Technical Soils Bulletin No. 13

REVIEW OF AGRO-CLIMATIC SOFTWARE MODULES OF JAMPLES
(November 1988)

MINISTRY OF AGRICULTURE
RURAL PHYSICAL PLANNING DIVISION
SOIL SURVEY PROJECT

ABSTRACT: The inter-annual and spatial variability of seasonal rainfall is high throughout the island of Jamaica. In order to provide an understanding of this variability five agro-climatic software modules have been developed and incorporated in the Jamaica Physical Land Evaluation System (JAMPLES). Results generated with the modules can be used for crop zoning at the regional level. One example is given for Linstead in the parish of St. Catherine, Jamaica.

Key words: Agro-climatic analysis, statistical analysis, software, Jamaica.

This Technical Soils Bulletin is part of a series issued by the Jamaica Soil Survey Project (JAM/81/003), a bi-lateral undertaking of the Governments of Jamaica and the Netherlands. The software and report were prepared by Niels H. Batjes.

CONTENTS

1. INTRODUCTION

A good seasonal distribution of rainfall is essential for crop growth and production under rainfed conditions. The agronomist therefore must have a good understanding of the inter-annual variability of seasonal precipitation. With a view to provide such an understanding five agro-climatic modules have been developed and incorporated in JAMPLES, the computerized Jamaica Physical Land Evaluation System (SSU, 1986, 1987a, 1987b & 1988b).

Confidence limits for seasonal rainfall can be used to assess the general climatic suitability of an area for a specific crop. In islands, the rainfall distribution curves are often skewed, prohibiting the use of statistical tests applicable to Normally distributed data. Such tests can however be applied following the transformation of the original data into a Normally distributed frequency curve (see Snedecor & Cochran, 1980).

This paper reviews the modules of JAMPLES which allow for the management and analysis of climatic data files (Section 2). The transformation and statistical testing procedure is discussed in Section 3. Examples of computer print-outs are included in the Appendix. Recommendations for further agro-climatic modelling are made in the final section of the report.

2. MATERIALS AND METHODS

2.1 Data sources

Daily rainfall data were recorded for a period of 30 to over 60 years at over 130 stations in Jamaica (JMS, 1973). Following checks for systematic errors and inconsistencies in the data the Meteorological Service issues manuscript files of monthly rainfall data which form the basic material for the climatic data base of JAMPLES.

Potential evapo-transpiration and air temperature are measured on a routine basis at a limited number of locations in Jamaica, mainly in the Plains (JMS, 1973). The existing data, therefore, need to be extrapolated to other areas of the island. A number of linear regression functions have been developed to this end (IICA, 1983; SSU, 1988a).

2.2 The agro-climatic modules

JAMPLES version 3.0 includes five modules which permit creation, update and analysis of data stored in the climatic data base. They are briefly explained below.

ENTERAIN creates a data file for a specific climate station. The variables stored in this file are station name and number, elevation above mean sea level, first year of data record, length of this record followed by the monthly rainfall totals which are entered on a year by year basis, mean potential evapotranspiration and mean daily air temperature.

Climatic data files can be corrected/updated with the RAINCOR module which further automatically deletes all the existing statistical output-files for the station under study.

POWSTAT carries out statistical analyses of monthly and annual rainfall using the testing procedure discussed in Section 3. The results generated by POWSTAT are stored in a computer disk-file. RAINSTAT prints the contents of this file and includes a subroutine to calculate the time of occurrence of the 'dependable growing period' (see Appendix for concept).

The statistical testing procedure in POWSTAT and RAINCUM is similar but there is some difference, i.e. RAINCUM carries out a statistical analysis of seasonal rainfall. Seasonal rainfall is defined as the total precipitation recorded during time-periods of 1 up to 5 consecutive months that occur within the 'dependable growing period'.

2.3 Hardware requirements

The JAMPLES software is written in release 3.0 of the BASIC language and can be operated on an IBM PC/AT or compatible micro- and mini-computer with MS-DOS version 2.1 or higher. Required peripherals include a monochrome monitor and a line printer with 80 column capability. The JAMPLES User's Guide (SSU, 1987b) explains how to use the software.

