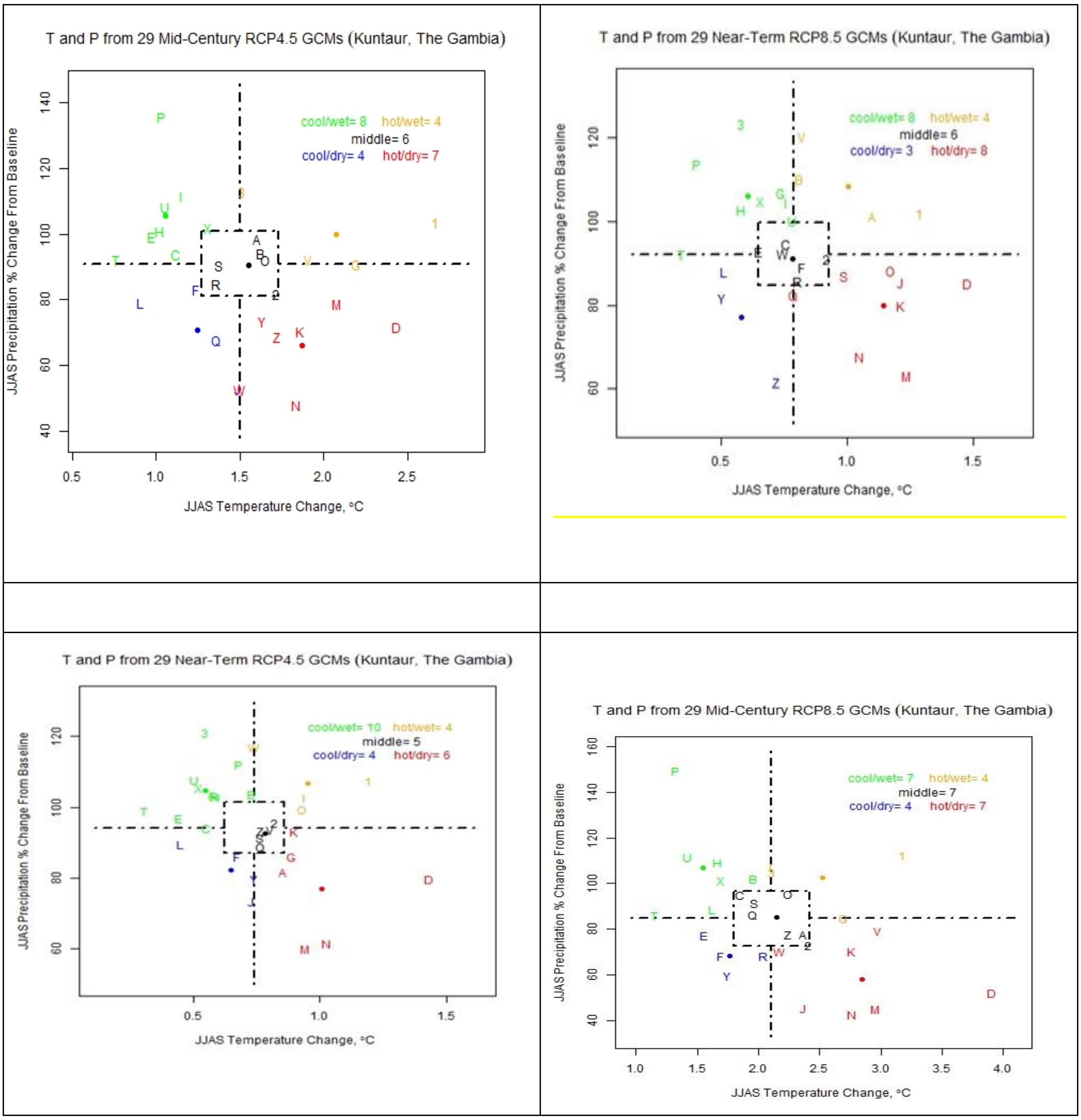


Figure 4: Temperature and Precipitation Change at Kuntaur, The Gambia

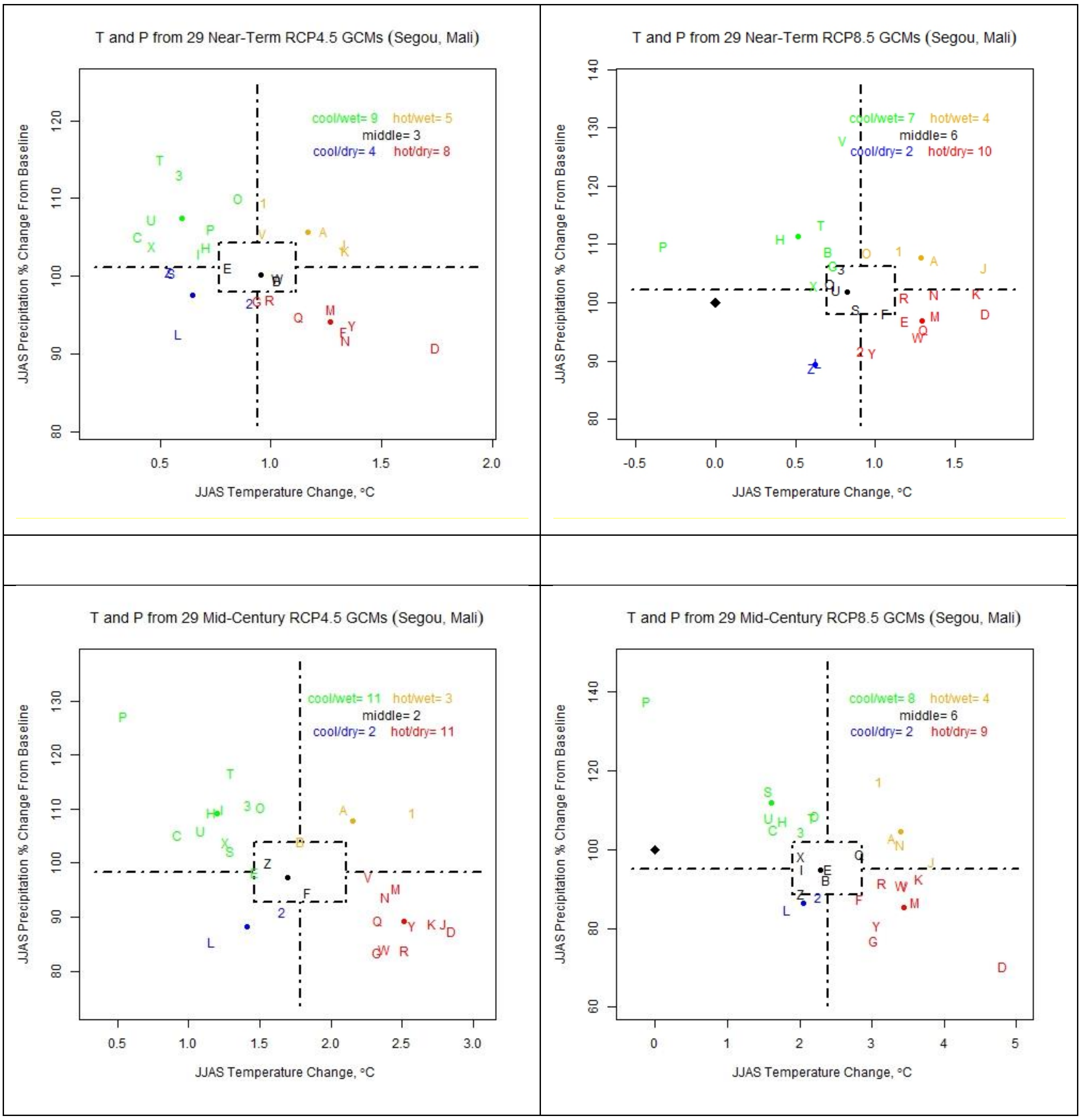


Figure 5: Temperature and Precipitation Change at Segou, Mali.

Table 10 Selected GCMs for Kuntaur location

Kuntaur, Gambia				
	Cool wet near term	Cool wet mid-century	Hot dry near term	Hot dry mid-century
RCP 4.5	GFDL-ESM2	GFDL-ESM2	HadGEM2-ES	HadGEM2-ES
RCP 8.5	GFDL-ESM2	GFDL-ESM2	HadGEM2-ES	HadGEM2-ES

Table 11 Selected GCMs for Segou Location

Segou, Mali				
	Cool wet near term	Cool wet mid-century	Hot dry near term	Hot dry mid-century
RCP 4.5	GFDL-ESM2	GFDL-ESM2	MPI-ESM-LR	MPI-ESM-LR
RCP 8.5	GFDL-ESM2	GFDL-ESM2	MPI-ESM-LR	MPI-ESM-LR

4.2.2.5 Data analysis

To achieve the aim of the study, two different types of simulation were conducted using DSSAT simulation model. The weather data were replaced by the projected weather data of near term and midcentury climate scenarios. Baseline grain yield were compared with simulated grain yield as projected by three selected GCMs for RCP 4.5 and 8.5 near and mid-century time periods. In the first simulation CO_2 was kept at baseline level, both RCPs were run separately for all the transplanting dates. But for the second simulation, the CO_2 levels were replaced for both RCPs depending on their future estimations from CMIP5 (Taylor, et al., 2012). The model was run for grain yield response to future climate scenarios with or without projected CO_2 concentration.

$$\Delta \boldsymbol{Yield} = [(\boldsymbol{Yield}_{\boldsymbol{scenario}} - \boldsymbol{Yield}_{\boldsymbol{baseline}})/\boldsymbol{Yield}_{\boldsymbol{baseline}}] * \mathbf{100}$$

4.3 Results

4.3.1 Analysis of climate parameters at Kuntaur and Segou (1980-2018)

- Rainfall

The trend of rainfall figures for both Kuntaur and Segou showed high variability, the highest rainfall for the period was observed in the month of August with about (300 and 250mm) as shown in **Figure** 6.

Monthly rainfall analysis is of paramount importance as it captures seasonal forcast in rainfall over the course of the year. Indeed, knowledge of the onset and end of the rainy season is a major factor in the planning of the cropping calendar. This operation consists of helping farmers better cope with the vagaries of the climate, particularly the rainfall deficiency, which often makes agricultural production more difficult. This kind of situation is crucial for agricultural production especially rain fed rice production. Therefore, suitable adaptation processes must be adopted for sustainable rice production.

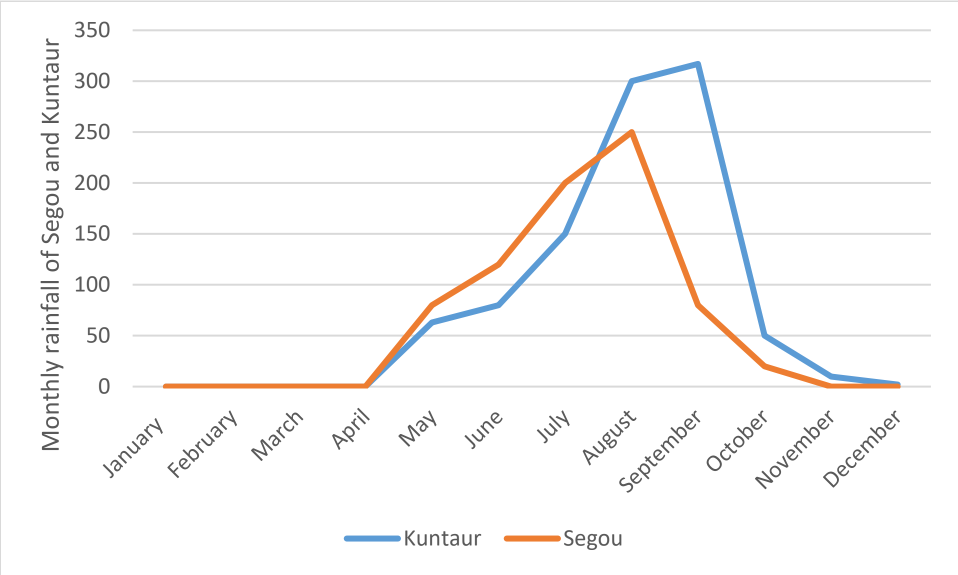


Figure 6 monthly rainfall 2010-2018 for Kuntaur and Segou

- Temperature

The inter annual observation of variability of temperature is eminent during the growing period of rice, the average highest monthly minimum temperature was 23°C and 26°C at Kuntaur and Segou, whilst the highest average maximum temperature was 36° and 40° in April at Kuntaur and Segou location as shown in **Figure** 7. This is a clear manifestation of variability of temperature for the growing period.

The temperature of the month is usually calculated from the mean temperatures, which is obtained from the minimum and maximum temperatures.

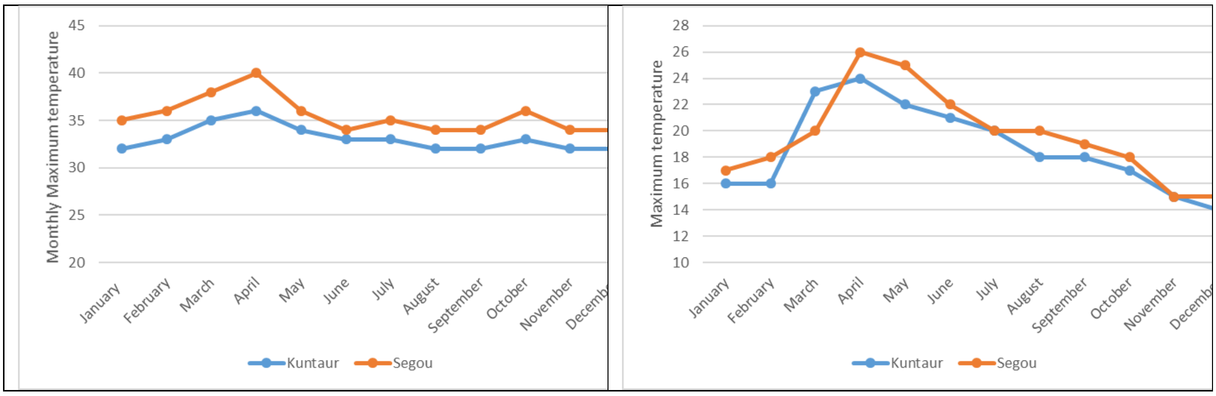


Figure 7 Average monthly Minimum and Maximum temperature 2010-2018 for Kuntaur and Segou

- Solar Radiation

The high monthly solar recorded from 1980-2018 was observed during the months of April with 25 MJ/m^2 and lowest solar radiation was notice in August 17 MJ/m^2 at Segou location and Kuntaur has recorded 21 MJ/m^2 in April and 16 MJ/m^2 in August. This observation is crucial for the suitable timing of transplanting as indicated in **Figure** 8.

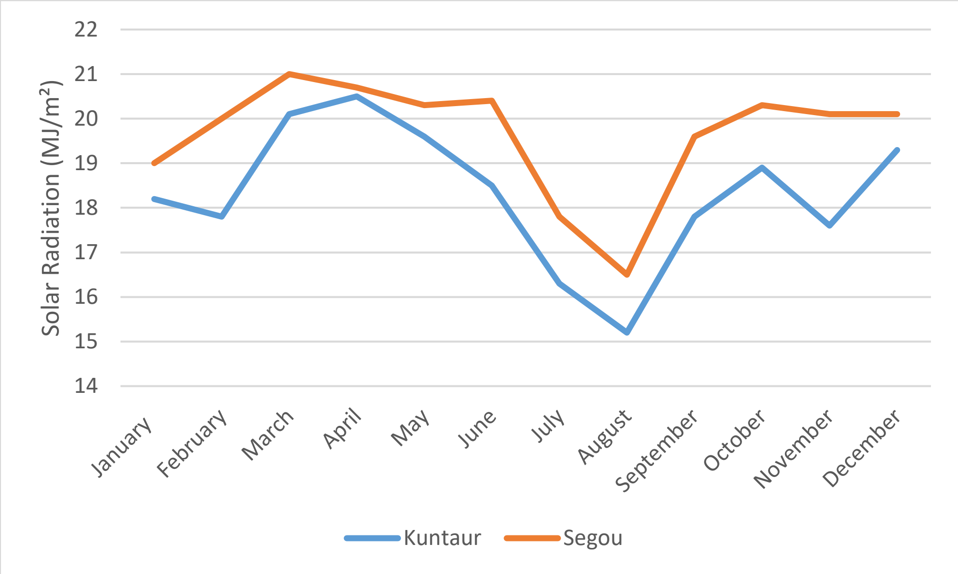


Figure 8: Average monthly solar radiation for the 1980 to 2018 period in Kuntaur and Segou

4.3.2 Rice Grain yield responses to Scenarios at Kuntaur, Gambia (without CO_2 enrichment)

Grain yield responses to scenarios without CO_2 availability at both transplanting dates across varieties under RCP 4.5 and 8.5 near term and mid-century. The analysis results of Gambiaka rice variety showed some little increase of yields from baseline at near term under RCP 4.5 1% at fertilizer level 90kg and 150kg. Under RCP 8.5 near term yield gains was only noticed at 150kg fertilizer level 2% as observed in **Figure** 9.

Yield reduction was noticed at both RCPs at 120kg and 150kg nitrogen fertilizer levels for near term. At mid-century time horizon yield reduction was noticed at both RCPs ranging from (-1 to -20) at different fertilizer levels.

As for IET 3137 rice variety, yield gain ranges from 1 to 5% for both RCPs near term and at 150kg fertilizer level, **Figure** 10.

Yield reduction was observed on near term at 120kg and 90kg nitrogen fertilizer level. Reduction was also observed at both RCPs under mid-century time period and at all fertilizer levels.

Sahel 134 rice variety have shown yield gain at 120kg and 150kg nitrogen fertilizer level for near term, and at both RCPs 2%.

Reduction in yield was shown at 90kg fertilizer level in both RCPs, at near term. But at mid-century time period, reduction in yield was noticed on all nitrogen fertilizer level and at both RCPs -1 to -23%, **Figure** 11.

