African Journal of Climate Change and Resource Sustainability
ajccrs.eanso.org
Volume 3, Issue 1, 2024
Print ISSN: 790-962X | Online ISSN: 790-9638
Title DOI: https://doi.org/10.37284/2790-9638

EAST AFRICAN NATURE & SCIENCE ORGANIZATION

Original Article

Medium Term Climate Change Effects on Millet Yields in Gulu District, Northern Uganda

George Oriangi[1], Yazidhi Bamutaze[2], Paul Isolo Mukwaya[2] & Edekebon Elaijah[1]*

[1] Gulu University, P. O. Box 166, Gulu, Uganda.
[2] Makerere University, P O. Box 7062, Kampala, Uganda.
[*] Author for Correspondence ORCID ID: https://orcid.org/0000-0002-4744-4034; Email: g.oriangi@gu.ac.ug

Article DOI: https://doi.org/10.37284/ajccrs.3.1.1919

Date Published:

12 May 2024

Keywords:

Climate Change, Millet yields, Medium term, Uganda.

ABSTRACT

Climate change is expected to adversely affect crop yields and livelihoods of agro-dependent societies, especially in Sub-Saharan Africa. However, there remain gaps on the effects of expected regional climatic changes on key food security crops. This study assessed the projected climatic conditions and expected changes in millet yields for Paicho Sub County (S/C) in Gulu District up to the year 2033 using a cross sectional study design. To determine future climatic conditions, PRECIS (Providing Regional Climates for Impact Studies) model was used based on projected conditions at a 50 km spatial resolution while millet yields were modelled using Penman Grindley soil moisture balance model. PRECIS projected changes for 2033 reveal a strong and significant decrease in rainfall ($p< 0.05$). This is likely to decrease millet yields by 2.6% below the average current yields of 1.8 tons per hectare per year under business-as-usual scenario. The finding indicates a need for improved millet varieties that can survive under changed climatic conditions.

APA CITATION

Oriangi, G., Bamutaze, Y., Mukwaya, P. I. & Elaijah, E. (2024). Medium Term Climate Change Effects on Millet Yields in Gulu District, Northern Uganda *African Journal of Climate Change and Resource Sustainability*, *3*(1), 150-164. https://doi.org/10.37284/ajccrs.3.1.1919.

CHICAGO CITATION

Oriangi, George, Yazidhi Bamutaze, Paul Isolo Mukwaya and Edekebon Elaijah. 2024. "Medium Term Climate Change Effects on Millet Yields in Gulu District, Northern Uganda". *African Journal of Climate Change and Resource Sustainability* 3 (1), 150-164. https://doi.org/10.37284/ajccrs.3.1.1919

HARVARD CITATION

Oriangi, G., Bamutaze, Y., Mukwaya, P. I. & Elaijah, E. (2024) "Medium Term Climate Change Effects on Millet Yields in Gulu District, Northern Uganda", *African Journal of Climate Change and Resource Sustainability*, 3(1), pp. 150-164. doi: 10.37284/ajccrs.3.1.1919.

IEEE CITATION

G. Oriangi, Y. Bamutaze, P. I. Mukwaya & E. Elaijah. "Medium Term Climate Change Effects on Millet Yields in Gulu District, Northern Uganda", AJCCRS, vol. 3, no. 1, pp. 150-164, May. 2024.

MLA CITATION

Oriangi, George, Yazidhi Bamutaze, Paul Isolo Mukwaya & Edekebon Elaijah. "Medium Term Climate Change Effects on Millet Yields in Gulu District, Northern Uganda". *African Journal of Climate Change and Resource Sustainability*, Vol. 3, no. 1, May. 2023, pp. 150-164, doi:10.37284/ajccrs.3.1.1919.

Article DOI: https://doi.org/10.37284/ajccrs.3.1.1919

INTRODUCTION

A compelling number of studies globally converge on the notion that climate change will variously impact agriculture, notably on crop yields under rain-fed agricultural systems (Jawoo, 2013; Silungwe et al., 2019; Saxena et al., 2018; Ullah et al., 2019; Liu et al., 2020; Wang et al., 2018). This will severely affect the poor due to their limited adaptive capacities manifested by low education levels, low technology, limited supporting institutions, limited access to financial assets, and high levels of poverty (Hepworth & Goulden, 2008; Silungwe et al., 2019). The Intergovernmental Panel on Climate Change (IPCC) (2001) defines climate change as a change in the state of climate identified using statistical tests by changes in the mean and/or the variability of its properties persisting for an extended period typically decades or longer caused by natural processes within the climate system or as a result of variations in natural or anthropogenic external forcing.

An evaluation of the projected changes in rainfall is inconclusive and gives mixed results. In the tropics and high-latitude regions, the intensity of precipitation events is likely to increase up to +46% by 2090s because of high evapotranspiration (IPCC, 2007). However, other studies indicate a decrease in rainfall amounts on average by 10% to 40% (Nicholson, 2000; Worishima & Akasaka, 2010). In Africa generally, rainfall is projected to increase (Mohamed et al., 2002; Sultan et al., 2013; Safo et al., 2022) with the exceptions of South Africa and parts of the Horn of Africa where rainfall is projected to decline by about 10% by 2050 (Worishima & Akasaka, 2010). Consequently, some areas under rain fed conditions are likely to become unsuitable for cropping. Thus, affecting livelihoods which are heavily dependent on agriculture. Furthermore, regional weather conditions are expected to become more variable in the future than at present characterized by increased frequency and severity of extreme events such as floods and hailstorms, changes in the onset dates of rainfall, delayed or even failed rains and these are likely to have negative effects on crop yields (Ziervogel et al., 2008; Vreiling et al., 2013). Projected increases in rainfall for Uganda are largest in the short rain seasons (-8 to +35%) and models consistently project overall increase in the proportion of rainfall that falls in heavy events ranging between 1% to 15% in annual rainfall by 2090's (ACCRA, 2012; Bashaasha et al., 2012). These projected changes will vary by region as a function of the biophysical conditions as well as the local and global climate control conditions. Irrespective of the direction and magnitude of the climate change, crop yields and food security is likely to be negatively affected (Bello et al., 2012; Hotz, 2013). Rainfall model results are not consistent and tend to vary from region to region or even in the same country. It is thus apparent that expected changes in rainfall are spatially constrained particularly in Africa where a large natural variability exists necessitating more studies which are location specific to understand climatic dynamics and the probable effects on crop yields.

Additionally, evidence points to the fact that in general, global mean surface temperatures are projected to rise between 1^0C to 6^0C by 2100 (IPCC, 2011; ACCRA, 2012; Parry, 2004; 2007; Hotz, 2013; Faye et al., 2018; Asori et al., 2022). IPCC (2001) projected a rise in global mean surface temperature from 1.8°C to 4.0°C by 2100 while Hotz (2013) projects a much higher rise from 4-6^0C by 2080 in Mekong region in Asia. While, some regions like the temperate regions may agriculturally benefit from temperature rise because of increase in the length of the growing season, expansion of agricultural land, and increase in warm temperatures (Parry et al., 2008). This temperature rise is likely to affect the tropical areas negatively due to direct exposure of the region to the sun throughout the year which will cause alteration of the length of growing season thus, reducing the yield potential (Vreiling, 2013). Generally, a 4^oC warming is expected to reduce crop yields by bwteen 15- 80% (Mastrandrea, 2010).