3. STATISTICAL ANALYSIS

3.1 Normalizing of rainfall frequency curves

In Jamaica the frequency curve of seasonal rainfall often departs from Normality; it may be skewed assymetrically to higher or lower values from the mode so that the mode, mean and median do not have the same value. Statistical tests, such as the "Student's" t-test, can only be applied to populations that are Normally distributed. Skewed data series can be normalized using a transformation function. The confidence points calculated in the new, transformed scale using a "Student's t-test" can be retransformed to the original scale so as to provide the required insight in the inter-annual variability of seasonal rainfall. The mathematical rationale of the above procedure has been documented by Snedecor & Cochran (1980). The testing procedure has been successfully applied to analyses of rainfall variablity for agricultural planning by several researchers including Manning (1956), Mutsaers (1979), Gregory (1984) and Batjes (SSU, 1986).

3.2. The statistical testing procedure

The departure from statistical 'normality' of a given rainfall frequency curve is tested using a power function:

$$T(i,j) = [R(i,j) + 1]^k$$

with i the ith month of the year,
j the jth year of the data series,
R(i,j) the seasonal rainfall in time period (i,j),
k the exponent, and
T(i,j) the new variable after transformation with the power (normalizing) function.

The value of the exponent (k) is varied until skewness does not depart significantly from zero (assumption of normality) at the 2 percent level of statistical confidence. The testing procedure is taken from Snedecor & Cochran (1980). Confidence points for individual observations in the transformed scale are calculated as follows (see Manning, 1956; Mutsaers, 1979):

$$Tp = \bar{T} - t(N-1,p) * ST * (1 + 1/N)^{1/2}$$

with Tp the confidence point for T at probability level p,

t the percentage point of the t-distribution at propability level p and (N-1) degrees of freedom,

$\bar{T}$ the mean of the transformed seasonal rainfall data,

ST the standard deviation, and

N the number of observations.

The above confidence points (Tp) are re-transformed to the original scale (Rp) using the inverse of the final transformation function:

$$Rp = (Tp^{1/k}) - 1$$

Confidence points are calculated at the five probability levels i.e. 10, 25, 50, 75 and 90 percent.

4. DISCUSSION

Studies of seasonal rainfall based on the analysis of monthly data may give a false impression of the adequacy of water supply to rainfed crops because the precipitation may fall in heavy showers interrupted by long dry spells. Such dry spells can be critical for the growth of a crop when they occur at a critical stage of its development. The severity of this impact varies with the type of climate, crop, soil and management (see FAO, 1979). A soil-water-balance can provide a better approximation of these complex inter-relationships than the present statistical analysis. At present, the author is testing a multiple-root-zone soil water balance.

The computerized data base for agro-climatic analyses should ideally contain 5-day or 10-day rainfall totals but this degree of resolution has not yet been achieved in Jamaica. Parallel to the preparation of such a computerized data base the network of meteorological stations, where comprehensive sets of climatic variables (air temperature, wind speed, radiation, relative humidity, class-A evaporation) are collected, should be intensified so that more detailed agro-climatic analyses can be prepared in the near future.

REFERENCES

FAO, 1979. Yield response to water. Irrigation and Drainage Paper No. 33, Food and Agricultural Organization of the United Nations, Rome.

Gregory S. 1984. Statistical methods for the geographer. 4th Edition, Longman, London.

IICA, 1983. Agro-climatic study of Jamaica. L' Homme, J-P & M. Eldin, Interamerican Institute for Cooperation on Agriculture/ORSTOM, San Jose, Costa Rica.

Jamaica Meteorological Service, 1973. The climate of Jamaica. First Edition, The Climatology Branch, Meteorological Service, Jamaica 68 p.

Manning H.L., 1956. The statistical assessment of rainfall probability and its application to Uganda agriculture. Proc. Roy. Soc. B 144:460-480

Mutsaers H.J.W., 1979. An agricultural analysis of rainfall reliability for Cameroon. Neth. J. Agric. Sci. 27:67-78

Snedecor G.W. and W.G. Cochran, 1980. Statisitical methods. Seventh Edition, Iowa State Univesity Press, Ames, Iowa.

SSU, 1986. Methodology and BASIC programmes for the assessment of rainfall probability. Batjes, N.H., Technical Soils Bulletin No. 4, Soil Survey Unit (SSU), Rural Physical Planning Division (RPPD), Ministry of Agriculture (MoA), Jamaica.

