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SIMULATION OF CLIMATE CHANGE EFFECT ON RICE (Oryza sativa L.) PRODUCTION IN KANO RIVER IRRIGATION SCHEME (KRIS) USING APSIM MODEL

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ABSTRACT

Climate change threatened rice production in the semi-arid region of Nigeria. Agricultural production is affected by variations in weather conditions and long-term climate patterns. The pattern of changing climate in the last three decades indicated that changes in rainfall and temperature reduced agriculture outputs and yields, which is significant in rice. A farm experiment was set up with six cultivars of rice. The APSIM model was used to simulate grain yield at maturity under a change in temperature scenarios to observe the effect of climate change on rice. Results showed that the mean annual temperature in KRIS has risen by about 0.62 degrees in a decade, while a rise of 0.9 degree Celsius between "2010-2040" respectively. Also, there was no significant difference in the measured yield between the rice varieties, however, their response to a change in temperature in the simulated yield is significant. effect of decreased temperature on the rice yield within the span of two decades and were simulated under 1 ^{o}C, 2 ^{o}C, and 3^{o}C rise in temperature. The overall yield is decreasing steadily and began to descend by 2025, in 2038 the yield began to rise again which was not clear as to the reason for the rise. However, on average there was a generally decreased yield over the two decades. It was recommended that a climate change adaptation strategy such as growing high yield short duration of rice variety to reduce the impact and ensure food security.

Keywords: APSIM, Climate Change, KRIS, Simulation, Rice

INTRODUCTION

According to the Intergovernmental Panel on Climate Change (IPCC), global temperatures will increase between 1.1 and 6.4 °C, and this is likely to affect precipitation patterns (Eric, 2013). Climate change can induce an increase in the potential for soil erosion, deteriorate soil quality, implications undermine food security and ultimately global sustainability, consequently leading to severe contemporary challenges. The variations in weather and climate will impact crop production as crops are very sensitive to these factors (Garuba et al., 2021). Climate change affects crop production by changing the main processes in soil and plant development, photosynthesis, and growth as well as biological and chemical transformations of nutrients in soils. Thus, climate change is now of great concern to farmers, scientists, environmental engineers, and other stakeholders worldwide.

Rice (Oryza sativa L.) is the most consumed cereal globally after wheat. Rice consumption is declining and is not far from changes in weather factors that are favourable to plants such as low rainfall, and an changes in temperature because of climate change (Ayinu et al., 2022). Climate change will have significant impacts on agriculture by increasing water demand, limiting crop productivity, and reducing water availability in areas where irrigation is most needed or has a comparative advantage. The change effect shows a general reduction in precipitation in semiarid areas, an increase in precipitation in temperate zones, higher variability in rainfall distribution, and an increase in the frequency of extreme events, (IPCC, 2014).

The Kano River irrigation scheme is the country's largest and most successful irrigation scheme with a development potential of 61,000 ha of irrigable land. Rain-fed agriculture remained the predominant land use, accounting for close to 50 per cent of the total land area, irrigated agriculture accounted for only 5 per cent of the total land area (Raji, 2003). Therefore, changes in temperature and precipitation patterns may likely have a devastating impact on crop productivity in the area. Rice is one of the major crops produced in the area and also one of the crops productions selected by the federal government to enhance food sufficiency.

"The Agricultural Production Systems Simulator (APSIM) is a modular modelling framework that has been developed by the Agricultural Production Systems Research Unit in Australia. It is capable of simulating a diverse range of farming systems including broad-acre dryland and irrigated cropping, smallholder farming and on-farm agroforestry systems. This includes the interaction of trees and crops and, through collaboration with other groups, integrated stock, and cropping enterprises. APSIM was developed primarily as a research tool to investigate on-farm management practices, especially where outcomes are affected by variable climatic conditions" (Holzworth et al., 2003).

