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Impact of Climate Change on Irrigated Rice Production in the Northern Region of Ghana

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Abstract: **As demand for effective management of water increase due to climate change, future rice production will depend on developing and adopting strategies and practices that use efficient water application regime. The objective was to assess the impacts of different irrigation application on dry season rice yield in the context of future climate change using the AQUACROP model. Two experiments were conducted using a *randomized complete block design* with 4 replications at On-Station and On-Farm in the Northern Region of Ghana in 2012/2013 and 2013/2014 dry seasons. The treatments were, surface irrigation with applied water equal to: the Field Capacity moisture content (W_1); Saturated soil moisture content (W_2); Continuous flooding up to 10 cm level, used as control (W_3); 10ETc (W_4) and 15ETc (W_5). A 115 days rice variety, *Gbewaa* (Jasmine 85) was used for the experiments. Data was collected on canopy cover, biomass, grain yields and harvest index. The results of the simulations suggested that increase in average temperatures will affect rice yield, biomass, harvest index and ET water productivity for the various water application regimes if increase by 1 to 4 °C, with +5°C being highly detrimental to growth and yield of rice in the Northern Region of Ghana.**

Keywords: **Aquacrop Model, Rice, Irrigation Regimes, Climate Change, Northern Ghana**

1. INTRODUCTION

As climatic patterns change, so also do the spatial distribution of agro-ecological zones, which can have significant impact on food security in the future [1]. Further, the projected increase of global mean temperature between 1.4 and 5.8 °C by 2100 [2] is expected to have considerable impact on the hydrological system, sea level, agricultural ecosystems and thus on crop production leading to food insecurity of the poor and marginalised population especially in the rural areas [3].

The climate risk assessment of agricultural ecosystems holds the key to understanding future food security situations in the changing climate scenarios. The existing practices of climate risk assessment are quite broad and crop specific assessment makes it 'actionable' for developing adaptation strategies at local levels [4].

Rice (Oryza sativa and Oryza glaberrima) is one of the important cereals grown across the world. Although it has been used as a model plant for many years, the growth responses of rice to high temperature are still poorly understood [5]. Temperature regimes greatly influence not only the growth duration, but also the growth pattern and the productivity of rice plant [6]. Mostly rice is currently grown in regions where present temperatures are already close to optimum for rice production.

The vulnerability of rice-based agro-ecosystems has been assumed taking into account the reduction in potential yield due to increase in the levels CO_2 and temperature. The increase in temperature under the limiting conditions of soil moisture represents drought conditions as well. It is therefore assumed that with the increase in temperature, drought would creep in as a result of climate change situation affecting the rice-based agro-ecosystems [4].Yields of rice have been estimated to be reduced by 41% by the end of the 21st Century [7].

The concerted and coordinated efforts to improve rice production through science, research and development in the 1970s and 1980s enabled global rice production to meet the demand of a growing population, created employment opportunities, increased the income of rice farmers, and enhanced access to rice for the poor living in urban centres across the world. The gains made during the Green Revolution, however, have begun to show diminishing returns in recent years. Since 2000, world rice production has been less than rice consumption and the deficit has been addressed by drawing on rice from buffer stocks. Additionally, 852 million people continue to suffer from hunger and malnutrition [8].

The food security of more than half the world's population depends on the ability of the world to supply and distribute rice. Rice supply depends on global rice production, while its distribution depends on the distance from production sites to consumers' residences as well as on transportation systems and facilities [9].

The world population continues to grow steadily, while land and water resources are declining. [10] reported that high temperatures would cause a marked decrease in world rice production. Understanding the potential impact of climate change on rice-based production systems is important for the development of appropriate strategies to adapt to and mitigate the likely outcomes on long-term food security based on the interaction between rice production and climate change.

Simulation analyses by using different models and field experiments have shown the potential impacts of climate change on the variability of rice productivity [11]-[13]. Studies have shown that the net effect of doubling of

CO_2increase in rice yield [13]. For every 75ppm increase in CO_2, rice yield will increase by 0.5 t/ha. However the yield will decrease by 0.6 t/ha for every 1^oC in temperature. Thus an assessment of the potential impact of interactive changes of CO_2 and temperature is crucial to determine the future of irrigated agricultural strategies maintaining higher rice productive

2. MATERIALS AND METHODS

A. Study site description and experimental design

The study area comprised on-station research at the Savanna Agricultural Research Institute (SARI) in Tolon District and on-farm research at Bontanga Irrigation Scheme in Kumbungu District, both in the Northern Region of Ghana. The two districts together used to be one district called the Tolon-Kumbungu District, which lies between latitudes 9^o 15′ and 10^o 02′ N and Longitudes 0^o 53′ and 1^o 25′ W.