SSU, 1987a. An analysis of rainfall variability in St. Catherine for agricultural planning. Batjes, N.H., Miscellaneous Soil Paper No. 4, SSU, RPPD, MoA, Jamaica.

SSU, 1987b. JAMPLES Users Guide. A computerized land evaluation system for Jamaica. Batjes, N.H., Technical Soils Bulletin No. 8, SSU, RPPD, MoA, Jamaica.

SSU, 1988a. The application of transfer functions to create the climate data layer of the Jamaica Geographical Information System (JAMPLES). Batjes, N.H., Miscellaneous Paper No. 5, SSU, RPPD, MoA, Jamaica.

SSU, 1988b. Agro-climatic characterization of the parish of Clarendon, Jamaica. Batjes, N.H., Technical Soils Bulletin No. 13, SSU, RPPD, MoA, Jamaica.

APPENDIX I: EXAMPLES OF LISTINGS PREPARED WITH THE AGRO-CLIMATIC MODULES OF THE JAMPLES SOFTWARE PACAKGE.

Tables generated with the POWSTAT, RAINSTAT, and RAINCUM modules of JAMPLES are discussed in this Appendix using Linstead as the example. The following abbreviations are used throughout the Tables:

N: The sample size -number of records- for each month, season or year.

Mean: The arithmetic mean for the season or year.

CV: The coefficient of variation provides a measure for the inter-annual variability of seasonal rainfall in the years under study.

Minim.: Lowest amount of total monthly rainfall recorded during the period under review (in millimeters).

R90: This amount (mm) of rainfall will be reached or exceeded in 90 percent of the years.

R75: As above, but this amount will be reached or exceeded in 75% of the years.

R50: As above, but this amount will be reached or exceeded in 50 percent of the years (median).

R25: As above, but this amount will be reached or exceeded in 25 percent of the years.

R10: As above, but this amount will be reached or exceeded in 10 percent of the years.

Maxim.: Highest amount of total rainfall recorded during the period under review.

PET: Potential evapo-transpiration according to the Priestley & Taylor method and calculated with linear regression functions developed by IICA (1983). PET values are in millimeters.

Tmin, Tmean and Tmax: Mean daily minimum, mean and maximum air temperature respectively as calculated with linear regression functions of temperature against elevation above mean sea level (SSU, 1988a). Air temperature is listed in degrees Celsius.

P(Xi<=.3): Probability of occurrence of a 'dry' month which has been defined as a month with less than 0.3*PET mm of rainfall.

P(Xi>.3 and Xi<=0.5): Probability of occurrence of rainfall in the 0.3*PET to 0.5*PET range. These conditions generally allow for field preparation, but this will only be meaningful when rainfall in the following months allows for satisfactory crop growth (i.e. Rain=> 0.5*PET).

P(X>0.5 and Xi<=1.0): Probability of occurrence of a "moist" month, i.e. a month during which rainfall varies between 0.5*PET and 1.0*PET.

P(Xi>1.0): Probability of occurrence of a 'humid' month during which rainfall exceeds the potential evapo-transpiration. A part of the water surplus can be stored in the soil as soil moisture reserve.

P(R>400): Probability of monthly rainfall surpassing a critical 'upper' limit for crops. This value is tentatively set at 400 mm/month.

RP90 and RP75 - the abbreviation for R90/PET and R75/PET - stand for '90% dependable' respectively '75% dependable' seasonal rainfall divided by the mean seasonal PET. These ratios give an indication of the potential supply of moisture to rainfed crops in 90 and 75% of the years respectively.

DGP is the dependable growing period in the given location, i.e. the minimum length of this period in 75 percent of the years. DGP is the time period during which rainfall exceeds 0.5*PET in 75 percent of the years. PET*0.5 is seen as the lower limit for satisfactory (not optimal) crop growth. The DGP is shown in Table 2 as periods of consecutive M's (moist months) and H's (humid months). For further details see SSU (1988b).