The study area happens to be affected by some of these climate complexities, some climate change challenges in the area include: Erratic weather patterns such as heat stress, longer dry seasons, rainfall variability increased incidence of new pest and diseases, crops failure due to prolonged dry spells or drought condition. Demand for food, fuel wood and forest products by locals expands this problem and the results are devastating effects that include climate change due to anthropogenic (human-induced), which affected agricultural production within the fragile semi-arid region of Kano state, Nigeria. The knowledge gap is to use the APSIM model to simulate the effects of climate change on yield and yield components of rice to plan ahead and take adaptation measures among others. Kano State is regarded among the rice-producing state in Nigeria; therefore, it is imperative to investigate the effects of climate change on rice yields and the selection of thriving genotypes that thrives in the face of climate change effect. However, simulation using APSIM would help to predict and quantify the effects on rice yield and provide valuable benchmark information on the effects of climate change for rice production in Kano state.

MATERIALS AND METHODS

Study Location

The Kano River Irrigation Scheme (KRIS) are divided into Phases I and II, with a total area of about 62,000 ha.The main source of water for irrigation in the region is the Tiga Dam and Ruwan kanya reservoir. Tiga Dam is located on River Kano, which is 70 km south of Kano city, it is the largest irrigation Dam in Nigeria and was designed and built during 1970-1974. The Kano River Irrigation Scheme Phase I Extension lies about 30 km south of Kano city, on either side of the Kano-Zaria expressway. The plan of the federal government of Nigeria was to transform agriculture from low-technology, semi-subsistence farming into modern market-oriented sectors. However, despite some issues (KRIS) is one of the most successful irrigation Schemes in Nigeria. Kano State of Nigeria locates at 11°59' E and 8°30'N with an average altitude of 486 m ASL and is blessed with abundant fertile land within the Sudan savannah region. According to NPC (2006), Kano has a population of over nine million, out of which 70% are engaged in agricultural activities. The area is characterized by a mean annual rainfall of about 730 mm all of which falls between June and October. The mean daily temperature ranges from 29 to 38°C (Jibrin et al. 2017). The length of the growing period is 90 to 165 days (for rain-fed crops), with most rains occurring between May and September. Air humidity is high during the wet season and very low during the dry season. Minimum temperatures occur from November to February, and the highest temperatures occur between March and April. Daily temperature variation is high during the dry season and low in the wet season (Maina et al., 2012).

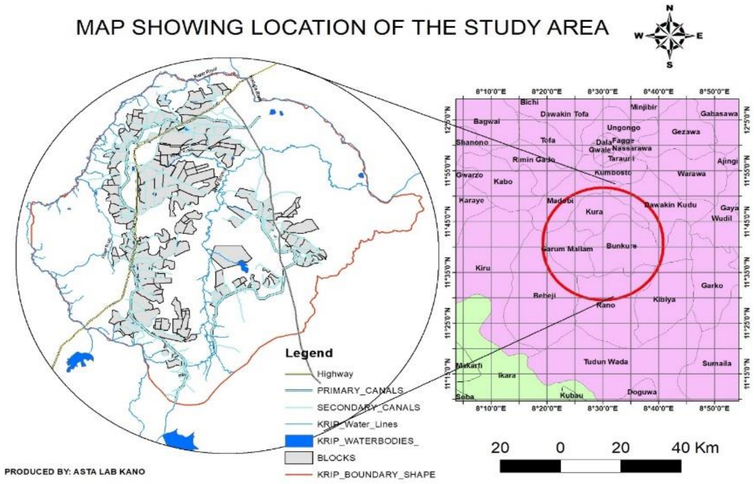

Figure 1: Kano River Irrigation Scheme (KRIS)

Model Calibration

Weather Data

Climatic data were used for the model calibration include daily rainfall amount (mm), daily solar radiation (Mj/m^2), minimum and maximum daily temperatures (OC). Data of one-year period (2022) planting season were obtained at KRIS. Data were entered into APSIM metrological file for Creating APSIM meteorological file for calibration.

i. Raw weather data were rearranged in Microsoft Excel to the following format:

Table 1: APSIM Met File Format

Title = KRIS						
[weather.met.weather]						
Latitude=11.3333						
Site	Year	Day	radn	maxt	Mint	Rain
()	()	()	(MJ/m2)	(oC)	(oC)	(mm)

ii. Rearranged data file was then Saved in the format as "Formatted Text/Space Delimited" (*.**prn**) file.
iii. The file extension was renamed to (*.met), KRIS.met.
iv. TavAmpGUI was then run and KRIS.met to create the APSIM met file.