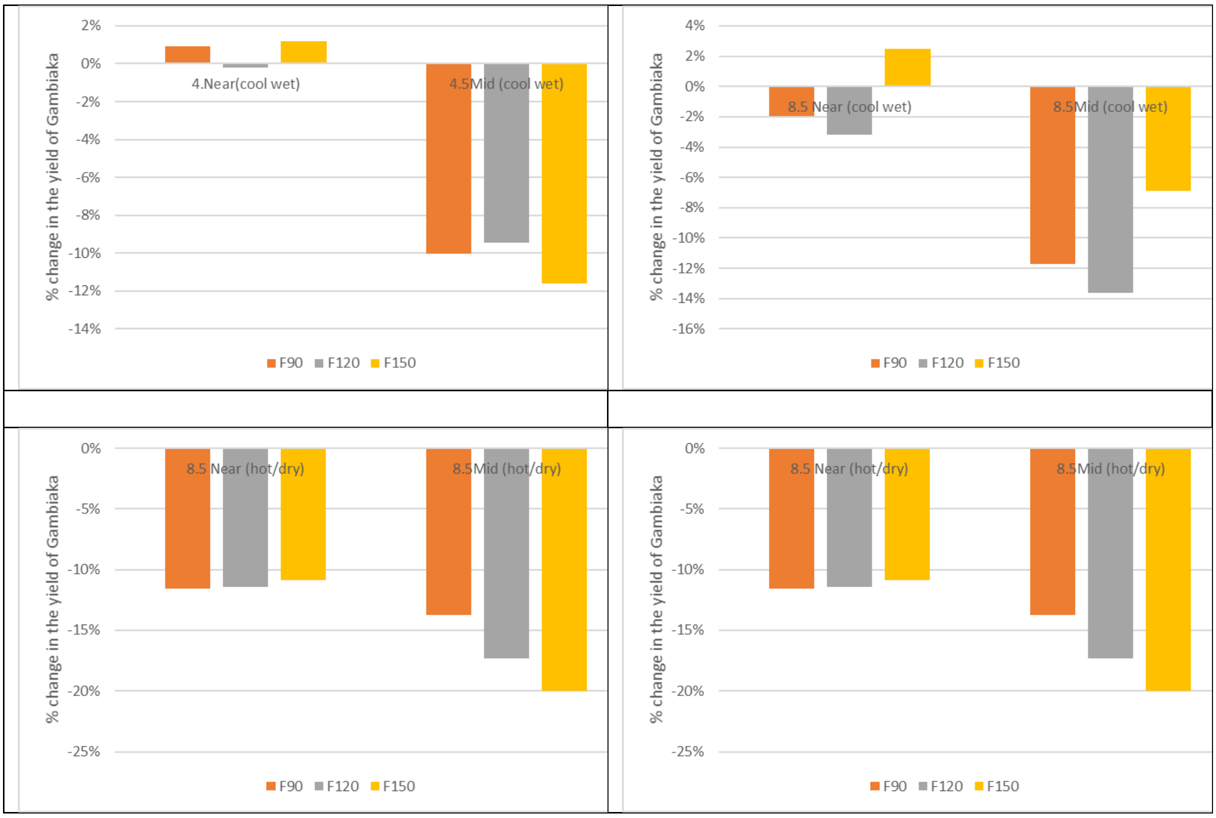


Figure 9 Gambiaka rice Grain yield responses to Scenarios at August 20 transplanting, Kuntaur, Gambia (without CO_2 enrichment)

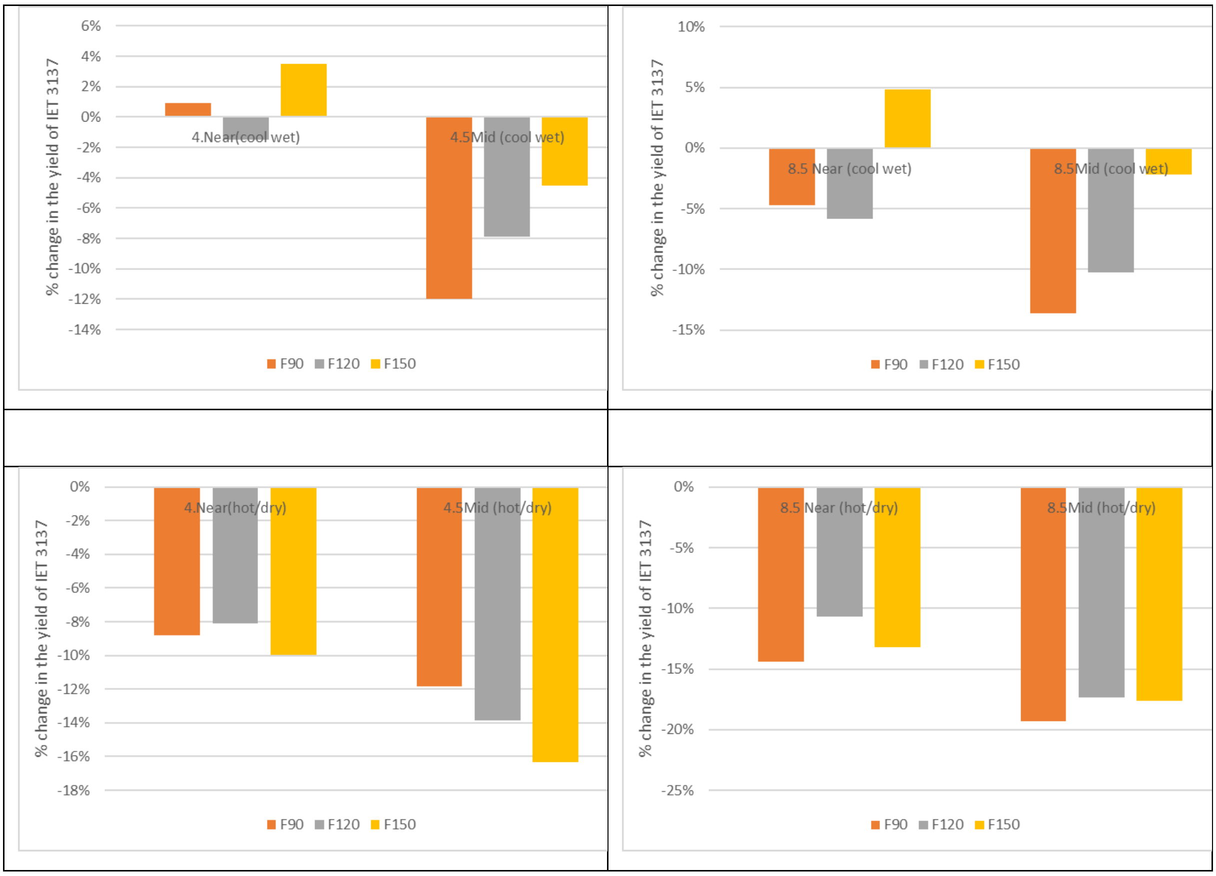


Figure 10 IET 3137 rice grain yield responses to Scenarios at at August 20 Transplanting, Kuntaur, Gambia (without CO_2 enrichment)

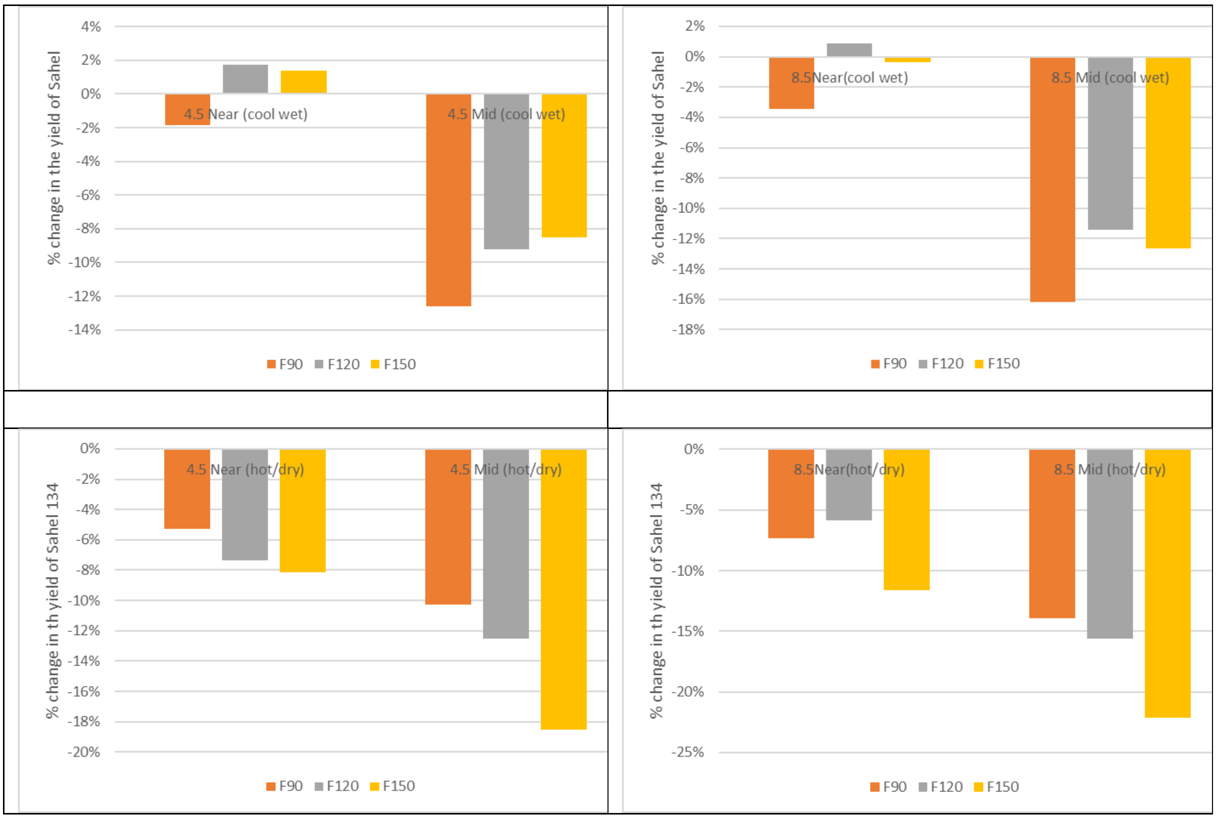


Figure 11 Sahel 134 rice Grain yield responses to Scenarios at August 20 transplanting, Kuntaur, Gambia (without CO_2 enrichment)

4.3.3 Rice Grain yield responses to Scenarios at Segou, Mali (without CO_2 enrichment)

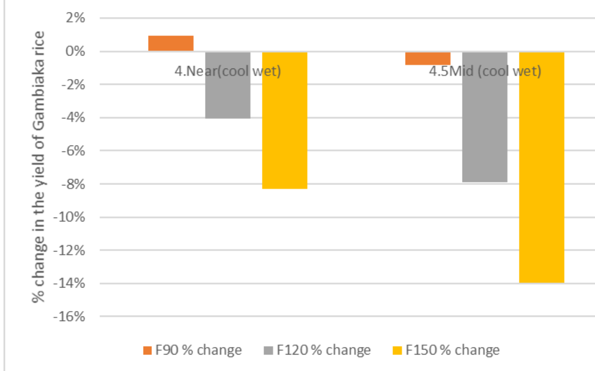
The analysis results of Gambiaka rice variety have shown some yield gains at near term under RCP 4.5 1% and at 90kg and 150kg nitrogen fertilizer levels whilst for RCP 8.5, yield gain was only noticed at 90kg fertilizer 1%, as shown in **Figure** 12.

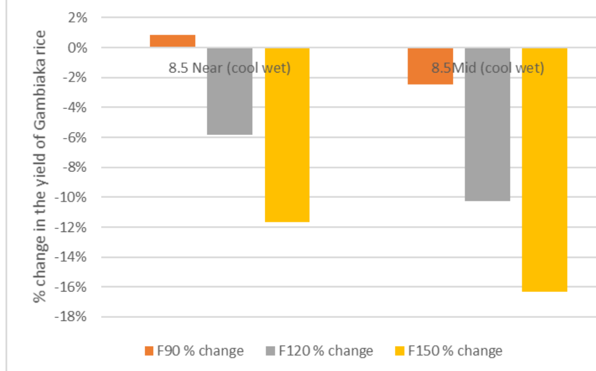
Yield reduction was observed at both RCPs and at 120kg and 150kg nitrogen fertilizer levels for near term. But at mid-century time horizon, yield reduction was noticed at both RCPs ranging from -1 to -23% at different fertilizer levels.

The IET 3137 rice variety showed a yield gain of 1% at RCP 4.5 near term and at 150kg fertilizer level.

Yield reduction was observed at near term and at 90kg and 120kg nitrogen fertilizer levels for RCP 4.5 and all fertilizer levels for the mid-century. Whilst RCP 8.5, had yield reduction on all fertilizer levels at both time periods, ranging from -1 to -18%, **Figure** 13.

Sahel 134 rice variety have shown yield losses at all fertilizer levels and time periods ranging from -1 to -29%, and at both RCPs when Co2 was not considered in the simulation, as noticed in **Figure** 13.





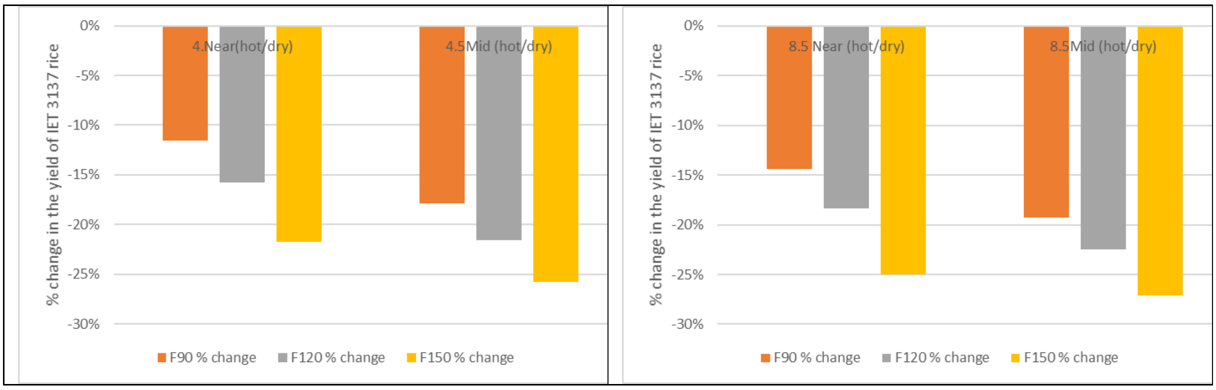


Figure 12 Gambiaka rice grain yield responses to scenarios at August 20 transplanting, Segou, Mali (without CO_2 enrichment).

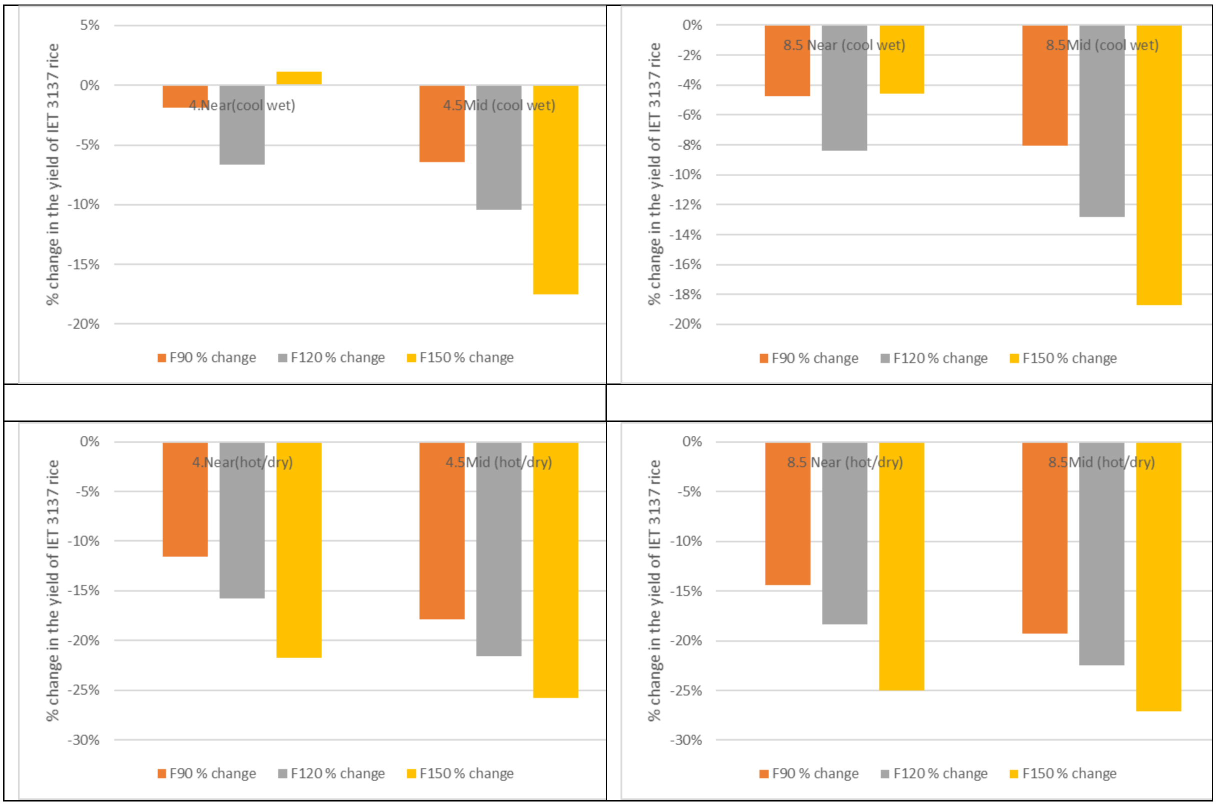


Figure 13 IET 3137 rice grain yield responses to scenarios at August 20 transplanting, Segou, Mali (without CO_2 enrichment).