B. Experimental Design

The experiments were laid out in randomized complete block design with four replicates. The treatments were distributed randomly and independently in each block using draw lots method. The variety of rice that was used for the experiments is the Jasmine 85 "Gbewaa" (115 days). Nursing of seeds was done at SARI for both on-station and on-farm experiments at 2012/2013 and 2013/2014 dry seasons. Seedlings were transplanted at 22 days after nursing. Transplanting was done manually at a spacing of 20 cm × 20 cm and one seedling per stand. Plot size was 1 m x 1 m for the on-station experiments and 1m x 7 m for the on-farm experiments. Data from dry season's On-Station experiments at SARI and On-Farm experiment at Bontanga Irrigation Scheme were collected using five (5) treatments comprising of the following:

(i) Surface irrigation with applied water equal to the Field Capacity (FC) moisture content of the soil, (W_1)
(ii) Surface irrigation with applied water equal to the Saturation soil moisture content (SC), (W_2)
(iii) Surface irrigation with applied water equal to Continuous flooding up to 10 cm to be used as control (W_3)
(iv) Surface irrigation with applied water equal to 10 ETc, (W_4)
(v) Surface irrigation with applied water equal to 15 ETc, (W_5).

All treatments were replicated four (4) times. These experiments were the basis for calibration and validation of the AquaCrop model using observed rice yield, biomass, harvest index and canopy cover for the simulation process.

Impact of variation in temperature on parameters such as rice yield, total above ground biomass, harvest index, evapotranspiration water productivity and days to maturity were simulated and compared with the base year run with the consideration of the default atmospheric CO_2 concentration from Manua Loa 1902 to 2099 and IPCC projections for A1B scenario in the AquaCrop Model.

C. AQUACROP Simulation Scenarios

Temperature Analysis Historic (1960-2011) climatic data including daily minimum and maximum temperatures were obtained from the Tamale Metrological Agency for the Tamale Synoptic Station for the various analyses. The data which was first entered into Excel spread sheet was arranged and carefully scrutinised to ensure quality control before any further analysis was carried out with the data. Further data sorting were done in Excel from which the average minimum and maximum as well as the mean monthly temperatures was calculated. The Instant software was also used to carry out series analyse of the temperature characteristics of Tamale, in view of climate change phenomenon.

Sensitivity Analysis of Increase in Temperature and Co_2 In a regional study on climate change impacts in West Africa, [14] computed an annual mean temperature increase of 1.2 to 1.3°C over the next 25 years from 1999-2000 to 2030-2039 across the Volta Basin. This temperature change significantly exceeds inter-annual variability. Therefore impact of increase in temperature and CO_2 on rice yield, biomass, harvest index ET water productivity and days to maturity were predicted by applying a combination of fixed increments in CO_2 concentration at 50 ppm (from the reference value of 369.41 ppm) from the default atmospheric CO_2 concentration from Manua Loa 1902 to 2099 and IPCC projections for A1B scenario and the relative temperature (T) changes of T+1 °C, T+2 °C, T+3 °C, T+4 °C and T+ 5°C to the monthly average series of minimum and maximum temperatures for over 30 years of climatic data in the Northern Region. The modified data were used as the inputs for AquaCrop model.

3. RESULTS AND DISCUSSIONS

A. Temperatures Characteristics of Tamale

Figure 1 shows the annual temperature variation for Tamale from 1960 to 2011. They illustrate mean-minimum, maximum-minimum, mean-maximum, maximum-maximum and mean-temperatures of Tamale as it varied across the years. As could be seen from the figure, even though the annual temperatures have shown variation across the years, there is an increasing trend in both minimum and maximum temperatures from 1970 to 2011 with average maximum of minimum and maximum of maximum temperatures exceeding 20 ^oC and 40 ^oC respectively in some years as shown in Figure 1. From the figure, it could also be observed that mean annual temperatures and mean maximum temperatures are also increasing approaching 30 and 35 ^oC respectively while mean minimum temperatures are also showing similar trend, exceed 20 ^oC. This phenomenon confirms the assertion that global temperatures are increasing due to climate change. These conditions have negative effects on rice growth, development and grain yield production. According to [15] temperature, along with photoperiod, is the main driving force for crop development. The optimum temperature for the normal development of rice ranges from 27 to 32 °C [16]. High temperature affects almost all the growth stages of rice, i.e. from emergence to ripening and harvesting. The developmental stage at which the plant is exposed to heat stress determines the severity of the possible damage to the crop [17].