Generating Future Weather Data

Marksim (the online software (http://gisweb.ciat.cgiar.org/MarkSimGCM)) was used to generate the future weather data needed for the simulation. The location was entered directly using a point-and-click system, using the keyboard. HadGEM2-ES model was selected because of its wider application. Representative Concentration Pathways (RCP) scenarios were selected based on the year under consideration.

Crop Parameter File

For calibration, all specific information for six (6) individual cultivars were entered into crop parameter file located in APSIM, the file contains cultivar co-efficient for the rice varieties including their genetic coefficients. APSIM requires a minimum dataset to simulate yield of a particular crop, the inputs dataset were weather data, Management data, crop data and soil data as illustrated in Figure 2.

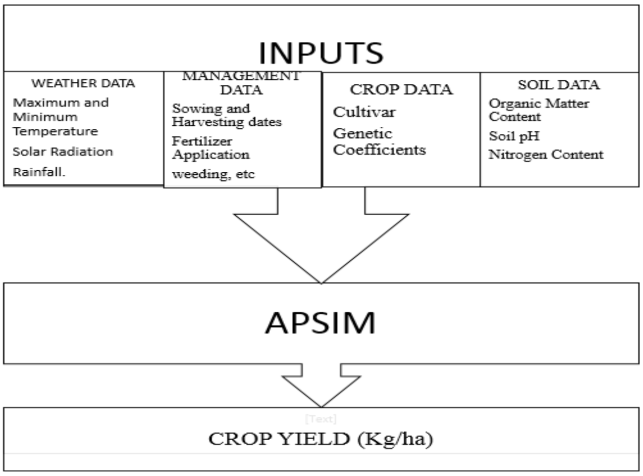

Figure 2: APSIM Simulation architecture

Soil Data

soil samples at a depth-wise 0-20cm, 20-40cm, 40-60cm, 60-80cm intervals were collected at the experimental site using augur, samples were taken at three different points to have full representation of the Site. The samples were put into various sampling nylons and taken to Agricultural and Environmental Engineering Laboratory for physical and chemical analysis. Percentage of sand, silt and clay (textural class), bulk densities, pH, nitrogen, phosphorus, potassium, percentage organic matter, cation exchange capacity (CEC), and other related parameters are determined for model parameterization (Solaraju-Murali et al., 2022).

Management data

The experimental design was a 3 x 2 factorial fitted trial in to a Randomized Complete Block Design (RCBD) with three replications each consisting of six (6) plots, totaling eighteen (18) experimental units, each plot being 15 x 3 ($45m^2$) in size (Fig. 3-6). Factor A was designated six rice varieties at three levels and factor B consisted of two fertilizer levels. Thus, optimum conditions were provided for plant grow, row spacing is 25 cm between rows (inter-row) and 25 cm within row (intra-row). Spacing of 50 cm were maintained between each replication and 35 cm between each Plot. Genetic coefficients used by APSIM for rice varieties are expressed in thermal degrees and photoperiod. Since the Intergovernmental Panel on Climate Change (IPCC) Schemes that global mean temperature may rise to 5 °C by the end of this century (Natural Resources Institute Finland 2015) The response of rice yield to 1°C, 2°C and 3°C rise in temperature were simulated. Results were then subjected to analysis to determine any significance difference between the yields in each scenario.

Research Field A

Figure 3: Rice seedling just transplanted

Research Field B

Figure 4: Land Preparation for planting

Figure 5: Vegetative growth stage of rice

Figure 6: Vegetative growth stage

RESULT AND DISCUSSIONS

The result of the experiment shows there was no significant different between the yield of rice varieties from the field experiment. Table 2 present the average and variance of the results of the observed data from the field and the simulated results from APSIM. The simulated rainfall for the next two decades was presented and shows there will be drop in the rainfall amount by 20%, this can have a huge effect on the rice yield in the future in KRIS (Fig. 7).