The use of simulation and regression models show mixed results on how crop yields will be affected by climate change (Wasige, 2009; Parkes et al.,

Article DOI: https://doi.org/10.37284/ajccrs.3.1.1919

2018; Boote et al., 2018). On average yields of maize, soya beans, and cotton are predicted to decrease by 30–46% before the end of the 21st century under the slowest (B_1) warming scenario, and a decrease by 63–82% under the most rapid warming scenario (A_1F_I) under the Hadley III model (Singh et al, 2013). Knox et al. (2012) reported an increase in maize yields by 10% in 2020-2030 and by 60% from 2050-2080 in Africa and South Asia, and sorghum yields will more than triple in Eastern and Central Africa (Bashaasha et al., 2012). This synthesis shows that model predictions of crop yields tend to vary even with the same crop necessitating more location specific investigations.

Millet is one of the crops which historically has been resilient to climate change (Sultan et al., 2013; Ullah et al., 2019). But this is likely to change in the future due to elevated temperatures (Boote et al., 2018). Projected climate change effects on millet grain yields widely vary from those recorded in the past because of the increasingly adverse role of higher temperatures in reducing yields (Defrance et al., 2020). Most areas in Africa are projected to be negatively affected by increasing temperatures (Silungwe et al., 2019), moreover over 70% of Africa's population is largely dependent on agriculture for their livelihoods. This implies that adverse shifts in climate will cause devastating effects on agriculture necessitating increased attention to be paid to assessing risks to Africa's agriculture under climate change. Findings from some studies have already projected moderate to severe effects on agricultural yields depending on whether adaptation to climate change is taken into consideration (Sultan et al., 2020; Falconnier et al., 2020; Traore et al., 2017). A summary of how climate change will affect crop yields in different parts of Africa was illustrated by Muller et al. (2000) showing that wheat yields would reduce by 15% with a 2^{o}C increase in temperature by 2040, and generally, crop yields may decline by 5-22% by 2050.

Furthermore, Mohamed et al. (2002) reported that by 2025 production of millet is estimated to reduce by 13% as a result of increase in temperature while Kilembe et al. (2012) projected a decrease in millet yields by 26% by 2080's in East Africa due to temperature rise. In Uganda, temperatures are projected to rise by between 1.5^0 and 4.3^0 by the year 2100 depending on the location (ACCRA, 2013). Some studies indicate that a 1.5^{0}C change in temperature is critical for crop yields (Kilembe, 2012; Traore et al., 2017). These temperature observations indicate variable results and underpin the need to understand the projected changes at a local level and their effects on crop yields. Uganda is a less resilient nation to climate change thus, a better quantification and understanding of site-specific effects of climate change on crop yields is urgently needed (Defrance et al., 2020). More so in Gulu District which suffered neglect in the scientific domain during the conflict period (1986-2006) and whose economy is largely dependent on rain fed agriculture for food supply. Besides, millet is a staple food crop forming an important element of food security in the region but is being abandoned by households due to reduced yields perceived to be exacerbated by climate change. Therefore, this study investigated the effect of climate change on millet grain yields on a medium-time scale in Paicho S/C in Gulu District in Northern Uganda. Thus, contributing to existing literature on climate change and crop yields and informs adaptation policies that can create resilient communities.

MATERIALS AND METHODS

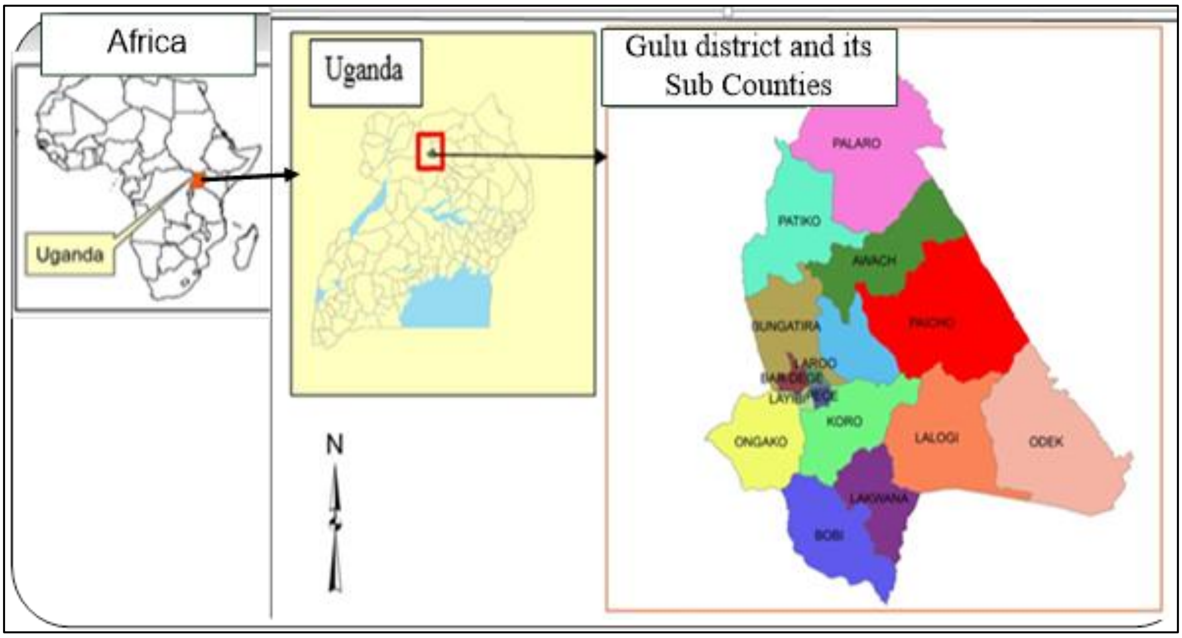
Description of the Study Area

The study was conducted in Paicho S/C in Gulu District in northern Uganda (Figure 1) in the year 2012. Paicho Sub County geographically lies between latitudes 2° 52'-2^{o}55' N and longitudes 32° 27'- 32^o 29' E. The total area covered by the sub county is 592.7km^2 (UBOS, 2011). The sub county is bordered by Awach Sub County in the North, Atanga Sub County in the northeast, Awere and Puranga in the East, Odek Sub County in the south east, Lalogi and Koro Sub Counties in the South, and Bungatira Sub County in the West (Okello, 2010). Paicho S/C in Gulu was purposively chosen based on its fragility and

Article DOI: https://doi.org/10.37284/ajccrs.3.1.1919

sensitivity to climate change. This is because Gulu is one of the districts that suffered from war for 20 years (1986-2006) thus climate change effects exacerbate the vulnerability of such a community.