Linstead

Table 1 : Extremes and variability of monthly and annual rainfall totals, mean potential evapo-transpiration, and mean air temperature for Linstead (in mm/month and degrees Celsius respectively) [data base: 1951 - 1977]

PERIOD	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	YEAR
N	27	27	26	27	27	27	27	27	27	27	27	27	26
Mean	55	52	55	91	217	187	166	169	178	232	123	97	1640
CV (%)	69	88	69	81	58	62	40	41	38	65	46	93	23
Minim.	7	4	5	7	25	10	8	71	52	56	34	1	838
R90	8	8	3	0	42	53	75	84	85	82	45	5	1110
R75	28	21	28	39	127	104	119	120	130	132	83	33	1365
R50	53	43	55	91	217	174	166	164	178	206	123	82	1640
R25	80	74	82	144	308	257	213	213	226	305	164	146	1914
R10	108	112	107	193	392	346	257	263	271	423	202	218	2170
Maxim.	155	167	154	244	516	585	312	391	312	631	254	367	2671
PET	103	109	138	142	150	145	155	144	124	122	104	103	1541
R75/PET	0.26	0.19	0.20	0.27	0.84	0.71	0.76	0.83	1.04	1.07	0.79	0.32	0.88
Tmin	19.1	18.7	19.1	20.1	21.4	22.1	22.1	22.1	22.2	21.8	21.2	20.2	20.9
Tmean	23.9	23.9	24.1	25.1	25.9	26.5	26.8	27.2	26.7	26.5	25.9	24.9	25.6
Tmax	28.9	29.0	29.5	30.1	30.4	30.9	31.5	31.6	31.3	31.0	30.2	29.5	30.3

Table 2 : Agro-climatic analysis for Linstead and minimum length of the dependable growing period in 75% of the years (probabilities in percent). [Data base: 1951 - 1977]

Xi=R/PET	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
N	27	27	26	27	27	27	27	27	27	27	27	27
P(Xi=<0.3)	33	48	42	37	7	3	3	0	0	0	0	25
P(.3<X=<.5)	22	22	23	14	0	3	3	3	7	3	7	22
P(.5<Xi=<1)	29	14	30	22	33	37	40	37	11	14	40	18
P(1<Xi)	16	16	5	27	60	57	54	60	82	83	53	35
P(R>400mm)	0	0	0	0	11	7	0	0	0	14	0	0
DGP	-	-	-	p	M	M	M	M	H	H	M	u

Table 3 : Analysis of seasonal rainfall and PET variability for the Linstead area [Data base: 1951 - 1976].

Time period	PETm	N	Min	R90	R75	R50	R25	R10	Max	CV%	RP90	RP75
Jan.-Jan.	103	26	7	10	30	54	82	109	155	66	0.09	0.28
Jan.-Feb.	211	26	25	28	68	111	154	195	248	54	0.13	0.32
Jan.-Mar.	349	26	48	51	107	166	226	281	367	50	0.14	0.30
Jan.-Apr.	491	26	87	122	185	254	323	387	513	38	0.24	0.37
Jan.-May	641	26	193	247	354	470	586	693	830	34	0.38	0.55
Jan.-June	786	26	203	359	504	659	814	959	1067	33	0.45	0.64
Feb.-Feb.	108	26	7	11	24	44	74	113	166	85	0.10	0.21
Feb.-Mar.	246	26	30	23	60	105	155	205	290	63	0.09	0.24
Feb.-Apr.	388	26	50	70	129	195	264	330	479	48	0.17	0.33
Feb.-May	538	26	164	196	300	413	526	631	786	38	0.36	0.55
Feb.-June	683	26	196	314	453	602	751	890	1024	34	0.46	0.66
Feb.-July	837	26	330	426	592	771	949	1116	1252	32	0.50	0.70
Mar.-Mar.	138	26	5	3	28	55	82	107	154	69	0.02	0.20
Mar.-Apr.	280	26	29	40	89	143	197	246	324	52	0.14	0.31
Mar.-May	430	26	139	159	255	359	462	559	654	40	0.36	0.59
Mar.-June	575	26	178	271	404	548	692	825	938	36	0.47	0.70
Mar.-July	729	26	312	383	544	717	890	1050	1237	33	0.52	0.74
Mar.-Aug.	873	26	484	537	706	888	1070	1239	1369	28	0.61	0.80
Apr.-Apr.	142	26	6	0	35	85	137	188	243	83	0.00	0.24
Apr.-May	292	26	52	101	199	304	409	506	572	48	0.34	0.68
Apr.-June	437	26	155	212	348	493	638	773	918	41	0.48	0.79
Apr.-July	591	26	289	324	486	661	836	999	1217	37	0.54	0.82
Apr.-Aug.	735	26	413	475	648	833	1018	1190	1321	31	0.64	0.88
Apr.-Sep.	859	26	491	644	822	1013	1204	1381	1484	26	0.74	0.95
May-May	150	26	24	38	124	216	308	394	515	60	0.25	0.82
May-June	295	26	116	133	264	405	546	677	872	48	0.45	0.89
May-July	449	26	249	241	401	574	746	906	1172	42	0.53	0.89
May-Aug.	593	26	334	402	567	745	923	1088	1243	33	0.67	0.95
May-Sep.	717	26	433	574	743	925	1107	1276	1439	27	0.80	1.03
May-Oct.	839	26	489	687	915	1160	1405	1632	2025	29	0.81	1.09
June-June	145	26	10	52	104	175	261	351	585	62	0.35	0.71
June-July	299	26	121	161	243	344	460	578	885	45	0.54	0.81
June-Aug.	443	26	205	297	409	529	649	761	956	31	0.67	0.92
June-Sep.	567	26	400	479	590	709	828	939	1152	23	0.84	1.04
June-Oct.	689	26	456	584	757	944	1130	1303	1510	27	0.84	1.09
June-Nov.	793	26	489	688	872	1070	1269	1453	1685	26	0.86	1.09
July-July	154	26	7	77	121	169	216	260	311	39	0.50	0.78
July-Aug.	298	26	149	215	275	340	405	465	522	26	0.72	0.92
July-Sep.	422	26	294	381	448	520	592	659	670	19	0.90	1.06
July-Oct.	544	26	350	473	609	755	900	1036	1272	27	0.87	1.11
July-Nov.	648	26	383	580	725	881	1038	1183	1448	24	0.89	1.11
July-Dec.	751	26	464	627	798	980	1163	1333	1603	26	0.83	1.06