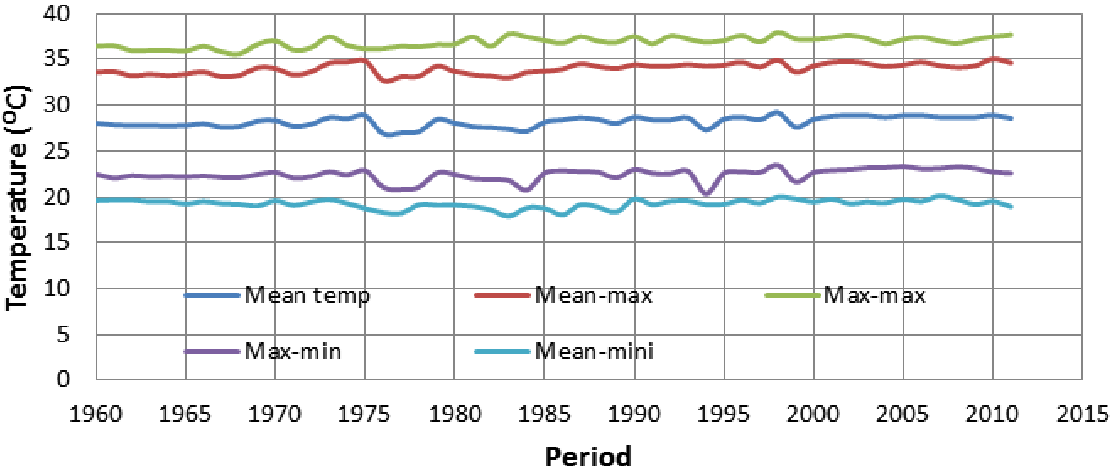
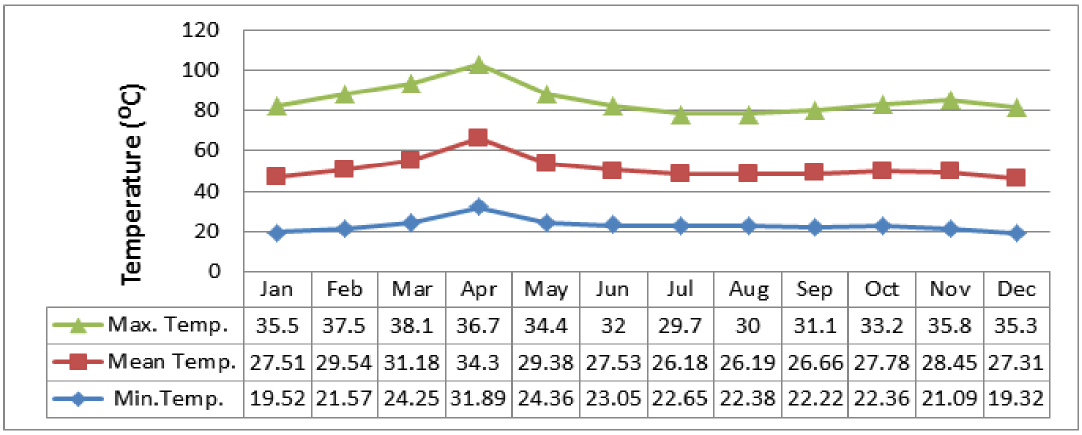


Fig.1. Temperatures Characteristics of Tamale

B.Minimum, Maximum and Mean Monthly Temperatures of Tamale (1974-2011)

Figure 2 shows the monthly maximum, minimum and mean temperature variation for Tamale. As could be seen from the graphs, temperatures are lower between May and October, which is the wet season of the year. However, temperatures start to rise from November when average minimum, maximum and mean temperatures are 21.1°C, 35.8 °C and 28.45 °C respectively and peak around April as could be observed from the Figure. This period is dry season at which time average evapotranspiration are also very high ranging from 136.8 mm in November to 198.9 mm in April. According to [18] Climate change includes gradually increasing average temperature as well as increased frequency and magnitude of extreme weather events. For rice, extreme maximum temperature is of particular concern during flowering which usually lasts two to three weeks.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max. Temp.	35.5	37.5	38.1	36.7	34.4	32	29.7	30	31.1	33.2	35.8	35.3
Mean Temp.	27.51	29.54	31.18	34.3	29.38	27.53	26.18	26.19	26.66	27.78	28.45	27.31
Min.Temp.	19.52	21.57	24.25	31.89	24.36	23.05	22.65	22.38	22.22	22.36	21.09	19.32

Fig.2. Minimum, Maximum and Mean Monthly Temperatures of Tamale from 1974-2011

C. Climate Change

Increase in Temperature Sensitivity Analysis

As temperature is expected to gradually increase up to 5°C by the end of the century in most part of the world [19] this simulation study investigated the impact of increase in temperature on rice yields and yield related parameters by applying relative temperature (T) changes of T+1°C,T+2°C, T+3°C, T+4°C and T+5°C to the monthly average series of temperature. The results of the simulations for the various parameters are presented in Figures 3-7.

