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AGRO-ECOLOGICAL LAND RESOURCES ASSESSMENT FOR AGRICULTURAL DEVELOPMENT PLANNING

A CASE STUDY OF KENYA

RESOURCES DATA BASE AND LAND PRODUCTIVITY

Technical Annex 1

LAND RESOURCES

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS

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Technical Annex 1
Land Resources

A.H. Kassam, H.T. van Velthuizen, G.W. Fischer and M.M. Shah

Land and Water Development Division Food and
Agriculture Organization of the United Nations
and
International Institute for Applied Systems Analysis
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Any part of this land resources data base may be modified in the light of new knowledge and/or new objectives. The data base has been specially compiled for district and national planning, and is expected to be expanded and refined with use.

The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of FAO or IIASA concerning the legal or constitutional status of any sea area or concerning the delineation of frontiers.

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Contents

Appendixes

Figures

Tables

REPORT AND TECHNICAL ANNEXES

This work is recorded in a main report and technical annexes.

Main Report:

Agro-ecological Land Resources Assessment for Agricultural Development Planning — A Case Study of Kenya
Resources Data Base and Land Productivity Technical Annexes:

1. Land Resources
2. Soil Erosion and Productivity
3. Agro-climatic and Agro-edaphic Suitabilities for Barley, Oat, Cowpea, Green gram and Pigeonpea
4. Crop Productivity
5. Livestock Productivity
6. Fuelwood Productivity
7. Systems Documentation Guide to Computer Programs for Land Productivity Assessments
8. Crop Productivity Assessment: Results at District Level

Chapter 1

Introduction

The 'Agro-ecological Land Resources Assessment for Agricultural Development Planning', is a study concerned with the development and implementation of a national level methodology for the determination of land use potentials of land resources of individual districts for policy formulation and development planning. This Kenya case study has been carried out by FAO and IIASA in collaboration with the Government of Kenya (FAO 1984).

The work is described in a main report entitled: Resources Data Base and Land Productivity. This report is supported by technical annexes which deal with details.

This technical annex deals with the land resources inventory, its make up, contents and computerization. The land resources inventory is made up of the climatic resources inventory and the soil resources inventory. In Section 3, the climatic data bank that has been assembled for the assessment is described. Section 4 presents a description of the analysis of growing period and its year-to-year variability. Sections 5 to 7 deal with the climatic resources inventory which is designed to provide a quantification of climatic parameters that relate to crop, pasture and fuelwood adaptability characteristics and productivity dealt with in Technical Annexes 2,3,4,5 and 6. In Section 8 the soil resources data base, containing data on soil, landform and geology/parent material is described. This information is derived from the 1:1 million scale Exploratory Soil Map of Kenya and the soil mapping unit composition table. In Section 9 the make-up of the mapped and computerized land resources is presented.

Chapter 2

Concepts of the climatic inventory

Temperature and water are the major climatic factors that govern distribution (both in space and time) of crops. In combination with solar radiation, these climatic factors condition the net photosynthesis and allow the plants to accumulate dry matter (and accomplish the successive development stages) according to the rates and patterns which are specific to cultivated plants.

While present knowledge does not allow full quantification of all agronomic consequences of climate in relation to crop adaptability and production, a number of important crop/climate relationships can be quantified in order to allow:

(i) an assessment of the influence of climate on the spatial and temporal distribution of the crops[1];

(ii) the production that can be attained under conditions that are free from constraints.

1 Crops of the assessment are: barley, maize, oat, pearl millet, rice, sorghum, wheat, cowpea, green gram, groundnut, phaseolus bean, pigeonpea, soybean, cassava, sweet potato, white potato, banana, oilpalm, sugarcane, pineapple, pyrethrum, sisal, tea, coffee, pasture and fuelwood.

The **growing period** has been used as a framework for the assessment of climatic resources. It is defined as the period in which temperature and moisture permit crop growth.

To take into account crop temperature requirements, prevailing temperature regimes have been inventoried by identification of **thermal zones.**

The inventory of climatic resources allows:

(i) a differentiation of the country into reference thermal zones, reflecting the geographical and 'seasonal' distribution of the prevailing temperature regimes;

(ii) a differentiation of the country into reference length and pattern of growing period zones, reflecting the prevailing moisture regimes including the year-to-year variations;

(iii) a quantification of potential yields (crops, livestock and fuelwood) that can be attained under constraint-free conditions;

(iv) an assessment of various agro-climatic constraints to take into account yield losses likely to occur.