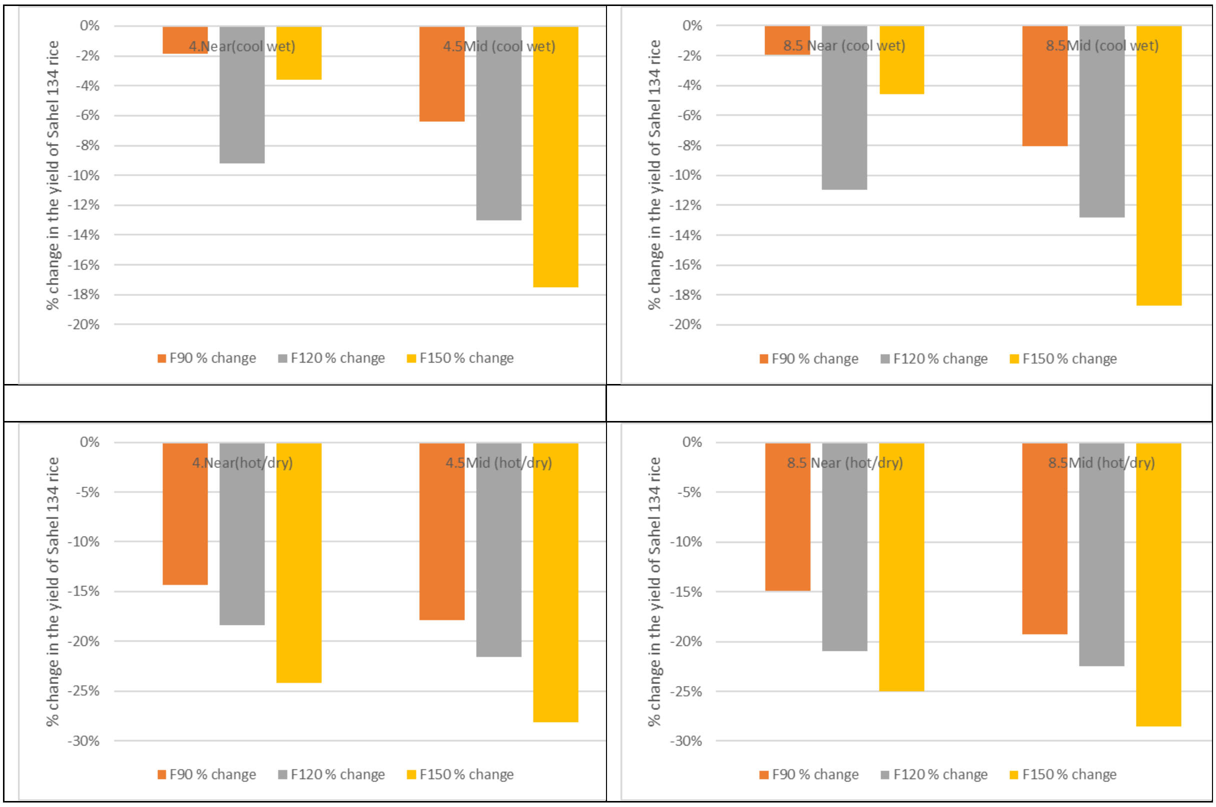


Figure 14 Sahel 134 rice grain yield responses to scenarios at August 20 transplanting, Segou, Mali (without CO_2 enrichment).

4.3.4 Rice Grain yield responses to Scenarios at Kuntaur, The Gambia (with CO_2 enrichment)

July 20 transplanting

The grain yield of Gambiaka rice variety as at July 20 transplanting estimated under cool GCM ranges from 2 to 5 tons per hectare were higher than the baseline yield 2 to 4 tons/ hectare. Yield gains for RCP 4.5 ranges from 2 to 9 % whilst RCP 8.5 was 1 to 10% at different fertilizer levels, RCP 8.5 recording the highest yield gain, (see **Figure** 15 and 16). Under hot GCM, the yield gain ranges from 1 to 3% for RCP 4.5 near term at 90kg and 150kg nitrogen fertilizer levels but for mid-century, yield gains was only noticed at 150kg nitrogen fertilizer level. Whilst RCP 8.5, yield gains was only observed at all fertilizer levels at near term whilst for the mid-century it was noticed on 90kg and 150kg nitrogen fertilizer level. A decrease on the yield was noticed at the fertilizer level 120kg across the RCPs on mid-century time period.

As for IET rice cultivar, the projected GCM yields ranges from 2 to 4 tons per hectare whilst the baseline yields were from 2 to 3 tons. Yield gains ranges between 9 to 18% for RCP 4.5 near term and mid-century for all fertilizer levels. The RCP 8.5 projecting higher grain yield gain of 11 to 20% at different fertilizer levels at near term and the mid-century under cool GCM of GFDL-ESM2G model. The RCP 4.5 recorded a yield gain of 2 to13% at near term and mid-century on all fertilizer levels under hot GCM. Similar trend was noticed on RCP 8.5, 9 to14 % in the near term and mid-century.

Sahel 134 rice variety has a yield gains ranging from 1 to 25% for RCP 4.5 near term and mid-century. The RCP 8.5 also projected grain yield gain of 1 to 28% for near term and mid-century at different fertilizer levels. Whilst under hot GCM (HadGEM2-ES), a simulated yield gains of 6 to 17% were recorded on 120kg and 150kg nitrogen fertilizer level.

for RCP 4.5 near term and mid-century. Under RCP 8.5, yield gains 6 to 18% was also observed on 120kg and 150kg nitrogen fertilizer level and at near term and mid-century respectively. A yield decrease was noticed on 90kg nitrogen fertilizer levels and across RCPs for near term and mid-century.

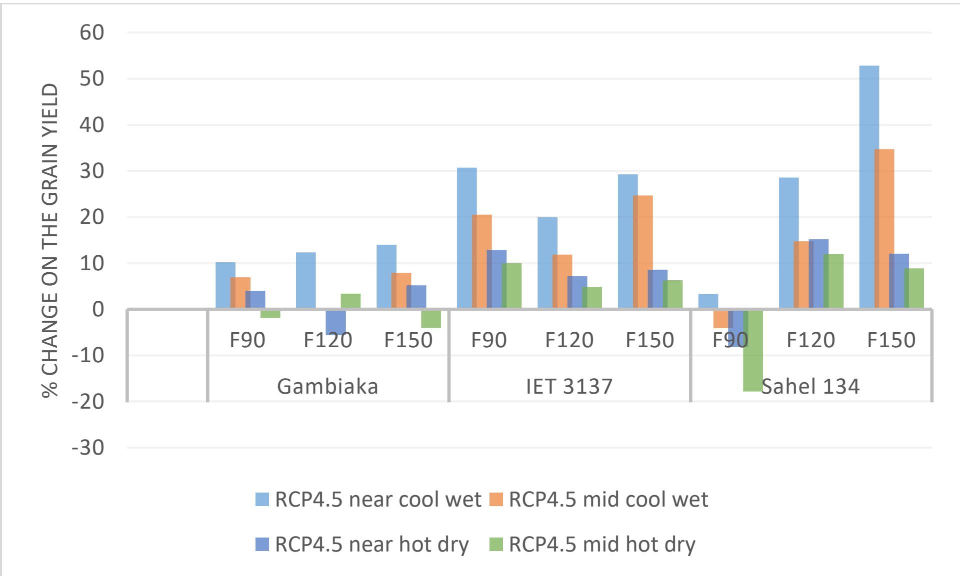


Figure 15: percentage of change on grain yield of rice varieties at RCP 4.5 near term(2010-2039) and mid-century (2040-2069).

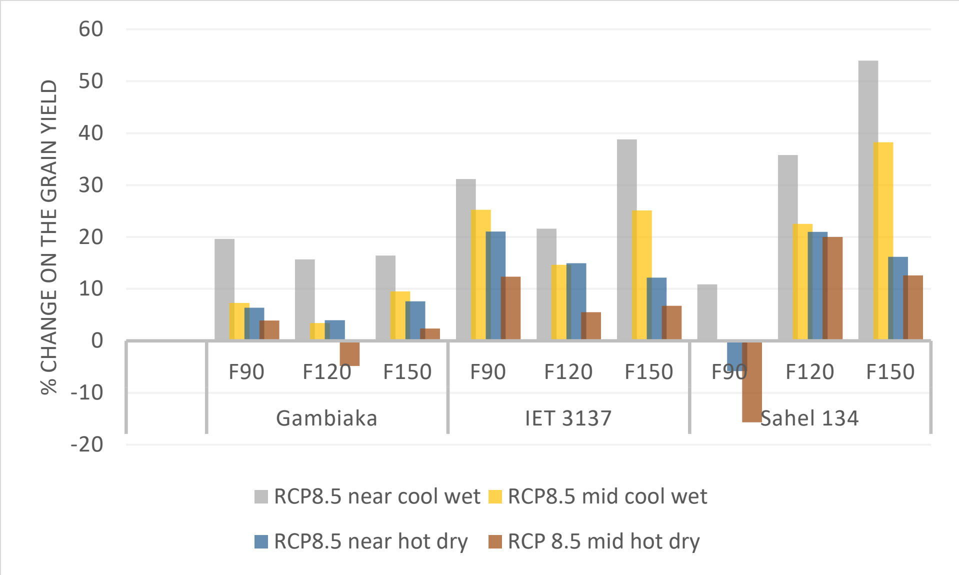


Figure 16 percentage of change on grain yield of rice varieties at RCP 8.5 near term(2010-2039) and mid-century (2040-2069).

August 20 transplanting

The Grain yield of Gambiaka rice at August 20 transplanting would not be severely impacted by climate change under cool GCM (GFDL-ESM2G) in both RCP 4.5 and 8.5 at near term and mid-century for Kuntaur; as noticed in **Figure** 17 and 18. The projected GCMs yields were higher than the simulated baseline yields in both RCPs at different fertilizer levels, the simulated GCMs yield at different fertilizer levels ranges from 2 to 5 tons per hectare whilst the baseline yields at different fertilizer levels ranges from 2 to 4 tons. Yield gains ranges between 1 to 18% for RCP 4.5 (near term and mid-century). The RCP 8.5 projecting higher grain yield gain of 9 to 24% (near term and mid-century) at different fertilizer levels. Whilst with the hot model (HadGEM2-ES) simulated yield gains was recorded on 150kg nitrogen fertilizer level for RCP 4.5 near term. With the RCP 8.5, yield gain was observed on all nitrogen fertilizer levels and at near term on 120kg nitrogen fertilizer level for the mid-century. A decrease on the yield was noticed under hot GCM, under 90kg and 120kg nitrogen fertilizer level at near term and mid-century time horizon. A similar trend was noticed at RCP 8.5 mid-century.

The projection results for IET 3137 rice variety under cool GCM (GFDL-ESM2G) in both RCP 4.5 and 8.5 near term and mid-century. The GCM projected yields ranges from 2 to 4 tons per hectare whilst the baseline yields ranges from 2 to 3 tons per hectare. Yield gains ranges between 10 to 16% for RCP 4.5 near term and mid-century. The RCP 8.5 projecting higher grain yield gain of 11 to 17% at different fertilizer levels at near term and mid-century. Yield gain was also noticed under hot GCM (HadGEM2-ES), (1 to 5%) for RCP 4.5 on all fertilizer level for both near term and mid-century. Similar condition was observed on RCP 8.5 with a yield gain of 2 to 7 % at the near term and mid-century.

Sahel 134 rice variety with regards to August 20 transplanting will not be severely impacted by climate change due to CO_2 fertilization as GCMs projecting positive yields under cool GCMs (GFDL-ESM2G) in both RCP 4.5 and 8.5. The projected GCMs yields were higher than baseline yields in both RCPs at different fertilizer levels, the GCM yields ranges from 2 to 4 tons per hectare whilst the baseline yieldsranges from 2 to 3 tons. Yield gains ranges between 20 to 28% for RCP 4.5 near term and mid-century at different fertilizer levels. The RCP 8.5 projecting higher grain yield gain of 15 to 35% for the near term and mid-century time periods. The RCP 8.5 recorded highest grain yield under cool GCM.Whilst under hot GCM (HadGEM2-ES), the simulated yield gains were recorded on RCP 4.5 near term 1 to 3% at all fertilizer levels but at mid-century, yield gains of 2% was only observed at 150kg nitrogen in fertilizer level. Under RCP 8.5, yield gains 2 to 5% was recorded at both near term and mid-century. A yield decrease was observed on RCP 4.5 near term and at 90kg nitrogen fertilizer level whilst at mid-century, it was noticed on 90kg and 120kg nitrogen fertilizer level.

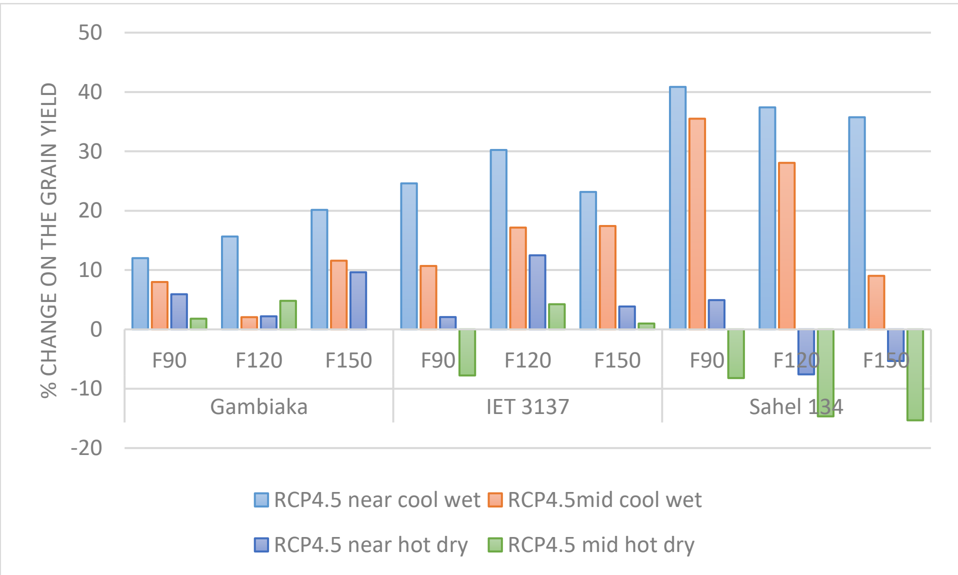


Figure 17 percentage of change on grain yield of rice varieties at RCP 4.5 near term(2010-2039) and mid-century (2040-2069).

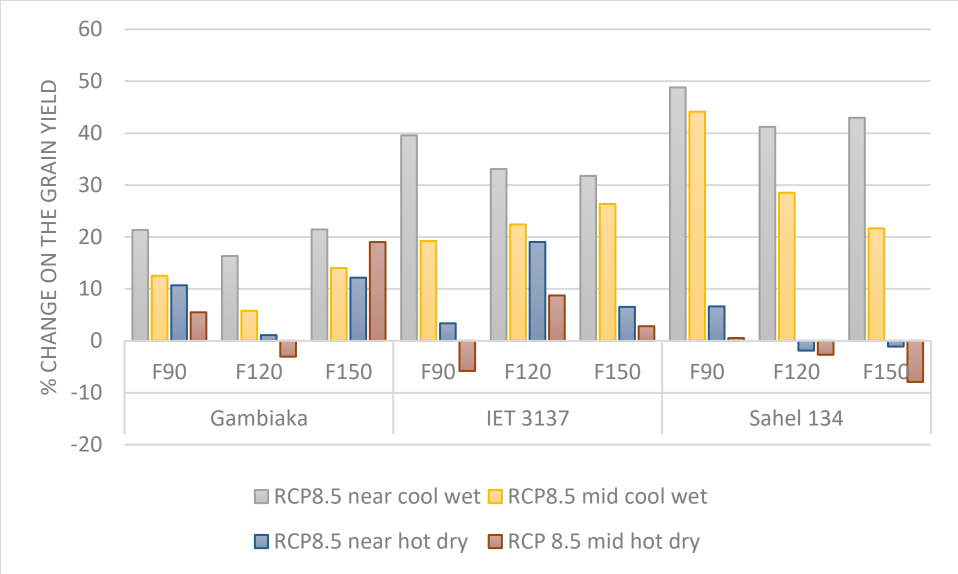


Figure 18 percentage of change on grain yield of rice varieties at RCP 8.5 near term(2010-2039) and mid-century (2040-2069).

September 20 transplanting

The Grain yield of Gambiaka rice under cool GCMs as at September 20 transplanting would not be severely impacted by climate change as estimated under RCP 4.5 and 8.5 in the near term and mid-century, as indicated in **Figure** 19 and 20. The projected GCMs yields were higher than baseline yields in both RCPs at different fertilizer levels, the simulated GCMs yield at different fertilizer levels ranges from 2 to 5 tons per hectare whilst the baseline yields at different fertilizer levels ranges from 2 to 4 tons. Yield gain ranges between 1 to 18% for RCP 4.5 (near term and mid-century) and RCP 8.5 projecting higher grain yield gain of 9 to 24% at different fertilizer levels. Whilst with the hot model (HadGEM2-ES), simulated yield gains were recorded on 150kg nitrogen fertilizer level for RCP 4.5 near term and mid-century. The RCP 8.5, had a yield gain on all fertilizer levels at near term 3 to 9% and 120kg fertilizer level for mid-century. A grain yield decrease was noticed on fertilizer levels 90kg and 120kg at near term and mid-century for RCP 4.5 and RCP 8.5, a decrease was noticed on fertilizer levels 90kg and 150kg under hot GCM.

Favorable yield increase was also noticed for IET 3137 rice variety as GCMs projecting higher yields on cool GCM (GFDL-ESM2G) in both RCP 4.5 and 8.5. The projected GCMs yields was higher than baseline yields in both RCPs and at different fertilizer levels. The projected yields ranges from 2 to 4 tons per hectare whilst the baseline yields ranges from 2 to 3 tons. Yield gains ranges between 17 to 36% for RCP 4.5 near term and mid-century for all fertilizer levels. RCP 8.5 projecting higher grain yield gain of 29 to 45% at near term and mid-century under cool GCM. Similar gains were also observed under hot GCM (HadGEM2-ES), as simulated grain yield gains under RCP 4.5 was recorded on all fertilizer level for both RCP 4.5 and 8.5 near term and mid-century. The RCP 4.5 recorded a yield gain of 2 to 19% at near term and mid-century on all fertilizer levels. Similar trend 7 to 27% was noticed on RCP 8.5 at near term and mid-century.

