Technical Soils Bulletin No: 7

CROPRISK: A computerized procedure to assess the agro-ecological suitability of land for rainfed annual crops.

N. H. Batjes

(April 1987)

MINISTRY OF AGRICULTURE
Rural Physical Planning Division
Jamaica Soil Survey Unit

ABSTRACT

Staff members of the Rural Physical Planning Division of the Ministry of Agriculture, Jamaica are developing the Jamaica Physical Land Evaluation System (JAMPLES). This software package includes the CROPRISK module which assesses the 'agro-ecological' suitability of the land for growing annual crops. This paper discusses the methodology and assumptions on which CROPRISK is based. The axis of CROPRISK is a statistical module which determines the most suitable period for sowing specific annual crops by calculating the probability of having a pre-defined relative decrease from the optimum yield obtainable in a specific geographic area. CROPRISK produces results that can be used to select agro-ecologically adapted crops for a specific location and is therefore highly useful for land evaluation and rural planning. The model will be refined and calibrated when more field data on soils and crops have been collected.

Table of Contents

1 INTRODUCTION 3

1.1 Previous work 3
1.2 The report 2

2 WATER BALANCE MODEL 2

2.1 Physical model 2
2.2 Boundary conditions 3

3 BASIC DATA AND ASSUMPTIONS 6

3.1 Monthly rainfall totals 6
3.2 Effective rainfall 6
3.3 Potential evapo-transpiration 7
3.4 Optimum and actual crop evapo-transpiration 8
3.5 Active root zone 9
3.6 Available soil moisture capacity 9
3.7 Crop available soil moisture reserve 12

4 YIELD RESPONSE TO WATER STRESS 13

4.1 Defining the probable growing period 13
4.2 Theoretical model 14
4.3 Normal yields obtainable 15

5 RATING SYSTEM FOR LAND EVALUATION 16

5.1 Agro-climatic suitability 16
5.2 Agro-ecological suitability 17

6 DISCUSSION AND RECOMMENDATIONS 22
7 REFERENCES 23
8 APPENDICES 27

1 INTRODUCTION

1.1 Previous work

Since November 1985 Jamaica Soil Survey Unit staff have been elaborating and testing their computerized Jamaica Physical Land Evaluation System (JAMPLES). This software package, which is written in the BASIC language for both CP/M and DOS operated systems, has been developed for land suitability appraisals at a scale of 1:25,000 to 1:50,000 (see Batjes, Bouwman & Sinclair, 1986).

JAMPLES determines the feasible crops for a specified map unit on the basis of the environmental characteristics of the land and the agro-ecological requirements of the crops. First, the temperature requirements of the crop are weighed against the temperature range that occurs in a map unit (Batjes, 1986a). If temperature is not a limiting factor, it is assessed whether the specified crop can be grown on a sustained basis considering the resistance to soil erosion of the land (Bouwman, 1985) and the water requirements of the crop (this Technical Bulletin). If none of these factors are limiting the remaining, relevant land qualities are matched against the soil requirements of the crop using the soil and crop data base and the matching module (Bouwman, 1986). The result so far has been a series of tables showing the degree of limitations of the soils for each crop.

The first release of JAMPLES did not give a land suitability class because this would have required for a statement on the yields obtainable and economic returns. This type of assessment was not possible because site specific data on water-soil-crop-yield relations are scanty in Jamaica so that correlation studies are not feasible. The necessity of making statements about the yield obtainable in a specific area, however, is crucial when assessing the agricultural potential of that area. The Rural Physical Planning Division recognized this and as a consequence CRIES (1985) developed a yield model for Jamaica. This model proved to be mainly of academic value and could not be used for planning. Considering this limitation, the author developed the CROPRISK module which is discussed in this paper.

The CROPRISK module calculates the probability of obtaining a set relative departure from the maximum yield level of specific crops which are grown in a specific location (temperature, rainfall, evapotranspiration and soils). Under these conditions the relative decrease from the maximum yield of a crop can be readily quantified because the maximum yield for the area will always be 100 percent. This type of approach thus requires far less data than a yield simulation model of the CRIES type, which is in line with the status of the actual data base in Jamaica, and will produce results that can be used for agricultural planning.

1.2 The report

Many physical relations have to be considered when modelling the soil water balance (Section 2) so that the assumptions and parameters must be defined clearly (Section 3). This discussion is necessary to validate the yield-water model which is discussed in Section 4, and to appreciate the limitations of the model when drawing conclusions for land evaluation. The agro-ecological suitability of a map unit for a given use can be rated with the 'key' which is discussed in Section 5. This key, which is in a developmental stage, considers both the climatic constraints of the land and the limitations of the soil for growing a specific crop. The key (CROPRISK) is applied to test cases from Jamaica in the Appendices which also include examples of the computer listings. The results are discussed in Section 6.

2 WATER BALANCE MODEL

2.1 Physical model

A water balance states that in a given volume of soil the difference in the amount of water added (WATin) and the amount of water used during a certain time period (WATout) is equal to the change in the water content (DWAT) during the same period:

$$[1] \qquad DWAT = WATin - WATout$$

When WATin exceeds WATout the change in water content is positive; the soil moisture reserve increases up to a plateau level. When DWAT decreases to zero the crop will increasingly suffer from water stress which in turn will depress the yield (see Section 4).

The variables in equation [1] need to be discussed separately. Water that reaches the soil as precipitation (R_j) and irrigation (I_j) partly infiltrates the soil, can stagnate at the surface or flow downhill as surface runoff (SR_j) depending on the characteristics of the land, the type of crop, and the level of management. Infiltrated water will be stored in the soil ($DWAT_j$). In periods of a temporary surplus a part of the infiltrated water can drain below the root zone (D_j). The stored water will partly evaporate through the soil surface (E_j), and partly be extracted by plant roots to be transpired to the atmosphere (T_j). Additional water may reach the solum either by capillary rise from moist and wet layers that occur below the rooted soil zone, and by runoff from adjacent fields. These amounts are added to WATin.

Summarizing, the amount of water that reaches the soil mainly consists of:

$$[2] \quad WATin = Rj + Ij$$

The water use component can be written as:

$$[3] \quad WATout = SRj + Ej + Tj + Dj$$

The total water balance for period j (e.g. months) reads:

$$[4] \quad DWATj = Rj + Ij - (AETj + Dj + SRj) + DWAT(j-1)$$

The months which constitute the growing season are termed j in equation [4]. For annual crops j varies between 3 and 4, that is 90 and 120 days of growth from planting to harvesting respectively. AETj is the actual evapo-transpiration of the crop, i.e the combination of terms Ej and Tj. DWAT(j-1) is the amount of water that is stored in a crop available form in the soil at the end of the previous time period (j-1).

Only the vertical flowing of water within a soil is described with equation [4], which is a simplification of reality. Sophisticated models, which describe the multi-directional flow of water in soils and the use of water by crops, have been developed by e.g. Makkink & van Heemst (1975) and Feddes, Kowalik & Zaradny (1978). These models require many input variables which mostly are not measured easily, and therefore are seldomly applicable in Third World countries. The CROPRISK module, however, requires data that are readily available for most areas.

2.2 Boundary conditions

The following boundary conditions need to prevail for an annual crop which requires k-months from sowing (j=i) to harvesting (j=i+k):

$$[5a] \quad DWAT1 = R1 + I1 - (AET1 + SR1 + D1) + DWAT0$$

$$[5b] \quad DWAT2 = R2 + I2 - (AET2 + SR2 + D2) + DWAT1$$

$$[5c] \quad DWAT3 = R3 + I3 - (AET3 + SR3 + D3) + DWAT2$$

$$[5d] \quad DWAT4 = R4 + I4 - (AET4 + SR4 + D4) + DWAT3$$

where $0 \le DWATj \le DWATmaxj$. The month of sowing/planting is i, with 1<= i <=12, and the number of months to harvesting is k (k= 3 or 4 months depending on the type of annual crop). The total length of the growing season is j, where 0 <= j <= 4.

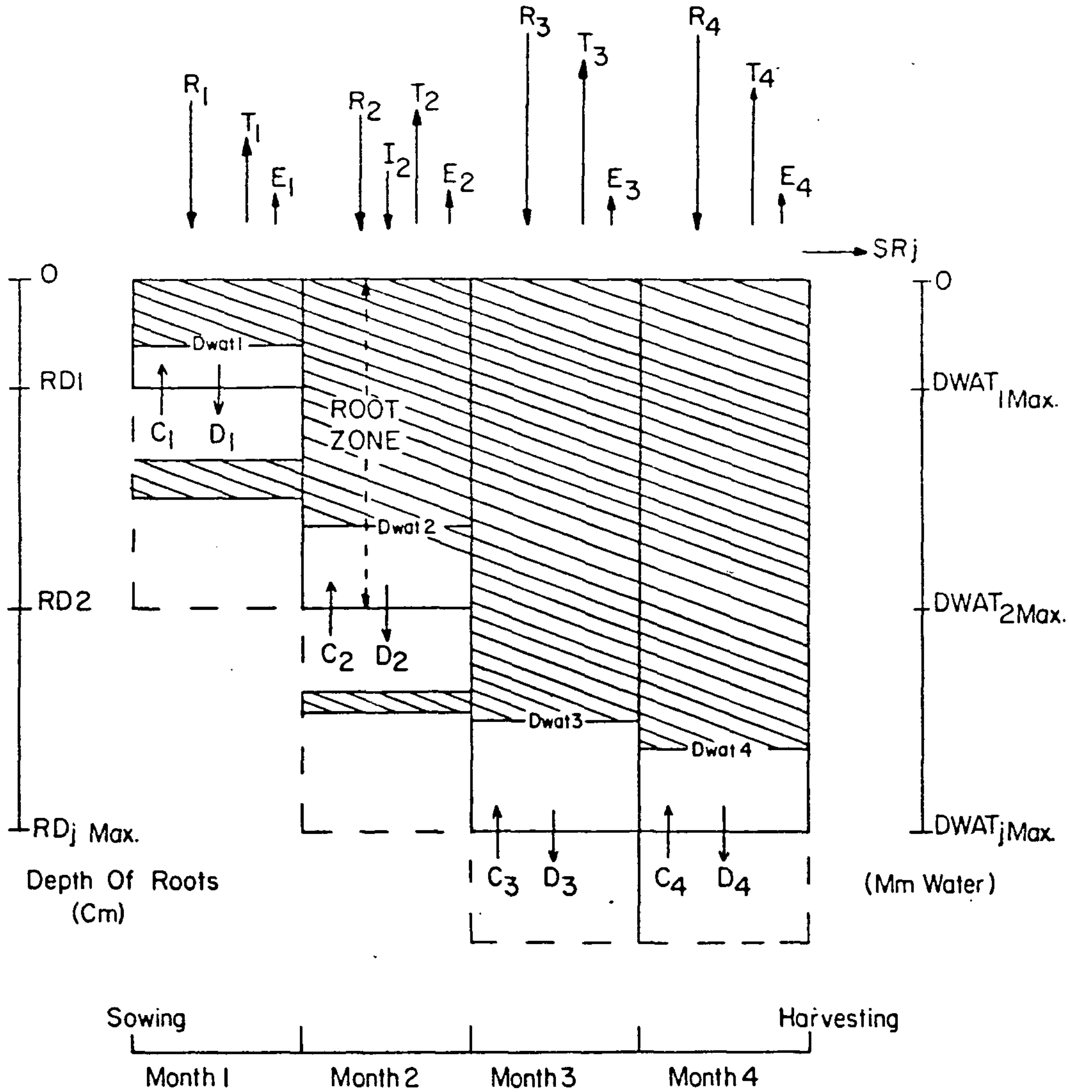
DWATj (e.g j in DWAT1 is 1) can either:

- a) exceed the plateau level for the volume of water that can be stored in the soil in a form available to crops. The surplus will be lost from the soil-plant system assuming that there is no significant capillary rise from below the rooted soil layers.

- b) range between the plateau level for plant-available water (DWATmaxj) and zero (DWATminj), in which case the plant will increasingly suffer from water stress.

- c) be equal to zero, in which case the soil will contain no plant available water so that the crop dies.

A schematic representation of the water balance model is given in Figure 1. The assumptions which underlie equations [5a] through [5d] will be discussed in Section 3.