The synthesis of the moisture attributes of the inventory has been based on the analysis of historical rainfall records, and average monthly potential evapotranspiration calculated according to the Penman method.

The identification of thermal attributes of the inventory has been based on mean daily temperature, as related to other temperatures.

The methodology used for the compilation of the climatic resources inventory is described in the following sections, and involves the quantification of the growing period (and its variability) and the associated temperature regime.

Chapter 3

Climatic data bank

The climatic data[2] bank compiled for the assessment consists of three data sets. Data set 1 (Historical Data, from Jaetzhold and Kutsch 1980) consists of the following information for 437 stations:

- Average decadal (10 day total) potential evapotranspiration (mm)
- Historical decadal rainfall (mm) for individual years.

Data set 2 (Average climatic data, from FAO/AGPC data bank) consists of 45 stations with mean monthly values for the following 11 climatic parameters:

- Precipitation (mm)
- Mean daily temperature (°C)
- Maximum temperature (°C)
- Minimum temperature (°C)
- Day-time temperature (°C)
- Night-time temperature (°C)
- Mean water vapour pressure (mbar)
- Mean wind velocity (m sec^{-1})
- Hours of bright sunshine as a percentage of maximum possible sunshine hours (%) -
- Solar radiation (cal cm^{-2} day^{-1})
- Potential evapotranspiration (mm).

Data set 3 (Average climatic data, from Kenya Soil Survey) provides average data on the following for 1489 stations:

- Annual daily temperature (°C)
- Annual potential evaporation (mm)
- Annual potential evapotranspiration (mm)
- Annual Rainfall (mm)
- Monthly rainfall (mm)
- Type of rainfall pattern; monomodal (M), bimodal (B) or trimodal (T).

Extracts of the three data Sets are presented in Tables 2.1, 2.2 and 2.3 respectively. The complete climatic data bank is available on diskettes (ASCII).

[2] The primary source of the climatic data is the Kenya Meteorological Department.

TABLE 3.1
Extract agroclimatlc data bank - Data set 1 - Historical data

STATION: EMBU NUMBER: 9037008 LAT: 0.32° S LONG: 32.27° E ALT: 1410 FT 40 YEARS' RECORDS

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
AVERAGE PET	DECAD 1	40.8	43.2	44.8	40.0	37.6	34.4	32.8	32.8	37.6	40.8	36.8	36.8	
	DECAD 2	42.4	43.2	45.6	37.6	37.6	33.6	32.0	32.8	39.2	41.6	35.2	36.8	
	DECAD 3	42.4	44.0	44.0	37.6	36.8	33.6	32.0	34.4	40.0	40.0	36.0	38.4	
	MONTH	125.4	130.4	134.4	115.2	112.0	101.6	96.8	100.0	116.8	122.4	108.0	112.0	1375.0
RAINFALL (1927)	DECAD 1	1.8	0.0	29.0	20.0	47.3	0.3	8.1	2.9	6.6	0.0	19.3	14.5	
	DECAD 2	0.0	2.0	167.8	64.5	19.1	52.2	2.1	7.0	0.0	58.3	68.1	16.8	
	DECAD 3	0.0	1.5	52.3	75.3	3.1	0.3	0.8	2.8	4.1	82.8	8.9	0.0	
	MONTH	1.8	3.5	249.1	159.8	69.5	52.8	11.0	12.7	10.7	141.1	96.3	31.3	839.6
RAINFALL (1928)	DECAD 1	15.6	0.0	40.9	10.2	101.1	16.2	0.0	2.6	0.0	6.4	40.7	21.9	
	DECAD 2	39.1	0.0	0.0	140.2	103.0	1.1	6.7	0.0	0.0	0.0	108.2	0.0	
	DECAD 3	0.0	0.0	7.1	80.4	62.1	3.8	0.0	5.6	5.1	17.3	49.2	0.0	
	MONTH	54.7	0.0	48.0	230.8	266.2	21.1	6.7	8.2	5.1	23.7	198.1	21.9	884.5
RAINFALL (1929)	DECAD 1	51.6	0.0	0.0	12.4	66.7	0.8	10.9	0.0	32.8	1.0	108.7	102.9	
	DECAD 2	6.6	0.0	66.5	12.4	7.9	7.9	14.3	0.0	27.2	34.0	104.5	38.0	
	DECAD 3	6.4	0.0	5.1	153.5	14.3	2.0	12.5	5.8	0.0	80.8	4.6	12.3	
	MONTH	64.6	0.0	71.6	178.3	88.9	10.7	37.7	5.8	60.0	115.8	217.8	153.2	1004.4
RAINFALL (1930)	DECAD 1	0.0	28.7	76.5	57.8	66.9	12.5	0.0	10.7	2.6	26.7	122.8	42.9	
	DECAD 2	0.0	0.0	20.6	109.7	28.3	0.0	7.6	6.1	5.6	28.4	94.7	28.0	
	DECAD 3	43.0	0.0	80.7	107.3	5.4	6.6	0.8	33.0	2.5	66.1	53.9	1.0	
	MONTH	43.0	28.7	177.8	274.8	100.6	19.1	8.4	49.8	10.7	121.2	271.4	71.9	1177.4