[Continues overleaf]

Table 4 : Analysis of seasonal rainfall and PET variability for the Linstead area [Data base: 1951 - 1976].

Time period	PETm	N	Min	R90	R75	R50	R25	R10	Max	CV%	RP90	RP75
Aug.-Aug.	144	26	71	86	122	166	216	266	390	40	0.59	0.84
Aug.-Sep.	268	26	172	222	284	351	418	481	529	26	0.82	1.05
Aug.-Oct.	390	26	228	329	453	586	720	844	1088	32	0.84	1.16
Aug.-Nov.	494	26	261	433	568	713	858	993	1263	28	0.87	1.14
Aug.-Dec.	597	26	342	469	634	812	990	1155	1419	30	0.78	1.06
Aug.-Jan.	700	26	351	514	685	869	1052	1223	1466	29	0.73	0.97
Sep.-Sep.	124	26	52	86	131	180	228	274	311	38	0.69	1.05
Sep.-Oct.	246	26	107	201	291	401	525	653	942	42	0.81	1.18
Sep.-Nov.	350	26	141	291	408	538	671	798	1117	34	0.83	1.16
Sep.-Dec.	453	26	222	334	473	632	800	963	1273	36	0.73	1.04
Sep.-Jan.	556	26	231	359	522	697	872	1035	1320	35	0.64	0.93
Sep.-Feb.	664	26	235	397	567	750	933	1103	1341	34	0.59	0.85
Oct.-Oct.	122	26	55	81	132	208	309	431	630	65	0.66	1.08
Oct.-Nov.	226	26	89	156	248	355	469	581	806	44	0.68	1.09
Oct.-Dec.	329	26	170	205	315	448	594	741	961	44	0.62	0.95
Oct.-Jan.	432	26	179	244	367	509	660	806	1009	40	0.56	0.84
Oct.-Feb.	540	26	183	272	411	566	726	877	1126	39	0.50	0.76
Oct.-Mar.	678	25	356	370	488	629	785	940	1250	34	0.54	0.72
Nov.-Nov.	104	26	33	50	87	127	166	203	253	44	0.47	0.83
Nov.-Dec.	207	26	107	91	156	226	296	361	458	43	0.43	0.75
Nov.-Jan.	310	26	120	126	201	282	363	439	614	40	0.40	0.64
Nov.-Feb.	418	26	127	166	245	333	424	509	706	37	0.39	0.58
Nov.-Mar.	556	25	173	216	305	401	497	586	757	33	0.38	0.54
Nov.-Apr.	698	25	254	295	385	482	580	670	785	28	0.42	0.55
Dec.-Dec.	103	26	1	5	34	84	149	223	366	92	0.05	0.33
Dec.-Jan.	206	26	28	34	79	142	219	303	521	70	0.16	0.38
Dec.-Feb.	314	26	45	70	121	193	280	376	614	59	0.22	0.38
Dec.-Mar.	452	25	69	101	172	261	360	459	664	51	0.22	0.38
Dec.-Apr.	594	25	108	158	251	352	453	546	693	40	0.26	0.42
Dec.-May	744	25	214	329	443	566	689	803	973	30	0.44	0.59