Sahel 134 rice variety will not be severely impacted by climate change as projected under cool GCMs (GFDL-ESM2G) in both RCP 4.5 and 8.5. The projected GCM yields were higher than baseline yields in both RCPs and at different nitrogen fertilizer levels, the GCM simulating yields at different fertilizer levels ranges from 2 to 4 tons per hectare whilst the baseline yields at different fertilizer levels ranges from 1 to 2 tons. Yield gains ranges between 1 to 12% for RCP 4.5 near term and mid-century. The RCP 8.5 projecting higher grain yield gain of 9 to 13% for near term and mid-century and at different fertilizer levels. The RCP 8.5 recorded highest grain yield gain under cool GCM. Whilst under hot GCM (HadGEM2-ES), simulated yield gains were recorded on RCP 4.5 near term 1 to 9% and at all fertilizer levels but at the mid-century, yield gains was only observed on 90kg nitrogen fertilizer level 4%. The RCP 8.5, projects a yield gains under hot GCM at near term and only at 90kg and 120kg nitrogen fertilizer level for the mid-century. A yield decrease was observed on 150kg nitrogen fertilizer level for RCP 4.5 and 8.5 at mid-century.

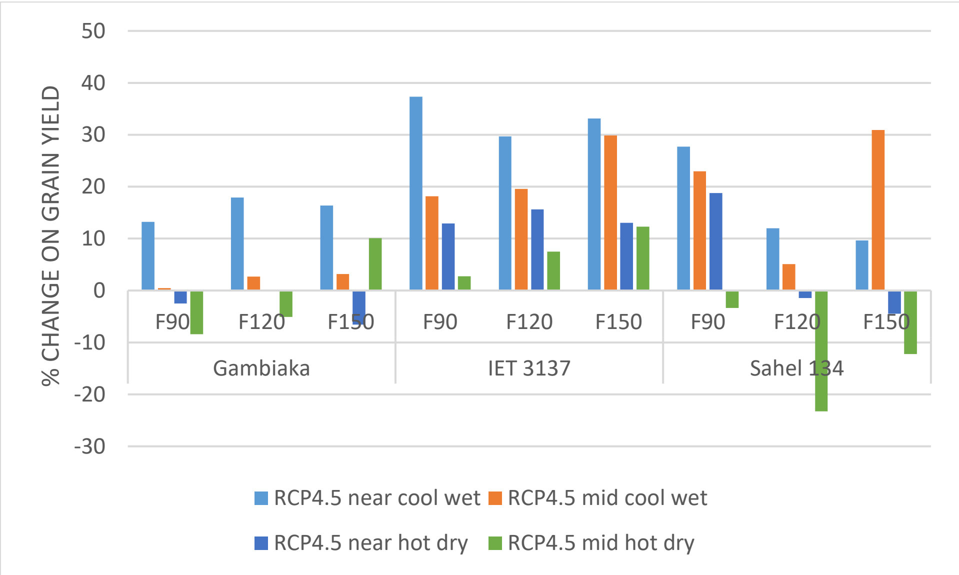


Figure 19 percentage of change on grain yield of rice varieties at RCP 4.5 near term(2010-2039) and mid-century (2040-2069).

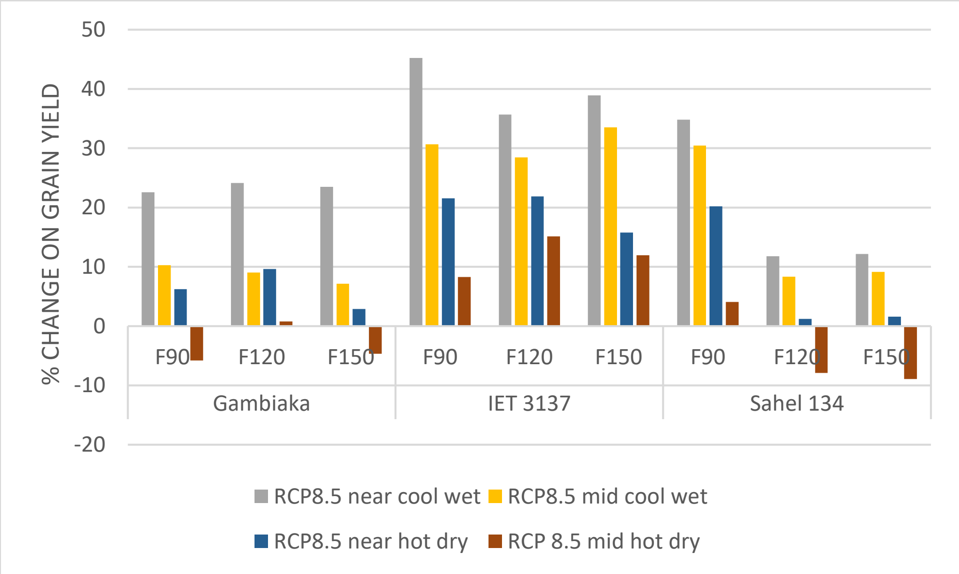


Figure 20 percentage of change on grain yield of rice varieties at RCP 8.5 near term(2010-2039) and mid-century (2040-2069).

4.3.5 Rice Grain yield responses to Scenarios at Segou, Mali July 20 transplanting (with CO2 enrichment)

Gambiaka rice yields at Segou location on July 20 transplanting will not be severely impacted by climate change due to CO_2 fertilization as GCM projecting positive yields (GFDL-ESM2G) in both RCP 4.5 and 8.5. The projected GCM yields were higher than the simulated baseline yields in both RCPs and at different fertilizer levels, the GCMs yields ranges from 4 to 6 tons per hectare whilst the baseline yields were2 to 5 tons, as shown in **Figure** 21 and 22.Yield gains ranges between 3 to 9% for RCP 4.5 near term and mid-century at different fertilizer levels. The RCP 8.5 projecting higher grain yield gain of 3 to 15% for near and mid-century at different fertilizer levels. The RCP 8.5 recorded highest grain yield gain under cool GCM.

The hot GCM (MPI-ESM-LR), simulated yield gain ranges of 2 to 4% were recorded on 90kg and 150kg nitrogen fertilizer level for RCP 4.5 near term. The RCP 8.5 had a yield gain of 1 to 6% on all fertilizer levels at the near term. A decrease in the grain yield was observed on 120kg nitrogen fertilizer levels for the RCP 4.5 near term and 120kg and 150kg fertilizer levels for 4.5 mid-century. The RCP 8.5 had a yield decrease on 150kg nitrogen fertilizer level for the mid-century.

The IET 3137 rice variety yields will not be severely impacted by climate change due to Co2 fertilization as GCMs projecting positive yields under cool GCMs (GFDL-ESM2G) in both RCP 4.5 and 8.5. The projected GCMs yields were higher than the baseline yields in both RCPs at different fertilizer levels, the GCMs yieldsranges from 4 to 5 tons per hectare whilst the baseline yieldswere3 to 4 tons.Yield gains ranges between 9 to 18% for RCP 4.5 near term and mid-century at different fertilizer levels. The RCP 8.5 projecting higher grain yield gain of 11 to 20% for near term and mid-century and at different fertilizer levels. The RCP 8.5 recorded the highest grain yield under cool GCM.

Whilst on hot GCM (MPI-ESM-LR), the simulated yield gains were recorded on 120kg and 150kg nitrogen fertilizer levels for RCP 4.5 near term and mid-century as well as RCP 8.5 near term and mid-century. Yield reduction was noticed on 90kg nitrogen fertilizer level at near term and mid-century.

The simulated grain yield of Sahel 134 rice variety at July 20 transplanting, as cool GCM (GFDL-ESM2G) projecting higher yields in both RCP 4.5 and 8.5 at near term and mid-century time periods. The projected GCMs yields were higher than the simulated baseline yields in both RCPs and at different fertilizer levels. The projected GCMs yields at different fertilizer levels, ranges from 3 to 4 tons per hectare whilst the baseline yields at different fertilizer levels was 2 to 3 tons. Yield gain ranges between 3 to 16% for RCP 4.5 near term and mid-century. The RCP 8.5 projecting higher grain yield gain of 5 to 20% at different fertilizer levels at near term and mid-century time horizon.

Simulated yield gains were observed on hot GCM (MPI-ESM-LR), as RCP 4.5 near term recording a yield gain on all fertilizer levels for the near term and mid-century, yield gains was noticed on 120kg and 150kg nitrogen fertilizer levels. Whilst the RCP 8.5 under hot GCM has a yield gain on all fertilizer levels in both near term and mid-century time horizons.

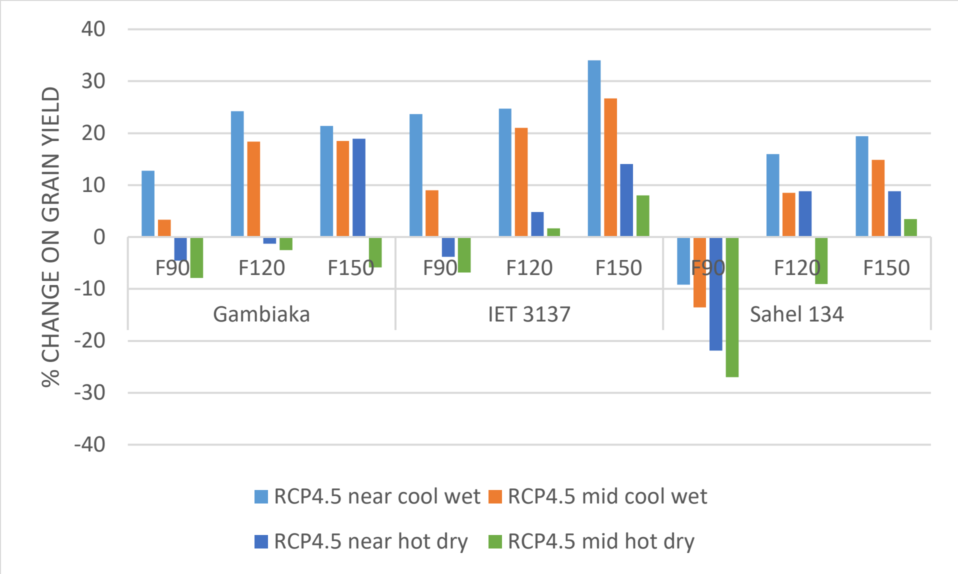


Figure 21 percentage of change on grain yield of rice varieties at RCP 4.5 near term(2010-2039) and mid-century (2040-2069).

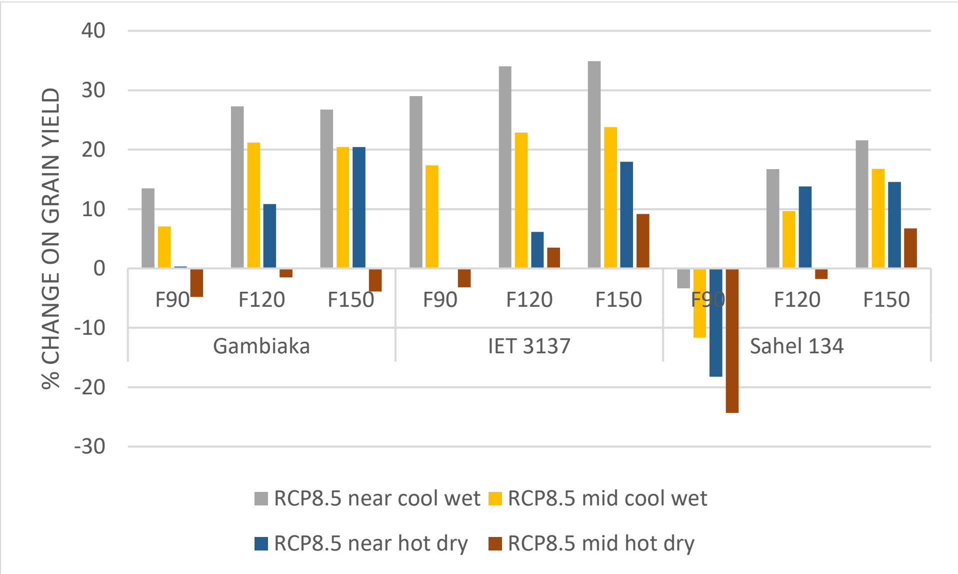


Figure 22 percentage of change on grain yield of rice varieties at RCP 8.5 near term(2010-2039) and mid-century (2040-2069).

August 20 transplanting

Gambiaka rice depending on Segou climate at August 20 transplanting will record grain yield gain due to CO_2 fertilization as projected by cool GCM (GFDL-ESM2G) in both RCP 4.5 and 8.5. The GCM projected higher yield than the simulated baseline yields in both RCPs and at different nitrogen fertilizer levels, the GCM yields ranges from 3 to 5 tons per hectare whilst the baseline yieldsranges from 3 to 4. Yield gain ranges between 2 to 9% for RCP 4.5 near term and mid-century whilst RCP 8.5, projecting grain yield gain of 3 to 6% for near term and mid-century. The RCP 4.5 recorded highest grain yield **Figure** 24 and 25.

Whilst under hot GCM (MPI-ESM-LR) simulated yield gains were recorded all fertilizer levels 1 to 4% for RCP 4.5 near term and mid-century 2 to 4 %. Under RCP 8.5, yield gains under hot GCM was recorded on both fertilizer levels for near term and mid-century 1 to 6%.

A closer situation was observed on IET 3137 rice variety at August transplanting, as cool GCM (GFDL-ESM2G) projecting higher yields in both RCP 4.5 and 8.5. The projected GCM yields was higher than the simulated baseline yields in both RCPs at different fertilizer levels. The projected GCM yields ranges from 3 to 5 tons per hectare whilst the baseline yields were 3 to 4 tons. Yield gain ranges between 5 to 13% for RCP 4.5 near term and mid-century. The RCP 8.5 projecting higher grain yield gain of 7 to 16% at near term and mid-century time horizon.

Some reduction on the yield were observed under hot GCM (MPI-ESM-LR), as simulated yield gains were recorded on all fertilizer levels for RCP 4.5 near term. But RCP 4.5 mid-century, yield gains were noticed on 120kg and 150kg nitrogen fertilizer levels. The RCP 8.5 under hot GCM has a yield gain on all fertilizer levels in the near term and 120kg and 150kg nitrogen fertilizer level at the mid-century.

The cool GCM (GFDL-ESM2G) projecting higher yields in both RCP 4.5 and 8.5 at near term and mid-century time periods for Sahel 134 rice variety. The projected GCM yields ranges from 3 to 4 tons per hectare and the baseline were 2 to 3 tons per hectare at different fertilizer levels. Yield gains were between 10 to 29% for RCP 4.5 near term and mid-century. The RCP 8.5 has projected grain yield gain of 19 to 25% at different fertilizer levels and at near term and mid-century time horizon, RCP 8.5 simulating higher grain yield gain.

The RCP 4.5 near term under hot GCM (MPI-ESM-LR) has recorded a yield gain on all fertilizer levels for the near term and at mid-century, whilst RCP 8.5 under hot GCM has a yield gain on all fertilizer levels in both near term and mid-century time horizons. Yield reduction was noticed on fertilizer level 90kg at RCP 4.5 mid-century and 90kg fertilizer level for RCP 8.5 at the mid-century.

Closer situation was observed on Sahel 134 rice variety at August 20 transplanting, as GCMs projecting higher yields on cool GCM (GFDL-ESM2G). The projected GCM yields was higher than the simulated baseline yields in both RCPs at different fertilizer levels. The GCMs projected yields at different fertilizer levels, ranges from 2 to 4 tons per hectare whilst the baseline yields at different fertilizer levels was 2 to 3 tons. Yield gain ranges between 10 to 25% for RCP 4.5 near term and mid-century time horizons. The RCP 8.5 projecting higher grain yield gain of 10 to 29% at different fertilizer levels at near term and mid-century.

Similar gains were also observed under hot GCM (MPI-ESM-LR), simulated yield gains 5% under RCP 4.5 was recorded on 90kg nitrogen fertilizer level for the near term. The RCP 8.5 under hot GCM had a yield gain of 4 to 9% in the near term and mid-century. Yield reduction was observed on 120kg and150kg nitrogen fertilizer levels for the RCP 4.5 near term and mid-century.

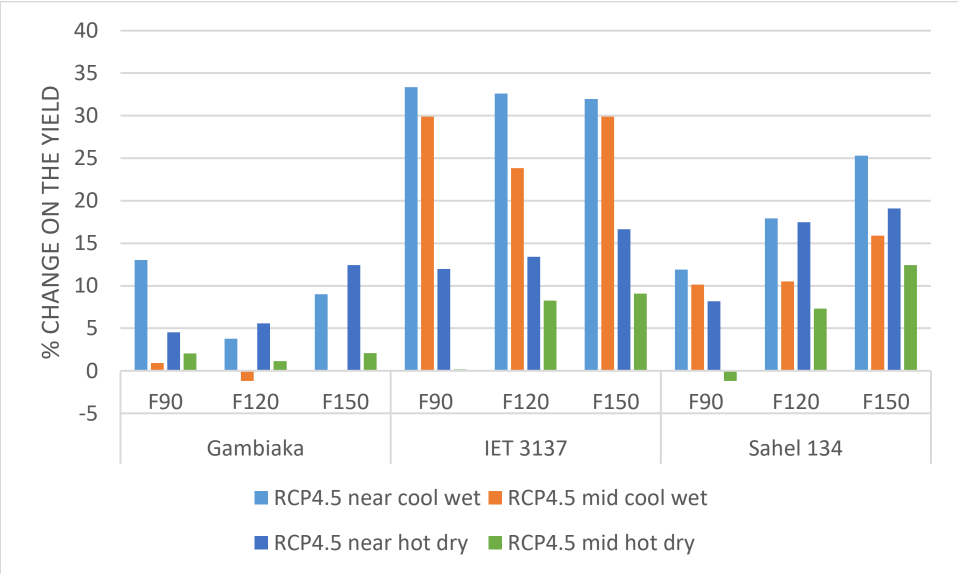


Figure 23 percentage of change on grain yield of rice varieties at RCP 4.5 near term(2010-2039) and mid-century (2040-2069).

