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Research Paper

Green gram yield projections for Kibwezi east subcounty Kenya using the APSIM model under RCP's 4.5 and 8.5

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ABSTRACT

Green gram is widely grown in Kenya for food and income. However, climate change has shown unprecedented effects on its production in Kibwezi East Sub County affecting its yielding capacity. In this study, the Agricultural Production Systems Simulator Model (APSIM) (green gram module) was used to evaluate climate change impacts on its production by simulating the yields under present scenario (2001-2023), and future (2041-2070) under Representative concentration Pathways (RCPs) 4.5 and 8,5. The model was parameterized and evaluated using soil data, daily climate data and phenological characteristics for three green gram varieties, Biashara, KS 20 and N26. Yield data was obtained from a field experiment carried out during the October - November – December (OND) planting seasons in 2020 and 2021. The developed models had a Coefficient of Determination (R^2) ranging from 0.58 to 0.84 and a Root Mean Square Error (RMSE) ranging 3.0 and 13.3 meaning the models were reliable in simulating future yields. Varieties KS 20 and Biashara showed relatively high resilience to increased temperatures. Model predictions showed that performance of green gram under RCP 4.5 and RCP 8.5 would greatly reduce. Varieties KS 20 and Biashara showed relatively high resilience to increased temperatures. This calls for employment of innovative and sustainable strategies for climate change adaptation.

Key words: Green gram, Climate scenarios, Climate change, APSIM, Kibwezi East Sub County Kenya, RCP 4.5, RCP 8.5

Green gram (*Vigna radiata* R. Wilczek) also known as Mung bean or Moong is a legume crop which is adapted to a wide range of agroecological zones and has minimal nutritional requirements during production. One of the major production areas in Kenya is Kibwezi East Sub County whereby green gram is grown majorly by small holder farmers. The crop has multiple uses such as for food, fodder, manure making and industrial use among others (Anonymous, 2020). Green gram production in Kenya and in Kibwezi east sub county has been declining despite the high economic importance of the crop, widening the gap between demand and supply (Anonymous, 2020). The country's average green gram yield ranges between 0.5-0.6 t ha^{-1} compared to crop potential of 1.5 t ha^{-1} and global average yield of 0.73 t ha^{-1} (Muchomba *et al.,* 2023). The average grain yields per ha are low due to inadequate and quality planting material, poor agronomic practices, variability of weather factors and climate change (Ahmed *et al.,* 2023). Due to the unprecedented changes in weather patterns brought about by climate change, it is becoming increasingly challenging to adhere the to current management approaches in an effort to increase grain yield. Therefore the need to improve the effectiveness and efficiency in its production (Mohanty *et al.,* 2015). Indicated that climate factors such as carbon dioxide concentration, relative humidity, solar radiation and temperature had significant effects on the processes of photosynthesis and dry matter allocation in plants. Crop simulation models are useful tool to study the climatic variability on crop production. Simulation of crop performance under different climate change scenarios is important in assessing crop growth and yield dynamics (Asseng *et al.,* 2014). This study aimed to simulate the yields of green grams using the APSIM green gram module for Kibwezi East Sub – county in Makueni County,

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Table 1: The genetics coefficients used to model green grams in APSIM

Phenology	Units	Biashara	KS20	N26
Emergence	^{0}C days	94.3	94.2	94.2
Emergence to end of Juvenile phase	^{0}C days	421	421	503
Flowering to start of grain filling	^{0}C days	206	206	204
Start of grain filling to maturity	^{0}C days	313	320	301

Table 2: Model validation statistics

Year	Variety	Observed Yield (kg ha^{-1})	Predicted Yield (kg ha^{-1})	R^2	RMSE
2020	Biashara	1001.1	1023.7	0.63	5.3
2021	Biashara	835.3	621.4	0.68	3.0
2020	KS20	786.1	1101.4	0.71	12.1
2021	KS20	866.4	987.6	0.84	8.7
2020	N26	896.8	797.2	0.77	7.8
2021	N26	890.1	610.6	0.58	13.3

Kenya.

MATERIALS AND METHODS

Study location

The study location was Kibwezi East Subcounty, Makueni County, Kenya which is approximately 200 km south east of Nairobi. The longitude is 37°58'4.25" E and the latitude is 2°24'37.89"S. The climate of the area is hot and dry and receives a bimodal type of rainfall. The long rains from March - April - May (MAM) and the short rains from October-November - December (Anonymous, 2013). The average annual rainfall for Makueni County is 300mm - 400mm, while the average temperatures are from 18ºC to 35ºC. The soils are moderately deep, well drained, dark reddish brown sandy clay loams. The subcounty is located in the Lower middle agroecological zone and is predominantly occupied by natural vegetation, indigenous trees, such as Acacia and Baobab and other shrubs (Anonymous, 2013).