Figure 1: Location of the study area



Source: (GIS generated map, UBOS Shape files, 2010)

Gulu District experiences tropical type of climate (wet and dry) (NEMA, 2009). The average total annual rainfall received is 1500 mm with the monthly average rainfall varying between 1.4 mm in January and 230 mm in August. Normally the wet season extends from April to October with the highest peaks during May, August, and October, while the dry season begins in November and extends up to March. Rainfall is mainly convectional characterized by afternoon and evening occurrences. Although the annual rainfall totals are theoretically good enough to support crop growth, its temporal distribution appears to be constraining since the rains come in one season, consequently, there is one crop growing season coupled with occasional experiences of long droughts and irregular rains (NEMA, 2009) hence threatening crop production and affecting the yield potential of the area. The average maximum temperature is 30^{0}C, and the average minimum temperature is 18 ^{0}C (UBOS, 2011).

Subsistence agriculture is the dominant land use type in Gulu District that employed over 90% of the total population (UBOS, 2011). The major crop grown is finger millet and other crops grown include maize, sorghum, beans, peas, sesame, ground nuts, cassava, and potatoes. However, the growing of finger millet is being abandoned due to reduced yield that are perceived to be a result of changing climate.

In addition, the district is characterized by Leptosol soils which have a high percentage of sand (NEMA, 2009). These soils have low water retention capacity, high rate of water infiltration, and moderate fertility (UBOS, 2011) hence, may require the addition of fertilizers for maximum output of crop yields but given the low incomes of the population (UNDP, 2012), purchase of fertilizers, and other modern agricultural inputs is limited for most households resulting to low crop yields. The district was characterized by a low socioeconomic status with 62% of the population living below the poverty line (UNDP, 2012) and this has a negative implication to crop production. The main option for income is the sale of crops, and others include casual labour and sale of forest products. However, a smaller proportion of the population are involved in petty trade activities such as selling of crop produce, brewing, and selling alcohol, selling local consumable goods,

Article DOI: https://doi.org/10.37284/ajccrs.3.1.1919

handcrafts, and foodstuffs which are mainly sold in the shift/village markets. Furthermore, the vegetation of Picho Sub County is majorly woodlands and savannah grasslands (Environment, Social Management & Monitoring Plan, 2019). The sub-county had a total population of 24,488 according to the 2014 population census (UBOS, 2011).

Data Collection and Analysis

Soil data was required to determine some parameters required in the Penman-Grindley soil moisture balance model, used to simulate the effects of climate change on millet yields. The study adopted the gravimetric sampling technique which involves collecting soil samples from representative sites in the study area at a depth of 0-30 cm, considered for root penetration according to FAO (2013). Three sites were visited, and at each site, three points were selected, and three soil cores taken from each point. The soil cores of approximately 200g were collected in a plastic bag and taken for laboratory analysis. The parameters which were determined include soil moisture deficit, wilting point, drying point and root constant which formed some of the inputs to the Penman-Grindley soil moisture balance model (refer to *Appendix 3*).

Data on millet yield patterns for previous years was required to facilitate calibration of the model to simulate future changes owing to climate change. Millet yield data for Gulu District was obtained from the Production Office, Gulu District. The obtained data covered a period of 6 years, from 2007 to 2012 (*Table 1* and *Appendix 1*).

Table 1: Observed millet yields for Gulu district for the period 2007-2012

Years	Observed millet yields (Kg/ha/yr.)
2007	1607
2008	1400
2009	1600
2010	1000
2011	1300
2012	1500

Future climatic conditions for the period 2013 to 2033 were obtained using the PRECIS model. This served two related purposes of the study; (a) understanding the future climate conditions at a relatively finer resolution using downscaled data, and (b) using the projected climatic conditions to simulate the effects on yields of millet. Details of the PRECIS model are widely available in Marengo et al. (2009), Yong et al. (2006), and Kumar et al. (2008). PRECIS is a Regional Climate Modelling (RCM) system based on the third generation of the UK's Hadley centre's regional climate model (Kumar et al. 2008; Marengo et al., 2009). PRECIS downscales climate up to a spatial resolution of 25 km. RCMs represent an effective method of adding fine-scale detail to simulated patterns of climate change as they resolve better local land-surface properties such as torography, coasts and vegetation, and the internal regional climate variability through their better resolution of atmospheric dynamics, and processes (Marengo et al., 2009). The PRECIS model was calibrated using historical climatic data obtain from Uganda National Meteorology Authority. The obtained PRECIS data was downscaled to a resolution of 50 km. For this study, projections of future climatic conditions were confined to a medium temporal scale (year 2033) to obviate the uncertainty associated with long timescale projections.

Modelling of millet yields was done using the Penman Grindley soil moisture balance model to test whether climate change will lead to a 20% decrease in millet yield in Paich S/C, Gulu District by the year 2033. This model was first developed by Penman (1950), and later revised by Lerner et al. (1990). The model was considered suitable, putting soil moisture at the centre and has variously been used under African conditions by

Article DOI: https://doi.org/10.37284/ajccrs.3.1.1919

several researchers e.g. Mileham et al. (2009), and Taylor and Howard (1999). The basic structure of the model is represented by two equations as follows;

$R = (P - RO) - E_t$ when SMD = 0 Equation (1).

R = 0 when SMD > 0 Equation (2).

According to the model represented in Equation (1) and (2), direct recharge (*R*) occurs when incoming precipitation (*P*), less surface runoff (*RO*) exceeds evapotranspiration (Et), and raises soil-moisture content beyond field capacity, a condition at which any additional net influx of water is not stored within the soil but drains to underlying strata. When the water content of the soil is less than field capacity, a soil-moisture deficit (SMD) is said to exist and direct recharge is prevented. Soil-moisture balance models provide estimates of direct groundwater recharge (i.e. from the infiltration of rainfall based on changes in the moisture content of soil (Karongo, 1990; Penman, 1950; Lerner et al., 1990).

The major inputs of the model are climatic, soil, and land use data, while, the major output is the net change (gain or loss) of soil moisture in milimeterds (mm). Climate parameters were precipitation, runoff, pan evaporation, and potential evapotranspiration. Data for pan evapotranspiration for Gulu station which also facilitates derivation of potential evapotranspiration was not available. However, data for the nearest station (Lira) was considered since the two stations lie in the same agro-climatic zone. The soil parameters cover the root constant, wilting point, and soil moisture deficit. The land use type considered was agriculture (Mileham et al., 2009).

The soil samples were analyzed using standard procedures according to Allen (1998) and FAO, (2013) to determine the soil moisture deficit, the wilting point, and drying point as depicted in *Appendix 3*. Equation 3 indicates how the resulting output of the soil moisture balance model was computed.

$SM\ g/l = f\ (C, D, F, RO, SMD, P, PE_t, E_o)$ ……………………………….Equation (3)

Where, SM g/l is the net gain/loss of soil moisture, C is the root constant, D is the wilting point, F is the drying point, RO is runoff, SMD is soil moisture deficit, P is precipitation, PE_t is potential evapotranspiration, E_o is pan evaporation.

Equation 4 was used to simulate millet yields for the period 2013-2033

$\mu = \beta/\infty \times \alpha$ Equation (4)

Where; μ is the simulated millet yields, β is maximum yield if all conditions are favourable, ∞ is moisture requirement for millet, and α is the net moisture.

Trend analysis was performed on rainfall, maximum temperature, and minimum temperature data to assess the strength of change in future precipitation, and temperature for the period 2013-2033. While regression analysis was done to examine the significance of change in temperature, and precipitation for the period 2013-2033.

