RAINFALL RELIABILITY FOR CROP PRODUCTION A CASE STUDY IN UGANDA

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ABSTRACT

Uganda's population is sustained by crops, which are largely produced under rainfed conditions. In recent years, however some areas have experienced significant drought. This phenomenon requires the attention of those involved in the formulation of agricultural policies. To address some of these concerns, a study was carried out to determine the reliability of rainfall in relation to crop water requirements, for different crops in climatic region in Uganda. Available rainfall data from the these regions were examined for consistency using the double mass curve and infilled using Markov generation methods. The data was then subjected to statistical tests to determine the probability distributions that best fit them. Probability distributions were selected from among the Log-Normal, Pearson Type III, Log-Pearson Type III and the Gumbel Extreme Value Type I distributions. Two methods were applied in determining the most suitable distribution, namely, the Chi-square goodness of fit test and regression analysis of the probability plots. Representative crops from the districts were then selected and their crop water requirements determined. These were compared to the rainfall to determine the effectiveness of the rainfall in meeting crop water requirements. The crop water requirements were adjusted with respect to the effective rainfall to find a planting date that minimizes the additional water requirement. Crops that required additional water were identified and the yield reduction due to moisture stresses determined. Irrigation schedules were then developed for the crops that required additional water.

Key words: crop water requirements; goodness of fit; probability plot; rainfall reliability; return period; yield reduction.

INTRODUCTION

Like for many of her neighbours in the East and Central African region, rainfall is the primary determinant of crop production in Uganda. However, rainfall is highly variable in most parts of the country both in terms of length of the rainy season and amount of rainfall (DWD, 1995). This variability means that Uganda can be divided into different climatic regions using various statistical methods and according to the parameters determined. This variability has also had a significant impact on rainfed agriculture as well as the environment of Uganda. Drought has occurred in various parts of Uganda many times seriously affecting crop production, food market prices and ultimately, the cost of living (NEMA, 2001). This uncertainty regarding agricultural production as well as investments in agricultural improvements has caused concerns in both local authorities and world bodies alike, which have been collaborating to combat drought.

In order to optimize the use of available rainfall, the crop water requirements for the different representative crops need to be determined in order to asses their suitability for a particular area. Other factors like soil moisture content and recharge, potential evapotranspiration, soil type, planting seasons and cropping methods all need to be considered. It is therefore necessary to give adequate attention to rainfed agriculture as a key element in food security in Uganda. Alternatives to meet additional water requirements, by irrigation, can subsequently be considered so that crop production can be increased appropriately. Herein, the rainfall reliability with respect to meeting crop water requirements in each of the regions has been investigated. Knowledge of the rainfall characteristics will facilitate the improvement of crop scheduling and irrigation where necessary.

The objectives of this study were therefore to: determine the most suitable statistical probability distribution that represents rainfall data and the rainfall depth return period relationship, in the selected region, estimate the effective rainfall in a region and crop water requirements of selected crops; determine the rainfall deficiency and consequent reduction in yield and to estimate the irrigation requirements to correct the deficit.

METHODS

The study covered the regions of Hoima (D), Masindi (E), Kitgum (F), Lira (H), Soroti (I), Kumi (K), Tororo (L), and Kabale (C) which are shown on fig. 1 and represent the areas in parenthesis, according to the classification of Uganda into climatic regions by Basalirwa (1995) . These include some of the areas that have been predominantly hit by drought in recent times.

The available daily rainfall data was collected from the Meteorological Department of the Ministry of Water, Lands and Environment. The number of years of data available for each of the stations ranged from 23 to 38 years. It was examined for consistency using the double mass curve technique. Missing values were synthetically generated using the Markov generation technique (Haan, 1982). The annual rainfall values were analyzed to obtain the statistical distribution using the following methods (Viessman & Lewis, 1996;Shaw, 1994; Subramanya, 1995; Wilson, 1978) . They were ranked and plotted on different probability paper according to Weibull formula as follows:

$$P \quad = \quad m/(N+1) \tag{1}$$

where:

P is the probability of an event being equaled or exceeded
m is the order of rainfall event
N is the number in the sample