Table 2: Descriptive statistic of the observed and simulated results

Groups	Count	Sum	Average	Variance
Observed	6	36.40741	6.067901	1.907499
Simulated	6	39.4	6.566667	2.258667

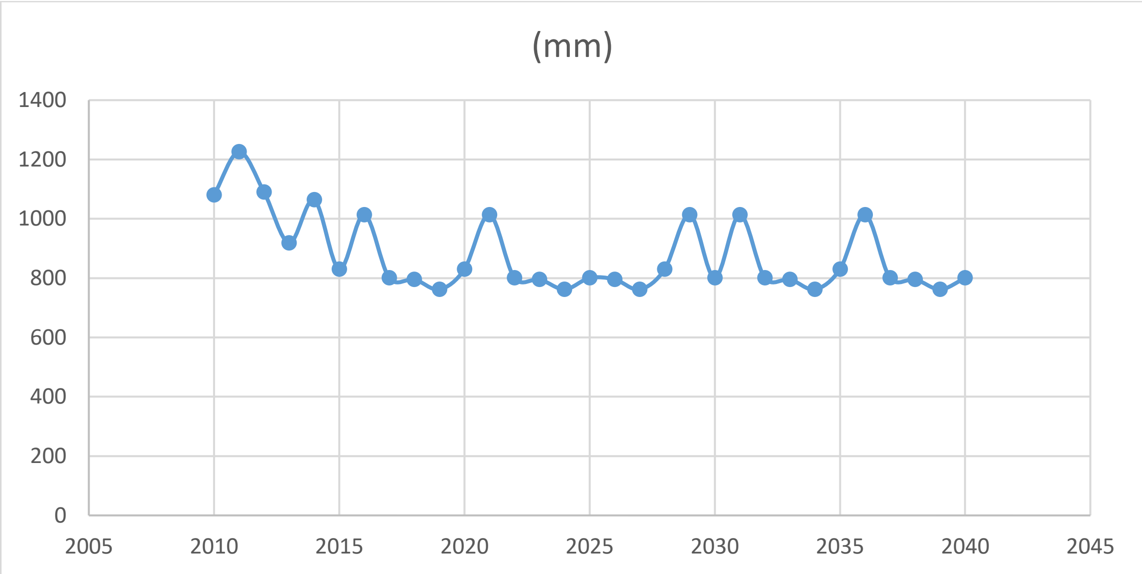

Figure 7: Projected rainfall of KRIS

The model has succesfully simulated yields of rice varieties, which shows that the observed data was close to the simulated data with variance difference of 0.3. The results of the simulated yield was slightly overstimated. Mean of the observed data was 7.6% lower than simulated data. Results revealed APSIM is an adequate tool to simulate rice crop yields, in most research model simulated data do exceed observed data due to influence of pest and disease which has significant effects on the outcome.