TABLE 3.2
Extract agroclimatic data bank - Data set 2 - Average climatic data

COUNTRY: KENYA STATION: LOKITAUNG NUMBER: 63610 LAT: 4.15° LONG: 35.45°E ELEVATION: 730 m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
PRECIPITATION (mm)	12	17	53	119	47	22	32	13	7	13	32	28	395
TEMPERATURE (°C; AVERAGE)	28.0	28.5	28.2	26.0	26.6	26.6	25.7	25.7	26.8	26.8	27.1	26.8	26.9
TEMPERATURE <°C; MEAN MAX.)	33.2	33.8	33.2	31.0	31.0	31.0	30.5	30.5	31.6	31.6	32.1	31.6	31.8
TEMPERATURE (°C; MEAN MIN.)	22.7	23.2	23.2	21.0	22.1	22.1	21.0	21.0	22.1	22.1	22.1	22.1	22.1
TEMPERATURE (°C; MEAN DAY)	29.8	30.4	30.0	27.8	28.1	28.1	27.5	27.5	28.5	28.5	28.9	28.5	28.6
TEMPERATURE (°C; MEAN NIGHT)	26.1	26.6	26.4	24.2	24.9	24.9	24.0	24.0	25.1	25.1	25.2	25.1	25.1
VAPOUR PRESSURE	21.1	22.7	23.0	23.0	22.5	20.8	20.5	20.1	20.1	21.6	23.0	22.0	21.7
WIND SPEED (at 2m ELEV.)	3.7	4.3	4.0	2.9	3.3	3.7	3.8	3.7	4.1	4.1	4.3	4.0	3.8
SUNSHINE (%)	84	81	75	78	83	83	76	83	88	84	76	81	81
TOTAL RADIATION	530	548	545	552	550	535	515	557	587	563	510	510	541
EVAPOTRANSPIRATION	188	184	198	157	171	171	169	178	194	191	174	173	2148

COUNTRY: KENYA STATION: LODWAR NUMBER: 63612 LAT: 3.07° LONG: 35.37°E ELEVATION: 515 m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
PRECIPITATION (mm)	15	8	27	56	27	6	23	10	2	9	21	16	220
TEMPERATURE (°C; AVERAGE)	28.8	29.8	30.2	29.6	29.7	29.0	28.2	28.5	29.3	29.8	29.0	28.6	29.2
TEMPERATURE (°C; MEAN MAX.)	35.5	36.5	36.0	35.0	34.8	34.1	33.0	33.3	34.8	35.2	34.6	34.5	34.8
TEMPERATURE (°C; MEAN MIN.)	22.2	23.1	24.3	24.3	24.6	24.0	23.5	23.5	23.8	24.5	23.5	22.6	23.7
TEMPERATURE (°C; MEAN DAY)	31.2	32.2	32.3	31.6	31.5	30.9	30.0	30.2	31.3	31.8	31.0	30.7	31.2
TEMPERATURE <°C; MEAN NIGHT)	26.5	27.4	28.1	27.7	27.8	27.2	26.5	26.6	27.3	27.9	27.0	26.3	27.2
VAPOUR PRESSURE	17.0	17.0	19.3	22.0	22.0	20.3	19.5	19.5	18.7	18.7	19.0	19.0	19.3
WIND SPEED (at 2m ELEV.)	2.6	2.8	3.0	2.8	2.8	2.6	2.4	2.8	3.0	3.2	2.8	2.4	2.8
SUNSHINE (%)	84	81	75	78	83	83	76	83	88	84	76	81	81
TOTAL RADIATION	537	553	546	550	545	529	509	553	587	567	516	517	542
EVAPOTRANSPIRATION	197	195	205	186	188	171	167	186	198	208	178	170	2249