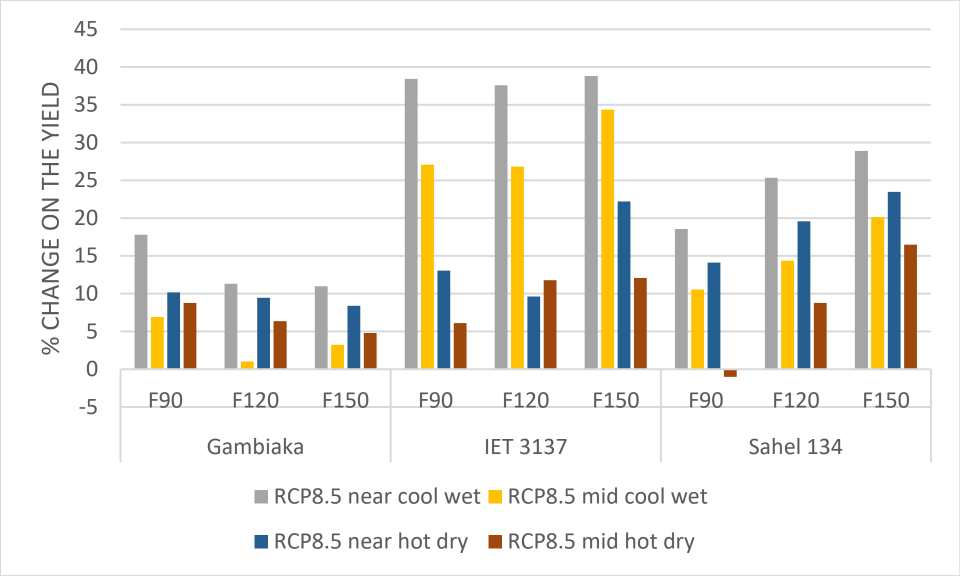


Figure 24 percentage of change on grain yield of rice varieties at RCP 8.5 near term(2010-2039) and mid-century (2040-2069).

September 20 transplanting

The Gambiaka rice grain yield at September transplanting has projected higher yields on cool GCM (GFDL-ESM2G) in both RCP 4.5 and 8.5.

The projected GCMs yields 4 to 5 tons were higher than the simulated baseline yields 3 to 4 tons in both RCPs at different fertilizer levels. Yield gains ranges between 1 to 10% for RCP 4.5 near term and midterm. The RCP 8.5 projecting grain yield gain of 4 to 14% at different fertilizer levels at near term and mid-century, as observed in **Figure** 25 and 26.

The reverse was observed under hot GCM (MPI-ESM-LR), as simulated yield gains was recorded on 90kg nitrogen fertilizer level at near term for both RCP 4.5 and 8.5. A yield decrease was observed on all fertilizer levels at mid-century RCP 4.5 and 8.5 time periods.

The simulated grain of IET 3137 rice variety at September transplanting under cool GCM (GFDL-ESM2G) in both RCP 4.5 and 8.5 at near term and mid-century time periods have shown that the projected GCMs yields were higher than the simulated baseline yields in both RCPs and at different fertilizer levels. The projected GCM yield ranges from 3 to 5 tons per hectare whilst the baseline yieldswere 3 to 4 tons. Yield gain ranges between 1 to 7% for RCP 4.5 near term and mid-century. The RCP 8.5 projecting higher grain yield gain of 3 to 13% at different fertilizer levels and at both near term and mid-century time horizon as compared to the RCP 4.5.

A yield gain was also observed under hot GCM (MPI-ESM-LR), a simulated yield gain under RCP 4.5 was recorded on120kg and150kg nitrogen fertilizer level for RCP 4.5 near term and at 120kg nitrogen fertilizer level for the mid-century. Whilst RCP 8.5 had a yield gain on all fertilizer levels in the near term and mid-century time horizon. Yield reduction was noticed on 90kg nitrogen fertilizer level for RCP 4.5 near term and 90kg and 150kg at mid-century.

Sahel 134 rice variety as at September 20 transplanting might not be severely impacted by climate change as projected by cool GCM (GFDL-ESM2G) in both RCP 4.5 and 8.5. The projected GCM yields was higher than the simulated baseline yields in both RCPs at different fertilizer levels. The projected GCM yields were 2 to 3 tons per hectare whilst the baseline yieldswere 2 tons. Yield gain ranges between 1 to 11% for RCP 4.5 near term and mid-century. The RCP 8.5 projected grain yield gain of 6 to 17% at different fertilizer levels at near term and mid-century.

Similar gains were also observed under hot GCM (MPI-ESM-LR), as simulated yield gains under RCP 4.5 was recorded on all fertilizer level for both RCPs and at near term and mid-century 1 to 6%. The RCP 8.5 had a yield gain of 3 to 14% in the near term and mid-century.

Yield reduction was observed on 120kg and150kg nitrogen fertilizer levels for RCP 4.5 near term and at all fertilizer levels for mid-century.

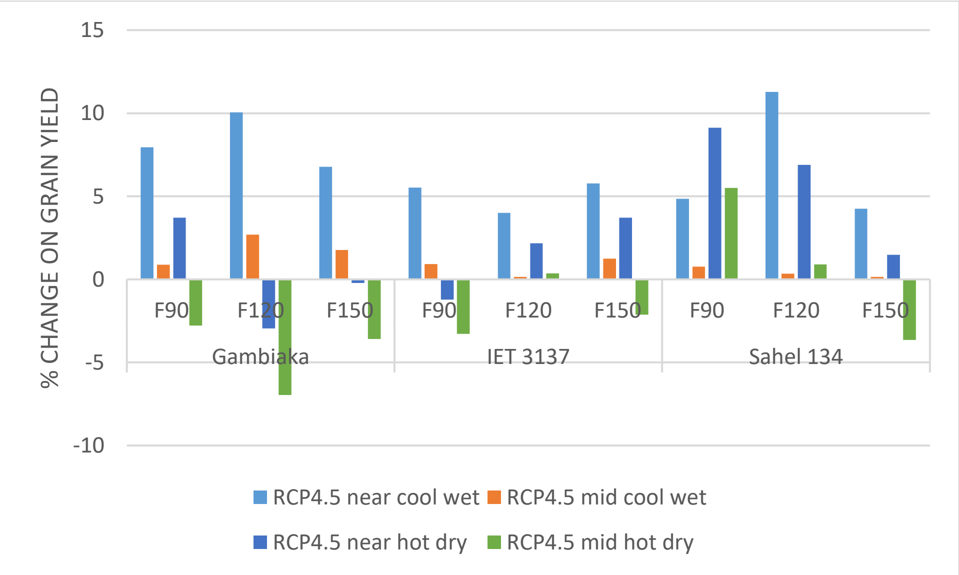


Figure 25 percentage of change on grain yield of rice varieties at RCP 4.5 near term(2010-2039) and mid-century (2040-2069).

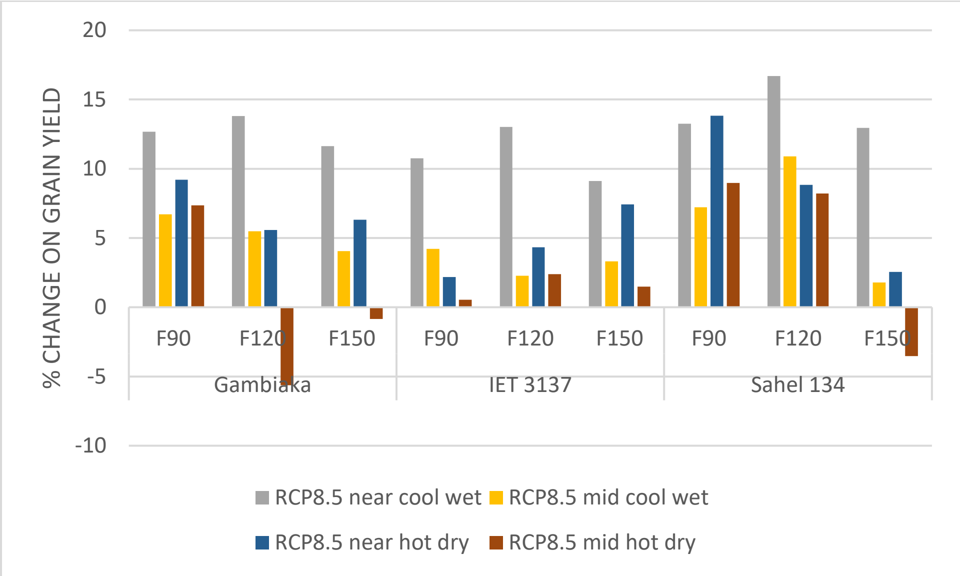


Figure 26 percentage of change on grain yield of rice varieties at RCP 8.5 near term(2010-2039) and mid-century (2040-2069).

Chapter 5: Farmers perceptions about climate change, management practice and the on farm coping strategies at rice fields in Sapu and Kuntaur in The Gambia.

5.1 Materials and methods

5.1.1 Study sites

The field experiment was conducted in the Central River Region (CRR) on latitude 13.56 and longitude -15.93. the detail description of the study site were found in chapter 2.

5.2.2 Data collection methods

A reconnaissance visit was made to the selected two villages of Sapu and Kuntaur for the validity of the study. A pretesting of 15 rice farmers was carried out to ascertain the quality of the questionnaire. The validation of the questionnaire was done also with focus group discussion held with farmers (Heong et al., 2002). Key informants interview was conducted to facilitate optimum information regarding on rice production in the area and the targeted audience were the extension workers, farm leaders and village heads.

The respondents for the survey comprised of a population of 30 active rice farmers from each study site, comprising of 60 respondents for two study site. Rice farmers from each study location were randomly selected using simple random sampling and this comprised of more than 50% of the sampled population. The selection process was also aided by village extension worker and the village head. A semi-structured questionnaire was administered on the theme: socio- demographic information, perception of climate change, perception on chemical fertilizer use, perception on varieties, transplanting dates and adaptation measure to boost their rice production. The questionnaires were read out to farmers in their own dialects for those who cannot read and write, whilst others directly filled the questionnaire, since they have been to school.

5.2.3 Data analysis

Descriptive statistics such as percentages and sums were used to describe farmers' socio-demographic data, perceptions of climate change, selected rice varieties, chemical fertilizer application, transplanting of rice seedling and there on farm adaptation measures to climate change with statistical packages of SPSS software version 20 (SPSS Inc., Chicago, IL, USA).

5.3 Results

5.3.1 Socio- demographic characteristic

Majority of the respondents at Sapu and Kuntaur location were female 80%, rice production in the Gambia were female dominated, men regards it as a female job and as a results only few males are involved in the cultivation activity (Ceesay, 2004). This was in agreement with the focus group discussion and personal interview conducted with respondents. *"Men are generally involved in groundnut and Maize cultivation whilst our wives engaged in rice production because rice production is less tedious than groundnut and maize"*. Most of the respondents 85% were married and 76% were Muslim, which is main religious group in the country. About 68% of the respondents did not have formal education due to the income status of the family could not afford to send their children to school, only few undergone primary and secondary education (see Table 13).

Table 12: Socio-demographic characteristics of respondents

	Frequency	**Percentage (%)**
Sex		
Female	48	80
Male	12	20
Civil status		
Single	9	15
Married	51	85
Religion		
Islam	46	76
Christian	14	23
Education level		
No education	41	68
Primary education	12	20
Secondary education	8	13

5.3.2 Farmers perception of climate change impacts

As shown in **Table 14,** a majority of the respondents 77% have the perception that climate change would cause reduction of forest trees based on local experience, due to reduction in rains, many believed in the future there will be high losses of forest. Around 85% said climate change would increase temperature, which will have serious consequence on rice production, which productivity is highly impacted by extreme temperature especially at flowering and heading. When respondents were asked about the opinion that climate change will increase rice yield, an estimation of few respondents agreed to the motion and majority of them knew that climate change will not increase rice yield, even though rice is a C3 crop and have the chance to benefit from CO_2 fertilization under optimum temperature. C3 crops are the types of crops that undergo calvin cycle, that involves absorbing carbon dioxide from the atmosphere through the small opening of the leaves called stomata and convert it to sugars for its own use through the process called photosynthesis. From the personal interviews and focus group discussion held with rice farmers, they have said that rice crop is resistant to climate change as compared to maize and groundnut, because they were able to get good yields under climate situation. When the respondents were asked about the opinion that climate change will increase rice yield, around 35% disagreed to the opinion. About 50% of the surveyed participants disagree to the motion that pest and disease would favour climate change, they already have the perceived knowledge that pest and disease aggravate during hot weather. The main source of irrigation at both study location is river and many of them 56% said their water supply would be affected if the trend in the climate continues without adaptation in place.

Table 13 Rice Farmers perception on impacts of Climate Change

	Agree	**%**	**Disagree**	**%**	**Not sure**	**%**
Climate change would reduce forest trees	50	77	6	10	8	13
Climate change would increase temperature	51	85	3	5	6	10
Climate change will increase rice yield	21	35	29	40	10	25
Pest and diseases would be favoured by climate change	18	30	15	20	27	50
Water supply from the river would be reduced by climate change	34	56	20	33	6	11

5.3.3 Farmers perception on inorganic fertilizer use

The study, as it was shown in **Table 15,** states that most of the farmers 96% have the agreed to the concept that inorganic fertilizer increased grain yields. But due to their income status many of them cannot afford buying inorganic fertilizer and they rely on compost and farm yard manure. Regardless of their inability to have easy access to inorganic fertilizer, many still beliefs that there cannot be any effective rice production without applying inorganic fertilizer, according to focus group discussion and personal interviews held with them. Regarding the type of fertilizer many prefers NPK whilst other prefer urea as a choice of fertilizer. The opinion as whether inorganic fertilizer increased pest and disease occurrence, 35% agreed, 25% did not agree and 40% were not sure of the opinion. Many of them 58% disagreed to the motion that inorganic fertilizers are cheaper and better than organic fertilizer, they have the perception that the long term usage of inorganic fertilizer can destroy their soil. Most of them used it and they claimed that inorganic fertilizer gives quick response to rice crop.

Table 14 Rice farmers perception of inorganic fertilizer use

	Agree	**%**	**Disagree**	**%**	**Not sure**	**%**
More inorganic fertilizer more yields	54	96	6	4	0	0
Inorganic fertilizers increased pest and disease infestation on yield	21	35	15	25	24	40
Inorganic fertilizer is better and cheaper than organic fertilizer	20	33	35	58	5	8

5.3.4 Perception on Transplanting

Most of the respondents 80% have the belief that transplanting rice seedlings would give high yield as indicated in **Table 16** and due to that effect nurseries are conducted which are later transplanted into the field. Majority of the farmers 58% have the perception that transplanting rice seedling at closer distance would not to give high yields based on the interview conducted with them and if they are asked why no reason is given but based on their own instinct. About 71% of the respondents also mentioned that transplanting tall seedling would not give high yield and most of them transplant very young seedlings (around 10 days old) to their field and when asked why, many said the idea was introduced by extension workers and it yielded good results, that is why they adopt the innovation. Finally, about 66% agreed that transplanting during hot weather increases the attack of pest and diseases and that it is not advisable to transplant during that condition. All this answers were close to the current scientific findings(Ceesay, 2004).

Table 15 Rice farmers perception of Transplanting rice seedlings

	Agree	%	Disagree	%	Not sure	%
Transplanting of rice gives high yields	48	80	9	15	3	5
Transplanting at shorter distance gives high yields	10	16	35	58	15	26
Transplanting of tall seedlings gives high yields	7	11	43	71	10	18
Transplanting during hot months increases pest and diseases damage.	40	66	3	5	17	29

5.3.5 Perceptions on varieties selection

Based on the local experiences of the respondents on rice varieties as mentioned in **Table 17**, many 58% said improved rice varieties yield more than the traditional variety, thereby disagreeing the motion that traditional varieties yielded more than improved varieties. About 35% of the respondents also agreed that traditional varieties yield more than improved varieties. About 23% of the respondents were of the opinion that traditional varieties can tolerated extreme environments than the improved variety, whilst 46% of them did not agree that traditional variety withstand harsh environments that the improved rice variety and 31% were not sure whether it is the traditional. Their reason was that traditional varieties were in existence for a long period and they exhibit characters to withstand unfavourable climate. Most of the respondents 51% were not in agreement that traditional varieties are tastier than the improved rice variety. "*due to nice tasty nature of the traditional rice variety, it is highly used as porridge in many homes and the most preferred during ceremonies*", as quoted from focus group discussion. Almost 75% of the sampled rice farmers agreed that improved rice varieties are early maturing as compared to traditional varieties. About 81% of the respondents agree that traditional rice varieties are highly susceptible to lodging or falling down due to extreme events, due to their long height. Lodging is one of the problems farmers encounter in irrigated lowland rice production in the Gambia, most of grain yields are lost when lodging occurs in rice fields.

Table 16 Rice farmers perception of varietal selection

	Agree	%	Disagree	%	Not sure	%
Traditional rice varieties yield more than improved varieties	21	35	35	58	4	7

Traditional varieties withstand unfavourable conditions than improved varieties	14	23	28	46	18	31
Traditional rice varieties are more tastier than improved varieties	17	28	31	51	12	21
Traditional varieties mature late than improve varieties	45	75	5	8	10	7
Traditional varieties are exposed to lodging than the improved varieties	49	81	5	8	6	11

5.3.6 Adoption measures at the farm level

About 85% of rice farmers have adopted changing their farming calendar as their main on farm adaptation strategy. Based on their local experience, most of them know when to embark on cultivation, around 6% still maintain their usual time of cultivation whilst 9% of them were not sure if change of farming calendar could really help them boost their yields. Most of them 78% have stopped cultivating traditional varieties because it is late maturing and prefer to use improved varieties that are early maturing, about 16% of them still used their traditional varieties as an on farm adoption measures, and do not want to switch to other rice varieties whilst 6% of the respondents were not sure in both opinions. Few of them 9% who can afford inorganic fertilizer, prefers using it as an adaptation measures to climate change, they still have the beliefs that inorganic fertilizer can greatly contribute to high yields regardless of weather condition, whilst 51% did not agreed the use inorganic fertilizer as an on farm adoption strategy and 6% of them were not sure in both cases. Some of them 43% agreed using pesticides as an adoption measure to control pests and diseases on their rice fields, and many have the understanding that when rice fields are protected from pest and disease attack, grain yields would be improved, whilst about 40% did not agreed to the concept and 17% of them were not sure in both cases, (see **Table** 6).