Ri is the minimum amount of rainfall exceeded in i percent - i= 90%, 75%, 50%, 25% and 10% respectively- of the years during the time period under review. PET is the mean seasonal potential evapotranspiration. RPi is the abbreviation for Ri/PET ratio. N is the total number of observations for each analysis and CV the coefficient of variation.

Table 5 : Monthly and annual rainfall totals and PET figures in mm for Linstead (1951 - 1977).

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	YEAR
RAIN (mm):													
1951	14	37	5	243	256	113	131	390	105	136	106	25	1566
1952	20	35	41	236	109	192	135	134	300	112	76	36	1433
1953	137	46	21	41	392	130	311	108	140	212	89	30	1663
1954	34	154	87	237	257	159	174	156	134	262	69	37	1765
1955	13	159	25	36	171	195	223	128	56	160	103	59	1333
1956	26	28	82	181	190	294	236	190	143	308	140	22	1844
1957	83	54	72	181	299	106	209	138	261	157	65	61	1692
1958	112	33	121	6	413	357	265	204	160	504	71	153	2405
1959	29	7	22	109	231	103	109	197	274	193	92	366	1736
1960	155	92	50	28	146	408	174	230	105	221	221	102	1938
1961	36	65	25	102	141	134	194	147	183	536	107	242	1917
1962	42	25	25	119	164	204	165	247	196	200	187	143	1723
1963	43	132	84	54	515	237	184	145	311	630	175	155	2671
1964	47	20	20	164	163	227	132	178	179	152	76	77	1441
1965	25	29	51	17	277	212	7	155	190	144	143	104	1360
1966	74	14	19	45	287	585	299	71	195	144	190	1	1929
1967	44	71	154	11	117	158	156	82	195	108	108	36	1245
1968	59	20	23	6	126	172	190	132	66	284	99	7	1190
1969	25	32	7	86	485	255	226	266	153	265	207	30	2044
1970	86	22	68	30	367	93	109	156	211	192	153	50	1544
1971	52	22	70	79	128	56	65	84	215	105	179	45	1104
1972	113	45	50	77	120	110	154	146	150	150	101	263	1484
1973	54	24	86	27	24	214	124	139	194	584	65	233	1775
1974	76	166	123	58	84	77	141	292	236	173	253	20	1707
1975	7	17	23	38	106	10	134	212	256	104	172	185	1269
1976	58	50	66	57	33	106	121	120	52	55	33	81	837
1977	9	4	-1	180	250	136	98	100	131	161	37	36	-1
PET	103	109	138	142	150	145	155	144	124	122	104	103	1541

Appendix II: Identification of suitable time periods to grow maize in the Linstead area under rainfed conditions.

Assumptions:

This case study is based on a number of assumptions. It aims at identifying suitable periods for growing an early maturing maize variety in the Linstead area. This variety requires about 4 months from sowing to harvest. The soils in the area are deep, freely drained and do not present any limitations for maize.

Precipitation becomes 'limiting' for soil trafficability/workability when a given threshold for 'high' rainfall is exceeded in the month of sowing/planting and/or at harvest. The proposed value for this threshold is P(Rain > 400mm) => 10%. All rainfall is assumed to be 100% effective.

The crop coefficients required for good growth of the maize crop are shown in Table A. Satisfactory growth is only feasible when monthly rainfall exceeds 0.5*PET in 75% of the years. This assumption is commonly used internationally in agro-economic risk forecasting (see SSU, 1988b).