TABLE 3.3
Extract agroclimatlc data bank - data set 3 - Average data

Station code	Station name	°Lat (N/S)	°Long (E)	Alt (ft)	Average Annual Data				Average Monthly Rainfall Data												Yrs	RP type
					Temp	Eo	PET	P	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
9439000	Kilindini	4.03	39.39	64	26	2168	1734	1059	28	13	56	171	262	106	68	64	66	88	83	54	50	B
9439001	Kwale Agr. Dept.	4.11	39.28	1294	24	2075	1662	1089	34	19	60	159	227	98	81	64	67	99	102	79	60	B
9439002	Mombasa Old.	4.04	39.41	53	26	2169	1735	1193	26	16	62	199	313	113	86	67	68	87	99	57	81	B
9439003	Ramisi Ass. Sug.	4.31	39.25	50	26	2175	1740	1426	23	18	78	271	359	155	121	82	61	84	103	71	39	B
9439004	Gazi Kenya Sug.	4.25	39.30	150	26	2161	1729	1350	23	24	70	256	347	150	100	86	68	79	89	58	50	B
9439005	Waa	4.10	39.37	68	26	2175	1740	1289	28	10	71	240	340	118	28	77	122	90	96	69	10	B
9439008	Mrere Works	4.12	39.24	650	26	2161	1729	1049	26	20	52	109	255	102	71	70	69	104	98	73	23	B
9439009	Changamwe	4.02	39.38	200	26	2153	1722	1093	8	15	47	182	308	94	60	71	70	96	71	71	23	B
9439010	Msumbweni Hosp.	4.30	39.30	62	26	2171	1573	1376	20	16	62	293	356	142	111	79	66	93	86	52	30	B
9439013	Vanga Mudir's	4.40	39.13	40	26	2171	1737	1134	26	19	86	198	274	88	79	67	51	86	98	62	36	B
9439014	Gazi Mudir's	4.28	39.29	20	26	2175	1740	1388	21	18	69	275	377	133	108	81	66	86	104	50	35	B
9439015	Kwango Mudir's	4.08	39.19	650	26	2193	1754	814	20	33	52	119	150	55	58	49	39	84	105	50	27	B
9439016	Tiwi Disp.	4.14	39.35	30	26	2179	1743	1290	25	17	58	259	327	98	95	82	86	81	93	69	25	B
9439019	Mombasa Met. St.	4.03	39.39	52	26	2169	1735	1202	26	17	63	196	320	120	89	64	64	87	96	60	54	B
9439020	Ros Serani	4.05	39.41	30	26	2172	1737	1241	10	13	42	213	358	92	84	92	80	99	97	61	11	B
9439021	Mombasa Air.	4.02	39.37	185	26	2155	1724	1054	34	19	63	167	231	70	65	67	78	94	97	69	26	B
9439023	Bamburi	4.00	39.43	15	26	2173	1738	1146	0	7	15	228	253	89	150	58	81	118	46	101	3	B
9439024	Mkomani	4.03	39.41	50	26	2170	1736	969	2	1	0	143	178	83	117	71	61	91	91	131	2	B
9439025	Kinango Pump.	4.09	39.25	400	26	2193	1738	930	34	21	55	151	171	67	64	52	48	81	101	85	24	B
9439026	Kisauni	4.02	39.40	50	26	2178	1741	1096	20	8	40	236	275	88	98	62	63	65	80	61	11	B
9439027	Mwangulu	4.25	39.07	400	27	2243	1794	839	24	27	74	112	135	48	54	59	47	70	122	67	12	B
9439028	Ndavaja	4.15	39.10	500	27	2239	1791	810	32	21	61	109	134	47	67	64	42	76	103	54	22	B
9439029	Makuja	4.10	39.34	400	26	2151	1721	947	29	13	47	154	251	57	74	51	47	75	98	51	11	B
9439030	Muhaka	4.20	39.31	150	26	2173	1738	1129	23	19	50	204	260	104	93	79	59	93	105	40	19	B