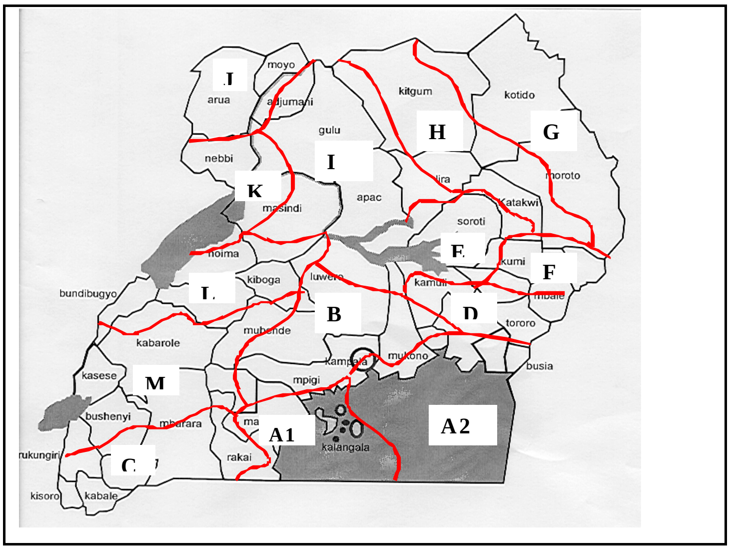

Figure 1: Map of Uganda showing the different climatic regions
(Delineation of the Climatic Zones in Uganda, *Basalirwa*) [3]

The coefficient of correlation provided an indication of the best fit. The results obtained were compared with the Chi squared goodness of fit test given below as:

$$c^2 \quad = \sum \left(\frac{O - E}{E} \right)^2 \tag{2}$$

Where:
c^2 is a value that should be the smallest among the distributions tested
O is the actual (observed) value and
E is the expected (predicted) value.

The distributions tested were the Log Normal, Pearson Type III Log Pearson and Extreme Value Type One. The rainfall data was then described according to the best fitting probability distribution and the rain fall return period relationship determined.

For crop water calculations, the following formulae were used;

$$ET_o = \frac{0.408\Delta(R_n - G) + g\dfrac{900}{T+273}u_2(e_s - e_a)}{\Delta + g(1 + 0.34u_2)} \tag{3}$$

$$ET_c = K_c ET_o \tag{4}$$

$$P_{eff} = \frac{P_{tot}(125 - 0.2P_{tot})}{125} \qquad \textbf{for P < 250 mm} \tag{5}$$

$$P_{eff} = 125 + 0.1P_{tot} \qquad \textbf{for P > 250 mm} \tag{6}$$

$$IR = ET_c - P_{eff} \tag{7}$$

$$\left(1 - \frac{Y_a}{Y_m}\right) = K_y\left(1 - \frac{ET_{cadj}}{ET_0}\right) \tag{8}$$

where ET_o is the reference crop evapotranspiration, R_n is net radiation at the crop surface, G is the heat flux density, T is the mean daily temperature, u_2 is the wind speed at 2m height, e_s is the saturation vapour pressure, e_a is the actual vapour pressure, Δ is the slope vapour pressure curve and γ is the psychometric constant, P_{eff} is effective rainfall, P_{tot} is actual rainfall measured, IR is irrigation requirement, K_c is crop coefficient, ET_c is crop evapotranspiration. Y_a is the actual crop yield. Y_m is the maximum crop yield when $ET_c = ET_{c\ adj}$; K_y is a yield response factor that describes the reduction in relative yield according to the reduction in ET_c caused by soil water shortage and $ET_{c\ adj}$ is the adjusted actual evapotranspiration (FAO, Doorenbos & Pruitt, 1977).

The reference crop evapotranspiration was calculated according to equation (3) and then the crop evapotranspiration according to equation (4) for the different crops according to their growth stages. The effective rainfall for the average year in a region was estimated according to equations (5) and (6). When comparing the effective rainfall and crop water requirements, the planting date was adjusted so as to minimize the irrigation requirements. The irrigation requirements (rainfall deficiency) were then estimated using equation (7).