R_j = Rainfall

I_j = Irrigation

E_j = Evaporation

T_j = Transpiration

SR_j = Surface Runoff

C_j = Capillary Rise

R_j = Drainage

$DWAT_j$ = Crop Available Moisture Reserve

RD_j = Rooting Depth

Figure 1: Schematic representation of the water balance model used in CROPRISK.

3 BASIC DATA AND ASSUMPTIONS

3.1 Monthly rainfall totals

The CROPRISK module requires monthly rainfall totals on computer disk files as one of its input variables. Rainfall files can be created with the JAMPLES package using option-A (ENTERAIN), updated/corrected with option-B (RAINCOR), and statistically analyzed with option-C (POWSTAT) (Batjes, 1986a). Listings of the input and output files can be printed with option-D (RAINSTAT, see Appendix I).

A minimum of 20 years is needed to create meaningful climatic data files; simulation with data series over 20 years long allow to express the seasonal variation in soil moisture content, and hence in obtainable yield levels, due to climate. Ideally, shorter period rainfall totals - 5 or 10 days - should be used in water balance-yield studies but such data are not readily available in computer format in Jamaica.

3.2 Effective rainfall

Rainfall that reaches the surface of the soil will infiltrate or runoff. Runoff occurs when the intensity of the rainfall exceeds the capacity of the soil to absorb water and the land is sloping. The figures in Table 1 show that runoff can be reduced to acceptable proportions by using cultural practices which help maintain the infiltration capacity of the topsoil.

Table 1: Relative efficiency of soil surface treatments in preventing runoff.

Soil surface treatment	runoff (%)	maximum infiltration rate (mm/hr)
Bare soil:		
undisturbed	69	13
hoed fortnightly	51	23
hoed after every storm	43	31
Mulched soil:		
groundnut shells	11	>127
dead grass	10	>127
sorghum stalks	2	>127

After Lawes (1966), quoted in Lal (1981).

The efficacy of the cultivation practices depends on the soil characteristics and cropping methods. Soils developed on shales of the Richmond Beds are noted in Jamaica for their inherently poor infiltration rate and low permeability (Vernon, 1960). Multiple cropping and crop rotation substantially reduce splash erosion and runoff when the crops are adequately selected due to the continuous crop cover (Wahab et al., 1976).

According to Lal (1981) soil management practices are more crucial to runoff and erosion control than the selection of suitable crops and slopes. Similarly, De Meester et al. (1979) found the runoff from a Typic Chromoxerert and a Typic Xerochrept to be less for the deeper ploughed soils and that runoff seems to be independent of slope. 'Erosion promoting' crops, like maize and cassava, hence can be grown on a wide range of slopes provided that the management techniques are good.

The amount of runoff in CROPRISK is estimated from the general range in slope angle of the land and ranges from 5 to 40 percent. The ranges are in line with results of runoff studies discussed in Greenland & Lal (1981).

3.3 Potential evapo-transpiration

Potential evapo-transpiration (PET) is the maximum evapo-transpiration from an extensive area of 8 to 15 cm tall, healthy green grass that is actively growing, completely shading the ground, and in ample supply of water and nutrients.

PET can be estimated from a score of methods depending on the amount, accessibility and quality of the available meteorological data (see ILACO, 1981; Bookers, 1984; Samani & Hargreaves, 1986; IICA, 1983). Monthly PET rates, which are used at RPPD, are derived from IICA (1983). IICA applied the Priestley & Taylor formula to eleven stations in Jamaica for which monthly temperature and insolation readings were available for approximately 10 years. These values were extrapolated to other rainfall stations using linear regressions of monthly PET against elevation. The predictive value of these equations is fair to good ($0.43 < r\text{-squared} < 0.84$).

PET is an important factor in determining the water requirements of a crop (see Section 3.4). Therefore, its size will strongly influence the outcome of the model. The value which is calcultated for PET, however, varies markedly with the calculation method. Table 2 illustrates this point for Monymusk, in the Clarendon Plains, where monthly PET values have been calculated with the Penman, Radiation, Blaney & Cridle, Pan and Priestley & Taylor method. In this specific case, the PET values according to Priestley & Taylor are in the middle of the range observed for the other calculation methods.

Table 2: Potential evapo-transpiration at Monymusk calculated with 5 different methods (mm/day).

Method	J	F	M	A	M	J	J	A	S	O	N	D
Penman	3.4	4.2	5.3	5.6	5.7	5.4	5.9	5.7	5.3	4.3	3.6	3.5
Radiation	3.8	4.4	4.7	5.8	5.0	4.7	5.0	5.1	4.6	4.0	3.6	3.6
Blaney-Cr	3.4	3.5	3.7	4.0	3.9	3.9	4.0	4.2	3.7	3.4	3.3	3.3
Pan (.85)	2.8	3.5	4.5	3.9	3.7	4.5	5.0	4.3	4.4	3.7	2.8	3.5
Priestley	3.4	3.9	4.6	4.8	4.9	5.1	5.0	4.8	4.4	4.3	3.6	3.4

Source: Chanduvi & Arletti (1986) and IICA (1983).

3.4 Optimum and actual crop evapo-transpiration

The optimum evapo-transpiration (ETc) of a healthy agricultural crop grown under optimum agronomic conditions and irrigation is:

[6] ETc = kc * PET

where kc is the crop coefficient for the specific growing stage and type of crop under the prevailing conditions of climate. Indicative values for crop coefficients have been derived from FAO (1979a, p.25). They need to be checked against results from field trials under Jamaican conditions.

The actual rate of evapo-transpiration by a crop (AET) will depart from ETc when water deficits occur in the rooted soil zone:

- a) AET = ETc when the soil moisture supply is near field capacity;
- b) AET = FI * ETc, where 0 <= FI <= 1, when the soil holds water in the crop-available suction range away from the field capacity (see Section 3.6 & 3.7);
- c) AET = 0 when the roots cannot extract water from the soil due to high suction forces.

Conditions a) and c) are simple to program. This is not so for condition b) since a restriction occurs which is due to the nature of the climatic data base (monthly values for PET and rainfall). AET can be approximated with the equations of FAO (1979b, p. 171) and Wood & Dent (1983, p. 4.15) when 5-day or 10-day data are available. An alternative approach to quantify the change from ETc to AET with decreasing amount of the crop-available, soil moisture reserve is needed when monthly rainfall totals are used. This method is discussed in Section 4.

3.5 Active root zone

Roots grow in a soil according to a genetically determined pattern as modified by environmental factors like crop density, soil characteristics, climate, tillage practices and fertilizer use (see Russel, 1980). Accurately describing and modelling the proces of root growth for individual crops would be a tedious and cumbersome task. Hence, a simple subroutine to simulate the growth of roots, has been developed.

The subroutine assumes a 'plateau-level' for the rooting depth in time, where the plateau corresponds with the average maximum rooting depth of the crop (rd) in the specified time period. The rooting depth of the crop has been set at rd/5, rd*3/5, rd and rd in month 1, 2, 3 and 4 respectively. '1' stands for the month of planting, and '3' or '4' for the month of harvesting, which varies with the period needed by the crop to reach its physiological maturity. 'rd' in CROPRISK can never exceed the effective depth of the soil (RDm; e.g. depth to hard rock or to an extremely acid subsoil). An indicative value for RDm can be derived from soil profile descriptions in the survey reports prepared by JSSU staff, or from FAO (1979b) and Bookers (1984).

The amount of water in a soil that can be extracted by plant roots varies with the intensity, type and the depth of occurrence of the roots (e.g. ILACO, 1981; Russel, 1980). The CROPRISK module is based on the assumption that all roots contribute equally to the water demand of the plant.

3.6 Available soil moisture capacity

The intensity with which water is held by a soil can be expressed in units based on the concept of suction (matric head). Water which is held at a given suction can only be extracted if a crop can apply a higher suction to the soil. As the soil becomes drier (higher pF value) and shows higher content of dissolved salts the stored moisture will become less readily available to crops. The crops will wilt and eventually die in case of severe stress.

A crop can only extract some of the moisture stored in a soil. Soil moisture is considered to be available for most crops over the 100 to 16000 cm water range. This corresponds with the pF2 to pF4.2 range. The corresponding volume of soil moisture is termed 'Total Available Water Capacity' (TAWC, in mm water/dm soil) in this report.

pF2 is often referred to as the 'field capacity' and pF4.2 as the 'permanent wilting point'. pF4.2 is generally taken as the lower limit for plant available water in a soil; above pF4.2 most plants will never recover from water stress even when supplied with ample irrigation. In practice, however, a crop can only extract soil moisture with little constraints over a pF range which is narrower than from pF2 to pF4.2. Yields decrease towards the higher pF values; crops are therefore irrigated before the permanent wilting point is reached. For most crops this is as soon as the soil is at pF3 or when a given depletion of the TAWC has occurred (see FAO, 1979a). The pF2 to pF3.7 range is often used as an indication for the 'Readily Available Water Capacity' (RAWC) under rainfed conditions (e.g. Wielemaker & Boxem, 1982).

The RAWC (pF2-pF3.7) to TAWC (pF2-pF4.2) ratios of a limited number of soils from the Netherlands have been calculated from the data presented by Wosten, Bannink & Beuving (1986) (Table 3). The ratios vary from 93 percent for coarse textured soils to 75 percent for very fine textured soils. The rule of thumb for the tropics is that about 75 percent of the TAWC is readily available to most crops (see Bookers, 1984; FAO, 1979b).

Table 3: Effect of soil texture on the RAWC/TAWC ratio in a number of soils from the Netherlands.

	clay size minerals				
	<8%	8%-18%	18%-35%	35%-50%	>50%
RAWC/TAWC (%)	93	87	81	82	75

The relative amount of the TWAC that will be readily available to plant roots is higher for coarse textured than for fine textured soils (Table 3). Coarse textured soils hold their relatively small volumes of available water at suctions close to field capacity; water in that suction range is most readily extracted by plant roots. A large part of the TAWC of fine textured soils is stored in very fine pores and in the diffuse electric double layer. Fine textured soil with a high content of water by volume at pF4.2 can therefore contain a small amount of plant-available water.

The above is clearly illustrated by the following examples from the St. Catherine Coastal Plain. A silt loam from a Typic Haplustoll (Caymanas soils; 60-100 cm depth) holds 30.9 percent of water by volume at pF2 and 15.4 percent at pF4.2. The TAWC of this soil is 15.5 percent. A clay sample from a Typic Chromustert (Lodge soils; 60-100 cm depth) retains 51.9 percent of water at pF2 and 43.5 percent at pF4.2. The TAWC of this fine textured soil is 8.4 percent.

Curves which depict the relation between the moisture content of a soil and its pF value (pF-curves) often are approximately linear over much of the pF2 to pF4.2 range. The CROPRISK module therefore assumes a linear decrease and increase of the soil moisture content over the pF2 to pF4.2 range. Departures from this assumption are most obvious for compact, swelling clay soils (Vertisols), coarse textured soils (Arenosols), and peat soils (Histosols) which show marked hysteresis.

The Jamaica Soil Survey Unit (JSSU) at present does not have sufficient pF-results to correlate the soil moisture content at given suctions with the textural class, organic matter content, bulk density and mineralogy class of the soil. Multilinear regression functions, which encompass the previous set of data, would allow to estimate the TAWC of any soil from its physical and chemical characteristics. Such functions have been used for interpolation when they have a good predictive value (see Saxton et al., 1986), but generally they cannot be extrapolated from one area to the other.

The TAWC of soils in Jamaica can be estimated from the general figures in Table 4.

Table 4: Estimated Total Available Water Capacity (TAWC) for different textural classes.

	TAWC in cm water / m soil							
	sand	sandy loam	loam	silt loam	clay loam	silty CL	silty clay	clay
ILACO ('81)	6-10	9-15	14-20	----	16-22.	----	18-23	20-25
Bookers(84)	7-10	13-15	16	17-18	13-15	15	14	10-13
JSSU	----	7-14	11-15	17	16-24	19-25	13-20	6-14

The TAWC of three clayey, gibbsitic, isohyperthermic members of Typic Eutrorthoxs, which are formed on bauxitic deposits in Jamaica, is 12.5 +/- 4.7 % by volume (n=8). Andriesse & Scholten (1982) reported similar TAWC values for a clayey, gibbsitic, isohyperthermic, Haplic Acrorthox from Jamaica, namely 14.5% for the topsoil and 11.4% for the oxic horizon. These clayey, gibbsitic Oxisols thus have moisture retention characteristics that are similar to those of coarse textured soils, except that they retain a higher amount of water at the wilting point. This feature is well documented for Oxisols (see Wambeke, 1974; Andriesse & Scholten, 1982 p. 36).