9439031	Mrore I	4.13	39.25	1335	24	2081	1665	987	34	19	48	150	195	76	63	73	52	87	117	73	22	B
9439032	Mrore II	4.15	39.23	1160	25	2108	1686	1040	36	26	47	161	219	83	83	73	52	99	73	88	12	B
9439033	Mrore III	4.17	39.26	720	25	2139	1711	1094	13	26	53	154	237	93	96	83	50	130	75	84	10	B
9439034	Mrore IV	4.17	39.21	980	25	2132	1706	1077	30	26	45	162	219	84	96	79	50	101	77	108	10	B
9439038	Waa Disp.	4.10	39.35	100	26	2172	1738	1070	24	15	42	191	266	107	79	62	60	80	99	45	18	B
9439040	Mombasa Rest.	4.03	39.39	70	26	2167	1734	1246	54	12	71	267	241	110	86	67	85	81	105	67	10	B
9439041	Mombasa Fields	4.03	39.40	55	26	2169	1735	1145	47	16	58	239	233	114	85	61	75	73	87	57	11	B
9439043	Simba Hills	4.22	39.25	800	25	2120	1696	1290	44	13	71	223	270	106	104	81	66	127	122	63	19	B
9439044	Kikoneni	4.28	39.17	500	26	2172	1738	1242	25	14	92	209	234	117	107	89	70	84	124	77	16	B
9439045	Kimansi W.	4.03	39.39	50	26	2170	1736	1257	28	16	62	192	369	114	87	68	72	88	101	60	78	B
9439046	Vangalunga	4.33	39.07	200	27	2205	1764	911	31	21	77	146	176	61	51	44	38	72	123	71	20	B
9439050	Changamwe	4.01	39.37	100	26	2164	1731	860	31	47	46	87	211	65	80	0	42	83	109	59	2	B
9439051	Timbwani	4.07	39.40	50	26	2175	1740	814	1	0	63	154	228	130	69	41	38	25	24	41	2	B
9439054	Mwena School	4.29	39.08	250	27	2247	1798	752	21	11	75	62	99	90	72	44	38	99	83	58	3	B
9439057	Puma Camp	4.06	39.14	600	27	2226	1781	442	0	0	12	64	127	64	64	22	30	2	2	55	2	B

Stations 8535201 to 8940003 latitude North and stations 9034001 to 9439057 latitude South.
Temp: Mean daily temperature (celcius) - Eo: Potential evaporation (mm) - PET: potential evapotranspiration (mm)
P: Rainfall (mm) - RP type: Rainfall pattern type - M = Monomodal, B = Bimodal, T = Trimodal

Chapter 4

Growing period analysis

The analysis of growing period is required in the assessment in order to quantify the time period in each year when moisture supply from rainfall is considered adequate, from a climatic viewpoint, to permit crop[1] growth. More specifically, quantification is needed in terms of:

(a) lengths of growing periods and number of such periods per year;

(b) the quality of moisture conditions during the various parts of the growing period;

(c) the year-to-year variation of each length of growing period and its moisture conditions.

1 The word crop is used here in generic form and refers to annual and perennial field crops, including pasture and tree crops.

Length of growing period from climatic viewpoint alone, and independent of a specific crop, soil and landform, can only be defined in a 'reference manner'. During the matching exercise in the land suitability assessments, for field crops (Technical Annexes 3 and 4), pasture and livestock (Technical Annex 5) and fuelwood (Technical Annex 6), the reference length of growing period (with its associated features of moisture quality, long-term variability, temperature and agro-climatic constraints) is then interpreted and evaluated for suitability of specific land utilization types of field crops, pasture and livestock and fuelwood, taking into account soil factors and landform.

4.1 Computer Printout and Symbols

The full growing period analysis as used in the assessment is explained in the following sections using the computed results for one selected station (Lamu Meteorological Station, No 9240001, 2°16'S, 40°54'E) with 42 years of rainfall records as an example. The results are presented in Appendix 4.1 and are arranged in two parts, namely:

(i) analysis of moisture periods;
(ii) statistical analysis.