RESULTS

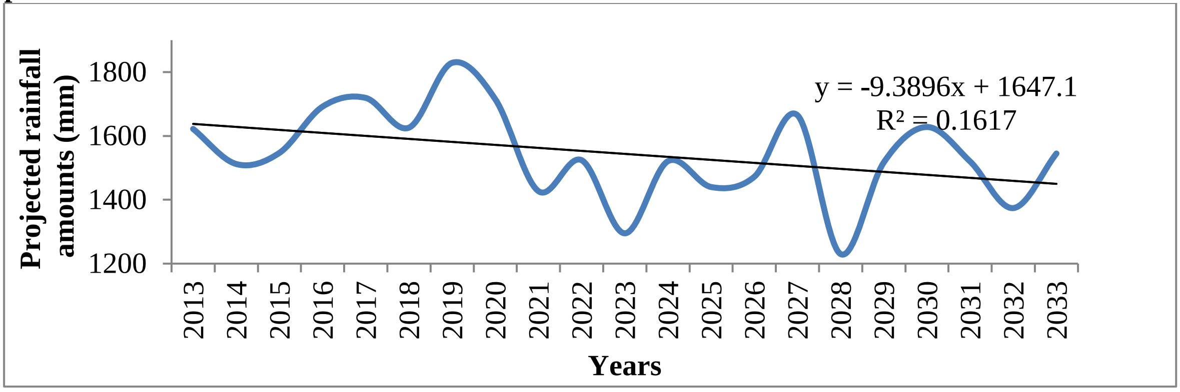
Projected Changes in Climate

Trends in Projected Changes in Rainfall

The trends observed in projected annual rainfall amounts for the period 2013-2033 (*Figure 2*) revealed that projected annual rainfall amounts are likely to have no strong but significant decrease ($R^2 < 0.5$), and ($P > 0.05$) respectively for the period 2013-2033. This implies that changes in rainfall are likely to occur in Paich S/C in Gulu District by 2033.

Article DOI: https://doi.org/10.37284/ajccrs.3.1.1919

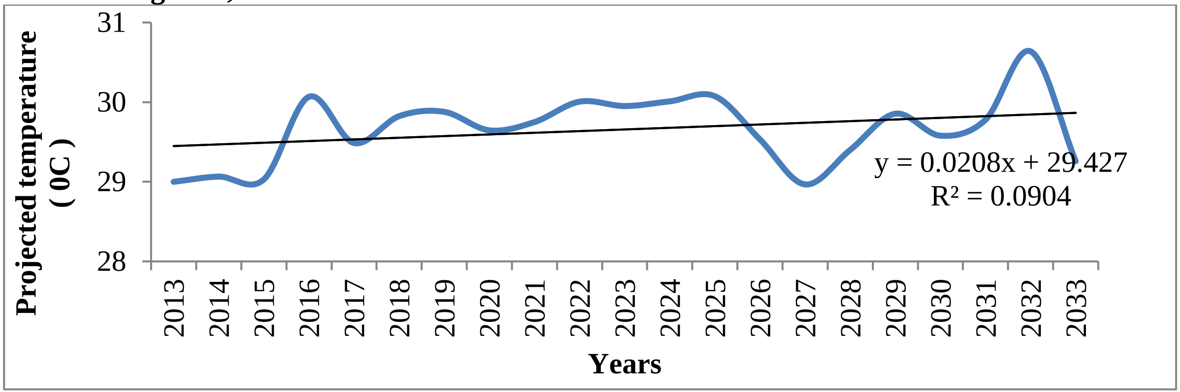
Figure 2: Projected trend in rainfall for Paicho S/C, Gulu District in Northern Uganda for the period 2013-2033



Trends in Projected Changes in Maximum, and Minimum Temperature

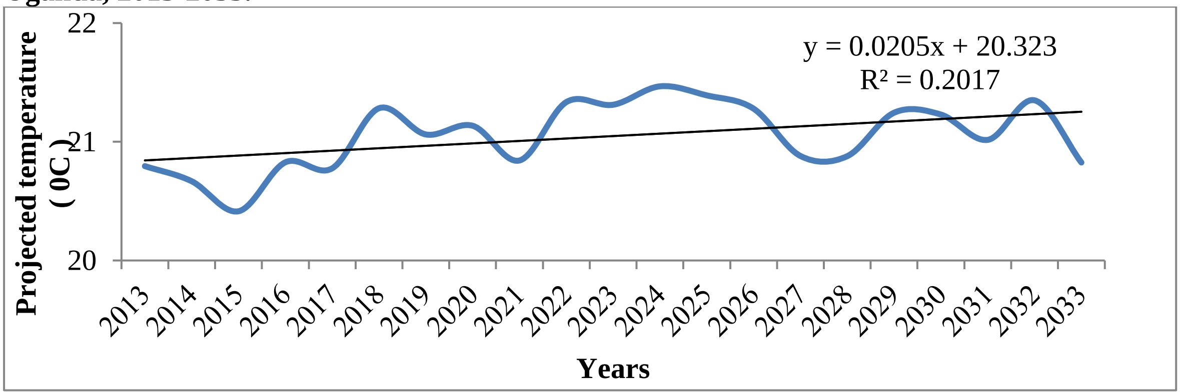
The trends observed in projected mean annual maximum temperature for the period 2013-2033 (*Figure 3*) indicates that annual maximum temperature is likely to remain quasi uniform ($R^2 > 0.5$), and ($P > 0.05$) for the period 2013-2033. This implies that mean annual maximum temperature is likely to vary but not change by 2033 characterized by slight oscillations.

Figure 3: Projected trend in mean annual maximum temperature for Paico S/C, Gulu district in Northern Uganda, 2013-2033.



The trend observed in projected mean annual minimum temperature for the period 2013-2033 shows that annual minimum temperature is likely to remain quasi uniform for the period 2013-2033 ($R^2 < 0.5$), and ($P > 0.05$) (*Figure 4*). This implies that mean annual minimum temperature for Paicho S/C in Gulu District is likely to vary rather than change by 2033 characterized by oscillations.

Figure 4: Projected trend in mean annual minimum temperature for Gulu District in Northern Uganda, 2013-2033.