The fact that the water release characteristics of a soil are strongly influenced by the type of mineralogy follows also from the results in Table 5. Fine, montmorillonitic, isohyperthermic members of Chromusterts and Chromuderts, which are formed on old alluvial sediments, limestone and shales in Jamaica, have similar values for TAWC.

Table 5: TAWC's of fine, montmorillonitic, isohyperthermic Chromusterts and Chromuderts formed on old alluvial sediments, limestone and shales in Jamaica.

Lithology	n	mean +/- stand. error	CV (%)
Old alluvium	20	9.2 +/- 2.7	30
Limestone	12	9.2 +/- 2.9	32
Shales	11	10.9 +/- 3.9	36
All samples	43	9.7 +/- 3.3	33

CV= coefficient of variation

The capacity of a soil to store water in a crop-available form varies with cultivation practices. A 40 to 60 percent decrease of the TAWC in three medium textured Haplustolls occurred presumably as a result of compaction due to wheel traffic of heavy farm machinery (in Campbell, Commissaris & de Wit, in press).

From the foregoing it follows that soils with a similar textural class can have widely varying water release characteristics. These differences can be due, amongst others, to a varying mineralogy and the cultivation history. Hence, the clear need for additional site specific research on pF-soil moisture retention relations by JSSU.

3.7 Crop available soil moisture reserve

The maximum amount of soil moisture that is readily available to roots ($DWAT_j$) of a specific crop in time period j can be approximated from the figures in Table 4 and 5 using:

$$[7] \qquad DWAT_j = TAWC * RD_j * 0.75$$

where RD_j is the effectively rooted soil zone in period j. The depletion factor (0.75) is the average percentage of the TAWC that can be used before the crop will suffer markedly from water stress, that is before the crop's AET will drop below ETc. The depletion factor is set at 75 percent for all soils pending further field studies.

The use of equation [7] implies that several assumptions are understood: a) that the RAWC of a soil does not vary with depth, and b) that the water it holds in a crop-available form is equally available over the corresponding pF-range, irrespective of its depth of occurrence within the rooted soil layer. These assumptions hold only for uniformly textured soils, as the volume of crop-available water varies with depth in a layered soil and this water will not be equally available to all roots. The hydraulic conductivity as a function of soil depth will further influence the redistribution of water within the soil and thus influence the rate of water uptake by a plant.

The concepts of TWAC and RAWC apply mainly to freely drained soils, and will therefore have shortcomings when applied to soils with an impeded drainage.

4 YIELD RESPONSE TO WATER STRESS

4.1 Defining the probable growing period

FAO (1981) defines the growing season as the continuous period during which rainfall exceeds more than half the potential evapo-transpiration (PET, Penman method) including a number of days required to evaporate 100 mm of soil moisture reserve. Wood & Dent (1983) varied the possible, maximum available soil water capacity from 50 to 200 mm in their model. A variable view of the crop available water capacity is also used in the CROPRISK module.

FAO's (1981) definition of the growing period excludes any period during which a crop cannot grow because temperature is unfavourable. In Jamaica, these conditions are assessed by linear regression of air temperature against elevation (Batjes, 1986b).

The probability of having one or more growing seasons, and their expected respective lengths, must be statistically assessed in agro-ecological studies (see FAO, 1983). Appreciating the importance of rainfall variability and reliability when assessing the beginning and the length of the growing season(s) is crucial in any agro-economic study. And this especially when the amount and distribution of monthly rainfall is highly variable in time and space as is the case in Jamaica (Batjes, 1986a, 1987; IICA, 1983; Samani & Hargreaves, 1986). IICA (1983) used the 'one-out-of-four years' chance of having monthly rainfall totals exceed 0.5 times PET in at least two consecutive months as the measure for the growing season. This criterion is commonly used in agro-economic studies for tropical regions because it relates well to a risk bearable by small farmers who operate under rainfed conditions.

The minimum length of the growing season in 75 percent of the years can be computed with the RAINSTAT module of JAMPLES (Appendix I). This assessment indicates when annual crops could grow satisfactorily -not necessarily optimum yield- but it can not specify the most suited month(s) of sowing. The methodology for assessing the most suitable period of sowing a specific annual crop is discussed in Section 4.2.

4.2 Theoretical model

Crop yields and crop transpiration under experimental conditions are often reported to be directly proportional (De Wit, 1958; Hanks, 1984). The effect of water deficit on the yield of many crops have been discussed by Doorenbos & Kassam (FAO, 1979a). Their study shows that a linear relationship between yield and the actual evapo-transpiration of a crop is a good approximation for many practical yield-water studies where other factors (constraints) are equal.

The relation between the relative decrease in yield and the relative evapo-transpiration deficit of a crop can be described with:

[8] $(1- Ya/Ym) = ky * (1- AET/ETc)$

where Ya is the actual harvested yield; Ym is the maximum harvested yield; ky relates the decrease in Ya to the unit decrease in AET; AET is the actual evapotranspiration of the crop and ETc its maximum evapotranspiration (FAO, 1979a).

Equation [8] reflects that AET will drop below ETc when the soil water reserve is less than the water demand of a crop. The growth of the plant will be restricted and its yield negatively affected. Equation [8] also indicates how big at least AET should be to obtain a specific relative decrease (DY) form the optimum yield of the crop in the area. This value of AET can be used in the soil water balance model under the assumption that the water deficit will be spread evenly over the growing season. In any time period during which total rainfall and storage exceed this value for AET the crop can produce at least the pre-specified yield level (DY). Conclusions based on the CROPRISK module therefore should be of a conservative nature.

[9] $(Ym - Ya)/Ym = ky * (ETc - AET)/ETc$
[10] $DY = ky * (ETc - AET)/ETc$
[11] $DY * ETc = ETc*ky - AET*ky$
[12] $AET = (1 - DY/ky) * ETc$

Equations [8] and [12] can predict the relative departure from the optimum yield (DY= 1 -Ya/Ym) under conditions of stress that are due to a limited availability of water when management levels are optimal for the crop. The effect of excess water, which may result in waterlogging, cannot be accounted for with equation [12] (see appendix IV).

Each growing crop suffers in a varying way from water deficits. This effect is taken into account in the 'yield response factor' (ky). 'ky' reflects that the effect of water stress will be proportionally less for crops with a ky factor smaller than 1 than for those with a ky factor bigger than unity (see Appendix IV). 'ky factors' for the eleven annual crops that are included in CROPRISK are shown in Table 6.

4.3 Normal yields obtainable

A rating system to assess the suitability of the land for specific annual crops under rainfed conditions, which is based on the statistical likelihood of achieving a specified departure from the maximum yield obtainable in the area, is presented in Section 5. Therefore, an inventory should be drawn of the actual and obtainable yields in Jamaica which is done in this section.

Table 6 shows the mean yield and the range in yield for eleven annual crops widely grown in Jamaica. These figures, which are extracted from MINAG (1978, 1985) and Barker (1985), correspond with yield data on a parish basis. Hence, they cannot be related to specific conditions of soils, climate or management. Table 6, however, gives an insight to the overall yields that are commonly reached in Jamaica. 'Normal' yields are the target yields set out by the Ministry of Agriculture in its Crop Notes. Ultimate yields can be obtained in the tropics when high yielding varieties are grown under average conditions of management and with good irrigation (source ILACO, 1981).

Table 6: Normal, mean, ultimate and range and in the marketable yield of selected annual crops commonly grown in Jamaica (1000kg/ha).

Crop	days to harvesting	ky factor	normal yield	mean yield	yield range	ultimate yield
Beans (dry)	60- 90	1.15	1.2	0.8	0.7- 1.4	1.0-1.5
Cabbage	90-120	0.95	13.4	12.4	8.1-15.2	---
Cotton (seed)	120-150	0.85	---	1.9	---	2.0-3.0
Maize (grain)	90-120	1.25	---	1.3	1.2- 2.2	4.0-5.0
Irish Potato	120-150	1.10	---	11.1	7.5-15.3	12-18
Groundnut	90-100	0.70	1.7	1.2	0.6- 2.9	1.5-2.0
Sorghum	90-120	0.90	---	1.1	0.8- 1.6	4.0-5.0
Soya	100-130	0.85	---	1.7	1.5- 2.5	1.5-2.0
Sunflower (s)	90-130	0.95	---	2.0	---	1.5-2.0
String beans	60- 70	1.15	6.7	4.9	3.3- 6.7	---
Sweet pepper	60- 80	1.10	16.8	6.9	0.4-14.1	6.0-12
Tomato	60- 80	1.05	13.4	12.9	7.4-22.2	20-40

Sources: Barker (1985), ILACO (1981) and MINAG (1978, 1985)

Ultimate yields in tonnes/ha under rainfed and average conditions of management in the tropics are respectively: .5 to 1 for beans (seeds), 10 to 12 for cabbage, 1 to 2 for groundnut (50% oil), 1.5 to 3 for maize and sorghum (grain), 8 to 12 for irish potato, 3 to 6 for sweet peppers, .5 to 1.5 for tobacco, and 10 to 20 for tomato (ILACO, 1981 p.519). These figures are well in line with those shown for Jamaica in Table 6.

The relatively wide range in yields in Table 6 is due to the variability in soils, climate and management conditions since the data are on an island wide basis. According to ILACO (1981) the yield of a crop can vary by up to 50 percent as a result of the variability in soil conditions and management levels. Similar ranges are likely to occur in Jamaica. The year to year variability of climatic conditions and incidence of pests and diseases can result in a yield range of 40 percent for rainfed crops (ILACO, 1981).

5 RATING SYSTEM FOR LAND EVALUATION

5.1 Agro-climatic suitability

The growing season is the period during which a) equations [5a] through [5d], and b) the temperature requirements of a given crop are met. Combining equations [5a] to [5d] and equation [12] gives:

$$[13] \quad DWAT_j = R_j + I_j - (1 - DY/KY)*ETc - SR_j - D_j + DWAT(j-1)$$

where j is the serial number of the month in the growing season.

Equation [13] allows to calculate the probability of obtaining a pre-specified relative yield decrease, as compared to the maximum yield obtainable for the considered crop and location, as a function of the initial month of planting and the rainfall characteristics during the following period to harvesting. The number of months that will be needed to reach phenological maturity, varies with the type of crop grown (see Table 6).

The rating module for the 'agro-climatic' suitability of a map unit for a given crop is based on the estimated probability of obtaining a 'good' marketable yield. A 'good' marketable yield has been considered to be the 'target' yield set out by the Ministry of Agriculture (see Table 6), which on the average is 20% to 40% less than the maximum yield obtainable under average conditions of management and under irrigated conditions.

In the context of this study a 'good' yield is defined on the basis of the joint probability of obtaining:

- a) 80 percent of the crop's maximum marketable yield obtainable in the study area (DY=20%), and

- b) a 40 percent departure from this maximum marketable yield (DY=40%).

The calculated range in these two probabilities forms the basis of the 'agro-climatic' rating system.

The *'agro-climatic'* suitability classes, which have been distinguished for annuals which are grown under rainfed conditions, are (see Appendix II):

- Highly suitable (HiS): 80 percent of the crop's maximum yield can be obtained in at least 6-out-of-10 years, and 60 percent of this yield in at least 8-out-of-10 years.

- Moderately suitable (MoS): 80 percent of the crop's maximum yield can be obtained in at least 4- to 6-out-of-10 years, and 60 percent of this maximum in at least 6- to 8-out-of-10 years.

- Marginally suitable (MaS): 80 percent of the crop's maximum yield can be obtained in at least 2- to 4-out-of-10 years, and 60 percent of this maximum in at least 4- to 6-out-of-10 years.

- Not suitable (NS): 80 percent of the crop's maximum yield will be obtained in less than 2-out-of-10 years, and 60 percent of this maximum in less 4-out-of-10 years.

An example of an 'agro-climatic' assessment for maize in the Linstead area is shown in Figure 2,and explained further in the Appendices.