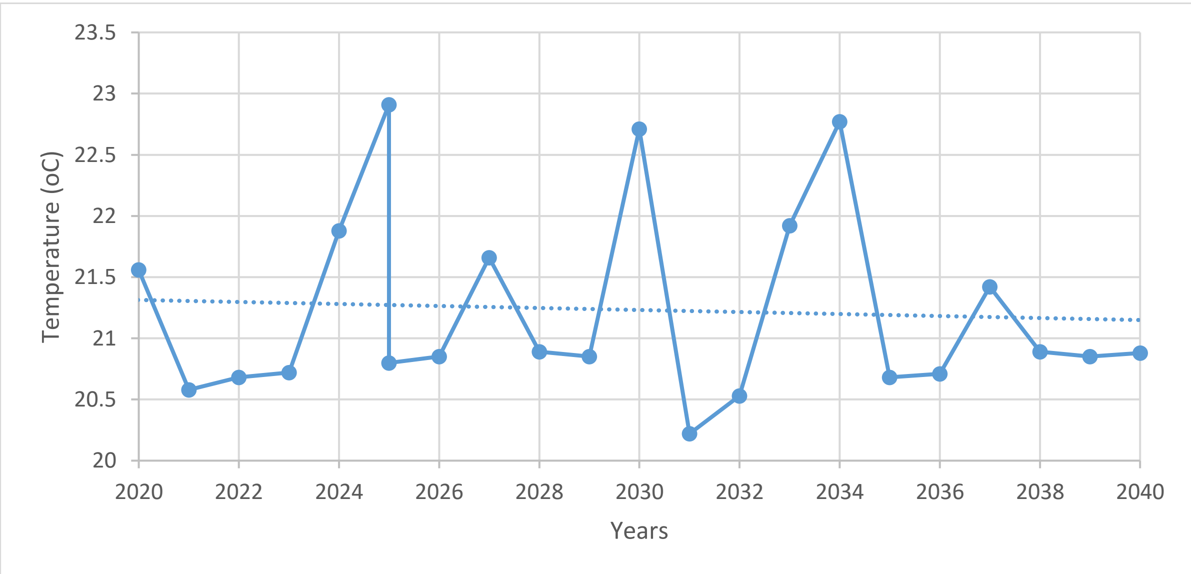

Figure 8: Simulated temperature over next two decades.

The temperature for the simulated period was observed to have increasing mildly in two decades which clearly indicates high temperatures which is good for rice production, however, the gap between the maximum and minimum temperature can cause low night temperature and that might have negative effect on the plant senescence. By 2024, 2030 and 2034 average annual temperatures will be raised to above 22.5ºC (Figure 8).

Table 3: Observed and simulated rice yield varieties and percentage deviations

Rice Varieties	Observed	Simulated	% deviation
Jamila	6.7	5.8	13.5
Jif	5.2	6.8	30.2
Yar das	6.0	6.9	15.7
Kwandala	3.8	4.0	4.9
Natore'	7.5	8.2	9.6
Yar gafan	7.2	7.7	6.6

The effect of Climate change on crop production is becoming a serious issue in the sub-Sahara region. The rise in temperature and variability in rainfall had adversely affected rice production in particular. Rice yield in the face of climate change has dropped mainly due to the increased gap between minimum and maximum temperature during the growing season. Figures 9 & 10 shows a result of the field experiment of different cultivars displays an observed yield data for both seasons, the Natore gave the highest yield while the lowest was recorded in Kwandala variety.

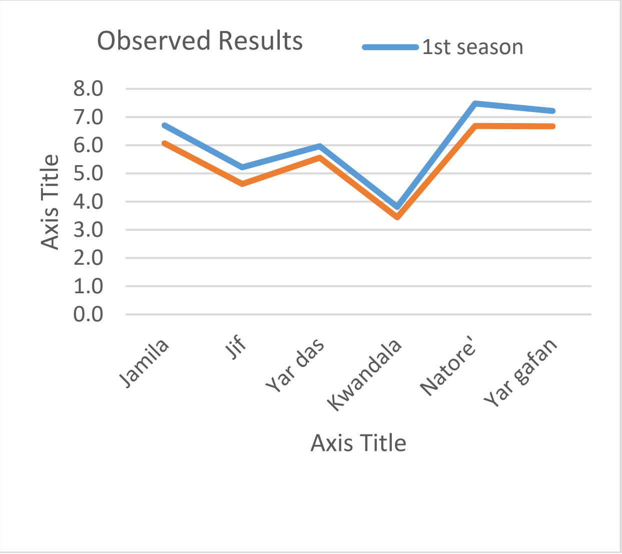

Figure 9: Observed Yield of different rice cultivars

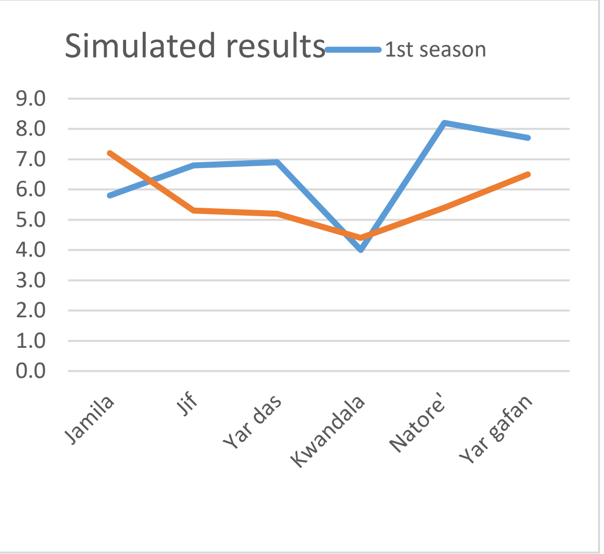

Figure 10: Simulated yield of different cultivars.