Field experimental design

This study was carried out in 2020 and 2021 rainy seasons for the purpose of collecting the green gram phenological datafro model parameterization. A farm in the study area was purposely chosen to carrying out the experiment. Varieties KS 20, N26 and Biashara commonly grown varieties in the area were purposely chosen for the study. The experiment adopted the Randomized Complete Block Design (RCBD) (Dahiya *et al.,* 2020) with three replications. Each variety of green gram was randomly allocated and sown in a plots measuring 5m x 5m making a total of 9 plots. Prior to planting, animal manure was incorporated in all the fields. Planting was carried out at a spacing of 45cm between rows and 15cm between plants and at a of depth of 3-5 cm. Hand weeding was carried out twice during the production of the crop. Integrated pest management practices were used for crop protection. Measurements on the crop phenological stages such as emergence, end of juvenile stage, floral initiation, flowering, pod formation and physiological maturity were recorded/estimated. (Chauhan *et al.,* 2010). Upon physiological maturity, harvesting was done by hand separately for each plot, the harvest was threshed, cleaned by hand per variety, per plot and the yields were recorded. Totals and means for the recorded data on yields at the time of harvest were computed and tabulated.

Climate data

Historical weather data for Kibwezi east (Latitude = -2.41 and Longitude = 37.97) for the last 22 years from 2001 to 2023 was obtained from the National Aeronautics and Space Administration (NASA) Power and the Climate Hazards InfraRed Precipitation with Station Data (CHIRPS), which is the rainfall global station using the weather tab in APSIM (https://www.chc.ucsb.edu/data/chirps).

Soil data

The soil profile data for the study location was obtained from the Sub - County Agriculture office in Kibwezi East. Soil analysis had been done by the National Agricultural Laboratory within the past one year (Chauhan *et al.,* 2010).

Model calibration and parameterization

APSIM next generation model (green gram module) was used to simulate the grain yields of the three green gram varieties. Since APSIM platform is not calibrated for the three green gram varieties used in the field experiment, it has to be parameterized. Green gram has nine distinct phenological phases in relation to growing temperatures (Chauhan *et al*, 2010). The temperature requirement for each stage is called thermal time or degree days. The model uses base, optimal and extreme temperature to calculate degree days (Chauhan *et al.,* 2010). The degree days from sowing to emergence, emergence to end of the juvenile phase, flowering to start of grain filling and start of grain filling to end of grain filling, date of sowing as well as crop spacing were computed/estimated and input into the APSIM model. Crop management data included, seed quantity per ha, spacing, depth, weeding and application of fertilizers. APSIM model requires input of daily weather patterns such as temperature, rainfall and solar radiation as a .met file in chronological order (Mohanty *et al.,* 2012).

In APSIM, the degree days for each phenological stage were adjusted to match the simulated dates. Model calibration was performed by adjusting the Genetic Coefficients of the new varieties then the model was run to predict the yields. The developed APSIM models were evaluated by comparing the predicted (simulated) yield with the observed (measured) yields. Parameterization of the model was considered to be complete when the difference between the observed and simulated variables was minimum. The statistical indicators used for evaluation of the models were; Coefficient of Determination (R^2) and Root Mean Square Error (RMSE) (Chai and Draxler 2014). R^2 reflects the consistency between the observed value and the simulated value, and the closer their value is to 1, the better the quality of the simulation results of the model. RMSE measures the average difference between predicted and observed values. The smaller the RMSE, the better the accuracy of the model. The models were considered acceptable when the RMSE was very small compared to the mean (Chai and Draxler, 2014) and thus the MAE would be a better metric for that purpose. While some concerns over using RMSE raised by Willmott and Matsuura (2005

Performance of green gram varieties under RCP4.5 and RCP 8.5

To simulate the effect of climate change on green gram yield under different future climate scenarios, Coordinated Regional Climate Downscaling Experiment (CORDEX) RCA4 model ensemble data for the future RCP 4.5 and 8.5 climate scenarios (2041 to 2070) were used as inputs in the model. In an excel spreadsheet, this data was saved as a .prn file and then converted to .met in excel using the TavAmp program written in FORTRAN language (Mugo, 2023). These .met files were fitted into the APSIM weather module. Three separate APSIM simulations were set namely: present/ historical climate data (baseline), RCP 4.5 simulation and RCP 8.5 simulation. Green gram yield data from the three simulations was recorded and compared (Mohanty *et al.,* 2012). Using *ggplot2* package in R, yield under three scenarios were plotted. The trend in predicted yields data from 2041 to 2070 was determined through Mann-Kendal test of trend using *Kendall* package in r statistical software.