Increase in Temperature and CO_2 Effect on Maturity Period

Figure 3 presents the sensitivity analysis of increase in temperature and CO_2 on days to maturity of dry season irrigated rice production. As could be seen from the graph, the average maturity period for the base year is 115 days; however, days to maturity reduces to 113 days as the mean temperature increase by 1°C, the scenario continues as the temperature increases +2 °C (111 days), +3 °C (106 days), but remain constant for +4 °C increases in temperature (106 days) . However, the maturity period reduced to 104 days as the temperature increase by 5 °C. The crop growing periods of rice decrease with the increase in temperatures ranging from 2 days to 11 days compared with the base year maturity period. Particularly, when temperature increased from +1 to +5°C, the rice phenology will be rapidly shortened ranging from 104 to 113 days in such a way that, the higher the temperature the lower the growing period to maturity. Though the trend is the same, but the range is different from that obtained by [20] where a temperature increase of 1 °C reduced the number of days from sowing to heading by 4– 5 days for some genotypes. The results support findings in Midwest of the USA for a study of different climatic scenarios for four different crops and concluded that temperature increase due to global warming would reduce maturity time, decrease water use efficiency and lower yield [21].

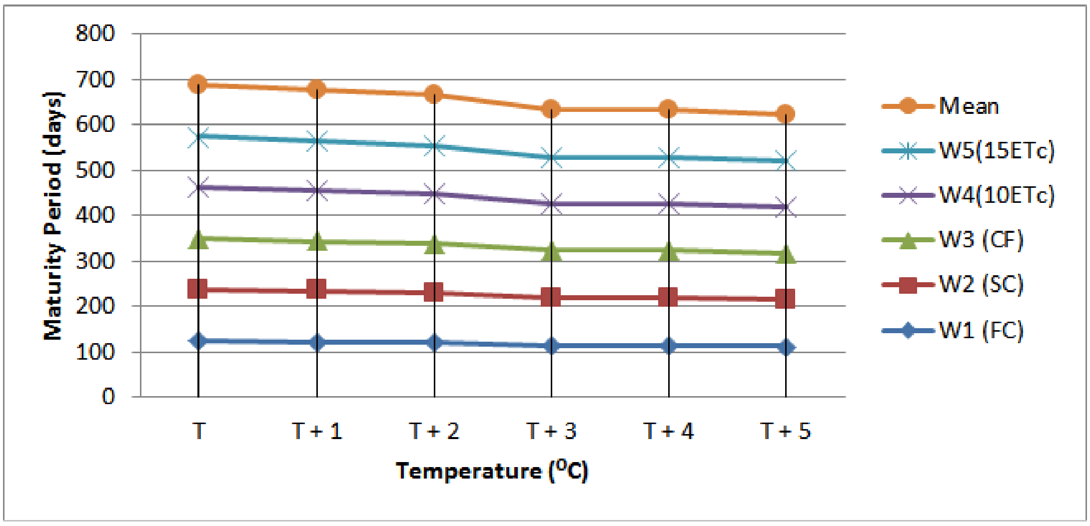


Fig.3. Increase in Temperature Effect on Maturity Period

Increase in Temperature and CO_2 Effect on Grain Yield

From Figure 4, it could be realised that as the mean temperature increases, rice yield decreases, showingsome inverse relationship between change in average temperature from (T + 2°C) to (T + 5°C) and rice yield. From the figure, average yield reduction (%) is in the range of 3.2 % to 32.3 % as temperature rises from 2°C to 5°C. However, there was slight increase in yield (4.81 to 5.55 t/ha) as temperature rises by + 1°C for FC. The slight increase in rice yield as the temperature increased by 1°C for the FC, support findings of [22] which indicates that the potential yield of rice with CO_2 at 50 ppm and 1°C increase in temperature would result in a slight increase in the potential yield of rice. However the yield reduction is mostly associated with decrease in sink formation, shortening of growth duration and increase in maintenance respiration [23].