The 'agro-climatic' suitability rating is based on the assumption that water is the only factor that will limit the development of the crop. In practice, however, other land qualities can be limiting, in which case the actual probability of having a 'good' yield will be less than the probability calculated with the CROPRISK module. It is difficult to quantify the impact of these land limitations on the yield levels, but it can be rated qualititatively with the 'agro-ecological' rating module.

5.2 Agro-ecological suitability

The degree of limitations of the remaining 'relevant' land characteristics/qualities - temperature regime of the map unit, erosion hazard, textural group of the control section, soil reaction of the topsoil, availability of oxygen in the rooting zone, availability of foothold for plant roots, salinity and sodicity hazard, content of finely divided calcium carbonate, nutrient retention, nutrient availability and workability for manual and mechanized labour respectively - are assessed with the matching module of JAMPLES (Bouwman, 1986). The results of this analysis in combination with those of the 'agro-climatic' analysis form the basis of the module which rates the 'agro-ecological suitability' of the land for a specific crop. The methodology of this module is dicussed in the following paragraphs.

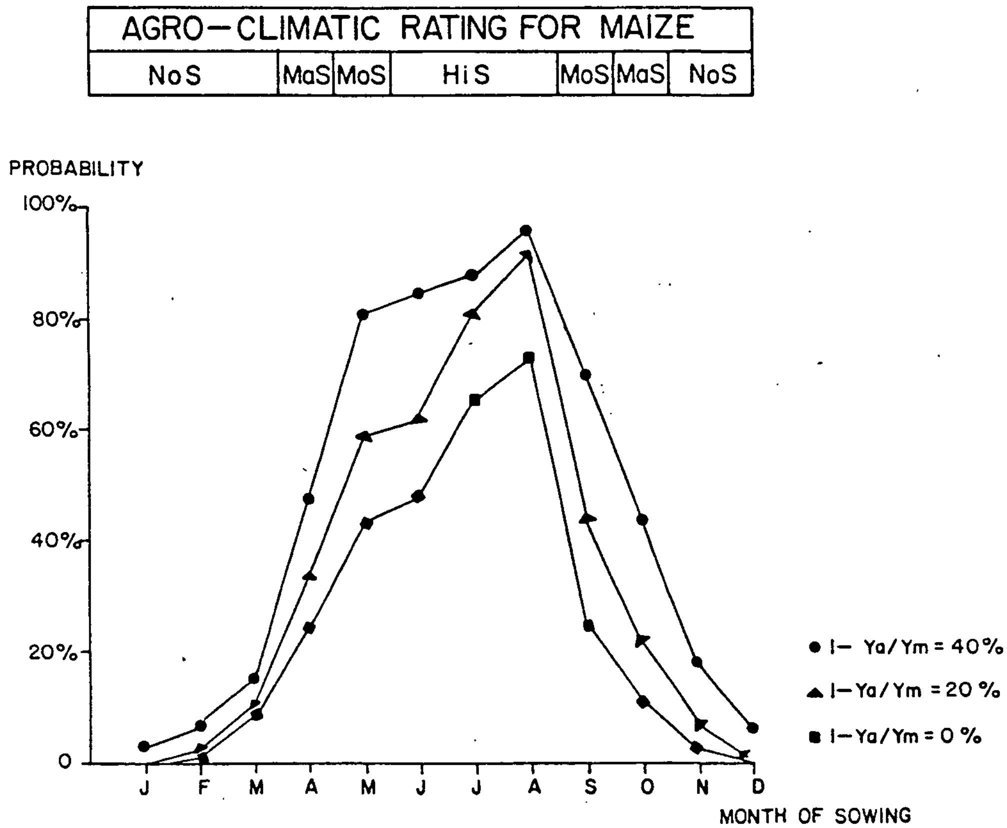


Figure 2: Agro-climatic assessment of individual months for sowing maize on Linstead and Rosemere soils in the Linstead area. (See Appendix 3 for details; maize= 120 days from sowing to harvesting; slope= 8-16%; runoff= 20% of total rainfall; RDm= 50cm; TAWC= 100mm water/100cm soil)

If a map unit does not present any 'soil' nor 'temperature' limitations for growing a specific crop in a given time period, the final *'agro-ecological suitability'* rating for rainfed agriculture is that of the CROPRISK module. If 'soil' or 'temperature' limitations occur, the CROPRISK suitability has to be downgraded. The way in which this should be done, varies with the type and the degree of the soil limitations for the considered crop and growing season. A proposed format for this system follows:

1. If rainfall is strongly limiting (NoS) the 'agro-ecological' suitability for rainfed agriculture is non suitable (N) irrespective of the rating of the other land characteristics/qualities.

2. If temperature is strongly limiting (LT2 and/or HT2) the agro-ecological rating is permanently non suitable (N).

3. If soil loss is not at a tolerable level (E) the 'agro-ecological' rating is currently non suitable irrespective of the rating of the other land characteristics/qualities.

4. If temperature is slightly limiting (LT1 and/or HT1) the 'agro-climatic' rating is downgraded by one class unless there are strongly limiting soil characteristics for the crop.

5. In case temperature is not limiting and soil loss is at a tolerable level, the 'agro-climatic' sutability rating is downgraded as follows:

   - a) Two classes if there are two or three <u>major</u> soil limitations that are strongly limiting (e.g. SA2 and O2);

   - b) Two classes if there is one <u>major</u> soil limitation that is strongly limiting and two to three <u>minor</u> soil limitations that are strongly limiting (e.g. SA2, and NR2 and WH2);

   - c) One class if there are two to three <u>minor</u> soil limitations that are strongly limiting (e.g. WH2 and NR2);

   - d) One class if there is one <u>major</u> soil limitation that is slighlty limiting and at the most two <u>minor</u> soil limitations that are slightly limiting (e.g. NA1 and WM1);

   - e) In case there are less than two <u>minor</u> soil limitations that are slightly limiting the agro-climatic suitability class is not downgraded (e.g. NA1).

6. If neither rainfall, nor temperature nor erosion hazard are limiting, and there are no significant soil limitations, the map unit is deemed 'agro-ecologically' suitable for the considered crop and growing period.

Major soil limitations in MATMOD are soil texture (T), soil reaction (pH), availability of oxygen (O), excessive salinity (SA) and sodicity (SO), content of finely divided calcium carbonate (CC) and soil depth (F). The minor soil limitations are nutrient retention (NR), nutrient availability (NA) and workability by hand (WH) and machine (WM). The relative importance of these soil limitations when assessing the 'agro-ecological' suitability will vary with the type of management used on the farm.

The physical limitations of a soil are of a rather permanent nature and only few of these can be modified if major inputs of capital and technical know how can be made (e.g. drainage and erosion). Such improvements therfore are out of the reach of most farmers. The chemical limitations of a soil, however, can be corrected with relatively simple methods (e.g. liming, fertilizing and mulching) in a modern type of agriculture provided the know how and capital required for this type of operation are available, and that the relevant products can be readily bought and delivered to the farm. In a modern type of agricultural venture the availability of nutrients should not affect markedly the 'agro-ecological' suitability of the land. In case of small farmers, however, a poor chemical status of a soil often remains a bottleneck. The chemical and physical constraints of the soil therefore will have to be rated differently depending on the type of management that is used. Consequently, the type of management should be included in any land evaluation study when describing the relevant land utilization types for the study area (LUT's). This topic will not be elaborated on in this study.

The definitions of the 'agro-ecological suitability classes' are in line with those of the Framework for Land Evaluation (FAO, 1976). Land that rates as 'N' generally has limitations which appear so severe as to preclude any possibilities of succesful sustained use of the land in the given manner. This implies that land which rates as 'N' for rainfed agriculture can rate as 'S1' when irrigated, when the amount and distribution of rainfall is the only constraint for the specified use (i.e. currently non-suitable).

The agro-ecological suitability rating system (Table 7) is applied to test cases from three areas in Jamaica, namely Worthy Park, Linstead and Dawkins in St. Catherine (Appendix III). The system will be used during the land evaluation exercise of the Linstead-Bogwalk area which will allow for the validation and calibration of the CROPRISK module. The BASIC program for 'Table 7' will be prepared after these studies.

Table 7: Provisional system to rate the agro-ecological suitability of land for rainfed annual crops at two input levels (manual and mechanized).

Final suitability class	rating for rainfall	temperature & erosion	No. of soil limitations major Str.	major Sli.	minor Str.	minor Sli.
S1: Highly suitable	HiS	not lim.	none	none	none	1-2
S2: Moderately suitable	HiS	LT1, HT1	none	none	none	1-2
	HiS	not lim.	none	none	2-3	=>1
	HiS	not lim.	none	1-2	1-2	=>1
	MoS	not lim.	none	none	none	1-2
S3: Marginally suitable	HiS	LT1, HT1	none	1-2	1-2	1-2
	HiS	not lim.	1	1-2	2-3	=>1
	HiS	not lim.	2-3	none	none	=>1
	MoS	LT1, HT1	none	none	none	1-2
	MoS	not lim.	none	none	2-3	=>1
	MoS	not lim.	none	1	1-2	=>1
	MaS	not lim.	none	none	none	1-2
N : Not suitable (rainfed)	HiS	LT2,HT2	=>1	=>1	=>1	=>1
	HiS	E	=>1	=>1	=>1	=>1
	HiS	not lim.	=>3	=>1	=>1	=>1
	MoS	LT2,HT2	=>1	=>1	=>1	=>1
	MoS	E	=>1	=>1	=>1	=>1
	MoS	not lim.	=>2	=>1	=>1	=>1
	MaS	LT1,HT1	none	none	none	1-2
	MaS	LT2,HT2	=>1	=>1	=>1	=>1
	MaS	E	=>1	=>1	=>1	=>1
	MaS	not lim.	none	1	2-3	=>1
	NoS		all other combinations that are more unfavourable			

Note: The occurrence of strong limitations (rainfall, temperature, erosion, major soil limitations) is the main factor in determining the final agro-ecological suitability rating, after which the minor soil limitations are considered.

6 DISCUSSION AND RECOMMENDATIONS

The CROPRISK module of JAMPLES assesses the general agro-ecological suitability of land for growing annual crops by weighing the climatic and soil requirements of these crops to the environmental characteristics of the land. As follows from the test cases presented in the Appendices, the results of CROPRISK can be used for land evaluation and rural planning studies at a scale of 1:25,000 to 1:50,000. This is an improvement of the previous situation when these effects could not be studied at the Rural Physical Planning Division. A shortcoming which remains is that the yield level cannot be specified in tonnes/hectare so that an economic assessment is not feasible at present.

The results of the CROPRISK module are based on theoretical soil-water-crop-yield relations and therefore need to be calibrated and validated against results obtained under Jamaican conditions of soils, weather, crops and management. The environmental data bases and crop data base consequently must be expanded to allow calibration and validation studies.

Recording data on crop yields is beyond the scope of the tasks of the Soil Survey Unit. Consequently, the working relation with staff of Agricultural Research Stations should be strengthened.

Additional data on pF curves and on the pF range over which each type of crop can readily extract water from a soil are needed for the CROPRISK module. This type of information will be collected by the Soil Survey Unit during their national soil survey programme. The feasibility of extrapolating this information to other soils with multi-linear regression functions should be investigated once the soil data base contains sufficient, accurate data.

7 REFERENCES

Andriesse, W. & J.J. Scholten (1982): Acri-orthic Ferralsol (Haplic Acrorthox). ISM Soil Monolith Paper No 6, Wageningen, The Netherlands. Anon. (1983): Census of agriculture 1978-1979. Preliminary report. Department of Statistics, Kingston, Jamaica.

Barker, G.H. (1985): Agro-climatic requirements of 59 crops commonly grown in Jamaica. Internal Communication, Rural Physical Planning Division, Ministry of Agriculture, Kingston, Jamaica.

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

Batjes, N.H. (1986b): General temperature zones for land evaluation in Jamaica. Technical Soils Bulletin No. 6, Soil Survey Unit, Rural Physical Planning Division, Ministry of Agriculture, Jamaica.

Batjes, N.H. (1987): An analysis of rainfall variability in St. Catherine for agricultural planning. Miscellaneous Soils Paper No. 4, Soil Survey Unit, Rural Physical Planning Division, Ministry of Agriculture, Jamaica.