RESULTS AND DISCUSSION

The genetic coefficients were almost similar on emergence (about 94 ^{0}C days) for varieties KS 20 and N26. Varieties Biashara and KS20 had the same genetic coefficients (421 ^{0}Cdays) on emergence to end of juvenile phase while N26 had a higher value of 503 ^{0}Cdays. In general, KS 20 had higher genetic coefficients compared to the other varieties (Table 1). Model validation results indicated that the developed models were reliable for simulating green gram yield in Kibwezi East Kenya. The models had RMSE values ranging from 3.0 to 13.3. The highest R^2 (0.84) was achieved by KS20 in 2021 season while the least R^2 (0.58) was by N26 in 2021 (Table 2).

The results revealed that the RMSE of the model ranged from 3.0 to 13.3. In addition, the models' R^2 ranged between 0.58 and 0.84. This result implied that the developed model was able to simulate green gram yields in Kibwezi East with high reliability. This result is in line with other studies carried out by Mohanty *et al.,* (2012), Mugo *et al.,* (2023)biomass and days to maturity under the baseline and future climate scenarios in Kitui County, Kenya. A field experiment was conducted during the March–April–May (MAM, and Yamusa and Akinseye (2018) which showed that APSIM models can be calibrated to reliably simulate crop yields.

Simulation results revealed large variations in the average yields for the three green gram varieties (Biashara, KS20 and N26) under the three climatic scenarios. The box plot in Fig. 1, showed a decrease in green gram yield whereby under RCP8.5 the yield loss was greater compared to the present climate scenario. The average simulated yield data showed that, KS20 had the highest yield while N26 had the lowest yield.

This loss was attributed to the predicted change in future climate conditions due to climate variability and predicted changes in precipitation patterns and increase in temperature (Ahmed *et al.,* 2023; Nishant *et al.,* 2021). Plant reproductive tissues and their functions are highly sensitive to heat stress. Temperature increase by a few degrees during crop flowering period can lead to loss of an entire crop cycle. High temperatures during the reproductive stage can lead to crop losses mainly due to low pollen quantities, poor pollen viability, poor anther dehiscence, poor pollination, flower abortion and poor pod formation (Kaur *et al.,* 2015).

Comparisons between the varieties under the present, RCP 4.5 and RCP 8.5 climatic scenarios showed that KS20 produced the highest simulated yield while N26 produced the lowest (Table 3). Variety KS20 produced higher yields across the three climate scenarios implying that it could be having some level of resilience to the effects of climate change. This variety was closely followed by Biashara in terms of production capacity. This phenomenon was similarly seen in Table 1 where varieties KS20 and Biashara had the same genetic coefficients. These results implied that the performance of the two varieties was nearly the same in Kibwezi East sub-county. On the other hand, variety N26 yields were low compared to the other two varieties.

Despite each variety maintaining its position in terms yields all through, there was reduction in yields under in predicted future climate scenarios (Fig. 1 and Table 3). This result relates a study by Mugo *et al.,* (2023)biomass and days to maturity under the baseline and future climate scenarios in Kitui County, Kenya. A field experiment was conducted during the March–April–May (MAM who reported variability of rainfall across RCP 4.5 and RCP8.5 climate scenarios leading to predicted low green gram yields in the future. Mohanty *et al.,* (2015) indicated that climate factors such as carbon dioxide concentration, relative humidity, solar radiation and temperature had significant effects on the processes of photosynthesis and dry matter allocation in plants. Increase in temperatures decreases crop yields even with minor deviations from the normal which impairs the efficiency of the inputs applied and directly affects food production. A similar study by Mulwa *et al.,* (2023), in Eastern Kenya testing 5 green gran varieties showed that