Equation (8) gives the relationship between the crop yield and available moisture. Finally, the reduction in yield according to the available moisture was estimated, providing a basis on which decisions regarding investments in irrigation can be made

RESULTS AND DISCUSSION

The results of the statistical analysis are presented in the Tables 1 and 2. Table 1 provides a summary for the testing of statistical distributions for the climatic regions using the Chi squared values and correlation coefficients. Table 2 provides a summary of the statistical parameters and the rainfall depth return period relationship for the regions.

The figures show results of the rainfall and crop water requirements are summarized under two categories. One region which requires additional water to sustain a particular crop. This is Hoima region L with bananas. The other region, which does not require any additional water to sustain a particular crop. This is Lira region I with groundnuts.

Fig.2 shows the trend of annual rainfall in Hoima, Fig.3 gives the probability plot for Hoima rainfall, Fig.4 shows the actual and effective rainfall in Hoima and Fig.5 the effective rainfall and crop water requirements for bananas superimposed with the irrigation requirements. It was noted in Fig.5 that the water requirement for banana is more or less constant with slightly more water required at planting and towards harvesting. For a planting date of 1-April, irrigation will be required during the months of December and January (Shima, 2002).

Fig.6 gives the trend of annual rainfall in Lira, Fig.7 gives the probability plot for Lira rainfall, Fig.8 shows the actual and effective rainfall in Lira, and Fig.9 shows the effective rainfall and crop water requirements for groundnuts in Lira. It was noted in Fig.9 the rainfall adequately provides the crop water requirements. The planting date of June 1 ensures enough rainfall even if the planting date is not strictly adhered to. Adjustments can be made by planting up to three or four weeks before or after the recommended planting date without need for irrigation (Kiiza, 2001).

Table 3, provides a summary of the regions selected crops their irrigation requirements and yield reductions if these requirements are not addressed.

