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Empirical Relationships between Banana Yields and Climate Variability over Uganda

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Abstract: Variations in weather and climate have a significant impact on rain-fed banana yields in East Africa. This study examined empirical linkages between banana yields and variations in rainfall and temperature over Uganda for the historical period (1971-2009) using time series moments, correlation and regression analysis. The Food and Agriculture Organization (FAO) Crop Water Assessment Tool (CROPWAT) was used to estimate banana crop water requirements, soil moisture deficits and their effects on banana yield levels under rain-fed conditions for different regions. The study observed high comparability in moment indices with some significant differences reflected in the values of the banana yields and rainfall and temperature moment indices. The cumulative effect of rainfall and temperature variations on banana yields was discernible from strong correlation coefficients of up to 78%. The CROPWAT simulations indicated up to 46% reductions in optimal banana yields due to soil moisture deficits within banana plantations. In conclusion, the study observed stronger linkages between banana yields and temperature variations than rainfall. In addition, temperature manifests both direct and indirect effects on banana growth while rainfall exhibits comparatively high intra-seasonal and intra-annual variability with lag effects on banana yields. The study provides a strong scientific basis for the development of coping, adaptation and mitigation strategies in the banana farming subsector in the region due to the anticipated shifts in rainfall and temperature extremes and changes across Uganda and neighbouring regions.

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1. Introduction

The Banana is a major perennial multi-cycle food crop that enhances food security in Uganda and sustains smallholder farmers' incomes in Uganda due to its ability to provide continuous cycles of mature fruits all year round. Banana has a life cycle of 15 to 18 months from planting to harvesting; the plantations can last for several years depending on environmental and biological conditions, soil characteristics and crop management practices (Wairegi et al., 2010; Nyombi, 2013). Recent studies (Van Asten et al., 2010; Wairegi et al., 2010) have observed that banana productivity (production per hectare or yield) has been declining in the recent years. Reports on the decline in banana yield in Uganda date back to the 1940s and 1950s (Masefield, 1949; McMaster, 1962). Gold et al. (1999b) observed that yield decline over Uganda accelerated in the 1970s and 1980s.

Factors that may lead to the loss in yield have been studied by several authors, including the loss in banana productivity associated with deteriorating soil fertility (Bekunda and Woomer, 1996; Gold et al., 1999a; Zake et al., 2000; Nyombi, 2013), drought occurrences and inadequate soil moisture (Okech et al., 2004; Van Asten et al., 2010; Nyombi, 2010; Van et al., 2012; Umesh et al., 2015), banana weevils, mainly *Cosmopolites Sordidus* (Gold et al., 1999), banana parasitic nematodes including *Radopholus similis* and *Helicotylenchus multicintus* (Jeger et al., 1996; Speijer et al., 1999b; Speijer and Kajumba, 2000), and banana plant diseases like Black Singatoka, Banana Streak Virus and Banana Wilt (Tushemereirwe, 2006). Besides a possible decline in the banana productivity, several experimental studies indicate that there exists a huge disparity between actual yields of 5 to 30 $t.ha^{-1}.yr^{-1}$ and on-farm and on-station trials attainable yields of 60 to 70 $t.ha^{-1}.yr^{-1}$ (Smithson et al., 2001; Tushemereirwe et al., 2001; Van Asten et al., 2004).

Based on current observations, the future state of climate variations and extremes is likely to affect banana productivity in Uganda. Wairegi et al. (2010) attributed the decline in banana yields in southwest Uganda to climate variations as they affect all ecosystems, including extreme rainfall (floods and droughts), hailstorms, and high surface air temperatures. The effects of climatic factors on banana crop and yields depends on the stage of the crop at the time of occurrence of climate extremes, as well as the overall cumulative effects depending on the duration and frequency of the extreme climate events within a given crop cycle (Van Asten et al., 2010; Nyombi, 2010; Nyombi, 2013).

Mainstreaming scientific climate information in banana farming for effective coping and adaptation mechanisms has the potential to promote banana productivity, food security, farmers' incomes and sustainable development in Uganda and neighbouring regions (Surendran et al., 2014; Ampaire et al., 2015). The objective of this paper was to examine the linkages between current banana yields and the observed variations in rainfall and temperature over Uganda.

2. Methodology

Banana data used in the study included information on banana production, area of banana harvested and banana yields at the national and district level for the period 1971 to 2009, including the data from the Uganda Census of Agriculture (UCA, 2008/09). Climate data consisted of insitu and gridded observations of rainfall and air temperature records over Uganda. The insitu climate datasets were obtained from the Uganda National Meteorology Authority (UNMA) and the IGAD Climate Prediction and Applications Centre (ICPAC) for the rainfall homogeneous zones over Uganda as shown in Fig. 1(a) (Ogallo, 1980; 1988; Basalirwa, 1991; Indeje et al., 2000; Komutunga, 2006).