Batjes, N.H., A.F. Bouwman & K.M. Sinclair (1986): Jamaica Physical Land Evaluation System: JAMPLES. Technical Soils Bulletin No. 3, Soil Survey Unit, Rural Physical Planning Division, Ministry of Agriculture, Jamaica.

Bouwman, A.F. (1985): Assessment of the resistance of land to erosion for land evaluation. Technical Soils Bulletin No 2, Soil Survey Unit, Rural Physical Planning Division, Ministry of Agriculture, Jamaica.

Bouwman, A.F. (1986): MATMOD: Matching module, Jamaica Physical Land Evaluation System. Technical Soils Bulletin No. 5, Soil Survey Unit, Rural Physical Planning Division, Ministry of Agriculture, Jamaica.

Bookers (1984): Booker tropical soil manual: A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Booker Agricultural International LTD., Pitman Press, Bath.

Campbell, V.A., A.T.L.M. Commissaris & H.A. de Wit (In press): Soil and land use survey of the Coastal Plains of St.

Catherine, Jamaica. Soil Survey Unit, Rural Physical Planning Division, Ministry of Agriculture, Jamaica. (1:50,000)

Chanduvi, F. & E. Arletti (1986): Sugar cane crop water requirements at Monymusk, Bernard Lodge and Inswood, Jamaica. Sugar Industry Research Institute, Mandeville, Jamaica.

CRIES (1985): Agro-economic information system: yield simulation module, version 1.00. Michigan State University, East Lansing.

De Wit, C.T. (1958): Transpiration and crop yields. Verslag Landbouwkundig Onderzoek No. 64, PUDOC ,Wageningen, The Netherlands.

Feddes, R.A., P.J. Kowalik & H. Zaradny (1978): Simulation of field water use and crop yield. PUDOC, Wageningen, The Netherlands.

Greenland, D.J. & R. Lal (1981): Soil conservation and management in the humid tropics. John Wiley & Sons, Chichester.

FAO (1976): A framework for land evaluation. Soils Bulletin No. 32. Food and Agricultural Organization of the United Nations, Rome, Italy.

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

FAO (1979b): Soil survey investigations for irrigation. Soil Bulletin No. 42. Food and Agricultural Organization of the United Nations, Rome, Italy.

FAO (1981): Report on the agro-ecological zone project. Methodology and results for South and Central America. World Soil Resources Report No. 48/3. Food and Agricultural Organization of the United Nations, Rome, Italy.

FAO (1982): Assessment of land resources for rainfed crop production in Mozambique. Land suitability assessment, Vol. 1: methodology and country results. Food and Agricultural Organization of the United Nations, Rome, Italy.

Lal, R. (1981): Soil-conserving versus soil-degrading crops and soil management for erosion control. Chap. 4.1 In: Greenland & Lal (1981).

Hanks, R.J. (1984): Model for predicting plant yield by water use. Agron. J. 66:660-665.

Hargreaves,, G.H. & Z.A. Samani (1986): Crop water requirements and agricultural drought assessment manual. International

Irrigation Centre, Utah State University, USA.

IICA (1983): Agro-climatic study of Jamaica. Inter-American Institute for Cooperation on Agriculture/ORSTOM, San Jose, Costa Rica.

ILACO (1981): Agricultural compendium for the tropics and subtropics. Elsevier Sci. Publ. Co., Amsterdam, The Netherlands.

Makkink, G.H. & H.D. van Heemst (1975): Simulation of the water balance of arable land and pastures. PUDOC, Wageningen, The Netherlands.

Meester, T. de, A.C. Imeson & P.D. Jongerius (1979): Some problems in assessing soil loss from small scale field measurements. In: Lal, L. & D.J. Greenland (Eds) Soil physical properties and crop production in the tropics. John Wiley & Sons, New York.

MINAG (1978): Handbook for credit officers. Volume-I: Crop husbandry guide. Ministry of Agriculture, Kingston, Jamaica.

MINAG (1985): Reports on domestic foodcrops 1982, 1983 and 1984. Data Bank and Evaluation Division, Ministry of Agriculture, Kingston, Jamaica.

Russel, E.W. (1980): Soil conditions and plant growth. Longman, London.

Saxton, K.E. et al. (1986): Estimating generalized soil water characteristics from texture. Soil Sci. Soc. Am. J.: 50:1031-1036.

Vernon, K.C. (1960): Soil and land use survey No. 10 - Jamaica: Parish of St. Mary. The Regional Research Centre, Imperial College of Tropical Agriculture, Trinidad, West Indies.

Wahab et al. (1976): Highlights of the pilot hillside agricultural project at Allsides and Lower River, Southern Trelawny. In: Investigations Bulletin No. 68, Ministry of Agriculture, Kingston, Jamaica.

Wambeke, A. van (1974): Les proprietes agricoles des Oxisols. Pedologie XXIV-2:191-195. (In French)

Wielemaker, W.G. & H.W. Boxem (Eds) (1982): Soils of the Kisii area, Kenya. Dept. of Soil Science and Geology, Agric. Univ. Wageningen/Kenya Soil Survey, National Agric. Laboratories, Ministry of Agriculture, Nairobi. PUDOC, Wageningen, The Netherlands.

Wood, S.R. & F.J. Dent (1983): LECS. A land evaluation computer system methodology. Ministry of Agriculture of

Indonesia/FAO, AGOF/INS/78/006, Bogor, Indonesia.

Wosten, J.H.M., M.H. Bannink & J. Beuning (1986): Water retention and hydraulic conductivities of topsoils and subsoils in the Netherlands. STIBOKA rapport No. 1932, Wageningen, The Netherlands. (In Dutch)

ACKNOWLEDGEMENTS

I would like to thank especially Ir. A.F. Bouwman for his constructive criticism on the methodology and Miss C.S. Clarke for editing the text. Special thanks are also due to Mr. G.M. Derby for drawing the figures.

8 APPENDICES

Computer listings of the RAINSTAT and CROPRISK module of JAMPLES and their application in agricultural planning.

APPENDIX I: Test runs of the RAINSTAT module of JAMPLES

MINISTRY OF AGRICULTURE
RURAL PHYSICAL PLANNING DIVISION
JAMAICA SOIL SURVEY UNIT

JAMPLES: rainstat

The RAINSTAT option gives you:
1] Listings of the climatic files (monthly rainfall totals and PET) in mm/period.
2] The probability of exceeding a given amount of rainfall in 1/10, 2.5/10, 5/10, 7.5/10 and 9/10 years.
3] The probable length of the growing period in 3 out of 4 years.

The following stations have been analyzed:
1 } WORTHY PARK
2 } LINSTEAD
3 } DAWKINS

Ref.: Batjes, N.H. (1986) Technical Soils Bulletin No. 4 & 7.
Jamaica Soil Survey Unit
Rural Physical Planning Division
Ministry of Agriculture

CLIMATIC ANALYSIS FOR WORTHY PARK

Table 1 : Extremes and variability of monthly and annual rainfall totals and potential evapotranspiration for WORTHY PARK in mm. [Data base: 1950 - 1980]

Period	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	YEAR
N	31	31	31	31	31	31	31	31	30	30	30	30	29
Mean	50	56	52	81	187	173	116	153	180	272	109	86	1527
CV (%)	61	66	64	71	64	76	40	48	44	48	54	71	21
Minim.	14	6	3	4	17	24	54	53	41	110	34	18	795
10%-L	19	13	8	16	36	39	60	64	82	130	38	21	1083
25%-L	29	29	28	39	100	81	83	101	122	181	67	42	1297
50%-	44	52	51	73	180	147	111	146	173	251	103	74	1527
25%-U	65	79	75	115	268	238	144	199	231	341	146	117	1757
10%-U	90	108	99	160	355	348	180	253	290	447	191	168	1971
Maxim.	164	170	138	237	518	572	272	422	477	599	283	241	2218
PET	93	96	121	120	124	123	130	121	105	102	93	93	1321

Table 2 : Minimum length of the growing period [LGP] at WORTHY PARK in X out of 10 years [data base: 1950 - 1980].

LGP[X]	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
X=7.5	*	*	*	*	M	M	M	M	H	H	M	*

LGP(X): The minimum length of the growing period in X out of 10 years is the sum of the M's and H's.
H [Humid period (Rain=>PET)] ; M [Moist period (Rain=>.5*PET)] ; * = Dry period (Rain<.5*PET)
In 8 out of 10 years total annual rainfall is in the 1083 - 1970 mm range.
Mean annual rainfall is 1526 mm/year, and mean annual PET is 1321 [IND= .9 in 75 percent of the years].
Note: Each month in a given year has been considered as an independent event.

CLIMATIC ANALYSIS FOR LINSTEAD

Table 1 : Extremes and variability of monthly and annual rainfall totals and potential evapotranspiration for LINSTEAD in mm. [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
10%-L	10	8	6	0	42	53	75	86	85	85	45	8	1110
25%-L	27	21	28	38	127	104	119	120	130	132	83	33	1365
50%-	51	43	54	88	217	174	166	162	178	202	123	78	1640
25%-U	79	74	81	141	308	257	213	212	226	300	164	142	1914
10%-U	108	112	108	193	392	346	257	263	271	422	202	219	2170
Maxim.	155	167	154	244	516	585	312	391	312	631	254	367	2671
PET	103	109	138	142	150	145	154	144	124	122	104	103	1540

Table 2 : Minimum length of the growing period [LGP] at LINSTEAD in X out of 10 years [data base: 1951 - 1977].

LGP[X]	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
X=7.5	*	*	*	*	M	M	M	M	H	H	M	*

LGP(X): The minimum length of the growing period in X out of 10 years is the sum of the M's and H's.
H [Humid period (Rain=>PET)] ; M [Moist period (Rain=>.5*PET)] ; * = Dry period (Rain<.5*PET)
In 8 out of 10 years total annual rainfall is in the 1109 - 2169 mm range.
Mean annual rainfall is 1639 mm/year, and mean annual PET is 1540.34 [IND= .8 in 75 percent of the years].
Note: Each month in a given year has been considered as an independent event.

CLIMATIC ANALYSIS FOR DAWKINS

Table 1 : Extremes and variability of monthly and annual rainfall totals and potential evapotranspiration for DAWKINS in mm. [Data base: 1950 - 1979]

Period	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	YEAR
N	29	29	29	29	28	29	29	29	29	29	28	28	27
Mean	25	26	27	50	94	80	56	88	115	198	90	41	859
CV (%)	101	89	122	102	95	133	99	77	92	85	66	88	38
Minim.	0	0	0	0	1	0	0	5	4	20	9	0	231
10%-L	0	0	0	5	7	0	2	9	21	34	21	0	410
25%-L	6	9	4	17	31	10	16	38	47	82	47	15	626
50%-	21	23	18	39	75	41	43	80	91	162	82	41	859
25%-U	39	39	41	72	138	108	84	130	159	278	125	66	1092
10%-U	59	57	71	115	213	216	133	182	248	420	171	90	1308
Maxim.	88	86	149	254	372	371	212	272	580	737	278	107	1659
PET	109	113	142	147	155	150	158	146	126	127	105	105	1583

Table 2 : Minimum length of the growing period [LGP] at DAWKINS in X out of 10 years [data base: 1950 - 1979].

LGP[X]	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
X=7.5	*	*	*	*	*	*	*	*	*	M	*	*

LGP(X): The minimum length of the growing period in X out of 10 years is the sum of the M's and H's.
H [Humid period (Rain=>PET)] ; M [Moist period (Rain=>.5*PET)] ; * = Dry period (Rain<.5*PET)
In 8 out of 10 years total annual rainfall is in the 409 - 1308 mm range.
Mean annual rainfall is 858 mm/year, and mean annual PET is 1583 [IND= .3 in 75 percent of the years].
Note: Each month in a given year has been considered as an independent event.

can occur in both areas in some years (estimated at 3% to 10%) due to excessive rainfall which can occur in either one of the following months: May, June and October. Planting and reaping should preferably not be done in these months. Droughts can be expected in about 3% of the years.

Note: When interpreting probabilities the following should be understood. A 10% chance of having a specific event implies that the event will occur in 10 out of 100 years, but it does not say in which years it will happen. For instance, it could happen in 10 successive years and not happen in the following 90 years, or happen 1 time in every 10 year period. Another point that should be stressed, is that the calculated probability will become more accurate with increasing length of the data series (e.g. rather 30 years than 20 years).