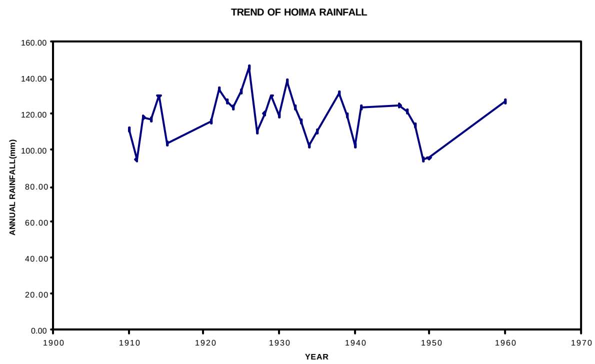

Fig 2: Trend of Hoima rainfall

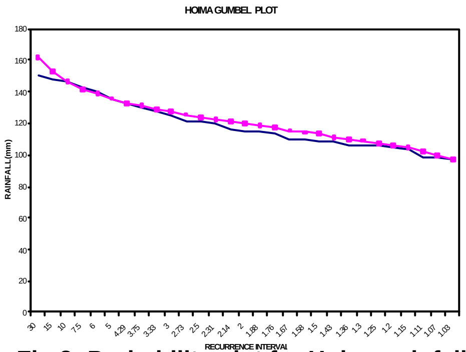

Fig 3: Probability plot for Hoima rainfall

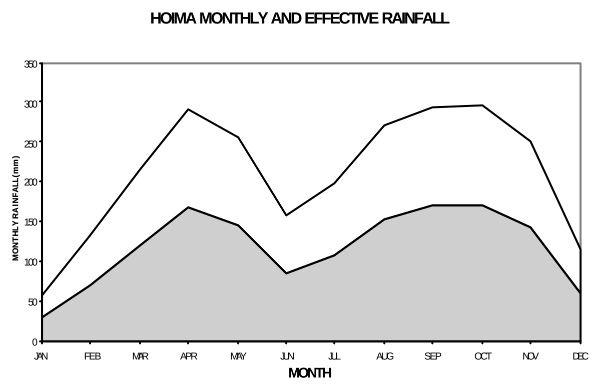

Fig. 4: Plot of actual and effective rainfall in Hoima

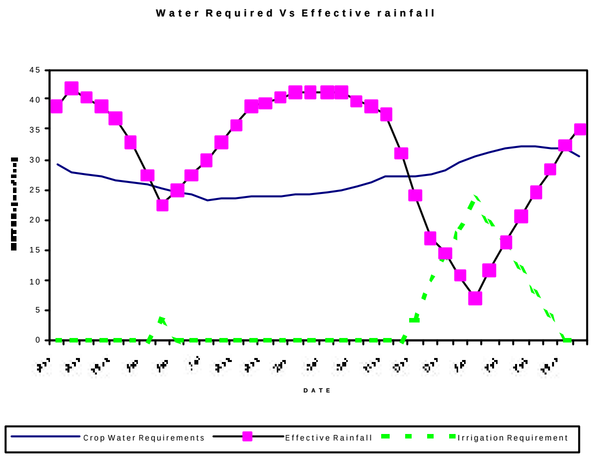

Fig 5: Effective rainfall and Banana water requirements

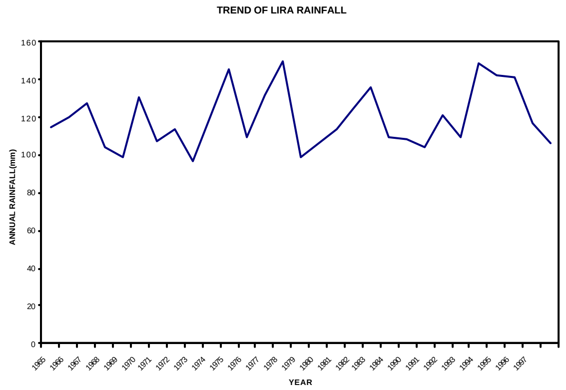

Fig 6: Trend of Lira rainfall

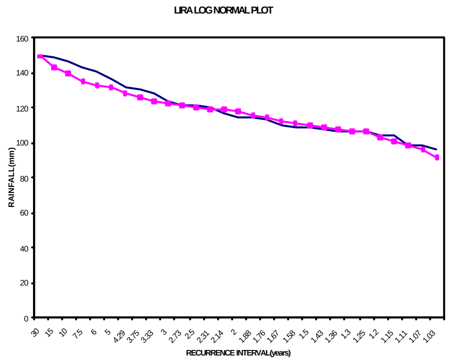

Fig 7: Probability plot for Lira rainfall

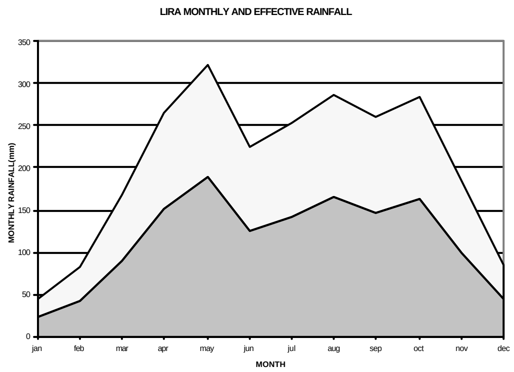

Fig 8: Plot of actual and effective rainfall in Lira

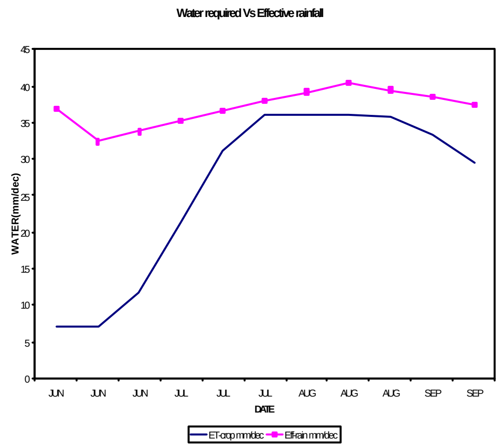

Fig 9: Effective rainfall and groundnuts

water requirements planting date June

Table 1 Testing of statistical distributions

Region	Chi Squared Values X^2				Correlation Coefficient			
	LN	P. III	LP	EV1	L N	P.III	L P	EV1
Hoima (L)	8.75	14.40	13.14	3.34	0.975	0.965	0.974	0.977
Masindi(K)	0.12	10.3	0.08	1.26	0.967	0.960	0.979	0.963
Kitgum (H)	5.22	21.24	28.54	6.78	0.981	0.961	0.955	0.974
Lira (I)	2.59	9.43	10.45	3.12	0.984	0.977	0.978	0.983
Soroti (E)	2.02	16.06	10.18	1.89	0.988	0.982	0.921	0.991
Kumi (F)	2.14	9.32	10.53	0.96	0.989	0.985	0.984	0.992
Tororo (D)	7.69	43.34	48.03	7.28	0.970	0.949	0.941	0.981
Kabale (C)	12.00	8.474	10.38	1.60	0.980	0.989	0.983	0.991

Key: LN - Log Normal, P. III -Pearson Type III, L P - Log Pearson EV1 - Extreme Value Type 1

Table 2 Statistical parameters and trend

Region	Mean annual Rainfall mm	Standard Deviation	Skewness	Best statistical Distribution	Rainfall depth return period relationship
Hoima (L)	118.76	12.6	-0.216	Extreme Value Type 1	$118.76 + 12.6K_T$
Masindi(K)	112.02	13.8	0.5092	Log Pearson Type III	$2.05 + 0.053K_T$
Kitgum(H)	117.75	21.24	-649	Log Normal	$2.064 + 0.077K_T$
Lira (I)	119.36	15.80	0.568	Log Normal	$2.073 + 0.056 K_T$
Soroti (E)	116.97	18.45	0.383	Extreme Value Type1	$116.97 + 18.45 K_T$
Kumi (F)	108.80	15.94	0.563	Extreme Value Type1	$108.8 + 15.94K_T$
Tororo(D)	124.45	19.93	-0.253	Extreme value Type 1	$124.45 +19.93 K_T$
Kabale(C)	86.7	10.73	0.3	Extreme Value Type 1	$86.7 + 10.73K_T$