Fig. 1(b) shows agro-climatic zones, the major agricultural systems and representative climate observational stations of Uganda. Banana is predominantly grown over the western, southwestern, central and eastern regions of Uganda. The study therefore mainly focussed on zones labelled B and C (Fig. 1b). Other regions were, however, included in the simulation of crop water requirements for the banana crop using the Food and Agriculture Organization (FAO) Crop Water Tool (CROPWAT).

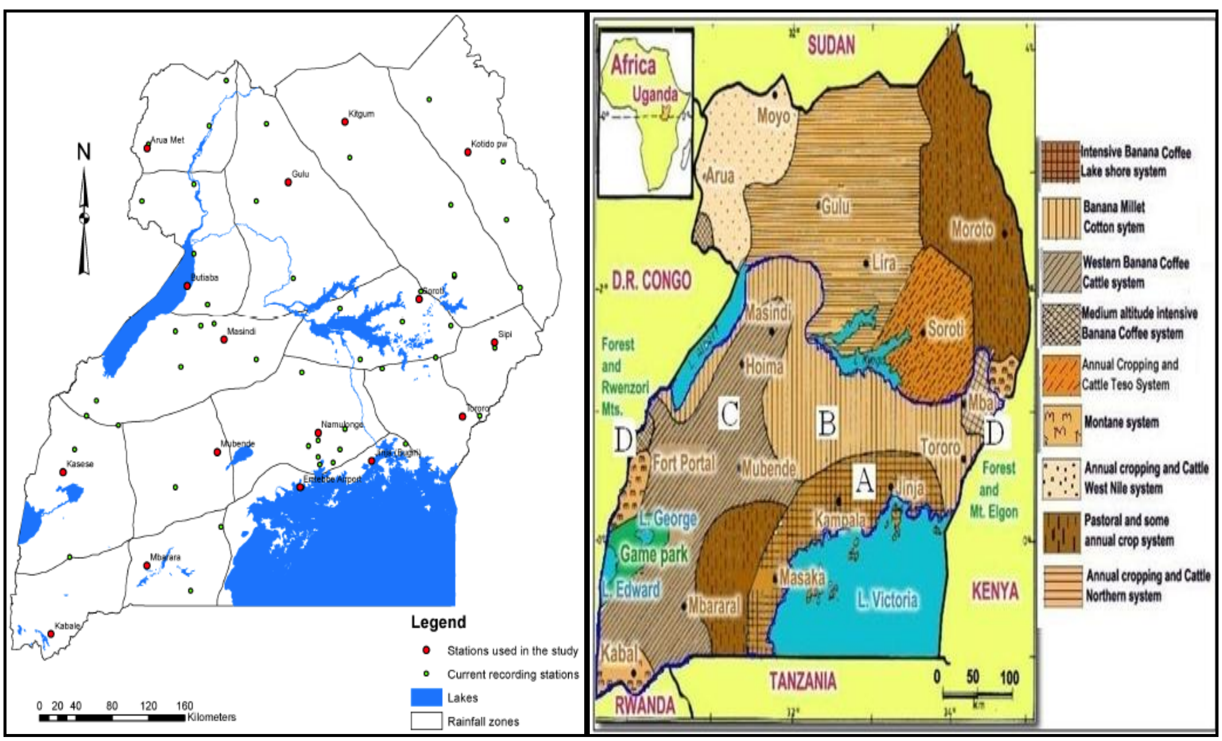

Fig. 1. Representative observational stations for different homogeneous zones (a) and Agro-climatic zones and agricultural systems (b) (Adopted from Mwebaze, 1999) of Uganda.

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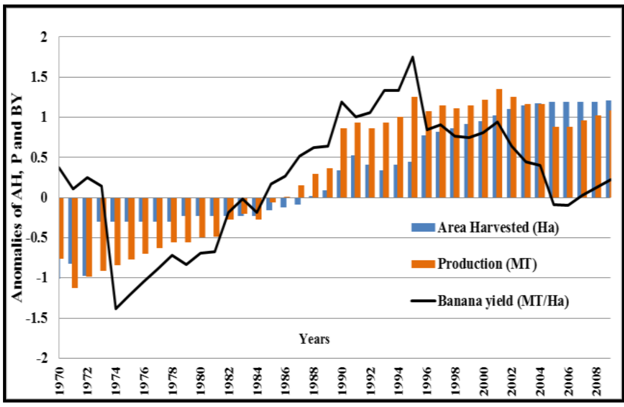

Fig 2. FAO estimated trends in Uganda's standardized Banana area harvested (blue bars), production (orange bars), and yield (black line) during the period 1971 - 2009.

Before data was analysed using moments, standardization was undertaken for easy comparison of moments. Several studies (Ogallo and Nasib, 1984; Ininda, 1995; Kabanda and Jury, 1999; Sabiiti, 2008; Omondi 2010; Otieno, 2013) have used standardized indices of variables to investigate relationships and linkages between variables.