Table 17 Rice farmers on farm adaption strategies

	Agree	**%**	**Disagree**	**%**	**Not sure**	**%**
Changing of farming calendar	51	85	4	6	5	9

Use of improved rice varieties	47	78	10	16	3	6
Use of inorganic fertilizers	5	9	51	85	4	6
Use of pesticides	26	43	24	40	10	17

Chapter 6: Discussion

6.1 : Objective 1 Discusion

6.1.1 Plant height

There were different plant heights at maturity depending on the variety which can be due to different internodal lengths. The rice cultivar with longer internodal length (Gambiaka) gives taller plants. Similar situations were observed by Ashrafuzzaman *et al.*, (2009) who mentioned that plant height is induced by inter nodal length. However, genetic differences also contributed to the variability in plant height (Mohammad *et al.,* 2002). This is in line with this study, Gambiaka rice variety with high inter nodal length has the highest height.

It can be confirmed from this experiment that lowland rice responds effectively to nitrogen fertilizer application and the control plot which has no fertilizer appeared to have taller plant height. Nitrogen fertilizer is indeed the most limiting nutrient in lowland rice productivity and its effects are highly noticed on the crop productivity. According to Awan *et al.,* (1984); Singh, and Sharma (1987); Irshad, (1996); Maqsood, (1998); and Meena *et al.,* (2003) , nitrogen fertilizer application level of 180 kilogram per hectare induce plant height in rice. In many instances varieties that do well in poor soils have mostly tall and slender, poor productive tillers, prone to lodging and high dry matter accumulation whilst rice varieties that had received enough fertilizer during their production cycles generally have optimum height, high tillering rate, more productive tillers and grain yield. A stated by Sta Cruz and Wada, (1994), the different utilization of nitrogen fertilizer among rice cultivars of different phenology is the period of lapses at their vegetative stage. Plant height is a great determinant of response to nitrogen fertilizer (ANDRIANARISOA, 2004).

There can be no form of life in crops without nitrogen which is the great stimulant of growth (Cedra, 1997). Deficiency of nitrogen in soils are the causes of stunted growth in rice (Dobermann, 2002 ; Courtois and Jacquot 1983; Lacharme, 2001; Akintayo *et al.,* 2008; Verma and Srivastava 1971). The results are were also supported with the finding of (Safdar *et al.*, 2008).

6.1.2 Panicle number per hill

It was mentioned by Kusutani et al., (2000) and Dutta, (2002), that cultivars or genotypes with greater number of panicles per hill produces more grain yields. This is being noticed in this experiment where Gambiaka rice variety that produces greater number of productive panicle has obtained greater grain yields

6.1.3 Tiller number per hill

The analysis result on tillering is in line with the research conducted by Singh and Sharma 1987; Rafey et al., 1989; Munda, 1989; Maqsood, 1993; Nawaz, 2002,and Meena et al., (2003b), which state that, tillering induced by fertilizer application might be possible that the fertilizer was applied during active tillering. The same authors have mentioned that, the number of panicles that increased with the levels of fertilizer rates might be due to nitrogen consumption of the plant during heading. This is very true for this experiment, top dressing with nitrogen fertilizers was done at active tillering and at heading.

Nitrogen fertilizer is the major factor for more tillering in lowland rice production and was stressed by De Datta, 1981, Adrao / WARDA, 1995 and Sibomona, (1999), that nitrogen is main factor responsible for high tillering rate in rice at vegetative period, although phosphorus fertilizers provides more active tillers to enable the rice to withstand unfavourable climate conditions (Courtois and Jacquot 1983; Adrao / WARDA, 1995). The rate of tillering is influenced or affected by the precipitation or irrigation, temperature, solar radiation, nitrogen and other essential elements for plant growth. Similar result was found by Patel *et al.,* (1995) Mazid and Ahmad (1975).

6.1.4 Weight of 1000 grains

The same results were observed from the research conducted by Rafey et al., 1989 and Awan *et al.,* (1984), which shows that 1000 grain weight increased with nitrogen application rates and this increase can be due to sufficient availability of photosynthesis during heading.

These observations are in good agreement with those of (Shekher and Singh 1991; Singh *et al.,* 1997; and Annie *et al.,* 2009).

6.1.5 Biomass yield

Transplanting dates have high influence on the yield and yield component of rice, the July transplanting produced more biomass yield which is in line with the findings of (Shaheen et al.; 2008). Nitrogen fertilizer also induce biomass yield, nitrogen is indeed the main limiting factor for lowland rice production and this is in line with the findings of (Mandal et al., 1991; Andrade et al., 1992; and Ehsanullah et al., 2001).

6.1.6 Grain yield

Lowland rice grain yield in our experiments was highly influenced by transplanting dates. This is in good agreement with those of Mahikar *et al.,* (2001); and Lin and Huang (1992)

Numerous studies have indicated the positive responses of lowland rice yield to fertilizer application rates (Kanade, 1986; Marazi *et al.,*1993; Dixit, 1994; Daniel, 1994; Nawaz, 2002; Meena *et al.,* 2003;Buresh *et al.,* 1993;Nayak *et al.,* 2003).

Research conducted by Manzoor et al., (2005)that transplanting rice seedlings at early stage of the rainy season induce good yields than late transplanting, but this does conform to the find. The July transplanting produces more gains on the yield and yield component.

6.2: Objective 2 Discussion

The findings of the study were in close collaboration with the findings of Kaur, P. and Hundal, (2001) which states that the usage of CERES-Rice simulation model to predict rice growth and yield from 1996 to 1999 at Ludhiana, Punjab study location. The model simulation outputs for the rice shows anthesis dates varied between -13 to +11 days for (variety PR-114). The estimated grain yield range from 78 to 120 percent for PR-111, PR-113 and PR-114, correspondingly. The performance of the model indicates good results between the observe and the simulated yields.

Similar studies was conducted by Swain et al., (2007) with DSSAT version 4.0 for the rice cultivar IR 36 at Cuttack, Orissa study location in 2001-2002 using experimental data of rainy seasons. The model effectively simulated rice phenology, which is also in line with the finding in The Gambia.

The study conducted by Sreenivas et al., (2010), on the adaptation of Ceres- rice model version 4.5 for the rice of MTU 1010 at Rajendranagar in the Agricultural Research Institute. The adaptation of the model was done using experimental data sets using different planting dates and nitrogen fertilizer levels for the year 2007-2010. The performance of the model was quite impressive. This is good agreement with findings of this study.

The results of Dass et al., (2012) on CERES-Rice model with experimental data sets of 2009 to calibrate the performance of the model output. The model evaluation was done using 2008 experimental data. The output of the model shows fair results for the observe and simulated data. Similar findings were observed from (Rai, 2005; Kumar et al., 2010; Athiyaman, B. and Singh, 2013;) .

6.3: Objective 3 Discussion

The outcome of this experiment showed that without CO2 enrichment under inceasing temperatures, rice grain yield would reduce by 19% under RCP 4.5 and 15% under RCP 8.5 at both study locations, this is in agreement with the findings of (see Kimball, 1983; Acock and Allen, 1985; Cure and Acock, 1986; Allen, 1990; Rozema *et al.*, 1993; Allen, 1994; Allen and Amthor, 1995).

Maclean *et al., (*2002), estimated that about 40 percent of rice production lands are considered rainfed either lowland or upland whilst the rest are considered deep water or flood prone regions. Floods was observed at August transplanting, where the newly transplanted rice remains inundated for long period. But the selected rice varieties were a bit resistant to inundation. Rainfall distribution and amount is very crucial in rice production and is one of the main factor limiting rice production yields, lowland production is affected by flood, the maximum days the rice crop can remain submergent in water is 14 days(Maclean *et al.,* 2002). According to Peng et al., (2004), the severity of temperature differed based on the variety, duration of the critcal temperature diernal changes and the physiological status of the crop.
Lowland rice production is highly impacted by extreme temperature, both low and high temperatures especially at tillering and panicle initiation will decrease grain yield. The impacts of increase temperature has great influence on the growth period and patterns of growth in rice. Excessive temperature causes grain sterility, reduce tillering and panicle formation. Studies conducted by Pathak *et al.*, (2003), Peng *et al.*, (2004), all stated that rice productivity would decline with extreme temperatures, this is in line with this study, low productivity was observed at March Transplanting, where temperature was more than 35°C.
The optimum temperatures for rice growth changes with physiological development processes as well as with the variety. The temperature range of 22°to 33°C is desirable for rice growth, there is linearlity with growth rate and the increasing temperatures. The temperature effects on growth rate are normally measured using temperature quotient (Peng *et al.,* 2004), tillering rates, leaf emergency are increased by higher temperatures, but during the reproductive stage the spiklet number increases with low temperatures (Bouman *et al.,* 2007)

Rice productivity in sub-Saharan Africa would be severely impacted by the events of climate change according to IPCC (2013).The output of the study showed that without CO_2 availability rice grain yields will reduce by 19% under RCP 4.5 and 15% under RCP 8.5 at both study locations. The increase in fertilizer levels and change of transplanting date would positively impacts on the yields. As indicated in most studies, this study shows high yield increase of 40% for Kuntaur and 35% for Segou at different fertilizer levels, across varieties and transplanting dates when future CO_2 values was considered in the model. Although most studies indicated that the rise in ozone could also lead to yield loss Long *et al.*, *(*2006) , but the model outputs shows yield increase at both near term and mid-century as result of CO_2 availability.

Simulations that were conducted by Sultan et al., (2013), involving eight different countries in the Sudano-Sahelian sites had shown yield decrease of -41% for millet and sorghum under extreme temperature and low rainfall by the end of the century. Grain yield reduction of 50% was also predicated by Muller et al., 2011 and Roudier et al., (2011).

6.4: objective 4 Discussion

The rice farmer's perception of management practices like the determination of optimum transplanting dates, selection of varieties and the application of inorganic fertilizers there on farm adoption strategies to combat climate change were in line with current scientific findings. Farmers already knew about extreme temperatures and variability in rainfall which is in agreement with meteorological records with exception of their perceived reduction of rainfall. This analysis results were in agreement with the findings of Cooper et al., (2008). Perception studies and scientific knowledge on climate change were also found in (Apata et al., 2009; Deressa et al., 2009). Optimum planting dates plays a significant role in the attainment of maximum yield (IPCC, 2007a; Thomas et al., 2007), as a result the findings of this experiment shows that majority of the respondents have changed their transplanting date to adjust to the current climate situation. Farmers already knew about the need for application of fertilizers but their decision are largely influenced by the cost of fertilizer, their knowledge in fertilizer application and the availability of fertilizer (Dobermann, 2012). Although rice fields at Sapu and Kuntaur study site did not have low water crises at the moment, since river is their main source of irrigation, but rice farmers do adjust their cropping calendar to avoid their production cycle been coinciding with extreme weather event, which is detrimental at panicle initiation and grain filling stage.

Chapter 7: Conclusions and Out look

The study provides evidence that varieties, nitrogen fertilizer, and transplanting dates were of paramount importance to the grain yields of lowland rice. Gambiaka been the late maturing rice variety produces more grain yields than the rest of the varieties and the application of 150 kg nitrogen per hectare out-yielded the lower rates of N, including the recommended rate of 90 kg in The Gambia. All the transplanting dates yielded high normal yield except that of March transplanting at both study locations.

The results from the DSSAT simulation model indicated good integration of physiological, weather, soil and experimental data that was built into the DSSAT to run a simulation for the three rice varieties in the Gambia for the year 2017 and 2018 respectively. The simulated grain yield, and Anthesis day were compared with measured values from the experiment. There was good closeness between the observed and the simulated values. There were yield reduction in some years which might be as a result bad weather influence and soil condition. DSSAT simulation tool can effectively simulate lowland rice yields in The Gambia.

Rice production will benefit from CO_2 availability under best temperature, the study showed that with both RCPs, the irrigated lowland rice yields would be severely impacted without CO_2 enrichment under increasing temperature. The application of nitrogen fertilizer has no influence on the yield under extreme temperature situation. But when CO_2 was considered in the simulation, yield gains was noticed for both model at RCP 4.5 and 8.5 time periods. More gain on the grain yield was noticed at Kuntaur study location. It is necessary to consider crop that will benefit from CO_2 to sequester enough greenhouse from the atmosphere, to mitigate climate change.

The findings of this research is in agreement with the finding of current scientific research, that to say farmers are aware of climate change and they are using their own initiatives to overcome the impacts at the farm level. Farmers productivity would be enhanced by the use of inorganic fertilizers, change of transplanting dates and varieties. Most of the farm adoption strategies included the change of crop calendar, use of inorganic fertilizer, use of improve rice varieties to adapt to climate variability. The education or training of farmers on weathers related area is crucial for effective adaptation strategy to enable decision making in agricultural production.

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Appendices

Apendix1 Grain yield of rice variety Gambiaka, Sahel 134, IET 3137 under RCP 4.5 and 8.5 scenarios for the coolest and hottest GCMs, Near-term (1980-2039) and Mid-century (2040-2069) time horizons. Transplanting on July 20, Kuntaur, The Gambia.

July 20DAT		current	4.5Near (cool wet	8.5Near(cool wet	4.5Mid(cool wet	8.5Mid(cool wet
	F1	3152	3474	3770	3371	3382
	F2	3557	3995	4115	3552	3678
	F3	4252	4848	4951	4587	4657
			4.5 Near (hot/dry	8.5 Near (hot/dry	4.5 Mid (hot/dry	8.5 Mid (hot/dry
			3278	3354	3092	3275
			3357	3699	3677	3386
			4472	4575	4082	4353
IET 3137		current	4.5Near (cool wet	8.5Near(cool wet	4.5Mid(cool wet	8.5Mid(cool wet
	F1	2447	3198	3209	2949	3065
	F2	3283	3949	3992	3671	3763
	F3	3519	4548	4884	4388	4404
			4.5 Near (hot/dry	8.5Near(hot/dry	4.5Mid(hot/dry	8.5 Mid (hot/dry
			2762	2926	2691	2750
			3520	3774	3442	3464
			3820	3948	3740	3757
Sahel 134		current	4.5Near (cool wet	8.5Near(cool wet	4.5Mid(cool wet	8.5Mid(cool wet
	F1	2688	2777	2981	2587	2690
	F2	2742	3576	3723	3146	3359
	F3	3055	4668	4704	4115	4224
			4.5 Near (hot/dry	8.5 Near (hot/dry	4.5 Mid (hot/dry	8.5Mid (hot/dry
			2468	2531	2209	2267
			3159	3317	3071	3290

			3423	3549	3325	3441

Appendices

Apendix2 Grain yield of rice variety Gambiaka, Sahel 134, IET 3137 under RCP 4.5 and 8.5 scenarios for the coolest and hottest GCMs, Near-term (1980-2039) and Mid-century (2040-2069) time horizons. Transplanting on August 20, Kuntaur, The Gambia.

AUGUST 20DAT		current	4.5Near (cool wet	8.5Near(cool wet	4.5Mid(cool wet	8.5Mid(cool wet
	F1	3057	3424	3710	3301	3440
	F2	3451	3991	4015	3522	3651
	F3	4052	4868	4921	4521	4620
			4.5 Near (hot/dry	8.5 Near (hot/dry	4.5 Mid (hot/dry	8.5 Mid (hot/dry
			3238	3384	3112	3225
			3527	3489	3617	3346
			4442	4545	4052	4823
IET 3137		current	4.5Near (cool wet	8.5Near(cool wet	4.5Mid(cool wet	8.5Mid(cool wet
	F1	2845	3545	3971	3149	3392
	F2	3020	3933	4020	3538	3697
	F3	3657	4504	4819	4294	4621
			4.5 Near (hot/dry	8.5 Near (hot/dry	4.5 Mid (hot/dry	8.5 Mid (hot/dry
			2904	2941	2924	2956
			3397	3595	3148	3284
			3798	3896	3693	3760
Sahel 134		current	4.5Near (cool wet	8.5Near(cool wet	4.5Mid(cool wet	8.5Mid(cool wet
	F1	2352	3313	3500	3187	3490
	F2	2769	3805	3910	3546	3659
	F3	2982	4448	4663	4151	4228
			4.5 Near (hot/dry	8.5 Near (hot/dry	4.5 Mid (hot/dry	8.5Mid (hot/dry
			2868	2908	2159	2665

			3259	3517	2662	3195
			3623	3849	3125	3246

Apendix3 Grain yield of rice variety Gambiaka, Sahel 134, IET 3137 under RCP 4.5 and 8.5 scenarios for the coolest and hottest GCMs, Near-term (1980-2039) and Mid-century (2040-2069) time horizons. Transplanting on September 20, Kuntaur, The Gambia.

SEPT. 20DAT		current	4.5Near (cool wet	8.5Near(cool wet	4.5Mid(cool wet	8.5Mid(cool wet
	F1	3152	3574	3870	3171	3482
	F2	3557	4195	4415	3652	3878
	F3	4252	4948	5251	4387	4557
			4.5 Near (hot/dry	8.5 Near (hot/dry	4.5 Mid (hot/dry	8.5 Mid (hot/dry
			3078	3354	2892	2975
			3557	3899	3377	3586
			3972	4375	4682	4053
IET 3137		current	4.5Near (cool wet	8.5Near(cool wet	4.5Mid(cool wet	8.5Mid(cool wet
	F1	2749	3775	3993	3249	3592
	F2	3110	4033	4220	3718	3995
	F3	3537	4710	4914	4593	4722
			4.5 Near (hot/dry	8.5 Near (hot/dry	4.5 Mid (hot/dry	8.5 Mid (hot/dry
			3104	3341	2824	2977
			3591	3791	3344	3581
			3998	4096	3973	3960
Sahel 134		current	4.5Near (cool wet	8.5Near(cool wet	4.5Mid(cool wet	8.5Mid(cool wet
	F1	2752	3515	3711	3384	3590
	F2	3469	3885	3878	3646	3759
	F3	2782	4048	4263	4951	4128

			4.5 Near (hot/dry	8.5 Near (hot/dry	4.5 Mid (hot/dry	8.5Mid (hot/dry
			3268	3508	2659	2865
			3419	3717	2662	3195
			3613	3842	3320	3444

Apendix4 Grain yield of rice variety Gambiaka, Sahel 134, IET 3137 under RCP 4.5 and 8.5 scenarios for the coolest and hottest GCMs, Near-term (1980-2039) and Mid-century (2040-2069) time horizons. Transplanting on July 20, Segou, Mali.