Appendix I (cont.): Application of RAINSTAT in agricultural planning.

Case 1: A farmer wishes to grow foodcrops under rainfed conditions in either the Dawkins, Linstead or Worthy Park area where he has land that has no soil limitations for the envisaged crop. Which of these areas would be most suitable for growing foodcrops under rainfed conditions?

Tables 1 and 2 in Appendix I show that the Worthy Park and Linstead area are most suitable for the envisaged use. The minimum length of the growing period in these areas is 7 months (May to November) in 75% of the years. At Dawkins, where the minimum length of the growing season in 75% of the years is 1 month (October, see Table 3), foodcrops cannot be safely grown unless supplemental irrigation can be added. Therefore it is recommended to carry out feasibility studies in the Linstead and Worthy Park area. We can now assess whether there are any major climatic differences between these two areas.

The following information on the variability and reliability of annual rainfall at Worthy Park and Linstead can be derived from the corresponding RAINSTAT analyses (in mm):

Area	min.	max.	PET	10%<R<90%	25%<R<75%	10%<I<90%	25%<I<75%
Linstead	838	2671	1540	1110-2170	1365-1914	0.7-1.4	0.9-1.2
Worthy Park	795	2218	1321	1083-1971	1297-1757	1.0-1.3	0.8-1.5

Note: R is the range in total annual rainfall in 80% resp. 50% of the years.
I is the range in the R/PET ratio in 80% resp. 50% of the years.
Data base: Linstead (1951-1977) and Worthy Park (1950-1980)

Very high amounts of rainfall can be expected in 3% to 10% of the years during the following months: May, June and October. The maxima, observed during the period covered by the data base, for these months are respectively 516, 585 and 631 mm at Linstead, and 518, 572, and 599 mm at Worthy Park. Such amounts of rainfall can cause serious damage in various ways. For example by causing severe runoff, landslides, flooding and waterlogging which can result in serious mechanical damage to people, property and crops.

The RAINSTAT analysis reflects that very dry years occurred in the Linstead area (838mm; R/PET=0.5) and Worthy Park area (795mm; R/PET=0.6) during the period under study in about 3% of the years. Rainfall in such years can result in wide spread crop failure of annual crops due to drought and in some damage to tree crops.

The above figures indicate that during most years annual crops can be grown safely in the Worthy Park and Linstead area from May to November. The reliability of rainfall at Worthy Park is higher than at Linstead, which is reflected by the size of the 'I' ratio. The Worthy Park area will be humid in 80% of the years, whereas in the Linstead area about 50% of the years will be humid and 80% of the years sub-humid to humid (see rating for IND in Batjes, 1987). Severe damage

APPENDIX II: Test runs of the CROPRISK module of JAMPLES.

Table 1 : General risk assessment for rainfed annual crops wich require 3 to 4 months from sowing/planting to harvesting and are grown in the WORTHY PARK area on rolling (8-16%) slopes with fine textured soils with a TAWC of 125 mm/100 cm depth under the assumption that 60 - 80 % of the monthly rainfall is effective.

PLANTING DATE:	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
#String bean [RDm = .7 m; 90 days to harvest]												
1-Ya/Ym= 20%	0- 0	0- 0	0- 6	12- 29	25- 48	6- 35	26- 63	62- 89	86- 96	30- 60	10- 20	0- 6
1-Ya/Ym= 40%	0- 16	0- 12	3- 19	29- 54	48- 64	32- 67	60- 83	86- 96	96-100	63- 80	23- 50	6- 16
Suit. rating	NoS-NoS	NoS-NoS	NoS-NoS	NoS-MaS	MaS-MoS	NoS-MaS	MaS-HiS	HiS-HiS	HiS-HiS	MaS-HiS	NoS-MaS	NoS-NoS
#Cabbage [RDm = .7 m; 120 days to harvest]												
1-Ya/Ym= 20%	0- 3	0- 3	3- 12	16- 38	19- 41	30- 63	58- 82	82- 96	44- 75	16- 30	6- 10	0- 3
1-Ya/Ym= 40%	3- 32	0- 29	22- 41	48- 64	54- 90	76- 90	93- 96	96-100	89-100	60- 83	23- 46	10- 33
Suit. rating	NoS-NoS	NoS-NoS	NoS-NoS	NoS-MaS	NoS-MoS	MaS-HiS	MoS-HiS	HiS-HiS	MoS-HiS	NoS-MaS	NoS-NoS	NoS-NoS
#Maize [RDm = .7 m; 120 days to harvest]												
1-Ya/Ym= 20%	0- 0	0- 0	3- 19	12- 41	19- 41	33- 66	65- 93	89- 96	48- 82	26- 43	6- 16	0- 6
1-Ya/Ym= 40%	0- 16	0- 25	12- 41	32- 61	48- 83	63- 90	89- 96	93-100	82- 96	50- 70	20- 36	6- 20
Suit. rating	NoS-NoS	NoS-NoS	NoS-NoS	NoS-MoS	NoS-MoS	MaS-HiS	HiS-HiS	HiS-HiS	MoS-HiS	MaS-MoS	NoS-NoS	NoS-NoS
#Sorghum [RDm = .7 m; 120 days to harvest]												
1-Ya/Ym= 20%	0- 9	0- 22	12- 41	32- 58	38- 74	60- 90	89- 96	93-100	82- 93	46- 66	20- 36	6- 20
1-Ya/Ym= 40%	22- 35	29- 41	41- 54	64- 77	83- 96	93-100	100-100	100-100	100-100	96-100	56- 96	23- 60
Suit. rating	NoS-NoS	NoS-MaS	NoS-MaS	MaS-MoS	MaS-HiS	HiS-HiS	HiS-HiS	HiS-HiS	HiS-HiS	MoS-HiS	MaS-MaS	NoS-MaS

*Two suitabilities are shown to account for the percentage of water which may run off the land, that is for the highest and lowest values respectively.

*Climatic suitability classes (see Batjes 1987: Tech. Soils. Bull. No. 7):

-HiS: 80% of the optimum yield (Ym) can be obtained in at least 6-out-of-10 years and 60% of the optimum yield in =>80% of the years.

-MoS: 80% of the optimum yield can be obtained in 40 to 60% of the years and 60% of the optimum yield in 60 to 80% of the years.

-MaS: 80% of the optimum yield can be obtained in 20 to 40% of the years and 60% of the optimum yields in 40 to 60% of the years.

-NoS: all conditions more adverse for crop growth than those listed under MaS.

*It is assumed that water is the only factor which may limit crop growth. The 'agro-climatic suitability', which also takes into account the limitations of the land for growing the crop, can be assessed from MATMOD and CROPRISK (Tech. Soils Bull. 5 & 7).

*The analysis is based on the 1950 - 1980 climatic data base for WORTHY PARK.

*The analysis is for the following soils: Carron Hall (Typic Chromudert).

[RAWC= 125 * .7 (in cm3/cm3)]

Table 2 : General risk assessment for rainfed annual crops wich require 3 to 4 months from sowing/planting to harvesting and are grown in the LINSTEAD area on rolling (8-16%) slopes with fine textured soils with a TAWC of 125 mm/100 cm depth under the assumption that 60 - 80 % of the monthly rainfall is effective.

PLANTING DATE:	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
#String bean [RDm = .7 m; 90 days to harvest]												
1-Ya/Ym= 20%	0- 3	0- 0	3- 11	22- 40	40- 66	44- 74	55- 70	66- 88	59- 96	33- 55	18- 29	3- 7
1-Ya/Ym= 40%	3- 11	0- 7	7- 11	40- 51	66- 77	66- 88	70- 88	88- 92	96- 96	62- 77	29- 48	7- 22
Suit. rating	NoS-NoS	NoS-NoS	NoS-NoS	MaS-MaS	MoS-MoS	MoS-HiS	MoS-HiS	HiS-HiS	MoS-HiS	MaS-MoS	NoS-MaS	NoS-NoS
#Cabbage [RDm = .7 m; 120 days to harvest]												
1-Ya/Ym= 20%	0- 0	3- 3	11- 11	22- 48	48- 74	55- 77	70- 85	81- 96	44- 62	25- 33	3- 14	0- 3
1-Ya/Ym= 40%	3- 15	7- 15	15- 26	48- 62	81- 81	88- 88	88- 96	96- 96	88- 88	48- 66	18- 40	11- 30
Suit. rating	NoS-NoS	NoS-NoS	NoS-NoS	MaS-MoS	MoS-HiS	MoS-HiS	HiS-HiS	HiS-HiS	MoS-HiS	MaS-MaS	NoS-NoS	NoS-NoS
#Maize [RDm = .7 m; 120 days to harvest]												
1-Ya/Ym= 20%	0- 0	3- 7	7- 11	18- 40	51- 70	40- 74	77- 85	85- 96	51- 74	29- 37	3- 14	0- 3
1-Ya/Ym= 40%	0- 7	3- 7	11- 15	44- 48	70- 81	81- 88	88- 92	96- 96	81- 92	44- 59	14- 29	7- 19
Suit. rating	NoS-NoS	NoS-NoS	NoS-NoS	NoS-MaS	MoS-HiS	MoS-HiS	HiS-HiS	HiS-HiS	MoS-HiS	MaS-MaS	NoS-NoS	NoS-NoS
#Sorghum [RDm = .7 m; 120 days to harvest]												
1-Ya/Ym= 20%	0- 7	3- 7	11- 23	40- 55	66- 81	77- 88	85- 92	96- 96	81- 92	40- 59	14- 29	0- 15
1-Ya/Ym= 40%	15- 30	15- 30	19- 50	59- 77	81- 92	88- 96	96- 96	96-100	96-100	81- 92	48- 66	30- 57
Suit. rating	NoS-NoS	NoS-NoS	NoS-MaS	MaS-MoS	HiS-HiS	HiS-HiS	HiS-HiS	HiS-HiS	HiS-HiS	MoS-MoS	NoS-MaS	NoS-NoS

*Two suitabilities are shown to account for the percentage of water which may run off the land, that is for the highest and lowest values respectively.

*Climatic suitability classes (see Batjes 1987: Tech. Soils. Bull. No. 7):

-HiS: 80% of the optimum yield (Ym) can be obtained in at least 6-out-of-10 years and 60% of the optimum yield in =)80% of the years

-MoS: 80% of the optimum yield can be obtained in 40 to 60% of the years and 60% of the optimum yield in 60 to 80% of the years.

-MaS: 80% of the optimum yield can be obtained in 20 to 40% of the years and 60% of the optimum yields in 40 to 60% of the years.

-NoS: all conditions more adverse for crop growth than those listed under MaS.

*It is assumed that water is the only factor which may limit crop growth. The 'agro-climatic suitability', which also takes into account the limitations of the land for growing the crop, can be assessed from MATMOD and CROPRISK (Tech. Soils Bull. 5 & 7).

*The analysis is based on the 1951 - 1977 climatic data base for LINSTEAD.

*The analysis is for the following soils: Carron Hall.

[RAWC= 125 * .7 (in cm3/cm3)]

Appendix II (cont.): Application of CROPRISK in agricultural planning.

Case: A small farmer wants to grow a crop of cabbage in either the Linstead or Worthy Park area where he owns land. The land, which consists of clayey Carron Hall soils, is on 8 to 16% slopes. In which of the two areas can he best grow his crop?

The recommendation can be derived from Table 1 and 2 in Appendix II, under the assumption that runoff is 20% of total rainfall, in conjuction with the output of the MATMOD module for Carron Hall soils (Typic Chromuderts).

1) Rainfall: the minimum length of the growing season in 75% of the years is 7 months (May to November) in both areas (from RAINSTAT, see Appendix I).

2) Temperature: Not limiting for cabbage in both areas (from MATMOD).

3) Erosion hazard: not limiting for cabbage (from SODEMOD).

4) Soil limitations for cabbage: (from MATMOD)

- major limitations: texture (T1), soil reaction (pH2) and availability of oxygen (O2),
- minor limitations: availability of nutrients (NA2), workability both by hand (WH2) and by machine (WM2)

5) Agro-climatically suited months for growing cabbage:

	MaS	MoS	HiS
Worthy Park	Apr;Oct	May	Jun;Jul;Aug;Sept
Linstead	Oct	Apr	May;Jun;Jul;Aug;Sept

6) Conversion to the agro-ecological suitability: (see Table 7 in section 5)

NoS --> N
MaS --> N
MoS --> N
HiS --> S3

7) Recommendation: Although rainfall is adequate to obtain a 'good' yield (see definition in Section 5) of cabbage in the Linstead (April to September) and Worthy Park area (May to September), this crop is not recommended for Carron Hall soils because these soils have limitations that strongly hamper the growth of cabbage. Hence a different type of crop, which can stand the physical limitations of Carron Hall soils (e.g. pasture), should be considered for the type of land under discussion.