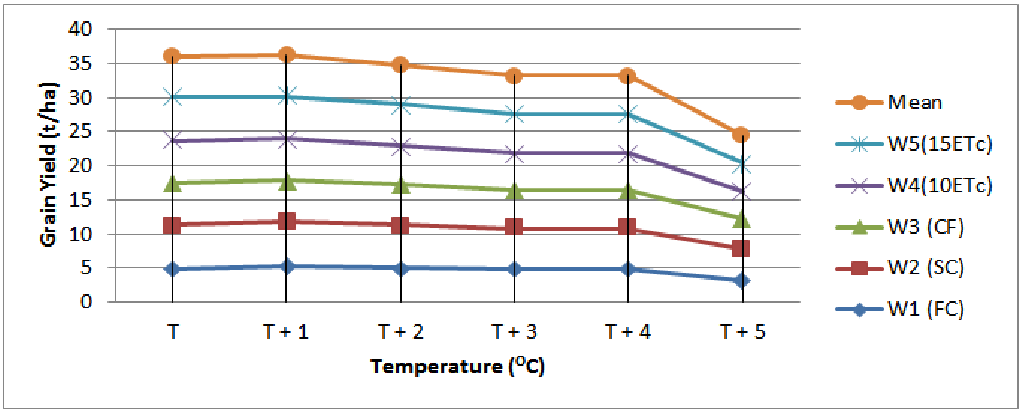


Fig.4. Increase in Temperature Effect on Grain Yield

Increase in Temperature and CO_2 Effect on Biomass

From Figure 5, it could be realised that as the base temperature increases, rice biomass decreases, showing some inverse relationship between change in average temperature from (T + 1°C) to (T + 5°C)and rice biomass. From the figure, average biomass yield of the base year is 15 t/ha, but as the mean temperature increase +1 °C to +5°C, biomass also reduces correspondently from 14.96 t/ha to 13.57 t/ha. The reduction (%) is in the range of 0.3 % to 9.5 % as temperature rises from 1°C to 5°C. This phenomenon could be attributed to limited pollination due to heat stress, especially with increase in temperature + 5°C. This findings is in line with the assertion by [24] in their research on the Effect of climate change on rice yield at Kharagpur, West Bengal that, higher temperature can negatively impact on crop production directly through heat stress. [25] reported altered responses of rice genotypes in terms of spikelet fertility to different levels of temperature increases. Greater increments in temperature resulted in higher proportions of sterility.

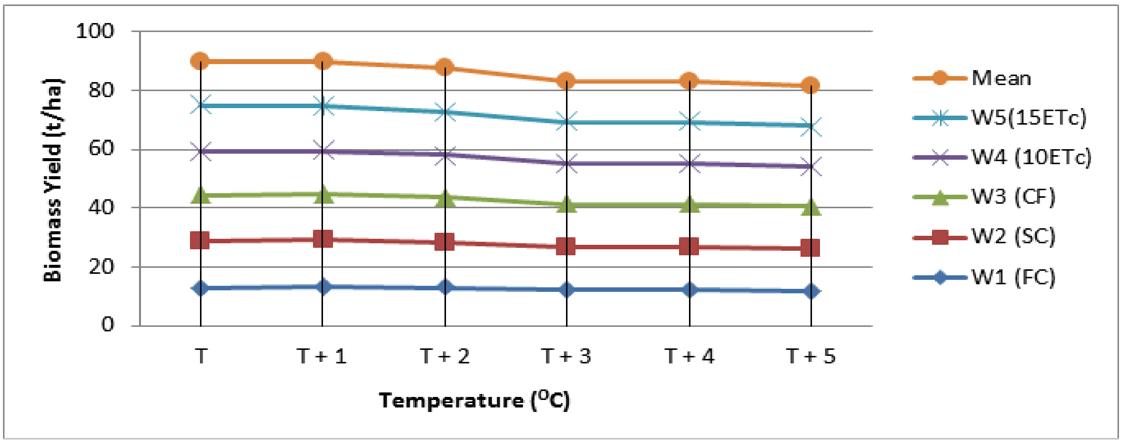


Fig.5. Increase in Temperature Effect on Biomass

Increase in Temperature and CO_2 Effect on Harvest Index

From Figure 6, it could be realised that as the mean temperature increases, HI initially increases as the temperature increases +1°C given a mean value of 39.4 %, but start to decrease, showing some inverse relationship between change in average temperature from (T + 2°C) to (T + 5°C)and HI as could be seen from the values of the means. From the figure, however, 15ETc, W3 and W2 showed constant value of HI from 1°C to 4°C, while W4 showed an increase in HI only at 1°C increase in temperature, but decrease to 39 % and remain constant as temperature increase from +2 °C to +4 °C. Like W4, W1 also showed an increase in HI only at 1°C increase in temperature, but also decrease back to the base value of 34°C at +2 °C and down to 33 °C, remain constant for +4 °C increase in temperature. Average HI reduction (%) for FC from the base year run is in the range of 0.5 % to 35 % as temperature rises from 2°C to 5°C. Even though, all the water regimes showed constant HI for +3°C and +4 °C increase in temperature they all however showed maximum reduction of HI at + 5°C increase in average temperature. The highest reduction in mean HI (35 %) at + 5°C increase in average temperature could be attributed to reduced yield and biomass due to limited pollination due to heat stress from high temperatures. The optimum temperature for the normal development of rice ranges from 27 to 32 °C [16]. High temperature affects almost all the growth stages of rice, i.e. from emergence to ripening and harvesting.