Table A. Seasonal crop coefficients for the maize crop.

month	1	2	3	4	total period
kc	0.50	0.75	1.05	0.80	0.78

To achieve good yields the maize crop will need about 400-600 mm of water. The sensitivity of maize to water deficits varies with the crop development stage (see e.g. FAO, 1979). During the vegetative (about month-1) and ripening (about month-4) stage the crop is relatively tolerant to water deficits. The greatest decrease in grain yield is caused by water deficits during the flowering period -tasseling, silking and pollination- which occurs around month-3, mainly due to the reduced number of grains per cob. Severe water stress at silking will result in little or no grain due to drying of the silk. Water deficits in the last month can lead to reduced yields due to a poor filling of the grains. Waterlogging can severly reduce crop growth and yields especially when it occurs during the flowering and yield formation stage (month-3 & -4) and can hamper field operations.

Discussion:

Air temperature is at no time limiting for maize during the dependable growing, i.e. in the period from May to November (App.-I, Table 1). The periods with mainly good rainfall and PET conditions for maize are shown in **bold print** in Table B & C. The months with less than satisfactory rainfall for maize are under-lined (R75<0.5*PET).

Total seasonal rainfall exceeds the minimum water requirement (ETm) for good growth in at least 90% of the years in the period June-September, July-October and August-November. In the period from May-August (R90= 402mm, R75= 567mm, ETm= 460mm), September-December (R90=334mm, R75=473mm, ETm=351mm), October-January (R90=244mm, R75=367mm, ETm=344mm) this minimum amount is surpassed in at least 75% of the years, while during the November-February period it is exceeded in about 50% of the years (R75=245mm, R50= 333mm, ETm=326mm).

Table B: Total rainfall (Rt) recorded in 80 percent of the years, mean potential evapo-transpiration and crop evapo-transpiration (ETm=kc*PET) for 4-monthly periods starting between May and November (DGP) in the Linstead area (mm).

Time period	R90<=Rt<=R10	PET	ETm
May - August	402 - 1088	593	460
June - September	479 - 939	567	439
July - October	473 - 1036	544	421
Aug. - November	433 - 993	494	382
Sept - December	334 - 963	453	351
Oct. - January	244 - 806	432	334
Nov. - February	166 - 509	418	326

Next, the distribution of monthly rainfall within each potential growing period is compared with the monthly water requirement for satisfactory growth (Table A & C).

Table C: Ri/PET ratios for selected time periods.

month in growing season	Total period		RP75 in month			
1 - 4	RP90	RP75	1	2	3	4
May-August	0.67	0.95	0.82	0.71	0.78	0.84
June-Sept.	0.84	1.04	0.71	0.78	0.84	1.05
July-Oct.	0.87	1.11	0.78	0.84	1.05	1.08
Aug.-Nov.	0.87	1.14	0.84	1.05	1.08	0.83
Sept.-Dec.	0.73	1.04	1.05	1.08	0.83	0.33
Oct.-Jan.	0.56	0.84	1.08	0.83	0.33	0.28
Nov.-Feb.	0.38	0.54	0.83	0.33	0.28	0.21

From the above discussion it follows that, from a 'statistical' point of view, the period from July-October and August-November are the most suitable for rainfed maize in the Linstead area.

Maize sown in July, however, will mature in October which is the wettest month (R90=431mm). When sown in August the month of October will correspond with the sensitive flowering and pollination stage. Somewhat less suitable is the June-September period since a moderate drought can occur in August, i.e. at the tasseling/silking stage. Maize sown directly at the onset of the dependable growing period, that is in the month of May, is likely to suffer from some degree of water deficit during month-2 and month-3. These are critical periods for good production. Maize sown later than September can suffer from water stress during the critical flowering and ripening stage; the water deficit will mainly occur during the grain filling stage.

The above approach indicates if and when a given crop variety can be satisfactorily grown, in most years, under rainfed conditions in the considered geographic location. Agronomists and planners can use these results to assess whether a specific crop can be grown in a particular location from a climatic-risk forecasting point of view. The procedure cannot be used to tell the farmers when the crop should actually be planted. Most farmers will plant their annual crops as soon as the 'first' showers of the rainy season have 'stabilized'. This date changes markedly from one year to the other seen the high inter-annual variability of seasonal rainfall (App.I, Table 1). If the 'first' rains fail the farmer often plants a second crop. This practice ensures the farmers of a better harvest security.