Appendix III: Application of the agro-ecological suitability rating system to tests cases from the Linstead area, St. Catherine, Jamaica.

Case: A small farmer in the Linstead basin wants to plant a variety of climatically adapted maize on his land. The soil map of the area shows that his farm consists of Rosemere and Linstead soils on 8 to 16% slopes. Which of these two soils is most suited to grow maize, and in which month(s) should the maize be sown to get the highest probability of having good yields?

General Methodology: Linstead area: crop= corn (120 days from sowing to harvesting); soil mapping units= Linstead clay and Rosemere clay; slope= 8-16%; assumed runoff= 20% of total montly rainfall; average rootable soil depth= 50cm due to the severe acidity of the compact subsoil.

The proposed classification for Linstead soils is fine, mixed, iso-hyperthermic, Oxic-Humic Paleustalfs (pit No.: 85/85B/114), whereas Rosemere soils are clayey, mixed, iso-hyperthermic members of Oxic Paleustults (pit No.: 85/84B/OP3).

1. Rainfall: The minimum length of the growing season in 75% of the years at Linstead is 7 months, from May to November (from RAINSTAT, see Appendix I).

2. Temperature limitations: not limiting for maize (from MATMOD).

3. Erosion hazard: not limiting for maize (from SODEMOD).

4. Soil limitations, kind and type: (from MATMOD)

	major limitations	minor limitations
Linstead soils	T1; O1	NR1; NA2; WH2; WM1
Rosemere soils	PH2; T1; O1	NR2; NA2; WH2; WM2

Source: Linstead-Bogwalk soil survey

5. Conversion of the agro-climatic rating to the agro-ecological suitability rating (Table 7 in Section 5.2):

Soils:	Linstead	Rosemere
NoS -->	N	N
MaS -->	N	N
MoS -->	S3	N
HiS -->	S2	S3

6. Assessment of the agro-climatically suitable months for growing maize and their respective suitabilities:

Soils:	Linstead	Rosemere
S2	Jun;Jul;Aug	none
S3	May;Sept	Jun;Jul;Aug
N	all remaining months	

7. The CROPRISK module indicates that maize can be sown from May to September with slight to strong limitations in the Linstead area on the soils studied. The period from June to August seems most suitable on the basis of this analysis.

8. Taking into consideration the results of the RAINSTAT analysis for Linstead (see Appendix I) the following, additional conclusions can be drawn. In 10% of the years the months of May and October can receive high amounts of rainfall which may damage crops to some degree (over 375mm/month). In about 3% of the years total rainfall in May, June or October will exceed 500mm and severely damage crops. High rainfall can result in waterlogged soils (Linstead soils are imperfectly drained and have slow permeability) and flooding. High rainfall can further reduce pollination in some crops (e.g. mango), or make the field poorly accessible for farm machinery because of excessive wetness. On the basis of the foregoing the following conclusions can be drawn:

planting	harvesting	crop damage due to excessive rainfall:
May	August	HR or VHR(May), or VHR(June)
June	September	VHR(June)
July	October	HR or VHR(October)
August	November	VR or VHR(October)
September	December	VR or VHR(October)

Note: VHR monthly rainfall over 500mm in about 3% of years
HR monthly rainfall over 375mm in 10% of years

9. Recommendations: Maize can be sown with moderate limitations in the Linstead area from June to August, and with strong limitations in May and September. The most suitable month of planting is June as the germinating crop will be damaged by very high rainfall in only 3% of the years. When maize is planted in either May, July, August or September high rainfall can damage the crop in about 10% of the years. The maize can best be grown on Linstead soils because they have relatively better soil characteristics than Rosemere soils. The chemical characteristics of Linstead soils can be upgraded through fertilizing, but the limitations due to texture and availability of oxygen are of a somewhat permanent nature.

Remarks: The total period during which maize can be sown with strong to no limitations is from May to September (CROPRISK). Using the independent and coarser method outlined in Appendix I gives comparable results for the probable length of the total growing period, namely from May to November with a 'humid' period in September and October. CROPRISK, however, allows for a refinement which is based on location specific information on soils, climate and crops. A further advantage is that it considers the successive months within a year in the statistical module (e.g. joint probability), whereas RAINSTAT (App. I) considers each month within a specific year as an independent event. The fact that rainfall generally is unreliable and erratic towards the beginning and end of the rainy season(s) therefore can be accounted for in the CROPRISK module. RAINSTAT allows to assess the risk of having excessive rainfall which may damage crops.

Table 1 : General risk assessment for rainfed annual crops wich require 3 to 4 months from sowing/planting to harvesting and are grown in the LINSTEAD area on rolling (8-16%) slopes with fine textured soils with a TAWC of 100 mm/100 cm depth under the assumption that 60 - 80 % of the monthly rainfall is effective.

PLANTING DATE:	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
#String bean [RDm = .5 m; 90 days to harvest]												
1-Ya/Ym= 20%	0- 3	0- 0	3- 11	18- 37	40- 62	37- 66	51- 70	66- 88	59- 92	29- 44	11- 14	3- 3
1-Ya/Ym= 40%	3- 7	0- 7	7- 11	40- 51	62- 77	66- 88	70- 88	88- 92	96- 96	48- 70	25- 44	3- 14
Suit. rating	NoS-NoS	NoS-NoS	NoS-NoS	NoS-MaS	MoS-MoS	MaS-HiS	MoS-HiS	HiS-HiS	MoS-HiS	MaS-MoS	NoS-NoS	NoS-NoS
#Cabbage [RDm = .5 m; 120 days to harvest]												
1-Ya/Ym= 20%	0- 0	0- 3	11- 11	18- 48	48- 70	51- 70	66- 81	81- 92	37- 55	14- 29	3- 7	0- 3
1-Ya/Ym= 40%	3- 15	7- 11	11- 26	48- 59	81- 81	81- 88	88- 92	96- 96	77- 85	37- 55	14- 33	3- 23
Suit. rating	NoS-NoS	NoS-NoS	NoS-NoS	NoS-MaS	MoS-HiS	MoS-HiS	HiS-HiS	HiS-HiS	MaS-MoS	NoS-MaS	NoS-NoS	NoS-NoS
#Maize [RDm = .5 m; 120 days to harvest]												
1-Ya/Ym= 20%	0- 0	3- 3	7- 11	18- 33	37- 59	29- 62	59- 81	62- 92	29- 44	14- 22	3- 7	0- 0
1-Ya/Ym= 40%	0- 3	3- 7	11- 15	29- 48	62- 81	62- 85	81- 88	96- 96	48- 70	25- 44	3- 18	0- 7
Suit. rating	NoS-NoS	NoS-NoS	NoS-NoS	NoS-MaS	MaS-MoS	MaS-HiS	MoS-HiS	HiS-HiS	MaS-MoS	NoS-MaS	NoS-NoS	NoS-NoS
#Sorghum [RDm = .5 m; 120 days to harvest]												
1-Ya/Ym= 20%	0- 7	3- 7	11- 23	29- 55	55- 81	66- 85	81- 88	92- 96	48- 66	22- 40	3- 18	0- 7
1-Ya/Ym= 40%	11- 23	7- 30	19- 38	55- 74	81- 88	88- 92	92- 96	96- 96	85- 96	51- 74	29- 48	19- 42
Suit. rating	NoS-NoS	NoS-NoS	NoS-NoS	MaS-MoS	MoS-HiS	HiS-HiS	HiS-HiS	HiS-HiS	MoS-HiS	MaS-MoS	NoS-NoS	NoS-NoS
#Tomato [RDm = .5 m; 90 days to harvest]												
1-Ya/Ym= 20%	0- 3	0- 0	3- 11	22- 37	37- 55	37- 62	40- 66	62- 88	62- 92	25- 40	14- 25	3- 7
1-Ya/Ym= 40%	3- 11	0- 7	11- 11	37- 51	70- 77	70- 88	70- 88	88- 92	96- 96	59- 81	29- 44	7- 18
Suit. rating	NoS-NoS	NoS-NoS	NoS-NoS	NoS-MaS	MaS-MoS	MaS-HiS	MoS-HiS	HiS-HiS	HiS-HiS	MaS-MoS	NoS-MaS	NoS-NoS
#Sweet pepper [RDm = .5 m; 90 days to harvest]												
1-Ya/Ym= 20%	3- 7	0- 0	7- 11	33- 48	48- 70	48- 77	59- 70	81- 88	77- 96	37- 48	18- 25	3- 7
1-Ya/Ym= 40%	7- 19	0- 11	11- 15	44- 55	70- 81	77- 88	74- 88	88- 92	96- 96	66- 81	29- 48	7- 18
Suit. rating	NoS-NoS	NoS-NoS	NoS-NoS	MaS-MaS	MoS-HiS	MoS-HiS	MoS-HiS	HiS-HiS	HiS-HiS	MaS-MoS	NoS-MaS	NoS-NoS

*Two suitabilities are shown to account for the percentage of water which may run off the land, that is for the highest and lowest values respectively.

*Climatic suitability classes (see Batjes 1987: Tech. Soils. Bull. No. 7):

-HiS: 80% of the optimum yield (Ym) can be obtained in at least 6-out-of-10 years and 60% of the optimum yield in 80% of the years.

-MoS: 80% of the optimum yield can be obtained in 40 to 60% of the years and 60% of the optimum yield in 60 to 80% of the years.

-MaS: 80% of the optimum yield can be obtained in 20 to 40% of the years and 60% of the optimum yields in 40 to 60% of the years.

-NoS: all conditions more adverse for crop growth than those listed under MaS.

*It is assumed that water is the only factor which may limit crop growth. The 'agro-climatic suitability', which also takes into account the limitations of the land for growing the crop, can be assessed from MATMOD and CROPRISK (Tech. Soils Bull. 5 & 7).

*The analysis is based on the 1951 - 1977 climatic data base for LINSTEAD.

*The analysis is for the following soils: Linstead, Rosemere.

[RAWC= 100 * depl (in cm3/cm3)]

Appendix IV: Application of CROPRISK in selecting suitable soils for sorghum in the Dawkins area.

Case: A wide range of soil occurs in the Dawkins area namely old alluvial soils and recent alluvial soils. A farmer wants to grow sorghum on the soil that is most suited. How big should the total available water capacity (TAWC) of the soil at least be to allow for rainfed cultivation of the crop?

Assumptions: All soils in the area have no limitations for growing sorghum, the rootable depth of all soils is 100cm, and runoff is 5% of total monthly rainfall. This means that in this *theoretical* case the agro-climatic and agro-ecological suitabilities will be identical.

From Table 1 the following conclusions can be drawn pertaining to the minumum value required for the TAWC as a function of the month during which sorghum is sown.

- November to May: The TAWC of the soil should at least be 200mm/100cm. Soils having such a value for the TAWC do not occur in the area. Hence sorghum should not be sown on any soil during this period under rainfed conditions.

- June: Only those soils which have a TAWC of 150mm/100cm or more will be marginally suitable for sorghum. Only a limited number of soils qualify in the area, namely the moderately fine textured, recent alluvial soils (possibly Whim soils). Planting of sorghum in June therefore remains a very risky business and cannot be recommended.

- July: All soils which have a TAWC of 50mm/month or more will be (very) marginally suitable. The probability of having a 20% decrease form the optimum yield obtainable is low (less than 33%) so that no sorghum should be planted in these months.

- August: August will be moderately suitable for sowing sorghum when the TAWC of the soil is over 50mm/m and the infiltration characteristics are good. The later is generally not the case for the Vertisols formed on old alluvium.

- September: Soils having a TAWC over 100mm/100cm will be highly suitable, and soils with a TAWC below 100mm/100cm will be marginally suitable. (see Table 3 in this Appendix under sorghum). Sorghum could be sown on deep, fine textured, recent alluvial soils.