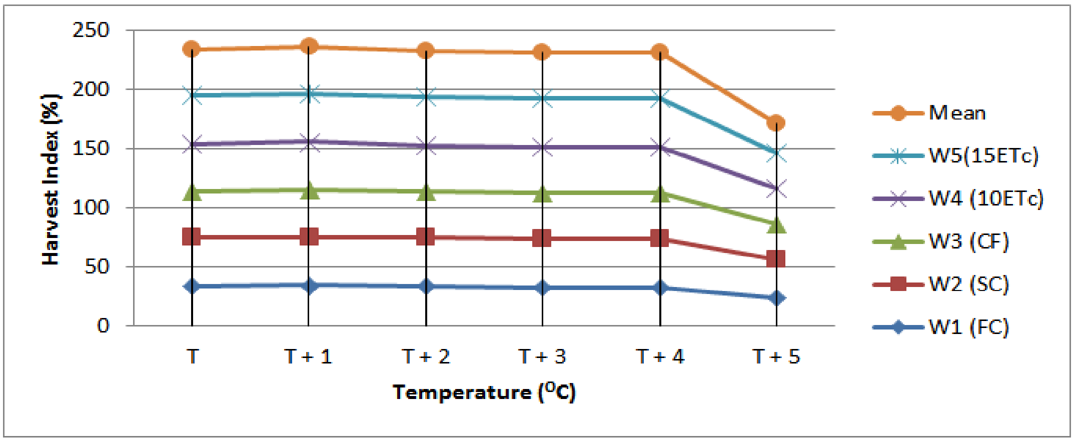


Fig.6. Increase in Temperature Effect on Harvest index

Increase in Temperature and CO_2 Effect on ET Water Productivity

From Figure 7, it could be realised that as the mean temperature increases, the WP_{ET} decreases, showing some inverse relationship between change in average temperature from (T + 1°C) to (T + 5°C). From the figure, average WP_{ET} for the base year is 1.22 kg/m^3, but this values reduces to 1.05 kg/m^3, 1.02 kg/m^3, 0.99 kg/m^3 and

0.73 kg/m^3 respectively as average temperature increases from (T + 1^{o}C) to (T + 5^{o}C). The average reduction (%) from the base year run is in the range of 13.93 % to 40.16 % as temperature rises from 1^{o}C to 5^{o}C. According to [26] water productivity with reference to evapotranspiration WP_{ET} takes into accounts only water evaporated or transpired and is therefore focused on plant behavior. Therefore as temperature increases, the rate of evapotranspiration also automatically increases thereby subjecting the rice crop to water deficit causing more water and heat stresses and hence low yield due to limited pollination. [21] on evaluation of different climatic scenarios for four different crops concluded that temperature increase due to global warming would decrease water use efficiency. Meanwhile, according to [27] at field level, WPET values under typical low land conditions range from 0.4 to 1.6 kg/m^3 and that, factors responsible for low values of WP include a high share (20 to 40%) of soil evaporation into ET for rice, percolation from fields and seepage losses (34 to 43% of the total canal inflow) from the conveyance system.