JULY 20DAT		current	4.5Near (cool wet	8.5Near(cool wet	4.5Mid(cool wet	8.5Mid(cool wet
	F1	4362	4918	4951	4508	4670
	F2	4501	5591	5730	5328	5454
	F3	4950	6008	6275	5865	5926
			4.5 Near (hot/dry	8.5 Near (hot/dry	4.5 Mid (hot/dry	8.5 Mid (hot/dry
			4163	4375	4018	4152
			4442	4990	4386	4434
			5888	5962	4661	4759
IET 3137		current	4.5Near (cool wet	8.5Near(cool wet	4.5Mid(cool wet	8.5Mid(cool wet
	F1	3770	4663	4863	4109	4425
	F2	3875	4834	5193	4689	4762
	F3	3938	5278	5313	4990	4875
			4.5 Near (hot/dry	8.5 Near (hot/dry	4.5 Mid (hot/dry	8.5 Mid (hot/dry
			3625	3772	3513	3650
			4061	4113	3939	4010
			4492	4645	4254	4300
Sahel 134		current	4.5Near (cool wet	8.5Near(cool wet	4.5Mid(cool wet	8.5Mid(cool wet

	F1	2917	3557	3786	3387	3460
	F2	3355	3890	3916	3640	3679
	F3	3789	4525	4606	4351	4428
			4.5 Near (hot/dry	8.5 Near (hot/dry	4.5 Mid (hot/dry	8.5Mid (hot/dry
			3061	3202	2859	2965
			3650	3818	3052	3295
			4123	4340	3920	4044

Apendix5 Grain yield of rice variety Gambiaka, Sahel 134, IET 3137 under RCP 4.5 and 8.5 scenarios for the coolest and hottest GCMs, Near-term (1980-2039) and Mid-century (2040-2069) time horizons. Transplanting on August 20, Segou, Mali.

AUGUST 20DAT		current	4.5Near (cool wet	8.5Near(cool wet	4.5Mid(cool wet	8.5Mid(cool wet
	F1	4085	4618	4812	4122	4368
	F2	5099	5291	5676	5038	5151
	F3	5237	5708	5812	5242	5405
			4.5 Near (hot/dry	8.5 Near (hot/dry	4.5 Mid (hot/dry	8.5 Mid (hot/dry
			4270	4500	4169	4443
			5384	5582	5158	5423
			5414	5677	5345	5489
IET 3137		current	4.5Near (cool wet	8.5Near(cool wet	4.5Mid(cool wet	8.5Mid(cool wet
	F1	3454	4606	4781	4487	4390
	F2	3752	4976	5163	4646	4759
	F3	3965	5233	5504	5151	5328
			4.5 Near (hot/dry	8.5 Near (hot/dry	4.5 Mid (hot/dry	8.5 Mid (hot/dry
			3868	3905	3459	3665
			4255	4413	4062	4195

			4625	4846	4325	4444
Sahel 134		current	4.5Near (cool wet	8.5Near(cool wet	4.5Mid(cool wet	8.5Mid(cool wet
	F1	2894	3239	3431	3187	3200
	F2	2937	3464	3681	3246	3359
	F3	2956	3704	3810	3426	3551
			4.5 Near (hot/dry	8.5 Near (hot/dry	4.5 Mid (hot/dry	8.5Mid (hot/dry
			3161	3302	2859	3065
			3450	3518	3152	3195
			3520	3650	3323	3444

Apendix6 Grain yield of rice variety Gambiaka, Sahel 134, IET 3137 under RCP 4.5 and 8.5 scenarios for the coolest and hottest GCMs, Near-term (1980-2039) and Mid-century (2040-2069) time horizons. Transplanting on September 20, Segou, Mali.

SEPT. 20DAT		current	4.5Near (cool wet	8.5Near(cool wet	4.5Mid(cool wet	8.5Mid(cool wet
	F1	4185	4518	4715	4222	4466
	F2	4899	5391	5575	5031	5168
	F3	5237	5588	5842	5325	5445
			4.5 Near (hot/dry	8.5 Near (hot/dry	4.5 Mid (hot/dry	8.5 Mid (hot/dry
			4340	4570	4069	4493
			4754	5172	4558	4623
			5222	5564	5045	5189
IET 3137		current	4.5Near (cool wet	8.5Near(cool wet	4.5Mid(cool wet	8.5Mid(cool wet
	F1	3670	3873	4065	3704	3825
	F2	3975	4134	4493	3981	4065
	F3	4138	4377	4515	4190	4275

			4.5 Near (hot/dry	8.5 Near (hot/dry	4.5 Mid (hot/dry	8.5 Mid (hot/dry
			3625	3750	3550	3690
			4061	4147	3989	4070
			4292	4445	4054	4200
Sahel 134		current	4.5Near (cool wet	8.5Near(cool wet	4.5Mid(cool wet	8.5Mid(cool wet
	F1	2994	3139	3391	3017	3210
	F2	3137	3491	3661	3148	3479
	F3	3456	3603	3904	3461	3518
			4.5 Near (hot/dry	8.5 Near (hot/dry	4.5 Mid (hot/dry	8.5Mid (hot/dry
			3267	3408	3159	3263
			3353	3414	3165	3395
			3507	3544	3330	3334

Appendix7: Rice Grain yield responses to Scenarios at July 20 transplanting, Kuntaur, Gambia (without CO_2 availability)

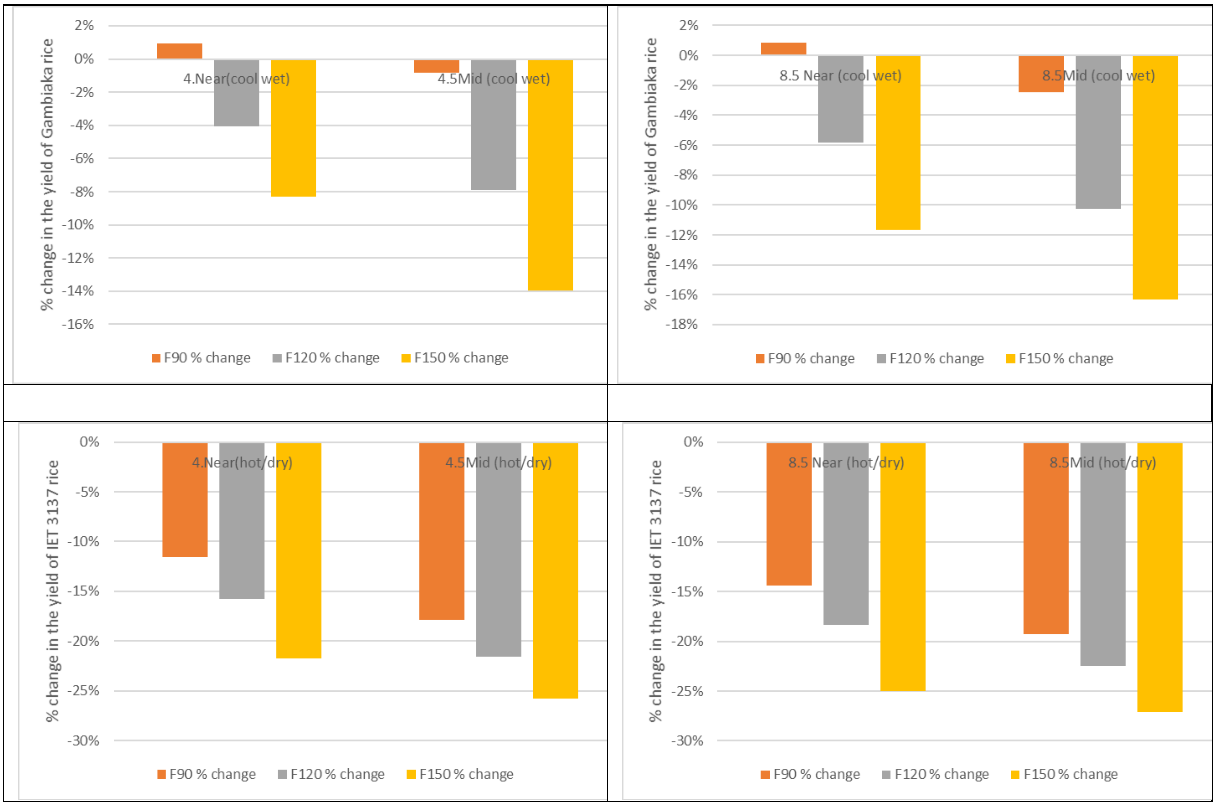


Figure 27 Gambiaka rice grain yield responses to scenarios at August 20 transplanting, Segou, Mali (without CO_2 availability).

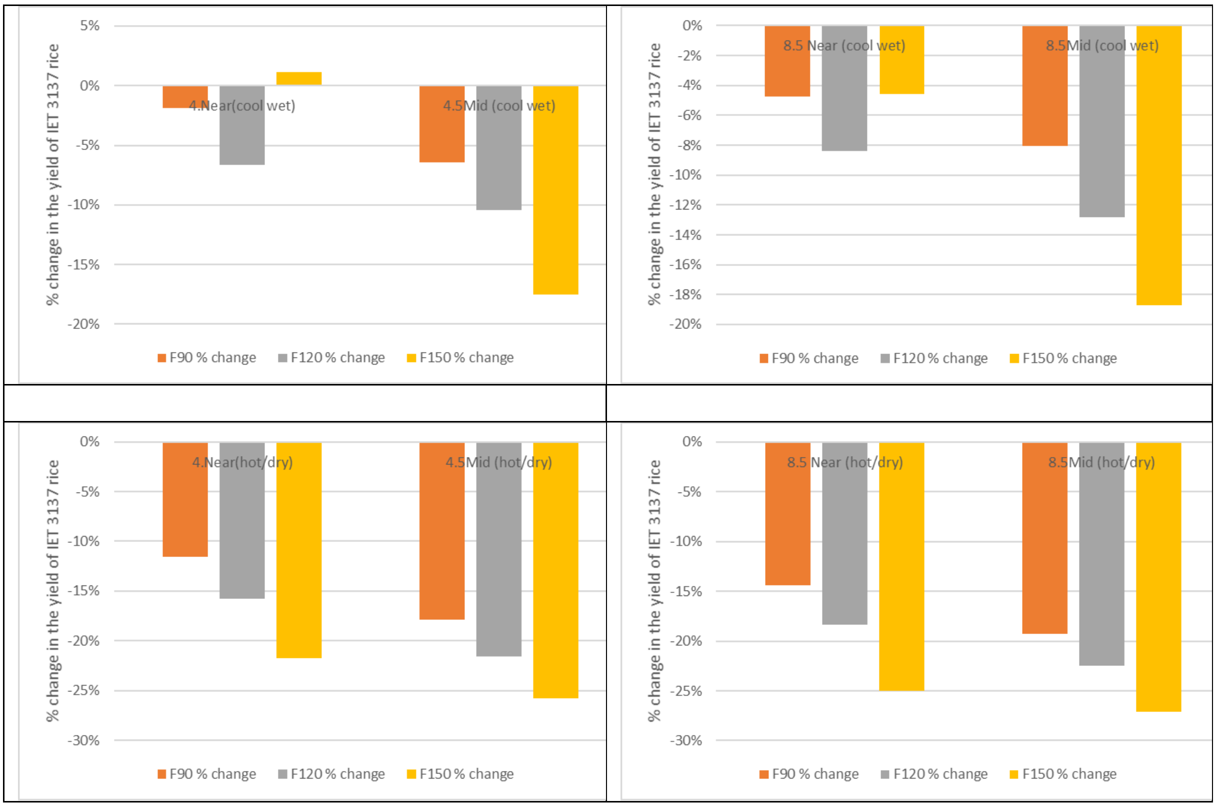


Figure 28 IET 3137 rice grain yield responses to scenarios at August 20 transplanting, Segou, Mali (without CO_2 availability).

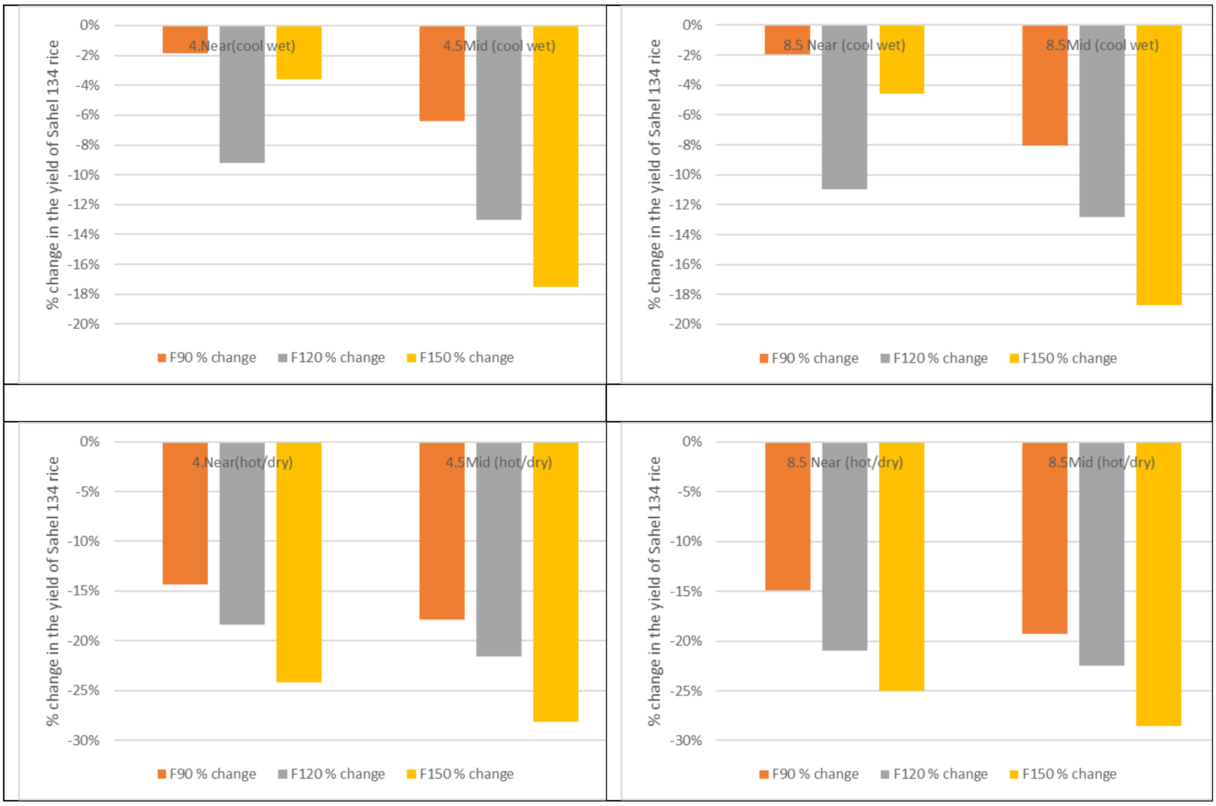
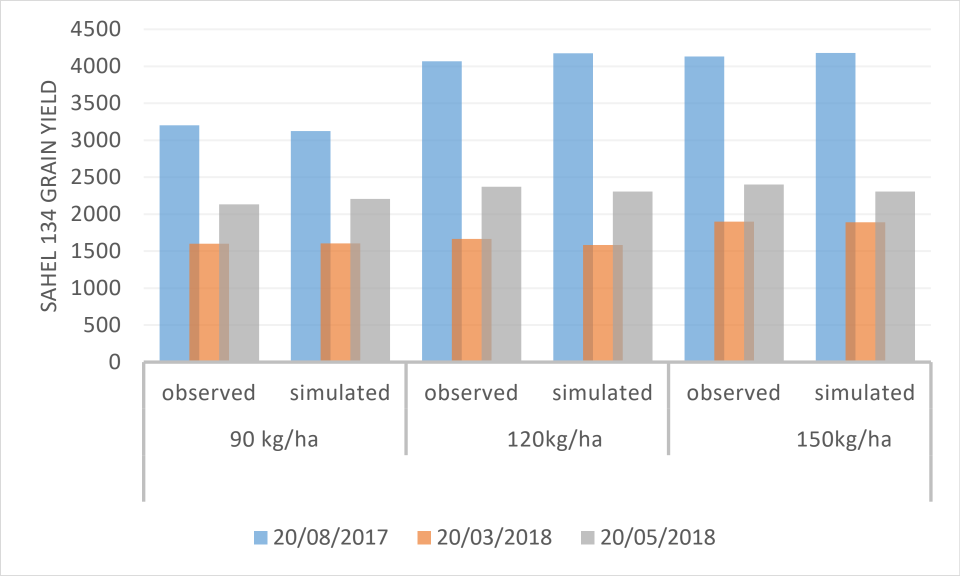
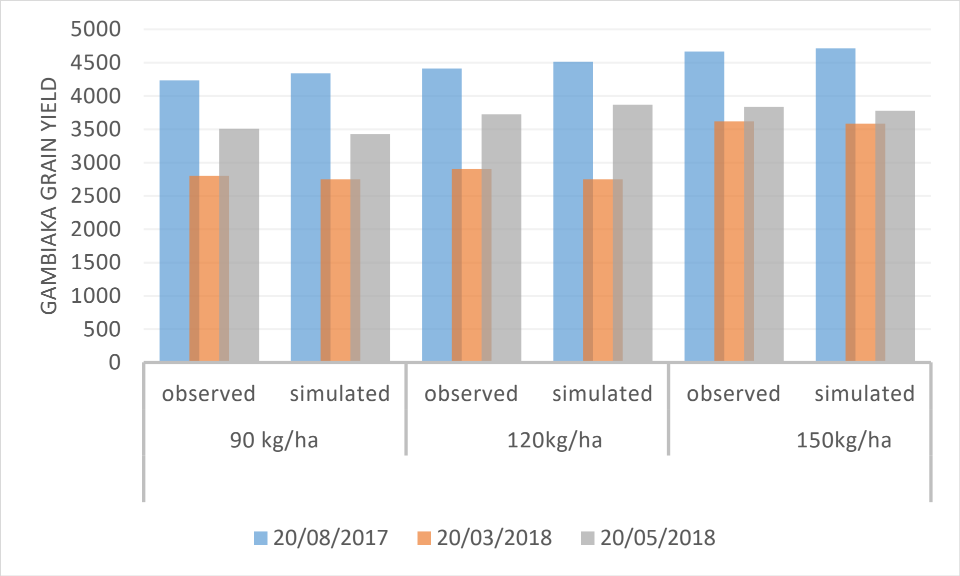


Figure 29 Sahel 134 rice grain yield responses to scenarios at August 20 transplanting, Segou, Mali (without CO_2 availability).