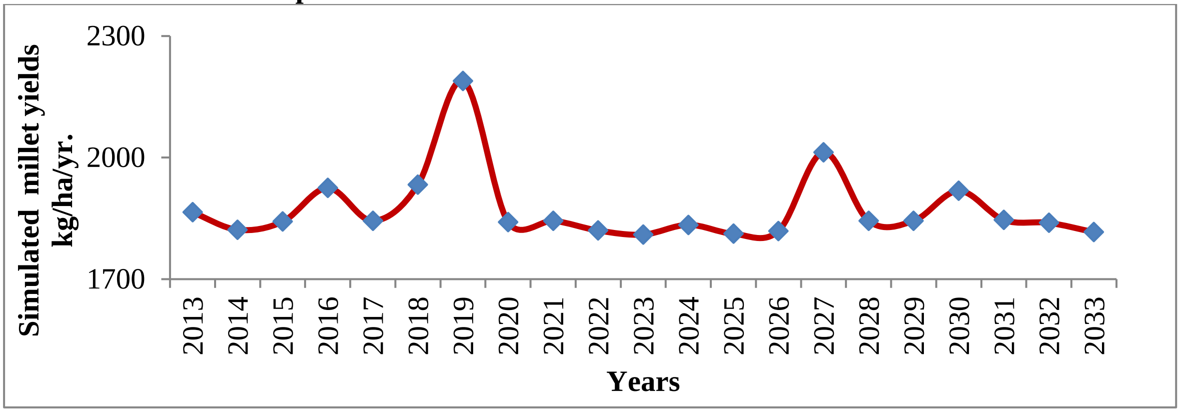


Article DOI: https://doi.org/10.37284/ajccrs.3.1.1919

Effects of Climate Change on Millet Yields

Millet yield simulation results for Paicho S/C, Gulu District indicated that annual millet yields for the period 2013-2033 are expected to oscillate from 1800 to 2189 kilograms per hectare per year for the period 2013-2033 (*Figure 5*). However, in the years 2019, and 2027 there will be drastic increases in millet yields as a result of increase in the net gain in soil moisture. Generally, a decrease in millet yields of 2.6% is expected for the period 2013-2033.

Figure 5: Simulated millet yields per Kilogram (Kg) per hectare (ha) per year (yr.) for Paicho S/C in Gulu district for the period 2013-2033.



DISCUSSION

Trends in Projected Changes in Rainfall

The trends in projected annual rainfall amounts for Paicho S/C in Gulu District was found to be decreasing for the period 2013-2033, and statistical analysis revealed that the decrease is not strong but statistically significant (Figure 2). This is likely to affect agricultural production because the S/C's population largely depend on rain fed agriculture for their livelihood. Contrary to this study finding, Nandozi (2012) assessed the future rainfall and temperature changes and their effects on suitability of coffee growing areas in Uganda for the period 2071-2100 using different Global Climate Models (GCMs). The models were evaluated using correlation, root mean square error, and model bias techniques. The ensemble mean output of ECHAM4, and HadAM3P were downscaled using UK-Met Office version of Regional Climate Model (RCM), and his findings indicated that March to May seasonal precipitation is likely to increase while a decline is noticed in the September to November season. Similarly, Sultan, et al. (2013) projected a likely increase in rainfall for the period 2001 to 2100 in Senegal, Mali, Burkina Faso, and Niger. It is thus clear that although the changes in rainfall are generally expected in tropical areas, the expected changes are diverse in terms of magnitude, direction and geography. Furthermore, studies report that the major potential drivers of changes in Uganda's rainfall span from climate variability mainly through the ENSO phenomena, changes in sea surface temperature gradients in the tropical Indian Ocean, the influence of trade winds, and subtropical high, and jet streams (Manatsa et al., 2013; IPCC, 2015).

Trends in Projected Changes in Maximum and Minimum Temperature

The trends in both projected mean annual maximum, and minimum temperature for Paicho S/C in Gulu District during 2013-2033 shows an increasing trend, and statistical analysis revealed that the increase is statistically insignificant. This finding agrees with the general notion that mean surface temperature will increase in the 21st century (IPCC, 2001; Kilembe et al., 2012). However, variations exist in the magnitude, and the temporal extent of predictions. IPCC (2001) utilized four families of socio-economic development, and associated emission scenarios, termed as Special Report on Emissions Scenarios (SRES) A2, B2, A1, and B1 (4) to project temperatures up to 2100. Climate models that

Article DOI: https://doi.org/10.37284/ajccrs.3.1.1919

were considered projected a rise in global mean surface temperature from 1.8°C to 4.0°C by 2100. In the temperate world, such high-temperature increase is likely to be profitable to agriculture because the length of the growing season will increase, cropping areas will expand, and yields of crops may increase. However, the tropical world is likely to be affected negatively because higher temperatures are likely to induce increased evapotranspiration, and lowering soil moisture levels, and as a result, some cropping areas may become unsuitable, some tropical grassland may become arid, and semiarid, and arid pastures are likely to reduce with negative effects on livestock productivity. Similarly, Kilembe et al. (2012) downscaled four global climate models from the IPCC AR4 to compare their projections for annual temperature and precipitation change for the periods 2000 and 2050 in Tanzania and found out that all the four models predicted A 2 ^{o}C increase in temperatures by 2050, adding that even a 1.5 ^{0}C increase is critical for crop yields.

Effects of Climate Change on Millet Yields

Millet simulation results for Paicho S/C in Gulu District for the period 2013-2033 revealed oscillations in annual yields ranging from 1810-2189 kilograms per hectare per year. However, millet yields are likely to decrease by 2.6% but the decrease is insignificant. The projected decrease is likely to occur due to the projected increase in maximum, and minimum temperature by 2033 as established by the study. One of the key food security crops in Uganda and Africa in general is millet and has been resilient to climate variability (Kilembe et al., 2012). But this is likely to change in future due to elevated changes in temperatures, and rainfall. This study finding conforms with the findings by Sultan et al. (2013) who used a process-based crop model to simulate the impacts of changes in temperature and rainfall on millet, and sorghum yields in the Sahel region (Senegal, Mali, Burkina Faso, Niger) for the period 2001 to 2100. They took into account 35 possible climate scenarios by combining precipitation anomalies from −20% to 20%, and temperature anomalies from +0 to +6 ◦C, and reported that 31/35 scenarios revealed a negative impact on sorghum and millet yields. Kilembe et al. (2012) employed a Decision Support System for Agro-technology Transfer (DSSAT) crop modelling software to model, and compare crop yields (maize, sorghum, rice, beans, and cassava) for the year 2000 and that of 2050 under changed climate. Using the MIROC model, results revealed that most localities in Tanzania are more likely to have a yield gain of more than 25% while other are likely to have a decline by more than 25%. Contrary wise, results for the CSIRO model indicated more moderate finding, with crop yields increasing or reducing by less than 25%. However, variations tend to occur in the percentage changes, the models used, and the period projected. Thus, location variations make generalizations unrealistic.

CONCLUSIONS

The annual rainfall projections for 2013-2033 revealed a decreasing trend which is significant. In addition, annual maximum, and minimum temperature projections for 2013-2033 revealed an increasing trend which insignificant. This imposes challenges on crop production and a need for farming systems to develop efficient and effective adaptation mechanisms in order to suit these changes. Millet simulation results for the period 2013-2033 reveal oscillations in annual yields ranging from 1810-2189 Kg/ha/yr. The projected decrease is likely to occur due to the projected increase in temperatures, and the projected decrease in rainfall by 2033. This implies that millet as a key food security crop in Uganda is likely to be affected due to an increase in temperature, and a decrease in rainfall. Thus, a need for improved soil management, and water conservation practices to enhance crop yields by the community in addition to improved millet varieties that can survive under changed climate conditions by agricultural researchers. Also, model results tend to be location and crop specific thus, making generalizations unrealistic.

Furthermore, this study contributes to literature on the effects of climate variability and change on crop yields and community coping and adaptation mechanisms thus, contributing to the achievement of the SDG 13 on climate actions but also, to the

Article DOI: https://doi.org/10.37284/ajccrs.3.1.1919

Uganda National Adaptation Plan of Action (NAPA) (2007). This study focused on the effects of climate change on millet grain yields, however, more assessments need to be undertaken on other food security crops.