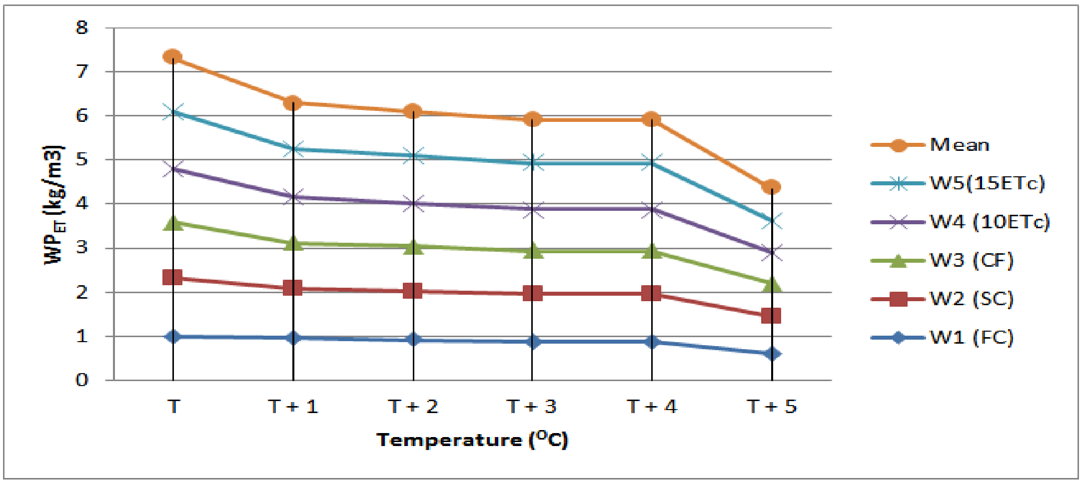


Fig.7. Increase in Temperature Effect on ET Water Productivity

D. Proposed Adaptation Strategies for Rice Production in Warmer Climate in Future

Adaptation involves adjustments to decrease the vulnerability of rice production to climate changes. There are a range of technological options that are presently available or which can potentially be developed in the near future for enhancing the rice production systems' ability to adapt to and mitigate the effects of global climate changes.

The modelling of impact of increase in temperature on rice yield and yield related parameters using AQUACROP model has indicated reduction in grain yield and yield related parameters as temperature rises. From predicting rice yield, biomass, harvest index and ET water productivity under the different temperature scenarios, it was clear that temperature is one of the most dominant climatic factors, which could affect rice production in Northern Region of Ghana, and its effectiveness was very high, if it rises to +5^{o}C. There is therefore the need to adopt certain technical and management options that could potentially enhance future rice production in the Northern Region of Ghana in view of the potential warmer climate in future. The following adaptation strategies were therefore suggested.

Management Options

As temperature varies from month to month, it is possible to select the right date for crop establishment in such a way that the critical stage of reproductive and grain filling phases of rice fall into those months with a relatively low temperature. Based on this, it is more appropriate to start dry season rice production under irrigation in Northern Ghana in early November so that crops will mature in February to avoid the high temperatures in March by using short duration varieties like "*Gbewaa rice*" (Jasmine 85). This would minimise the negative effect of temperature increase on rice yield as reported by [12]. Efforts to collect and disseminate the information on month-to-month variation in temperature regimes in major rice-producing tropical areas, therefore, are essential for helping rice production to adapt to climate changes. From the management point of view, it is essential to adjust the duration of varieties such that they avoid peak stress periods (by breeding short duration varieties). The AQUCROP model predictions for increase in temperature on rice yield indicated reduction in maturity period, for this reason, the development of varieties with suitable growth durations and tolerance of altered sowing times can play a vital role.

According [28], Wide variability in response to temperature exists in the current rice genetic resource. Replacement of the sensitive cultivars by tolerant cultivars in the field will increase the global rice production. The inherent diversity in rice agronomic systems, such as aerobic and flooded rice, may be quite effective for this targeted adaptation. Similarly, a shift in the cropping pattern from flooded to aerobic rice is expected in the near future. Keeping the field wet but not flooded and with added organic matter reduces the global warming potential from rice field without a decrease in yield [29]. With respect to AQUCROP model prediction for increase in temperature, it came out that by maintaining high and well compacted earth bund, around rice fields, well leveled and effectively puddled to reduce seepage and percolation could enhance rice yield. Management practices such as saturated soil culture (SSC), alternate wetting and drying (AWD) and aerobic rice cultivation in the case of drought stress, while growing improved varieties offer some adaptive options for the indirect stresses related to temperature increase.

Breeding perspective

Progress in rice breeding has rapidly accelerated due to the availability of the full rice genome sequence [30] and intensive quality mapping efforts for a wide range of traits [31]. Some of the breeding options which, if adapted, will help to mitigate the problem of rising temperature can be briefly summarised as follows:

Using the fertility of spikelets at high temperature as a screening tool for high-temperature tolerance during the reproductive phase.

Selection for heat tolerance should be done for those breeding materials which can tolerate temperatures higher than 38 °C [32].

Visible markers of high-temperature tolerance are required. Observing the length of the anther and the size of its basal pore as one of the morphological traits that can be easily identified.