In the computer printout the following terms, abbreviations and symbols are used:

ALTITUDE	Elevation above sea level (m).
TEMPERATURE	Average annual daily temperature (°C).
THERMAL ZONE (MAJOR CLIMATE)	Represents the temperature regime class of the station (see explanation in Section 6).
LGP	Length of growing period (days).
Po	Soil moisture supply without contribution from soil moisture storage (S=0 mm).
P100	Soil moisture supply with 100 mm contribution moisture storage (S=100 mm). S represents a reference soil moisture supply (mm).
BEG	Beginning of growing period (date).
BH	Beginning of humid period (date).
(BEG-BH)	1st intermediate period (days).
EH	End of humid period (date).
(BH-EH)	Humid period (days).
(EH-BH)	Inter-humid intermediate period (days).
*	Artificial end/beginning (date).
END	End of growing period (date).
(EH-END)	2nd intermediate period (days).
(BEG-END)	Growing period (days).
TYP	Type of growing period.
N	Normal type of growing period.
I	Intermediate type of growing period.
(END-BEG)	Dry period (days).
D	Moisture supply deficit (P100< ET), numerically negative (mm).
E or Excess	Excess moisture supply (P100> ET), numerically positive (mm).
D/E or DEF/EXC	Moisture supply deficit or excess (mm).
P/E or P/ET	Ratio of moisture supply (P100) over potential evapotranspiration.
TOTAL MOIST. PER.	Total moisture period, equal to the total length of growing period or periods (when more then one per year).
TOTAL DRY PER.	Total dry period, equal to the total length of dry period or periods (when more than one per year).
AVR	Average, representing LGP (and the associated parameters) computed using average rainfall as an input.
SD	Standard deviation.
CV	Coefficient of variation (%).
Dates	A month is regarded as having 30 days with 10 parts of 3 days. Calender months January, February, March, etc. are coded 1, 2, 3, etc. respectively. A date 12 July is shown as 7.4, 27 October as 10.9.

4.2 Growing Period Model

The quantification of the reference length of growing period is based on a water balance model comparing moisture supply from rainfall (P) and storage (S) with potential evapotranspiration (FAO 1978; Kassam, Higgins and Christoforides 1981; Kassam, van Velthuizen, Higgins, Christoforides, Voortman and Spiers 1982; Brammer, Antoine, Kassam and van Velthuizen 1988).

The following definitions and methodologies are employed in the model.

4.2.1 Beginning of the growing period (BEG)

The beginning of the growing period is taken as the time (in days) when moisture supply from rainfall and soil storage is equal to half potential evapotranspiration. This premise takes into account the fact that the amount of moisture required to sustain crop germination and emergence is much below full potential evapotranspiration and during crop emergence and establishment in the field it approximates to about 0.S ET (Kowal and Kassam 1978; Doorenbos and Kassam 1979). Therefore, the amount of moisture supply that is equal to (or greater than) 0.5 ET has been considered as being sufficient to meet the water requirements of establishing field crops. Consequently, in the model, the time when moisture supply is 0.5 ET is taken as the reference beginning of the growing period.

For the Lamu station, the computer printout (Appendix 4.1) shows that in the year 1931 the annual moisture supply without storage (i.e. Po, equal to rainfall) is 1231.1 mm. The reference beginning of the growing period is on 3rd April (date: 4.1).

4.2.2 Humid period (BH-EH)

A 'normal' type of growing period is defined as one with a period when there is a surplus of rainfall over potential evapotranspiration, i.e. a humid period. During such a period not only full or close to full evapotranspiration demands of crops (with complete canopy cover) are generally met, but also the soil moisture in the soil profile is replenished.

For Lamu, the humid period in the year 1931 is 60 days, from 15th April to 15th June. There is an excess of moisture supply over potential evapotranspiration of 701 mm, and the ratio of moisture supply over potential evapotranspiration is 3.55.

4.2.3 End of growing period (END) and moisture storage (S)

During the post-humid period, the moisture supply is again less than potential evapotranspiration, and crops have to rely on water stored in the soil to meet full water requirements. Subsequently, the frequency and amount of rainfall diminishes and soil moisture deficit increases. This results in a marked alteration of the environment and triggers pronounced changes in the eco-physiological responses of crops. Under such conditions, and in the absence of soil moisture reserves, crops are forced to mature when rainfall is less than 0.5 ET.

The time when Pn = 0.5 ET in the post-humid period is taken as the reference end of rains and rainy season.

However, the growing period of crops may continue beyond the rainy season when there is stored moisture in the soil, and in reality, to a greater or lesser extent, crops rely on stored moisture between rainstorms and often mature after the end of the rains on moisture reserves in the soil profile. Such moisture storage is therefore considered in defining the reference length of growing period. However, the amount of soil moisture stored in the soil profile and available to a crop varies with depth of the profile, the soil physical characteristics, the rooting pattern and other crop factors (Kowal and Kassam 1978; Doorenbos and Kassam 1979).