Table 3: Regions selected crops and irrigation requirements

Region	Crop	Irrigation	Yield reductions percentage	mm/dec
Hoima (L)	Bananas	Yes	30.1	130.8
Masindi (K)	Bananas	Yes	29.2	147.6
Kitgum (H)	Potatoes	Yes	10	225.5
Lira (I)	Ground nuts	No	0	0
Soroti (E)	Sorghum	No	0	0
Kumi (F)	Sun flower	No	0	0
Tororo (D)	Potatoes	Yes	10	216.2
Kabale (C)	Bananas	Yes	18.1	53.6

CONCLUSIONS

From the analysis, the statistical distributions for the annual rainfall for the selected climatic region were determined together with their rainfall depth return period relationships. Five of the stations are represented by EV1, two by Log Normal and one by Log Pearson Type III. It was also observed, in all cases there was slight decrease in rainfall over the years. The effective rainfall and crop water requirements were also determined for a selected crop in each of the regions. It was observed that in most cases the rainfall is bimodal this means two sets of crops can be grown per year like for legumes.

After synchronizing the planting date to keep additional water requirements to a minimum, Irrigation requirements were determined, where the effective rainfall was insufficient to cater for the crop water requirements. It was noted that all the cases of both bananas and potatoes, irrigation was required in all the regions investigated. The reduction in the yields when irrigation requirements were not met was also determined. It was also noted that yield reduction was more in clayey loams, as compared to coarser loams (Kiiza, 2001).

This study can provide a basis on which agricultural policy makers can plan for irrigation in particular regions and provide a strategy for combating drought. It can also be extended to other regions in order to target high yielding crops and those with a high market value as was done in the Sudan (Dafalla, 1996;Ibrahim, 1999). The authors are in the process of developing a computer programme that will handle this aspect The limitations in the study are because of insufficient and missing data and because of the inherent assumptions in frequency analysis (Subramanya 1995) .

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