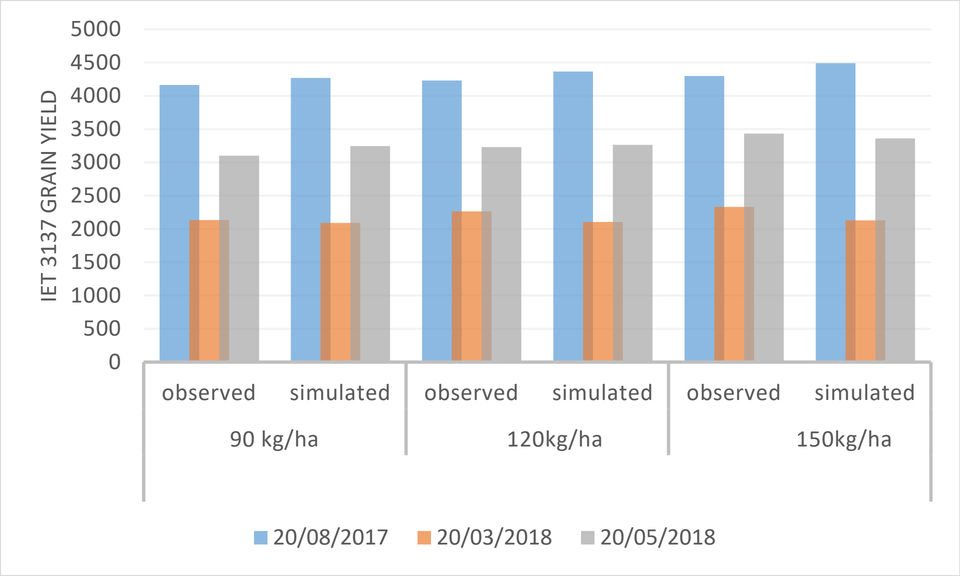
Appendix 7 comparison of simulated and observed values for rice Anthesis dates using DSSAT model at Kuntaur study location



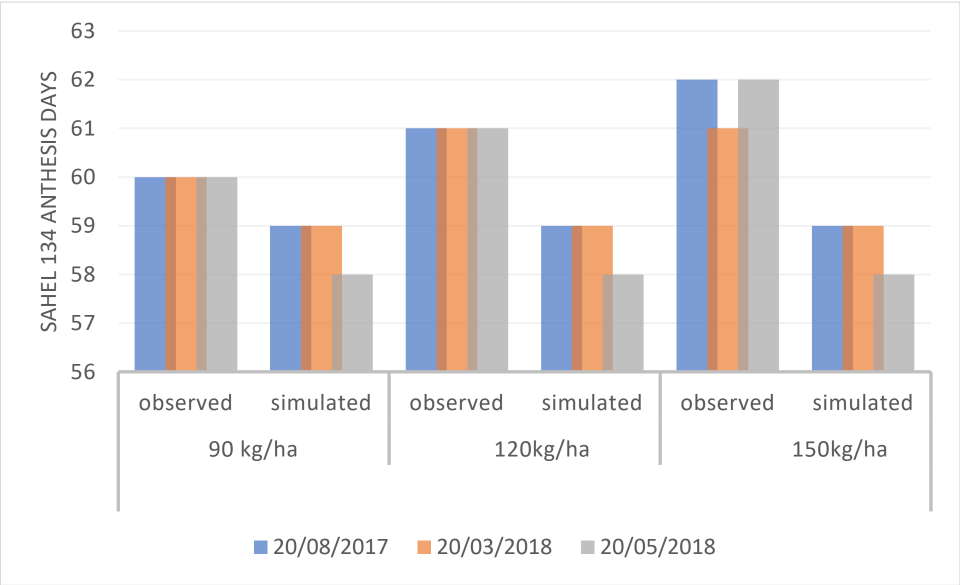
Appendix 8 comparison of simulated and observed values for rice Anthesis dates using DSSAT model at Kuntaur study location



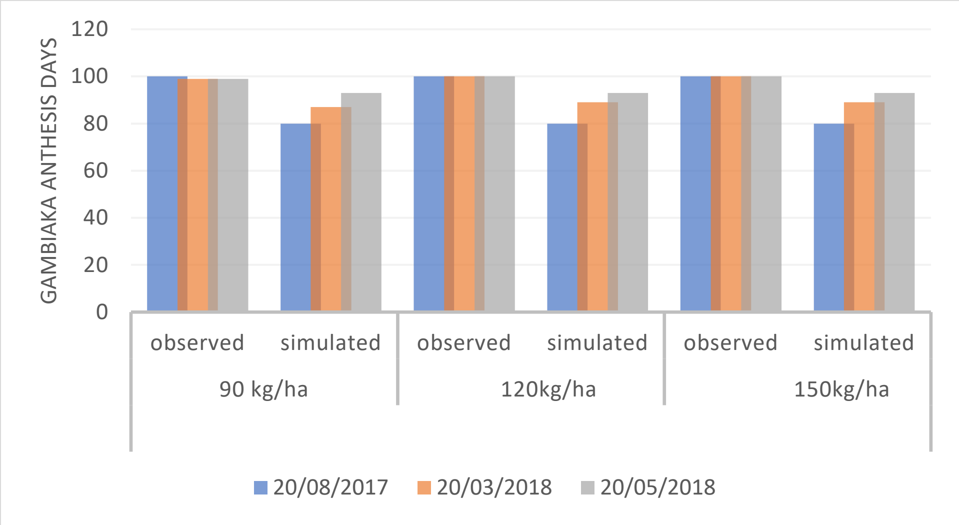
Appendix 9 comparison of simulated and observed values for rice Anthesis dates using DSSAT model at Kuntaur study location



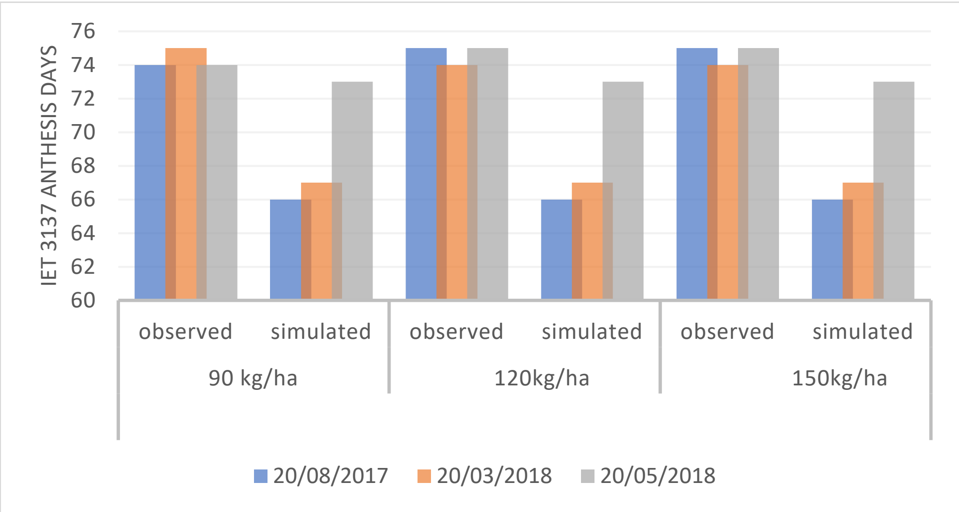
Appendix 10 comparison of simulated and observed values for rice Anthesis dates using DSSAT model at Kuntaur study location.



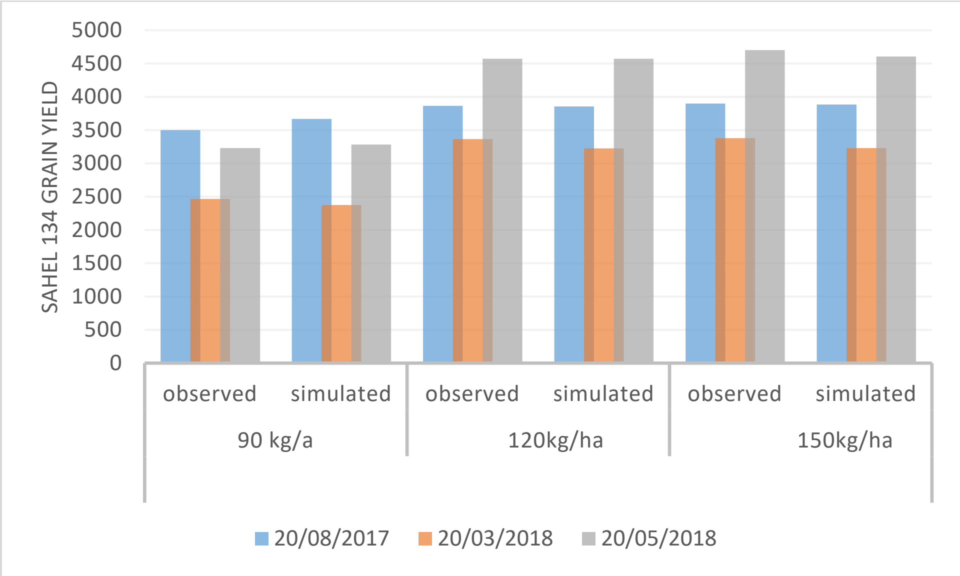
Appendix 11 comparison of simulated and observed values for rice Anthesis dates using DSSAT model at Kuntaur study location



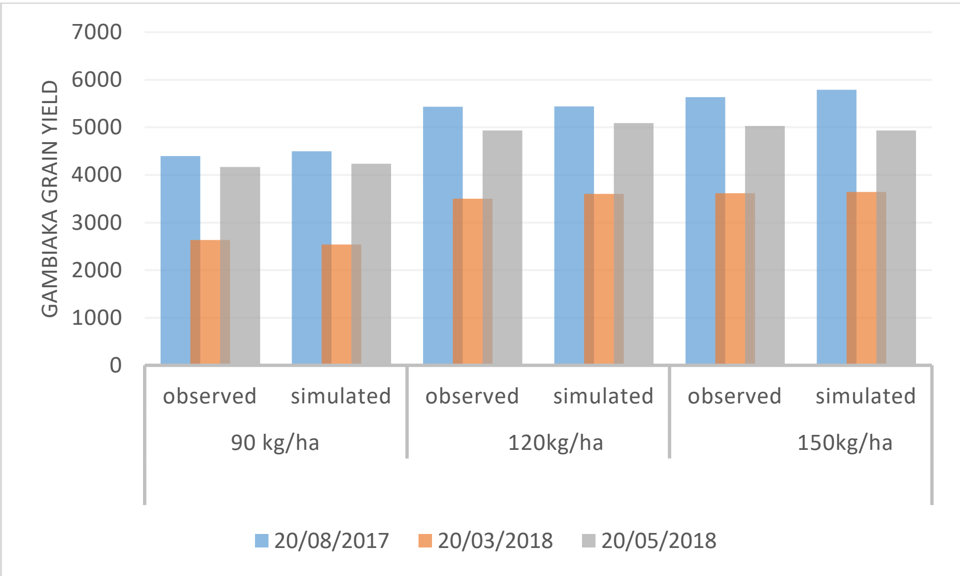
Appendix 12 comparison of simulated and observed values for rice Anthesis dates using DSSAT model at Kuntaur study location



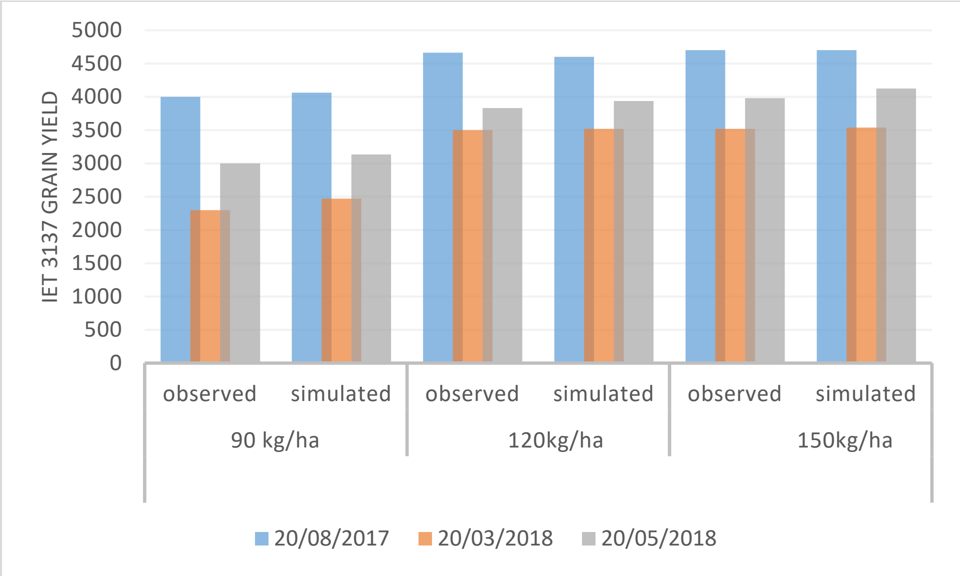
Appendix 13 comparison of simulated and observed values for rice Anthesis dates using DSSAT model at Sapu study location



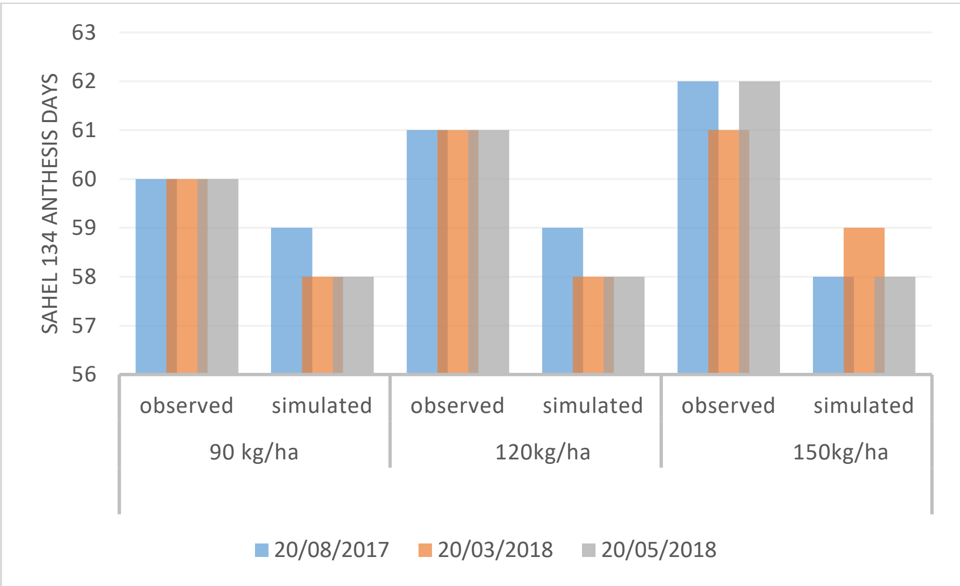
Appendix 14 comparison of simulated and observed values for rice Anthesis dates using DSSAT model at Sapu study location



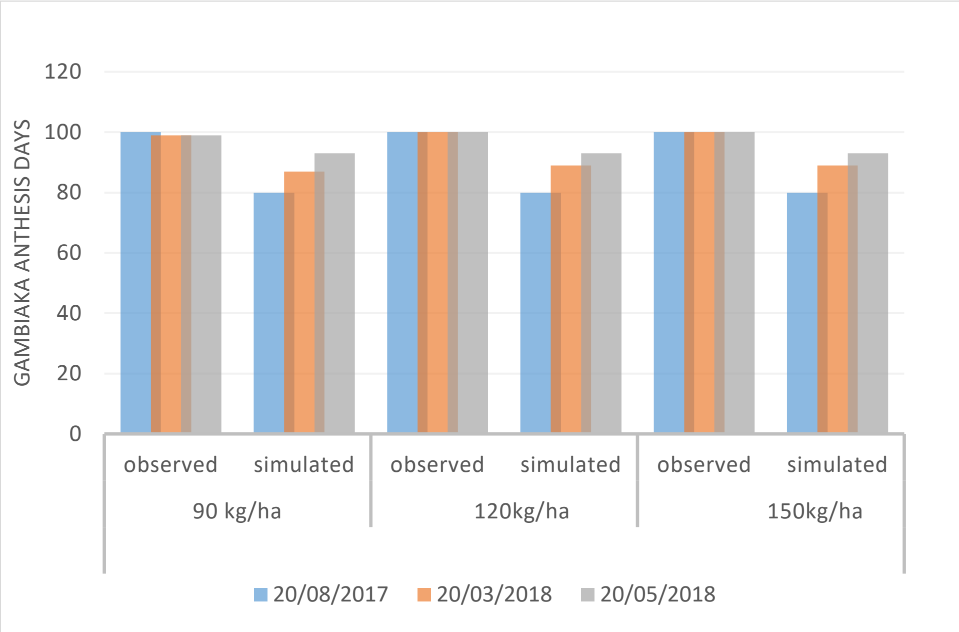
Appendix 15 comparison of simulated and observed values for rice Anthesis dates using DSSAT model at Sapu study location



Appendix 16 comparison of simulated and observed values for rice Anthesis dates using DSSAT model at Sapu study location



Appendix 18 comparison of simulated and observed values for rice Anthesis dates using DSSAT model at Sapu study location



Appendix 19 comparison of simulated and observed values for rice Anthesis dates using DSSAT model at Sapu{Bibliography} study location