The response of these varieties to biophysical factors and in addition to their genetic factor which influences rice yield and productivity. The difference between the first season and the second season yield of rice productivity was narrow which indicated no significant difference in the yield of rice. The analysis of variance for both the observed and the simulated yield for the first season shows no significant difference between them, likewise in the seasons there were no significant differences between the simulated and the observed values of the yield components of rice.

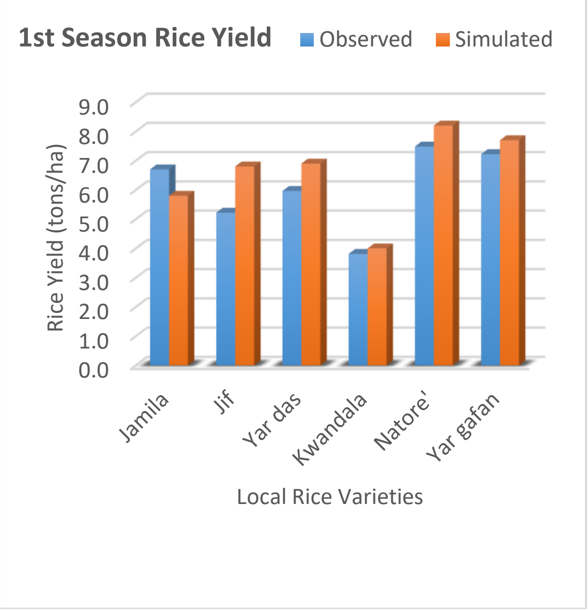

Figure 11: First season rice yield of different cultivars

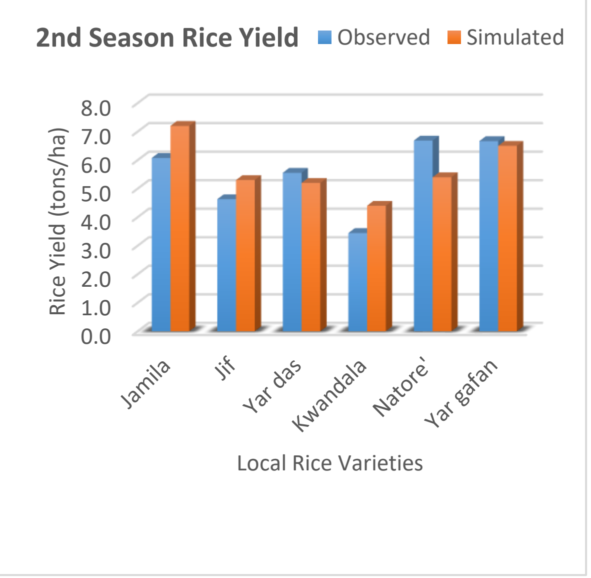

Figure 12: Second Season of rice yield of different cultivars

The six varieties of rice yield tried in the field experiment to test the productive capacity in the face of increased temperature and erratic rainfall, the yield performed differently as shown in the Figures 11 and 12. In both figures, Kwandala did not yield as expected, however, Notore and Yargafan performed well giving 7.5 and 8 tons/ha especially in the first season for both observed and simulated yields. The variety Jamila had performed well in the first season but dropped in the second season, however, the simulated yield of Jamila gave quite the opposite, and this was attributed to the Apsim sensitivity to some factors as the case may be in the capacity to simulate scenarios (Sharma et al., 2022).