Empirical parameters were derived from the first, second, third, and fourth moments of the specific time series represented by the mean, variance, skewness (extremes distributions), and kurtosis (peakedness) respectively. For the first moment, the inter-annual trends of the individual banana yields and rainfall and temperature time series were examined. Parameters examined under the second moment included recurrences of large positive/negative rainfall and temperature extremes. The study period was subdivided into two parts; 1971-1990 and 1991-2009. Means for standardized data were then computed and compared for rainfall, temperature and banana yields. Examining the changes in the third moment involved computing skewness coefficients. Under the same principle, the fourth moment represented by the Kurtosis (K) was computed for the two sub periods. The usefulness of the moments of time series in data analysis and comparing different series has been demonstrated graphically in the IPCC, 2012 on determining changes in extremes and changes in symmetry in climate variables.

Other methods used to further examine the existing linkages between banana yields and rainfall and temperature variability included correlation and regression. Under correlation analysis, Pearson's product-moment correlation coefficient was used as a measure of the degree of agreement between variables. The significance of the correlation coefficients was tested using the statistical t-test. It was assumed that cumulative annual rainfall and temperature stress has significant effects on annual banana yields and allows correlating annual rainfall and temperature and banana yield. The method of correlation analysis has been widely used (Shukla and Paolino, 1983; Ogallo, 1988; Ininda, 1994; Sabiiti, 2008; Omondi, 2010; Otieno et al., 2014) to investigate relationships between variables. Regression analysis was undertaken for cases where correlation coefficients were significant. The study used a degree 2 polynomial regression model to determine the threshold values of the climatic (independent) variables that would give optimal banana yield (dependent) levels under different/contrasting non-climatic factors. A test of the adequacy of the model was done by computing R^2 (the multiple coefficient of determination). For $R^2 = 0$, it implies lack of fit, while $R^2 = 1$ implies perfect fit. The adjusted R^2 has been recommended as a better measure of variance explained and has been used in interpretation of results. The F-test based on the Analysis of Variance (ANOVA) was used to test for the significance of the coefficients of the polynomial regressions. The approach adopted in this study is based on the banana growth – temperature curve.

The FAO Crop Water Assessment Tool (FAO-CROPWAT) was used to evaluate the current water stress (moisture deficits) and yield losses resulting from observed rainfall variability over different parts of Uganda. Based on the FAO CROPWAT, the study used the FAO Penman-Montieth method to calculate reference evapotranspiration (ET_o), banana crop water requirement (ET_m), cumulative moisture deficit (MDH) at harvest and yield losses/reductions (YR) for various locations. Since banana production in Uganda is predominantly rain-fed, the CROPWAT model (FAO, 2003; Karanja, 2006) was run under rain-fed conditions. Using the soil moisture content and evapotranspiration rates, the model determined soil water balance on daily basis.

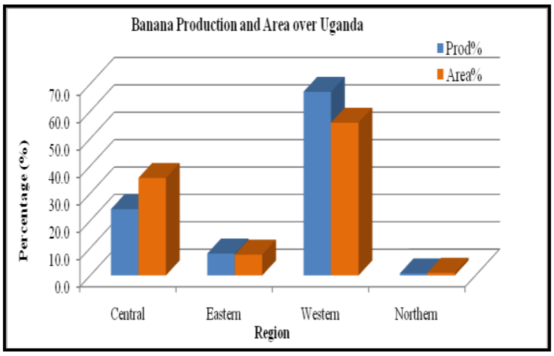

Fig. 3: Annual banana production (%, blue) and area harvested (%, orange) for Central, Eastern, Western and Northern regions of Uganda.

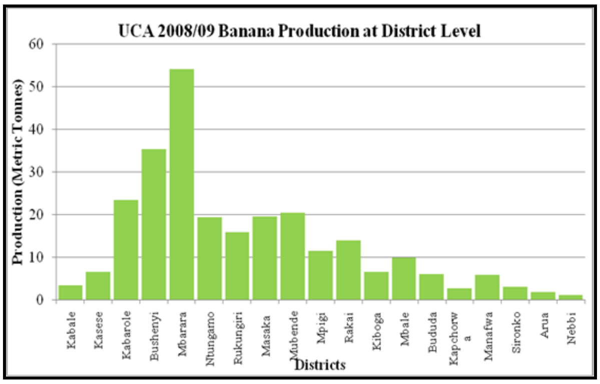

Fig. 4: Banana production (metric tones) for district during 2008/2009. Census of Agriculture in Uganda.

The output tables were then used for the assessment of the resultant effects of water/moisture stress and efficiency of rainfall (ER) on banana yield for two banana crop cycles across the Country.