ACKNOWLEDGEMENT

I acknowledge the generous funding for my Master's study by CARNEGIE Cooperation of New York, through a postdoctoral grant extended to Dr. Yazidhi Bamutaze. I also acknowledge the financial assistance granted by CARNEGIE Cooperation of New York through CECAP (Consolidating Early Career Academic Program) 2022-2024 postdoctoral grant extended to me through Makerere University that financed the publication costs.

DECLARATION OF INTEREST STATEMENT

The authors report there are no competing interests to declare.

REFERENCES

ACCRA (2012). *Preparing for the future in Uganda*: Understanding the influence of development interventions on adaptive capacity at the local level: Africa Climate Change Resilience Alliance (ACCRA) Uganda Synthesis Report, Kampala.

ACCRA. (2013). *Uganda Climate Change Vulnerability Assessment*. Kampala.

Allen, R.G., Pereira, L.S., Raes, D and Smith, M. (1998). *Crop evaporation guideline for computing crop weather requirements*. FAO Irrigation and drainage paper 56, 227-31, Rome, Italy.

Asori, M., Musah, A., & Gyasi, R. M. (2022). Bio-climatic impact on malaria prevalence in Ghana: A multi- scale spatial modelling. *Afri can Geographical Review*, 1-22.

Bashaasha, B., Waithaka, M., and Kyotalimwe, M. (2012). Climate change vulnerability, impact and adaptation strategies in agriculture in eastern and central Africa, ASARECA, Entebbe, Uganda.

Bello, O.B., Ganiyu, O.T., Wahab, M.K.A., Afolabi, M.S., Oluleye, F., Ig, S.A., Mahmud, J., Azeez, M.A., and Abdulmaliq, S.Y. (2012). Evidence of cslimate change impacts on agriculture and food security in Nigeria, Fountain University, Osogbo, Osun State, Nigeria.

Boote, K. J., Prasad, V., Jr, L. H. A., Singh, P., & Jones, J. W. (2018). Modelling sensitivity of grain yield to elevated temperature in the DSSAT crop models for peanut, soybean, dry bean, chickpea, sorghum, and millet. *European Journal of Agronomy*, *100*(November 2016), 99–109. http://doi.org/10.1016/j.eja.2017.09.002.

Defrance, D., Sultan, B., Castets, M., Famien, A. M., & Baron, C. (2020). Impact of Climate Change in West Africa on Cereal Production Per Capita in 2050. *Sustainability*, *12*(7585), 1–19. http://doi.org/doi:10.3390/su12187585.

Falconnier, G. N., Corbeels, M., Boote, K. J., Affholder, F., Adam, M., Maccarthy, D. S., … Priesack, E. (2020). Modelling climate change impacts on maize yields under low nitrogen input conditions in sub-Saharan Africa. *Global Change Biology*, (June), 1–23. http://doi.org/10.1111/gcb.15261.

FAO. (2013). Field measurements, *FAO Corporate Document Repository*, Rome, Italy.

Faye, B., Webber, H., Naab, J. B., Maccarthy, D. S., Adam, M., Ewert, F., … Gessner, U. (2018). Impacts of 1.5 versus 2.0 ° C on cereal yields in the West African Sudan Savanna OPEN ACCESS Impacts of 1.5 versus 2. 0 ◦ C on cereal yields in the West African Sudan Savanna. *Environmental Research Letters*, *13*(2018). http://doi.org/https://doi.org/10.10 88/1748-9326/aaab40.

Griggs, D. J., & Noguer, M. (2002). Climate change 2001: the scientific basis. Contribution of working group I to the third assessment report of the intergovernmental panel on climate change. *Weather*, *57*(8), 267-269.

Article DOI: https://doi.org/10.37284/ajccrs.3.1.1919

Hepworth, N and Goulden, M. (2008). Climate Change in Uganda: Understanding the implications and appraising the response. Edinburg. Retrieved from www.Itsi.co.uk.

Hotz, A. (2013). Mekong region facing six degree-warming, climate extremes. *SciDev. Net-Environment*.

Intergovernmental Panel on Climate Change (IPCC) (2001). Climate Change: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge Univ Press, Cambridge, UK).

IPCC. (2007). "Summary for policy makers", in M. Parry, Ocanziani, & P. Vander Linden (Eds) climate change 2007: Impacts Adaption and Vulnerability contribution of working group II for the Fourth Assessment Report of the intergovernmental Panel on climate change, Cambridge University Press.

IPCC (2015). Climate Change 2014 Synthesis Report. https://doi.org/10.1017/CBO97811 07415324. Switzerland.

Jawoo, K. (2013). 'Minding the yield gap in Africa': A country-level analysis, International Institute of Tropical Agriculture.

Karongo, S. K. (1990). *Evaluation of actual Evapotranspiration from Agricultural catchments, Kenya* (Doctoral dissertation).

Kilembe, C., Thomas, T. S., & Waithaka, M. (2012). East African agriculture and climate change: a comprehensive analysis-Tanzania.

Knox, J., Hess, T., Daccache, A., & Wheeler, T. (2012). Climate change impacts on crop productivity in Africa and South Asia. *Environmental research letters*, *7*(3), 034032.

Kumar, A., & Sharma, S. (2008). An evaluation of multipurpose oil seed crop for industrial uses (Jatropha curcas L.): A review. *Industrial crops and products*, *28*(1), 1-10.

Lerner, R. M., Huang, S. R., & Parker, K. J. (1990). "Sonoelasticity" images derived from ultrasound signals in mechanically vibrated tissues. *Ultrasound in medicine & biology*, *16*(3), 231-239.

Liu, Y., Li, N., Zhang, Z., Huang, C., Chen, X., & Wang, F. (2020). The central trend in crop yields under climate change in China: A systematic review. *Science of the Total Environment*, *704*, 135355.

Manatsa, D., Morioka, Y., Behera, S.K., Matarira, C.H., Yamagata, T., 2013. Impact of smascarene high variability on the East African "short rains". Clim. Dynam. 42 (5e6), 1259e1274. https://doi.org/10.1007/s00382-013-1848-z.

Marengo, J. A., Jones, R., Alves, L. M., & Valverde, M. C. (2009). Future change of temperature and precipitation extremes in South America as derived from the PRECIS regional climate modeling system. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *29*(15), 2241-2255.

Mastrandrea, M. D., Field, C. B., Stocker, T. F., Edenhofer, O., Ebi, K. L., Frame, D. J., ... & Zwiers, F. W. (2010). Guidance note for lead authors of the IPCC fifth assessment report on consistent treatment of uncertainties.

Mileham, L., Taylor, R. G., Todd, M., Tindimugaya, C., & Thompson, J. (2009). The impact of climate change on groundwater recharge and runoff in a humid, equatorial catchment: sensitivity of projections to rainfall intensity. *Hydrological Sciences Journal*, *54*(4), 727-738.