In the model[1] a general figure of up to 100 mm stored moisture has been assumed as being available to the crops. The choice of 100 mm is based on extensive evidence which indicates that annual crops grown during the rainy season (i.e. rainfed annual crops as opposed to annual crops wholly or largely produced from stored moisture in the dry season) can utilize stored moisture in the range of 75 -125 mm, by the time of maturity (Kowal and Kassam 1978). Accordingly, the extra time taken to evapotranspire this 100 mm of available stored moisture has been added to the duration of the rainy season to set the end of the reference growing period. The actual status of the reference soil moisture is evaluated in the matching exercise for specific crop and soil situations. The 100 mm of available stored moisture originates during the humid period when there is a surplus of rainfall over potential evapotranspiration. When there is less than 100 mm of surplus precipitation, the storage term is also proportionately less.

For Lamu (Appendix 4.1), the reference end of the growing period in the year 1931 is on 6th August (date: 8.2).

1 For the model to cater for a range in moisture contribution from soil storage, the computer program is set up to process the soil storage term in the range 0-250 mm, and the computer printout automatically provides the computed results of length of growing period for S equal 0, 50, 100, 150, 200 and 250 mm (Kassam *et al.* 1981; Brammer *et al.* 1988).

4.2.4 Growing period (BEG-END)

According to the above definitions, the reference growing period, from a moisture viewpoint, is therefore defined as a continuous period where moisture supply is greater than half potential evapotranspiration. It includes the time required to exhaust up to 100 mm stored soil moisture.

For Lamu (Appendix 4.1), the length of growing period in the year 1931 is 123 days.

Also, a reference growing period is type coded as 'normal' (N) when it has a humid period as is in the case of Lamu in the year 1931: when it has no humid period, the growing period is type coded 'intermediate' (I). During an intermediate type of growing period, therefore, rainfall does not exceed the full rate of potential evapotranspiration. This situation occurred in Lamu in the year 1949 when the first of the two growing periods of 67 days had no humid period. The two types of growing period are schematically shown in Figure 4.1.

The distinction between 'normal' and 'intermediate' type growing periods is useful because in the latter it is unlikely that full crop water requirements can be met during the rainy season without moisture conservation.

A normal growing period is made up of three moisture periods. For example, for Lamu for the year 1931, the three moisture periods during the normal growing period (BEG-END) of 123 days are 13 days from the beginning of the growing period to the beginning of the humid period (BEG-BH), the first intermediate moisture period, 60 days from the beginning of the humid period to the end of the humid period (BH-EH), the humid period, and SO days from the end of the humid period to the end of the growing period (EH-END), the second intermediate moisture period.

An intermediate growing period is made up of one moisture period; and for Lamu examples of intermediate growing periods (BEG-END) of 15 days, 24 days and 82 days occur in the years 1936, 1945 and 1958 respectively.

Two more growing period types have also been defined (Figure 4.1). These are: (a) all year-round humid with rainfall exceeding full potential evapotranspiration throughout the year, and (b) all year-round dry with rainfall not exceeding half potential evapotranspiration throughout the year. These situations have not occurred in Lamu.

4.2.5 Dry period (END-BEG)

A reference dry period is defined as the time when moisture supply from rainfall and storage is less than half potential evapotranspiration.

For Lamu, the reference dry period in the year 1931 is 237 days, from 6th August to 3rd April.

4.3 Quality of Moisture Supply

In addition to the lengths of the various moisture periods and the total lengths of growing periods, it is important to assess the quality of the moisture supply during each of the moisture periods. This has been achieved by quantifying the extent of moisture supply deficit (P100 less than ET) or excess moisture supply (P100 more than ET), and the moisture supply as a ratio of potential evapotranspiration, i.e. P100/ET (but shown as P/E in the computer printout).

For Lamu (Appendix 3.1), in the year 1931, there is a moisture supply deficit (D) of 26 mm during the period BEG-BH with a P/E ratio of 0.58. During the period BH-EH, there is an excess moisture supply (E) of 701 mm and the P/E ratio 3.55. During the period EH-END, there is a deficit of 32 mm and the P/E ratio is 0.86.