3.Results and Discussion

This section presents the results and provides some discussion on observed banana statistics, analysis of moments, correlation and regression analysis and the estimates of FAO CROPWAT simulation.

3.1 Observed banana production

Fig. 2 depicts interannual anomalies of banana area harvested, banana production and banana yield for the period 1971-2009. The mean value for analysis was computed for 1971-2000 period. The study observed a decline in banana production especially for the year 1973, while the year 1995 recorded the maximum in banana production. Major causes of this variability in banana yield figures have been attributed by many researchers to banana pests and disease outbreaks (Tushemereirwe et al., 2004), a shift from banana production to other crops by farmers (Wairegi et al., 2010), and occurrence of weather and climate extremes that lead to droughts in banana growing regions of Uganda (Van Asten et al., 2010; Van et al. 2012; Surendran et al., 2014; Umesh et al., 2015).

Fig. 3 shows the percentages of production and area harvested from the different sub regions of Uganda for the period 2008/09 following the Uganda Census of Agriculture (UCA, 2008/09). The results indicated that the central region contributed about 20% of the total production with 41% of total area harvested. Eastern region contributed about 3% of total production with less than 3% of the total area harvested; the western and southwestern regions combined contributed over 60% of total production with about 50% of the total area harvested. However, northern Uganda had the lowest production and area harvested of the banana crop. The western, southwestern and central Uganda, therefore, are the major banana production zones with the highest banana productivity reported in southwestern Uganda followed by central parts of the country (Fig. 3).

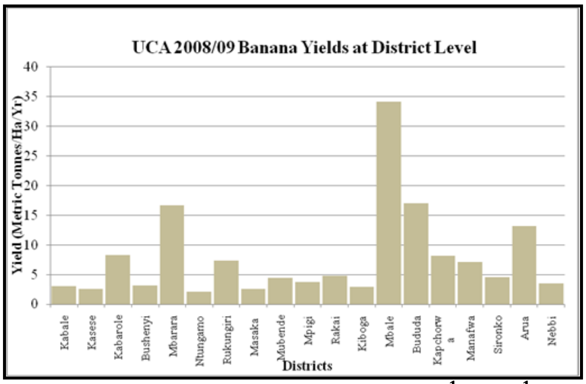

Fig. 5: Banana yields (metric tones ha^{-1} $year^{-1}$) per district for 2008/2009 Uganda Census of Agriculture in Uganda.

Table 1. Comparison of time series moments of normalized rainfall, air temperature (maximum, minimum) and banana yields over western Uganda

Variables/moments/ periods		Rainfall	Maximum Temperature	Minimum Temperature	Banana Yields
Mean	1971-2009	0.00	0.00	0.00	0.00
	1971-1990	**-0.63**	-0.06	**-0.60**	**-0.76**
	1991-2009	**0.60**	0.06	**0.56**	**0.72**
Standard deviation	1971-2009	1.00	1.00	1.00	1.00
	1971-1990	**0.56**	**1.07**	**0.78**	**0.67**
	1991-2009	**0.55**	**0.95**	**0.86**	**0.68**
Skewness coefficient	1971-2009	-0.42	0.23	0.35	0.06
	1971-1990	0.06	0.46	0.53	-1.42
	1991-2009	-0.04	-0.01	0.45	1.77
Kurtosis coefficient	1971-2009	-0.31	**0.15**	-0.43	**1.46**
	1971-1990	-0.99	**1.34**	-0.60	**1.08**
	1991-2009	-0.77	**0.92**	-0.82	**1.05**

Bold values indicate agreement on the direction)