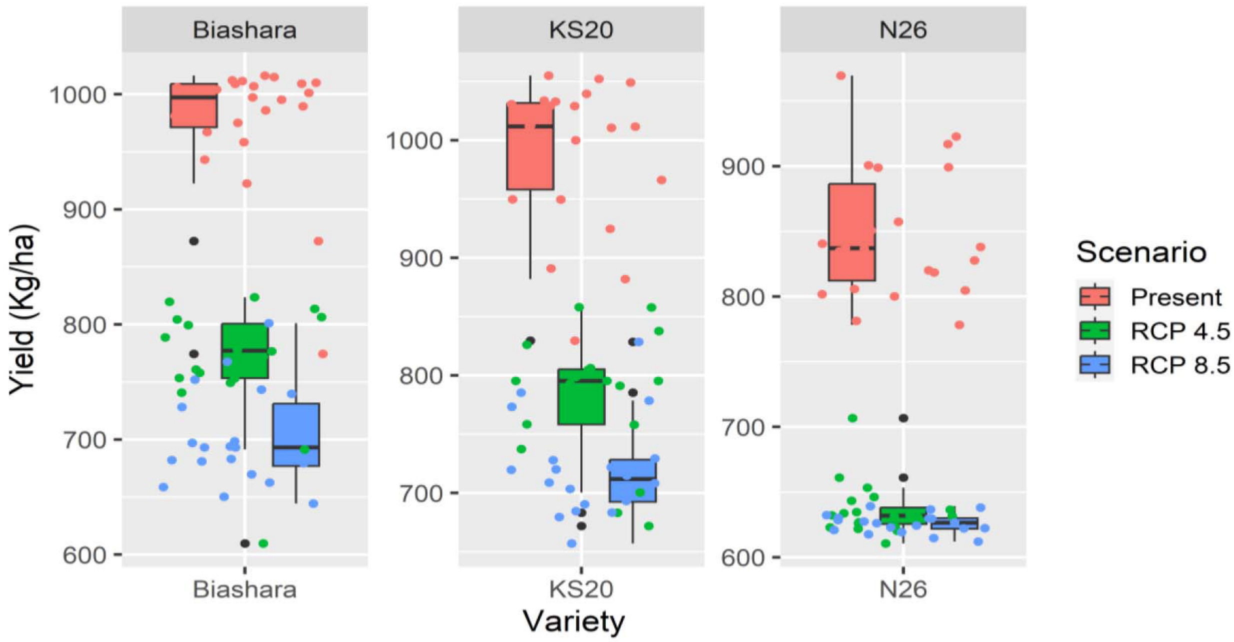

Fig. 1: Green gram yield performance for the three green gram varieties under the different climate scenarios

Table 3: Yield simulation data using APSIM under present, RCP4.5 and RCP 8.5

	Present	RCP 4.5	RCP 8.5
Biashara	997	774 (22.37%)	693 (30.49%)
KS20	1020	798 (21.76%)	713 (30.1%)
N26	838	622 (25.78%)	619 (26.13%)

Note: The value in bracket is the percentage yield loss

variety KS 20 matured earlier that all the tested varieties.

The Mann-Kendal test of trend for the simulated green gram yield data is presented in Table 4. The results indicated lack of trend for all varieties in the three climatic scenarios in all the years, with the exception of variety KS20 in present climatic scenario. This variety had a Mann-Kendal test p-value of 0.04, which means that there was a significant trend in this case, as shown by the Tau value which is a measure of slope monotony and ranges from -1 to 1, it is positive when the trend is increasing and negative when the trend is decreasing (Chen *et al.,* 2022). In all cases, Tau was positive and it ranged from 0.16 to 0.30.

The result from the Mann-Kendal test of trend (Table 4) showed that all test varieties in future climatic scenarios across the years showed no significant trend in their performance. This means that the general performance of these varieties in terms of yield varied every year. This could be attributed to climate change and variability. Similar findings in similar study area were reports by Mugo *et al.,* (2020), indicating projected decrease in green gram production under RCP 8.5 due to climate change.

CONCLUSION

Green gram yields decreased significantly under RCP 4.5

Table 4: Mann-Kendal test of trend for the simulated green gram yield data for the present and future RCP 4.5 and 8.5

Variety	Mann-Kendal test of trend		
	Climatic Scenario	P-value	Tau
KS20	Present	0.04*	0.30
	RCP 4.5	0.11	0.26
	RCP 8.5	0.21	0.21
Biashara	Present	0.11	0.24
	RCP 4.5	0.35	0.16
	RCP 8.5	0.18	0.22
N26	Present	0.26	0.17
	RCP 4.5	0.35	0.26
	RCP 8.5	0.09	0.28

and 8.5 climate scenarios in 2050s compared to the current scenario. This predicted loss in yield could be attributed to the effects of climate change and variability. In this regard it is important for farmers to adapt their farming practices to current and expected climatic variability and change. Varieties, KS 20 and Biashara showed high yields in the simulations. This may imply that they could have potential to perform well under the anticipated climate change scenarios and therefore further research is recommended.

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