- October: A TAWC below 50mm/100cm is not suitable; 50-100mm/100cm is marginally suitable; 100-150mm/100cm is moderately suitable and 150-200mm/100cm is highly suitable.

Recommendation: The month of September is best suited for planting sorghum. The soils must have a TAWC of over 100mm/m. Only a limited number of the recent alluvial soils will qualify, namely Ferry and Whim soils (see data in Campbell, Commissaris & de Wit, in press) provided there are no soil limitations. The other months should not be considered for any form of rainfed cultivation of annual crops irrespective of the type of soil encountered.

Note: Rainfall in the Dawkins area generally is low in most months, and therefore it cannot replenish fully the moisture reserve of the soil during most months. This explains why soils that have a moderate to high moisture storage capacity are nevertheless non suitable or marginally suitable for growing annual crops under rainfed conditions in the Dawkins area (see Figure1in this Appendix). The numerical value of the TAWC is of somewhat lesser importance in the Linstead area, where the supply of rainfall is higher and more reliable during the growing season (see Table 2 in this Appendix).

Table 4 : General risk assessment for rainfed annual crops wich require 3 to 4 months from sowing/planting to harvesting and are grown in the DAWKINS area on soils on almost level (0-2%) slopes with a TAWC of 50 to 100 mm/m depth assuming that 85 - 95 % of total monthly rainfall is effective.

PLANTING DATE:	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
*Sorghum [ROm = 1 m; 120 days to harvest]												
TAWC= 50												
1-Ya/Ym= 20%	0- 0	0- 0	0- 0	4- 4	4- 4	8- 16	22- 25	39- 42	21- 39	9- 13	0- 0	0- 0
1-Ya/Ym= 40%	0- 0	0- 0	5- 11	8- 13	17- 17	16- 20	40- 44	67- 71	65- 69	31- 31	0- 5	0- 0
	NoS-NoS	NoS-NoS	NoS-NoS	NoS-NoS	NoS-NoS	NoS-NoS	MaS-MaS	MaS-MoS	MaS-MaS	NoS-NoS	NoS-NoS	NoS-NoS
TAWC= 100												
1-Ya/Ym= 20%	0- 0	0- 0	0- 0	4- 4	13- 13	16- 16	25- 29	50- 50	69- 78	27- 36	0- 0	0- 0
1-Ya/Ym= 40%	5- 5	0- 0	11- 27	26- 30	26- 30	29- 37	51- 55	75- 75	86- 86	68- 72	36- 36	7- 7
	NoS-NoS	NoS-NoS	NoS-NoS	NoS-NoS	NoS-NoS	NoS-NoS	MaS-MaS	MoS-MoS	HiS-HiS	MaS-MaS	NoS-NoS	NoS-NoS
TAWC= 150												
1-Ya/Ym= 20%	0- 0	0- 0	0- 5	13- 13	13- 13	16- 20	25- 29	53- 57	82- 86	45- 59	0- 10	0- 0
1-Ya/Ym= 40%	5- 17	11- 11	11- 33	26- 34	39- 43	37- 54	59- 62	82- 82	91- 91	81- 86	52- 57	14- 21
	NoS-NoS	NoS-NoS	NoS-NoS	NoS-NoS	NoS-NoS	NoS-MaS	MaS-MaS	MoS-MoS	HiS-HiS	MoS-MoS	NoS-NoS	NoS-NoS
TAWC= 200												
1-Ya/Ym= 20%	0- 0	5- 5	5- 11	13- 13	21- 26	20- 25	25- 33	53- 57	86- 91	54- 63	10- 21	0- 0
1-Ya/Ym= 40%	5- 17	11- 11	11- 33	30- 39	47- 47	37- 58	59- 62	85- 85	91- 91	86- 95	57- 73	14- 28
	NoS-NoS	NoS-NoS	NoS-NoS	NoS-NoS	MaS-MaS	NoS-MaS	MaS-MaS	MoS-MoS	HiS-HiS	MoS-HiS	NoS-MaS	NoS-NoS

*Two suitabilities are shown to account for the percentage of water which may run off the land, that is for the highest and lowest values respectively.

*Climatic suitability classes (see Batjes 1987: Tech. Soils. Bull. No. 7):

-HiS: 80% of the optimum yield (Ym) can be obtained in at least 6-out-of-10 years and 60% of the optimum yield in =>80% of the years.

-MoS: 80% of the optimum yield can be obtained in 40 to 60% of the years and 60% of the optimum yield in 60 to 80% of the years.

-MaS: 80% of the optimum yield can be obtained in 20 to 40% of the years and 60% of the optimum yields in 40 to 60% of the years.

-NoS: all conditions more adverse for crop growth than those listed under MaS.

*It is assumed that water is the only factor which may limit crop growth. The 'agro-climatic suitability', which also takes into account the limitations of the land for growing the crop, can be assessed from MATMOD and CROPRISK (Tech. Soils Bull. 5 & 7).

*The analysis is based on the 1950 - 1979 climatic data base for DAWKINS.

*The analysis is for the following soils: [50 <= TAWC <= 200 cm3/cm3]

Table 2 : General risk assessment for rainfed annual crops wich require 3 to 4 months from sowing/planting to harvesting and are grown in the LINSTEAD area on soils on almost level (0-2%) slopes with a TAWC of 50 to 100 mm/m depth assuming that 85 - 95 % of total monthly rainfall is effective.

PLANTING DATE:	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
*Maize [RDm = 1 m; 120 days to harvest]												
TAWC= 50												
1-Ya/Ym= 20%	0- 0	3- 7	11- 11	37- 48	62- 74	66- 70	77- 85	88- 96	48- 51	22- 25	7- 7	0- 3
1-Ya/Ym= 40%	7- 7	7- 7	15- 26	51- 55	81- 81	85- 85	88- 88	96- 96	74- 81	44- 48	14- 25	7- 11
	NoS-NoS	NoS-NoS	NoS-NoS	MaS-MaS	HiS-HiS	HiS-HiS	HiS-HiS	HiS-HiS	MoS-MoS	MaS-MaS	NoS-NoS	NoS-NoS
TAWC= 100												
1-Ya/Ym= 20%	3- 7	7- 7	15- 15	44- 48	74- 81	81- 88	88- 92	96- 96	85- 92	40- 55	14- 25	11- 11
1-Ya/Ym= 40%	11- 19	11- 15	19- 30	55- 62	81- 85	88- 88	96- 96	96- 96	96- 96	66- 74	33- 44	19- 42
	NoS-NoS	NoS-NoS	NoS-NoS	MaS-MoS	HiS-HiS	HiS-HiS	HiS-HiS	HiS-HiS	HiS-HiS	MoS-MoS	NoS-MaS	NoS-NoS
TAWC= 150												
1-Ya/Ym= 20%	3- 11	7- 11	15- 15	44- 51	77- 81	85- 88	88- 96	96- 96	96- 96	66- 74	25- 37	15- 19
1-Ya/Ym= 40%	15- 19	19- 19	26- 42	59- 66	85- 92	88- 92	96- 96	96- 96	96- 96	88- 96	55- 66	34- 50
	NoS-NoS	NoS-NoS	NoS-NoS	MaS-MoS	HiS-HiS	HiS-HiS	HiS-HiS	HiS-HiS	HiS-HiS	HiS-HiS	MaS-MaS	NoS-NoS
TAWC= 200												
1-Ya/Ym= 20%	3- 15	11- 15	15- 19	44- 51	81- 85	85- 92	88- 96	96- 96	96- 96	81- 85	37- 55	19- 26
1-Ya/Ym= 40%	23- 30	19- 19	34- 42	62- 70	88- 96	92- 96	96- 96	100-100	96- 96	92- 96	66- 74	38- 53
	NoS-NoS	NoS-NoS	NoS-NoS	MoS-MoS	HiS-HiS	HiS-HiS	HiS-HiS	HiS-HiS	HiS-HiS	HiS-HiS	MaS-MoS	NoS-MaS

*Two suitabilities are shown to account for the percentage of water which may run off the land, that is for the highest and lowest values respectively.

*Climatic suitability classes (see Batjes 1987: Tech. Soils. Bull. No. 7):

-HiS: 80% of the optimum yield (Ym) can be obtained in at least 6-out-of-10 years and 60% of the optimum yield in =>80% of the years

-MoS: 80% of the optimum yield can be obtained in 40 to 60% of the years and 60% of the optimum yield in 60 to 80% of the years.

-MaS: 80% of the optimum yield can be obtained in 20 to 40% of the years and 60% of the optimum yields in 40 to 60% of the years.

-NoS: all conditions more adverse for crop growth than those listed under MaS.

*It is assumed that water is the only factor which may limit crop growth. The 'agro-climatic suitability', which also takes into account the limitations of the land for growing the crop, can be assessed from MATMOD and CROPRISK (Tech. Soils Bull. 5 & 7).

*The analysis is based on the 1951 - 1977 climatic data base for LINSTEAD.

*The analysis is for the following soils: [50 <= TAWC <= 200 cm3/cm3]

Appendix V: Yield response to water stress (theoretical example).

Maize and sorghum are grown in an area of low rainfall, low relative humidity and relatively high wind speed. The average daily potential evapo-transpiration is 6 mm/day. The average kc factor under these conditions is 0.9 (see report for explanation of terms used). The ky factor of maize and sorghum are 1.25 and 0.9 respectively (Table 6 in Section 5). Using equation 9 the following conclusions can be drawn.

Case 1: Water supply in the 120 days after sowing is 40 percent less than the total water requirement of the crop. The deficit is evenly spread over the growing period. Hence:

$$1 - AET/ETc = 40\%$$

The anticipated relative decrease from the optimum yield obtainable in the area will be:

maize: $.4 * 1.25 = (1 - Ya/Ym)$ --> $Ya/Ym=0.50$ --> $DY=50\%$
sorghum: $.4 * 0.90 = (1 - Ya/Ym)$ --> $Ya/Ym=0.64$ --> $DY=36\%$

The anticipated relative departure from the optimum yield is 50% for maize and 36% for sorghum. Sorghum, which has the lowest ky factor, can use water more efficiently than maize. Hence it could be a suitable crop in an area with good soils that lies in a dry zone where irrigation water is a scarce resource.

Case 2: An hypothetical farm survey has shown that small farmers can survive economically as long as the actual yield of maize and sorghum does not depart by more than 40% from the maximum yield obtainable. How much rain is needed to obtain such a decrease? Where are these areas located?

maize: $0.4 = 1.25 * (1 - AET/ETc)$ --> $AET => 0.68*ETc$
sorghum $0.4 = 0.90 * (1 -AET/ETc)$ --> $AET => 0.55*ETc$

Given that PET is 6mm/day and that the crops need 120 days from sowing to harvesting the amount of water needed for optimum yield will be: 120 * 6 * 0.9 = 648 mm. To obtain at the most the crucial 40% departure from its optimum yield, maize will need at least 441 mm of rain (0.68*648mm) and sorghum 356 mm (assuming that rainfall is 100% effective). Subsequently the probability of having such an amount of rainfallduring a specific time period (growing season) in a specific location can be calculated from the rainfall records after which the corresponding areas can be mapped.

Note: An identical relative decrease from the optimum yield obtainable in a given location will not correspond with the same amount of produce for different crops (see Table 6). Assuming that the optimum yield of maize is 4 tonnes and that of sorghum is 3 tonnes in the hypothetical area, a 40% decrease will correspond with 1.6 tonnes and 1.2 tonnes respectively.

Also issued in this series by the Soil Survey Unit:

Technical Soils Bulletin No. 1: Legends for semi-detailed soil maps: The entries proposed for Jamaica. (November 1985)

Technical Soils Bulletin No. 2: Assessment of the resistance of land to erosion for land evaluation. (December 1985)

Technical Soils Bulletin No. 3: Jamaica Physical Land Evaluation System (JAMPLES). (April 1985)

Technical Soils Bulletin No.4: Methodology and BASIC programs for the statistical assessment of rainfall probability. (August 1986)

Technical Soils Bulletin No. 5: MATMOD: Matching model, Jamaica Physical Land Evaluation System. (September 1986)

Technical Soils Bulletin No. 6: General temperature zones for land evaluation in Jamaica. (September 1986)

Technical Soils Bulletin No. 7: CROPRISK: A computerized procedure to assess the agro-ecological suitability of land for rainfed annual crops. (April 1987)