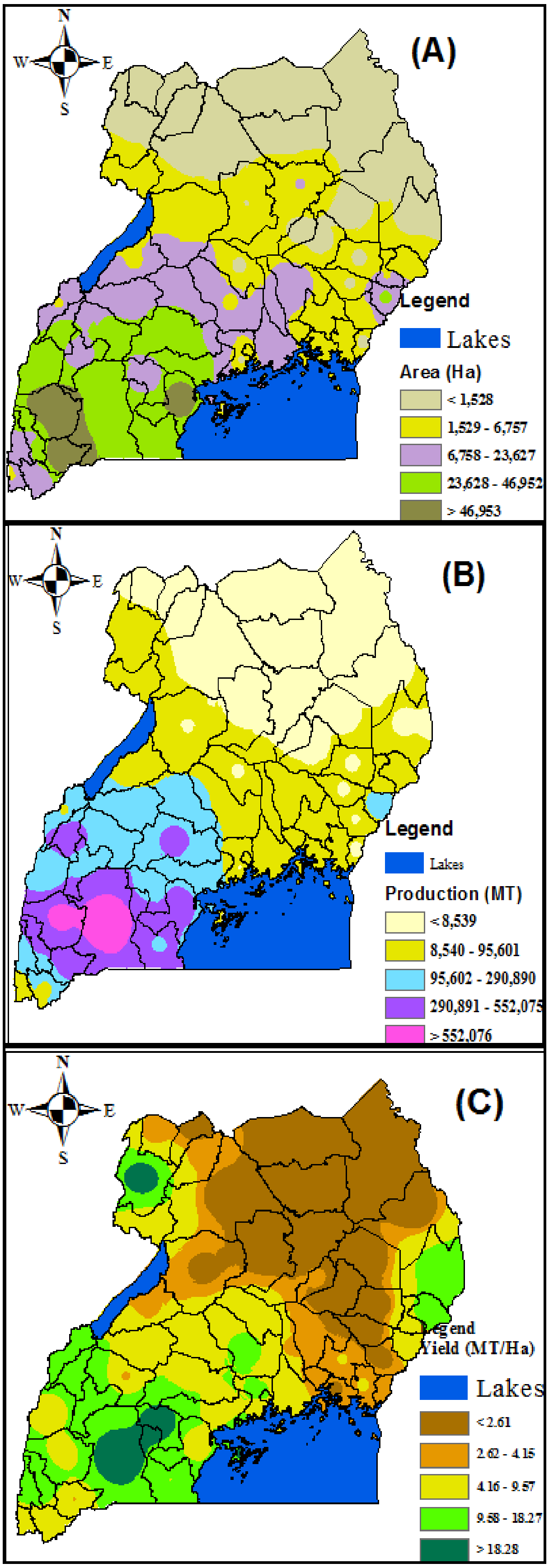

Fig. 6: Spatial patterns of banana area harvested (ha) (A), production (metric tones) (B) and yields (metric tones ha^{-1}) (C) for 2008/2009 over Uganda [based on GIS interpolation of banana data].

Figs. 4 and 5 show the production levels and yields for selected districts, respectively. Although the banana production level in Mbale and Bududa districts is still low (Fig. 4) due to a small area of growing bananas, this region shows the highest level of yield values (Fig. 5). The low production levels of banana in the some cases can be attributed to the cultural values of communities in these districts that prefer other alternative crops as food and cash crops (maize and millet) and limited market for bananas. On the other hand, the high yields (Fig. 5) of bananas in Mbale and Bududa areas can be associated with high rainfall on the windward side of Mt. Elgon that is evenly distributed throughout the year in addition to fertile soils down slope of mountain.

The results (Fig. 4) further indicated that western districts (Bushenyi, Mbarara, Kabarole and Ntungamo) of Uganda recorded higher production figures than central districts (Masaka, Mubende, Mpigi and Rakai). Fig. 5 on the other hand, indicated relatively high banana yields over the western districts than for both the central and eastern districts. The high productivity of bananas in the western region has been attributed to the relatively cool temperatures (Van Asten et al., 2010; Washington and Pearce, 2012; Nyombi, 2013; Surendran et al., 2014).

Spatial patterns of harvested area (ha), production (metric tones) and yields (metric tones .ha^{-1}) of banana for the year 2008/2009 (Fig. 6) showed that harvested area ranged from 1,529 – 23,627 ha (Central Region) to 46,953 ha (Southwestern region). Fig. 6 (B) shows that the production of banana is highest in the southwestern sector and estimated at 290,891 – 552,075 metric tones, that reduces towards central, eastern regions with very little or no banana production in the northern districts. On the other hand, Fig. 6 (C) depicts the productivity (metric tones per hectare) for the year 2008/09 over Uganda. The results in Fig. 6 (C) indicated that highest banana productivity is currently observable over southwestern parts of the Country especially Bushenyi, Mbarara and Ntugamo districts.

High to moderate productivity levels were observed in the Central (around L. Victoria), Eastern (areas around Mbale and Mt. Elgon), and northwestern parts of Uganda particularly Arua district. It is notable, however, that the production levels in the eastern and northwestern regions are still much lower compared to western and central districts.

Table 2: Comparison of time series moments of normalized rainfall, maximum, minimum surface air temperatures and banana yields (highlighted values indicate strong linkages) over central Uganda

Variables/moments/ periods		Rainfall	Maximum Temperature	Minimum Temperature	Banana Yields
Mean	**1971-2009**	0.00	0.00	0.00	0.00
	1971-1990	-0.83	-0.27	-0.79	-0.70
	1991-2009	0.60	0.26	0.75	0.66
Standard deviation	**1971-2009**	1.00	1.00	1.00	1.00
	1971-1990	0.98	0.97	0.66	0.45
	1991-2009	0.55	0.98	0.60	0.93
Skewness coefficient	**1971-2009**	-0.62	0.46	-0.04	0.95
	1971-1990	0.06	0.54	0.08	-0.18
	1991-2009	-0.17	0.52	0.62	0.76
Kurtosis coefficient	**1971-2009**	-0.41	0.27	-0.54	1.02
	1971-1990	-0.87	0.92	-0.70	-1.09
	1991-2009	-0.57	0.20	0.72	1.09