Selection of rice germplasms for high-temperature resistance [28]. Genetically modifying the male reproductive organ as a target in future breeding programmes as it is more sensitive to high temperature

4. CONCLUSIONS

Simulation results suggested that maximum and minimum temperatures could have significant effect on rice grain yield, biomass, HI and WP_{ET}, and this effect could become more pronounced if temperatures rises to5°Cand beyond and CO_2 concentrations by 50 ppm from the reference value of 369.41 ppm in the Northern Region of Ghana. As the mean temperature increases, the rice grain yield, biomass, HI and WP_{ET} decreases, thus showing an inverse relationship between change in average temperature from (T + 1°C) to (T + 5°C).

As management adaptation strategies, it is more appropriate to start dry season rice production under irrigation in Northern Ghana in early November so that crops will mature in February to avoid the high temperatures in March by using short duration varieties like “Gbewaa” (Jasmine 85).

Maintenance of high and well compacted earth bund, around rice fields, well levelled and effective paddling of soils to reduce seepage and percolation could enhance rice yield.

Management practices such as saturated soil culture (SSC), alternate wetting and drying (AWD) and aerobic rice cultivation in the case of drought stress, while growing improved varieties offer some adaptive options for the indirect stresses related to temperature increase.

Breeding of rice varieties for heat tolerance should be done for those breeding materials which can tolerate temperatures higher than 38 °C

Appendix: Changes in Average Temperatures and ETo for Tamale for Climate Change Analysis

Table 1a. Change in Minimum Temperatures (Monthly)

Month	T + 0°C	T+1°C	T+2°C	T+3°C	T+4°C	T+5°C
Jan	19.5	20.5	21.5	22.5	23.5	24.5
Feb	22.0	23.0	24.0	25.0	26.0	27.0
Mar	24.7	25.7	26.7	27.7	28.7	29.7
Apr	30.8	31.8	32.8	33.8	34.8	35.8
May	24.5	25.5	26.5	27.5	28.5	29.5
Jun	23.2	24.2	25.2	26.2	27.2	28.2
Jul	22.8	23.8	24.8	25.8	26.8	27.8
Aug	22.5	23.5	24.5	25.5	26.5	27.5
Sep	22.3	23.3	24.3	25.3	26.3	27.3
Oct	22.4	23.4	24.4	25.4	26.4	27.4
Nov	21.0	22.0	23.0	24.0	25.0	26.0
Dec	19.2	20.2	21.2	22.2	23.2	24.2

Table 1b. Change in Maximum Temperatures (Mean monthly)

Month	T +0°C	T+1°C	T+2°C	T+3°C	T+4°C	T+5°C
Jan	35.5	36.5	37.5	38.5	39.5	40.5
Feb	37.5	38.5	39.5	40.5	41.5	42.5
Mar	38.1	39.1	40.1	41.1	42.1	43.1
Apr	36.7	37.7	38.7	39.7	40.7	41.7
May	34.4	35.4	36.4	37.4	38.4	39.4

Jun	32.0	33.0	34.0	35.0	36.0	37.0
Jul	29.7	30.7	31.7	32.7	33.7	34.7
Aug	30.0	31.0	32.0	33.0	34.0	35.0
Sep	31.1	32.1	33.1	34.1	35.1	36.1
Oct	33.2	34.2	35.2	36.2	37.2	38.2
Nov	35.8	36.8	37.8	38.8	39.8	40.8
Dec	35.3	36.3	37.3	38.3	39.3	40.3

Table 1c. Change in Mean monthly Temperatures

Month	**MAX. Temp.**	**MIN. Temp.**	**Mean Temp.**	**T+1**	**T+2**	**T+3**	**T+4**	**T+5**
	°C	°C	°C	°C	°C	°C	°C	°C
Jan	35.50	19.52	27.51	28.51	29.51	30.51	31.51	32.51
Feb	37.50	21.57	29.54	30.54	31.54	32.54	33.54	34.54
Mar	38.10	24.25	31.18	32.18	33.18	34.18	35.18	36.18
Apr	36.70	31.89	34.30	35.30	36.30	37.30	38.30	39.295
May	34.40	24.36	29.38	30.38	31.38	32.38	33.38	34.38
Jun	32.00	23.05	27.53	28.53	29.53	30.53	31.53	32.53
Jul	29.70	22.65	26.18	27.18	28.18	29.18	30.18	31.18
Aug	30.00	22.38	26.19	27.19	28.19	29.19	30.19	31.19
Sep	31.10	22.22	26.66	27.66	28.66	29.66	30.66	31.66
Oct	33.20	22.36	27.78	28.78	29.78	30.78	31.78	32.78
Nov	35.80	21.09	28.45	29.45	30.45	31.45	32.45	33.45
Dec	35.30	19.32	27.31	28.31	29.31	30.31	31.31	32.31
Mean	34.12	22.89	28.50	29.50	30.50	31.49	32.50	33.49

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