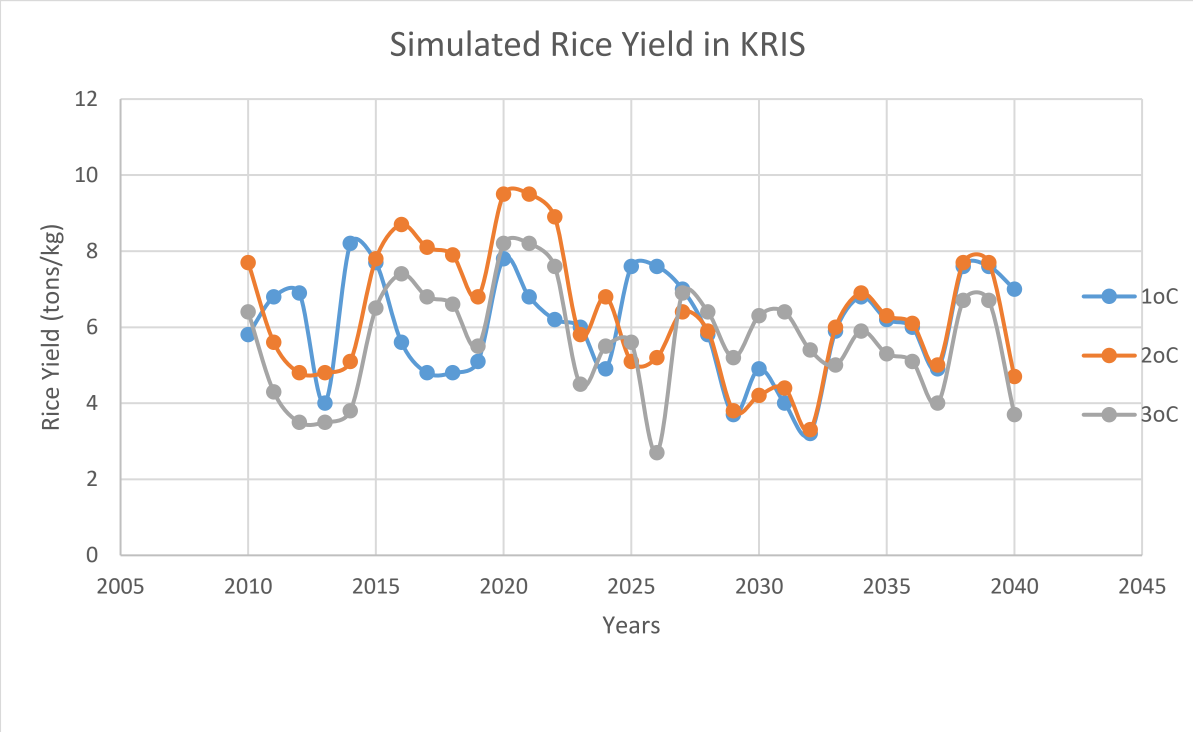

Figure 13: Rice yield under increased temperature of 1, 2 and 3ºC up to 2040.

Figure 13 presented the effect of decreased temperature on the rice yield within the span of two decades and were simulated under 1, 2, and 3ºC rise in temperature. The overall yield is decreasing steadily and began to decend by 2025, at 2038 the yield began to rise again which was not clear as to the reason for the rise. However, on average there is generally decrease in the yield over the two decades.

Simulating rice yield into the future is a complex activities which depend on many factors, but most of the negative consequences resulted from the changes in temperature were mostly night temperature. (Giri et al., 2022) observed that short episodes of high temperature at critical stages of rice crop development have impact yield independently of any substantial changes in mean temperature. Study conducted by Stewart *et al.* (1997) indicated that during vegetative growth, rice has a maximum response to temperature at between 25-30°C and during reproductive growth respectively, Rice responds well to temperatures above 12°C.

The study revealed that climate change is slow and study on climate change is based on the model findings and results, there is growing evidence that climate change is already affecting crop production in Kano State. For instance, mean annual temperature in KRIS has risen by about 0.62 degrees in a decade, while rise of 0.9 degree Celsius between "2010-2040" respectively. Furthermore, the rise in temperature in KRIS is more pronounced during March - May and has occurred along with significant increase in the frequency of hot days as well as hot nights during the research period, it is projected that rising temperatures will lead to more frequent extreme weather and subsequently affecting rice crop productivity.

CONCLUSION

The Simulation of climate change impact on rice yield had been conducted and the results obtained were presented. It can be deduced that increased in temperature and drop in rainfall amount and variability can affect rice production in KRIS. Two notable varieties (Notore and Jamila) that has capacity to thrive with good yield were recommended for adaptation in the future to curb the effect of climate change based on their performance in the field experiment and in the simulation. Rice-based cropping systems are continuously affected by the effects of climate change because large portions of rice-growing areas are located in vulnerable regions particularly in the semi-arid zones of sub-Sahara Africa in which KRIS is situated. Temperature and Rainfall are two climatic factors that significantly reduced rice production and threaten food security for this region.

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