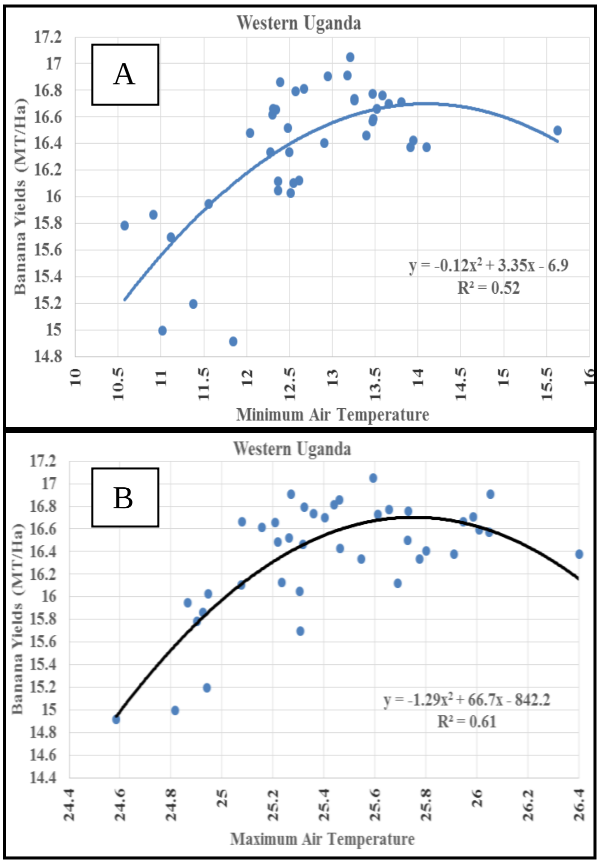

Fig. 7: Relationship between banana yield (metric tones ha^{-1}) and minimum surface air temperature (^{o}C) [A]; maximum surface air temperature (^{o}C) [B] for the western region of Uganda.

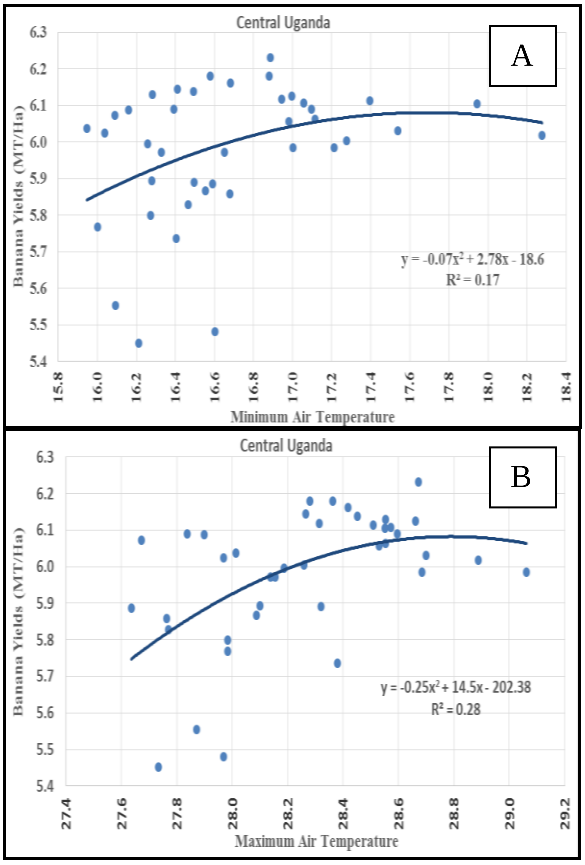

Fig. 8. Relationship between banana yield (metric tones ha^{-1}) and minimum surface air temperature (^{o}C) [A]; maximum surface air temperature (^{o}C) [B] for central region of Uganda.

There is limited banana production activity in the northern part of the Country with moderate productivity levels over northwestern parts of the Country. Despite high annual rainfall totals, the dry spells longer than three months and high surface air temperatures in the northern parts of the country have been a major limitation to banana production in the region.

3.2 Analysis of Moments

Tables 1 and 2 show the results of the time series moments for standardized climatic variables and banana yields over the western and central parts of Uganda, respectively. The results show that there were some cases when the moment values for both rainfall and temperature and bananas were

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comparable indicating close linkages between variations in banana yields and variability in rainfall and temperature series. Significant differences were, however, noted in the values of rainfall and temperature and bananas moment values. This may partly be attributed to other non-climatic factors that affect banana productivity including variations in soil fertility, pests and diseases, management practices and policies among others as illustrated by different studies (Salami et al., 2010; Washington and Pearce, 2012; Wiggins and Keats, 2013; Surendran et al., 2014; Ampaire et al., 2015).