Mohamed, B.A., Van Duivenbooden, N., & Abdoussallam, S. (2002). Impact of climate change on agricultural production in the Sahel–Part 1. Methodological approach and case study for millet in Niger. *Climatic Change*, *54*(3), 327-348.

Muller C., Bondeau A., Popp A., Waha K., and Fader M. (2010). Climate change impacts on

Article DOI: https://doi.org/10.37284/ajccrs.3.1.1919

agricultural yields (Washington DC, World Bank).

NEMA (2009). *Uganda Atlas of our Changing Environment*. UNEP-GRID Arendal, Norway

Nicholson, S., Some, B., & Kone, B. (2000). An analysis of recent rainfall conditions in West Africa, including the rainy seasons of the 1997 El Niño and the 1998 La Niña years. *Journal of climate*, *13*(14), 2628-2640.

Nandozi, C. S. (2012). Projected climate induced suitability changes in coffee prone areas of Uganda (Doctoral dissertation, Makerere University).

Okello, D (2010*). Uganda Communications Commission; Rural communication Development Fund Project in Gulu District*, Kampala, Uganda.

Parkes, B., Defrance, D., Sultan, B., Ciais, P., Wang, X., Parkes, B., … Wang, X. (2018). Projected changes in crop yield mean and variability over West Africa in a world 1.5 K warmer than the pre-industrial era. *Hall Achives*, *9*(1), 119– 134. http://doi.org/10.51 94/esd-9-119- 2018? ird-01763011? HAL

Parry, M.L., Rosenzweig, C., Iglesias, A., Livermore, M., and Fisher, G. (2004). *Effects of climate change on global production under SRES emissions and social-economic scenarios*, Goddard Institute for Space Studies, New York, USA.

Parry, M. L. (Ed.). (2007). Climate change 2007-impacts, adaptation and vulnerability: Working group II contribution to the fourth assessment report of the IPCC (Vol. 4). Cambridge University Press.

Penman, H.L. (1950). The dependence of evapotranspiration on weather and soil conditions. *Journal of Soil Science 1*, 74-89

Rosenzweig, C., Tubiello, F. N., Goldberg, R., Mills, E., & Bloomfield, J. (2002). Increased crop damage in the US from excess precipitation under climate change. *Global Environmental Change*, *12*(3), 197-202.

Safo Kantanka, S. N., Addaney, M., Akudugu, J. A., Anaafo, D., Apeatse, R. Q., & Clarke, L. (2022). Impact of land use and climate change on forest reserves in Ghana. *African Geographical Review*, 1-20.

Saxena, Rachit, Sai Kranthi Vanga, Jin Wang, V. O. and V. R. (2018). Millets for Food Security in the Context of Climate Change: A Review. *Sustainability*, *10*(2228), 31. http://doi.org/10.3390/su10072228

Silungwe, F. R., Graef, F., Bellingrath-kimura, S. D., Chilagane, E. A., Tumbo, S. D., Kahimba, F. C., & Lana, M. A. (2019). Modelling Rainfed Pearl Millet Yield Sensitivity to Abiotic Stresses in Semi-Arid Central Tanzania, Eastern Africa. *Sustainability*, *11*(4330), 18. http://doi.org/10.3390/su11164 330

Silungwe, F. R., Graef, F., Bellingrath-kimura, S. D., Tumbo, S. D., Kahimba, F. C., & Lana, M. A. (2019). Analysis of Intra and Interseasonal Rainfall Variability and Its Effects on Pearl Millet Yield in a Semiarid Agroclimate: Significance of Scattered Fields and Tied Ridges. *Water*, *11*(578), 17. http://doi.org/10.3390/w11030578

Singh, R. P., Prasad, P. V., & Reddy, K. R. (2013). Impacts of changing climate and climate variability on seed production and seed industry. *Advances in agronomy*, *118*, 49-110.

Sultan, B., Roudier, P., Quirion, P., Alhassane, A., Muller, B., Dingkuhn, M., ... & Baron, C. (2013). Assessing climate change impacts on sorghum and millet yields in the Sudanian and Sahelian savannas of West Africa. *Environm ental Research Letters*, *8*(1), 014040.

Taylor, R.G and Howard, K.W.F (1999). *The influence of tectonic setting on the hydrological characteristics of deeply weathered terrains*: Evidence from Uganda, Robins centre for public and environmental health, University of Surrey, Guildford, Surrey.

Traore, B., Descheemaeker, K., Wijk, M. T. Van, Corbeels, M., Supit, I., & Giller, K. E. (2017).

Article DOI: https://doi.org/10.37284/ajccrs.3.1.1919

Field Crops Research Modelling cereal crops to assess future climate risk for family food self-sufficiency in southern Mali. *Field Crops Research*, *201*, 133–145. http://doi.org/10.1016/j.fcr.2016.11.002

UBOS (2011). *Gulu District Statistical Abstract*, Kampala, Uganda

Ullah, A., Ahmad, I., Ahmad, A., Khaliq, T., & Saeed, U. (2019). Assessing climate change impacts on pearl millet under arid and semi-arid environments using CSM-CERES-Millet model. *Environmental Science and Pollution Research*, *10*(7). http://doi.org/https://doi.org /10.1007/s11356-018-3925-7

UNDP (2012). *Health Situation Analysis in African Region*, Afro Library Cataloging-Publication.

Van Bavel, C.H.M. (1966). Potential evaporation: The combination concept and its experimental verification. *Water Resource Research 2* (16): 455-446

Vrieling, A., Jan, D.L., and Mohamed, Y.S. (2013). *Length of growing period over Africa*: Variability and trends from 30 years of NDVI Time series, Faculty of Geo-information science and earth observations (ITC), University of Twente, Enschede, The Netherlands.

Wang, J., Sai K.V., & Rachit, S. (2018). Effect of Climate Change on the Yield of Cereal Crops: A Review. *Climate*, *6*(41), 19. http://doi.org/10.3390/cli6020041.

Wasige, J.E (2009). *An Assessment of the Impacts of Climate Change and Climate Variability on crop production in Uganda*, Department of soil science, Makerere University, Kampala, Uganda.

WFP, (2009). *Land use and crop yield assessment report in Acholi sub-region (Amuru, Gulu, Kitgum and Pader)*, DED, Kampala, Uganda.

Worishima, W., & Akasaka, I. (2010). Seasonal trends of rainfall and surface temperature over Southern Africa, Nihom University.

Yong, Z., Yinlong, X., Wanjie, Dong.,Lijuan, Cao and Sparrow Michael (2006). *A future Climate Scenario of regional changes in extreme climate events over China using the PRECIS climate model*, Chinese academy of agricultural sciences, Beijing China

Ziervogel, G., Cartwright, A., Tas, A., Adejuwon, J., Zermoglio, F…. (2008). *Climate change and adaptation in African agriculture*. *SEI* (Vol. 721 KEM). Stockholm. http://doi.org/10.4028/www.scientific.net/KEM.721.33.