3.3 Correlation and Regression Analysis

The use of zero time lagged correlation coefficients and polynomial regressions were employed to further investigate linkages between variations in banana yields and rainfall and temperature variations.

Table 3 shows results of correlation coefficients between banana yields and climatic variables. The results indicated close linkages between banana yields and surface air temperature variability with lower correlation values between banana yields and rainfall anomalies for the two regions. The western region showed a stronger response of variation in banana yields for both minimum and maximum surface air temperature than the central region.

Figs. 7 – 9 show the relationships between variations in banana yield and climatic parameters. The increase in minimum and maximum air temperatures is associated with an increase in banana yields up to an optimal value of air temperature beyond which any further increase in temperatures would result into a drop in yields. The results (Fig. 9) observed that an increase in rainfall progressively increases banana yields up to the optimal level beyond which the additional rainfall would negatively affect yields. The optimal levels for different locations vary across a location and depend on the environmental and soil characteristics for the location.

The results observed that in the western region, variations in minimum temperature explain about 52% of the variations in banana yields, variations in maximum temperature explain about 61% variations in banana yield and variations in annual rainfall explain about 14% of the variation in banana yields. The F-test based on the Analysis of Variance (ANOVA) confirmed the significance of the coefficients of the polynomial regressions. In the central region (Fig. 8A), results indicated that variations in minimum temperature explained about 17% of the variations in banana yields, variations in maximum temperature explain about 28% of the variations in banana yield (Fig. 8B).

Table 3. Correlation coefficients (coefficient of determination (R^2)) between climatic variables and banana yields for western and central regions of Uganda.

Region	Tmin	Tmax	Rainfall
Western	0.72 (R^2=52%)	0.78 (R^2=61%)	0.34 (R^2=12%)
Central	0.41 (R^2=17%)	0.53 (R^2=28%)	0.51 (R^2=26%)

The variations in annual rainfall explain about 14% (Fig. 9A) and 26% (Fig. 9B) of variation in banana yields for central and western regions of Uganda respectively. The results provide evidence that the responsiveness of banana productivity to variations in rainfall and temperature over the western region is higher than that observable over the central region. The Country's current minimum and maximum temperature levels in western and central Uganda still support favourable growth of bananas. Any further increases in temperatures beyond the optimal values will adversely affect banana production in many parts of Uganda. It has been noted in several other studies that warm temperatures are associated with the high population densities of banana nematodes and weevils (Speijer et al., 1993) especially in the central region that tend to affect banana productivity.

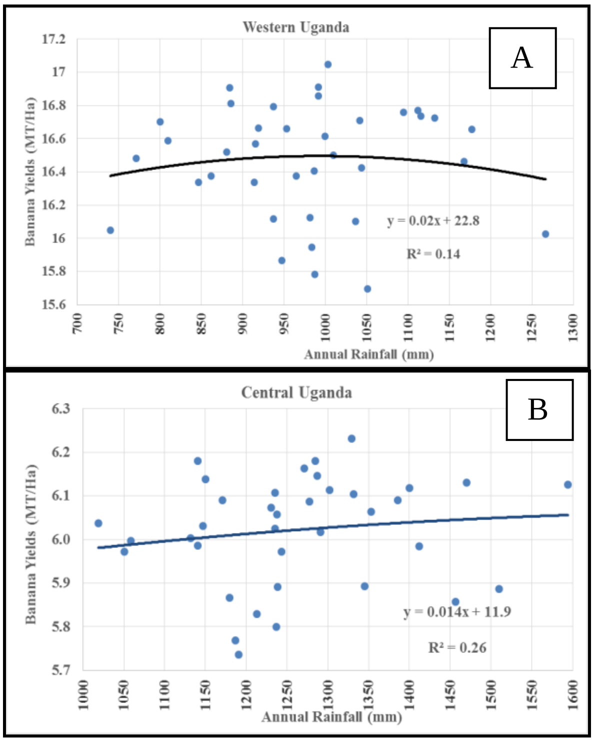

Fig. 9: Relationship between banana yield (metric tones ha^{-1}) and rainfall (mm) for western [A] and central [B] regions of Uganda.

Table 4. Banana crop water statistics and yield reductions (YR) from the CROPWAT model for two crop cycles (highlighted values indicate cases of high yield losses).

Location	First crop cycle					Second crop cycle				
	AWU (mm)	PWU (mm)	MD (mm)	ER (%)	YR (%)	AWU (mm)	PWU (mm)	MD (mm)	ER (%)	YR (%)
Kabale	898.6	945.9	8.5	88.1	5	654.2	872	78	97.3	25
Mbarara	885.2	1065.8	50.2	89.6	16	678.7	995.4	88.6	98.9	31.8
Kasese	888.5	1243.7	71	94.5	28.6	685.5	1099.2	106.9	97.6	24.6
Kitgum	888.5	1650.8	65.2	64.9	**46.2**	960.2	1348.4	121.8	85.5	28.8
Lira	950.2	1502.8	50.2	64.6	**36.8**	1021.5	1206.4	117	86.7	15.3
Mbale	915.3	1374.8	43.9	78	33.4	811.9	1152.1	113.6	92.3	29.5
Hoima	1000.7	1124.8	39.7	67	11	918	1061.9	74.2	81.5	22.9
Moroto	699.2	1281	62.2	73.8	**45.4**	683.3	1093.7	118.6	93.3	**37.5**
Mubende	1016.3	1316.1	60.3	79.5	22.8	925.5	1139.4	102.3	98.2	18.8
Namulonge	1020.3	1190.3	11.3	83.9	14.3	816.7	1031.9	91.3	96.2	20.9
Soroti	931.1	1451.7	40.9	67.6	**35.9**	993.2	1230.7	115.6	90.8	19.3
Tororo	1090.7	1309.2	17.8	76.4	16.7	944.4	1107.5	99.9	90.5	14.7
Jinja	1050.9	1163.9	11.1	81.2	9.7	855.5	1027	87.8	95.5	16.7
Arua	888.4	1385.9	71.7	58.1	**35.9**	1014.9	1122	114.5	81.5	9.5
Gulu	901	1417.6	40.8	56.5	**36.4**	990.6	1149.9	118.6	74.2	13.9

AWU: actual water use; PWU: potential water use ; MD: moisture deficit; ER:rain efficiency ; YR: yield reduction.

3.4 Results from CROPWAT simulations

The results (Table 4) observed that notable differences in the water requirements and actual water use by banana crop exist across the Country while variations in related parameters are evident. For example, in all banana growing regions, potential water use by the crop is still higher than actual water use implying that there is a moisture deficit and hence yield reduction in most areas is inevitable. Moisture deficits can either be reduced through irrigation or mulching, the latter is commonly practiced in the southwestern region to improve crop yields at farm level (Nyombi, 2013).

The results further indicated that the first cycle of banana harvest is associated with higher yield reductions (YR) and lower rain efficiency (ER) than the second cycle of crop harvest. This is attributable the differences in crop canopy for the two crop cycles. In addition the seasonal rainfall variations are important. Regions that experience more than three months of rainfall shortages including Kitgum, Lira, Moroto and Gulu areas can hardly sustain rain-fed banana production and have yield reductions greater than 35% of optimal yields. The results from this study are consistent with findings of previous studies (Van Asten et al., 2010; Nyombi, 2010; Van et al. 2012; Nyombi, 2013; Umesh et al., 2015) among many others who reported that moisture stress in one of the major banana yield loss factors in many parts of Uganda. Intensive mulching is necessary in the plantations to promote moisture conservation and minimize on the water shortages and hence promote yields.

4. Conclusion

This study focused on assessing the linkages between banana yields and rainfall and temperature variability over Uganda. The data used included banana yields, observed rainfall and air temperature for the period 1979-2008. All the data was standardized to allow for visual comparisons between banana yields and climate parameters. The relationship between banana yields and climate parameters was assessed using timeseries moments, correlation and regression analyses. These analyses focussed on the central and westerns regions of Uganda. In addition, process based crop water assessment tool, FAO-CROPWAT was used to investigate the effects of intra-seasonal rainfall variations on rain-fed banana yields over different parts of Uganda. The study found relatively strong linkages between banana yields and climate parameters over various locations. High comparability indices for both banana yields and climate parameters were noted from analysis of moment. Significant differences were, however, noted in the values of the rainfall and temperature and bananas moment values. The cumulative effect of rainfall and temperature variations on banana yields be seen from correlation and regression results [0.78 (R^2=61%)].

There are both direct and indirect effects of air temperatures on banana yields which make air temperature variations strongly linked to banana yields. The weak linkage between rainfall and banana productivity is attributed to stronger inter- and intra-seasonal and annual variations exhibited by rainfall that are important to understand effects of rainfall variations on banana yields. In addition, the effect of rainfall on banana yields may be lagged. The results have indicated varied levels of moisture deficits across banana growing areas of Uganda. These moisture deficits have been associated with yield reductions of up to 46% of optimal banana yields.

Current banana yields are affected by rainfall and temperature variability and extremes over Uganda. The study recommends detailed experimental studies to provide field based baseline information to characterise the relationships between banana yields and rainfall and temperature variations in addition to other factors that determine banana yields. The study results offer potent information to banana farmers, regional agricultural institutions and the Government of Uganda to adjust their farming practices to cope, adapt and mitigate the thrilling effects of rainfall and temperature variability on the yields of bananas and other crops over Uganda and neighbouring regions.

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Competing Interests: The authors declare that there is no potential conflict of interest.

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