APPENDIX

Appendix 1: Simulated millet yields with net moisture gain/loss, observed millet yields and rainfall amounts for the period 1980-2012 for Paicho S/C in Gulu district

Years	Rainfall (mm)	Net moisture	Simulated millet yield (kg/ha/yr.)	Observed millet yield (Kg/ha/yr.)
2007	1475	3116	1816	1607
2008	1486	3121	1821	1400
2009	1276	3131	1831	1600
2010	1690	3145	1845	1000
2011	1704	3144	1844	1300
2012	1735	3139	1839	1500

Appendix 2: Simulated millet yields for the period 2013-2033 for Paicho S/C in Gulu district in Northern Uganda

Years	Rainfall (mm)	Simulated millet yields (kg/ha)	Years	Rainfall (mm)	Simulated millet yields (kg/ha)
2013	1622	1865	2024	1521	1834
2014	1512	1822	2025	1440	1812
2015	1547	1842	2026	1472	1819
2016	1692	1925	2027	1665	2013

Article DOI: https://doi.org/10.37284/ajccrs.3.1.1919

Years	Rainfall (mm)	Simulated millet yields (kg/ha)	Years	Rainfall (mm)	Simulated millet yields (kg/ha)
2017	1719	1844	2028	1230	1844
2018	1626	1933	2029	1517	1844
2019	1829	2189	2030	1628	1918
2020	1715	1841	2031	1520	1846
2021	1427	1844	2032	1374	1839
2022	1524	1820	2033	1545	1816
2023	1295	1810			

Appendix 3: Derivation of climate and soil parameters

Climate Data

i. Potential Evapotranspiration (PE_t) Input in Millimetres

Evapotranspiration is the total water flux into the atmosphere, i.e. the sum of evaporation and transpiration (water flux through plant stomata) and Potential Evapotranspiration (PE) is the water flux under non-limiting soil water conditions (Allen et al., 1998). Direct measurement of evapotranspiration is impractical but a parallel approach to estimating evapotranspiration has been proposed by Penman (1950; Karongo, 1990). The approach is based on the observation that evapotranspiration from a completely vegetated, moist (i.e. continually supplied with water) surface (E_t) is related to evaporation from a surface of open water (E_o) (Karongo (1990). Under ideal conditions, evapotranspiration is referred to as potential evapotranspiration (PE_t) and is related to open- water evaporation by an empirical factor, f, which varies in response to the duration of daylight throughout the year (equation 3). In equatorial regions, the consistency in daylight hours yields a conversion factor that deviates by less than 5% throughout the year (Riou, 1984). Thus, a single factor can be applied throughout the year without encountering significant error.

$PE_t = fE_O$ Equation (5).

ii. Pan Evaporation (E_o) Input in Millimetres

Evaporation is the rate of water loss from a free water surface such as a reservoir, lake, pool, or saturated soil. E_O is estimated from either meteorological data or open-water evaporation pans. Van Bavel (1966) developed a 'semi-empirical' equation that requires records of wind velocity mean vapor pressure and mean surface temperature. Less empirical equations have subsequently been derived (Rijtema, 1965; Van Bavel, 1966) but limited data sets for many regions including Uganda; do not make their application viable. Therefore, evaporation from standardized pan (E_{pan}) is monitored and converted to E_o by use of a pan factor (Equation 4). A precise pan factor is not known however, the average of 0.70 is used. In the tropics, pan evaporation is often observed to exceed open-water evaporation due to exposure of the pan (Rijtema, 1965) so pan factors are less than unity.

E_o = (Pan factor) E_{pan} Equation (6).

Gulu station did not have data on pan evaporation which could have been used to also estimate potential evapotranspiration and this became a limitation of the model however, pan evaporation data for lira station was used since Lira district is located in the same agro-climatic zone with Gulu district.

iii. Run off (RO) input in Millimetres

In the absence of data regarding the intensity and duration of rainfall events, runoff is estimated on the basis of daily rainfall records, relief and an estimated soil infiltration capacity of 10 mmh^{-1}. For daily rainfall exceeding 10 mmd^{-1}, runoff was estimated to be 1% whereas rainfall events less than 10 mmd^{-1} runoff were estimated to be zero (Howard & Kurundu, 1992).

Soil Data

The soil samples were taken for laboratory analysis to derive soil parameters required by the Penman Grindley soil moisture balance model for millet yield simulations.

Article DOI: https://doi.org/10.37284/ajccrs.3.1.1919

i. Root Constant (C)

Rooting depth multiplied by soil porosity (0.3) provides a root constant of 127 for farmland (Taylor, 1999).

Soil Moisture Deficit, Wilting point and Drying point Calculations wer done according to the procedure by Allen (1998), Howard (1999), and FAO (2013).

The Soil Moisture Deficit (SMD**)** is a measure of soil moisture between field capacity and existing moisture content, $\square_{i}$, multiplied by the root depth and it is calculated as follows:

$SMD = (\square_{fc} - \square_{i}) * RD$ Equation (7).

$\square_{fc}$ is the volumetric moisture contents at field capacity, $\square_{i}$ is the existing moisture content, and RD is the rooting depth of the crop for this case it was millet.

Before calculating SMD, other important soil parameters have to be derived which include porosity, □□; its volumetric moisture content, □; its saturation**,** S**;** its dry weight moisture fraction W; its bulk density, $\square_{b}$; and its specific weight, $\square_{s}$. The relationships among these parameters are as follows.

The porosity, □, of the soil is the ratio of the total volume of voids or pore space, $\mathbf{V_p}$**,** to the total soil volume V:

$\square = V_p/V$ (1) Equation (8)

The volumetric water content, □, is the ratio of water volume in the soil, V_W, to the total volume, V:

$\square = V_b/V$ Equation (9)

The saturation, S, is the portion of the pore space filled with water:

$S = V_W/V_p$ Equation (10)

These terms are further related as follows:

$\square = S * \square$ Equation (11)

When a sample of field soil is collected and oven-dried, the soil moisture is reported as a dry

Weight fraction, **W**:

$$W = \frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Dry Weight}}$$ Equation (12)

To convert a dry weight soil moisture fraction into volumetric moisture content, the dry weight fraction is multiplied by the bulk density, $\square_{\mathbf{b}}$; and divided by specific weight of water, $\square_{w}$ which can be assumed to have a value of unity. Thus:

$\square = \square_{b} W/\square_{w}$ Equation (13)

The $\square_{b}$ is defined as the specific weight of the soil particles, $\square_{s}$, multiplied by the particle volume or one-minus the porosity:

$\square_{b} = \square_{b} * (1 - \square)$ Equation (14)

The volumetric moisture contents at field capacity, $\square_{fc}$, and permanent wilting point, $\square_{wp}$, then are defined as follows:

$\square_{fc} = \square_{b} W_{fc}/\square_{w}$ Equation (15)

$\square_{wp} = \square_{b} W_{wp}/\square_{w}$ Equation (16)

Where W_{fc} and W_{wp} are the dry weight moisture fractions at each point.

The total available water, TAW is the difference between field capacity and wilting point moisture contents multiplied by the depth of the root zone,

$TAW = (\square_{fc} - \square_{wp}) RD$ Equation (17)

The Soil Moisture Deficit, SMD, is then calculated as a measure of soil moisture between field capacity, □$\square_{fc}$ and existing moisture content, $\square_{i}$, multiplied by the root depth and it is calculated as follows:

$SMD = (\square_{fc} - \square_{i}) * RD$ as indicated at the beginning.