4.4 Moisture Periods

4.4.1 One growing period in a year

A year with one normal growing period has four moisture periods of which one is a dry period and the rest make up the growing period, namely:

(i) **first intermediate period (BEG-BH):** from the beginning of the growing period to the beginning of the humid period; the moisture supply during the period is greater than 0.5 ET but less than full ET, and there is a moisture supply deficit with a P100/ET ratio of less than 1.0;

(ii) **humid period (BH-EH):** the moisture supply during the period is greater than ET and there is an excess of moisture supply over ET, and the ratio P100/ET is greater than **1.0;**

(iii) **second intermediate period (EH-END):** from the end of the humid period to the end of the growing period; the moisture supply during the period is greater than 0.5ET but less than full ET, and there is a moisture supply deficit and the ratio P100/ET is less than 1.0;

(iv) **dry period (END-BEG):** from the end of the growing period to the beginning of the growing period; the moisture supply during the period is less than 0.5ET and there is a moisture supply deficit and the ratio P100/ET is less than O.S.

A year with an intermediate length of growing period has two moisture periods, namely:

(i) **intermediate period (BEG-END):** from the beginning of the growing period to the end of the growing period; the moisture supply during the period is greater than 0.5ET but less than full ET, and the ratio P100/ET is less than 1.0;

(ii) **dry period (END-BEG):** from the end of the growing period to the beginning of the growing period; the moisture supply during the period is less than 0.5ET and there is a moisture supply deficit and the ratio P100/ET is less than O.S.

4.4.2 More than one separate growing period in a year

In a year with more than one growing period, the pattern described above is repeated. In a year with two separate normal growing periods, there are a total of eight moisture periods of which four are intermediate, two are humid and two dry.

In a year with two growing periods of which one is normal and the other intermediate, there are a total of six moisture periods of which three are intermediate, one humid and two dry.

In a year with two separate intermediate growing periods, there are four moisture periods of which two are intermediate and two dry.

In a year with three normal growing periods, there are twelve moisture periods in all. If one of the growing periods is intermediate, then there are a total of ten moisture periods.

4.4.3 Inter-humid intermediate period

An additional moisture period has been defined to cater for situations when the end of a humid period (EH) is not followed by an end of growing period (END) but instead by a start of a second humid period (BH). This period is defined as an inter-humid intermediate period (EH-BH).

This period can occur in areas with a bimodal rainfall pattern when moisture supply between the two rainy seasons is greater than 0.5ET. The period can also occur where there is a 'drought' during a humid period.

When the inter-humid intermediate period occurs, its length and moisture characteristics are given under (EH-BH). For Lamu (Appendix 4.1), the year 1967 has an inter-humid intermediate period of 39 days with a moisture supply deficit of 58 mm and the ratio P100/ET of 0.68.

In the analysis of growing period, an inter-humid intermediate period has been treated as having two lengths of growing periods with no separation between the two periods at one end. To achieve this, the middle of the (EH-BH) period is taken to represent an artificial end (END) for the first growing period and an artificial beginning (BEG) of the next growing period. Consequently, there is no dry period between the end of the first growing period and the beginning of the second growing period. In the computer printout this is indicated by an asterisk.

4.5 Variability in Moisture Conditions

Variability in moisture conditions from year-to-year is quantified after the analysis of growing periods in each year is completed. This is done in three stages as described below.

4.5.1 Historical profile

Firstly, a historical profile is compiled showing groups of years each with a different number of growing periods per year, from zero to six. The proportional representation of each group in the total series of years is computed. Further, for each group, the number and percentage of years with normal and intermediate growing periods respectively are calculated.

In the case of all-year humid and all-year dry, the information on the number and percentage of years is provided separately.

For Lamu, the historical profile (Appendix 4.1) shows that of the 42 years, 28 years (67%) have one length of growing period and 14 years (33%) have two lengths of growing periods.

Of the 28 years with one length, 27 years have normal growing periods and 1 year has intermediate growing period. In the group of 14 years with two lengths, the first and the second lengths are normal in 13 years (93%) and 6 years (43%) respectively and are intermediate in 1 year (7%) and 8 years (57%) respectively.

4.5.2 Mean, standard deviation and coefficient of variation

Secondly, for each group of years with different number of growing periods, mean, standard deviation and coefficient of variation are calculated for the lengths of growing periods, length of individual moisture periods, deficit or excess and the ratio of moisture supply to potential evapotranspiration.

For Lamu, the mean length of growing period for the years with one growing period is 125.6 days, SD is 28.1 days and CV is 22%.

4.5.3 Frequency distribution tables

Thirdly, for each group of years with different number of growing periods, frequency distribution of each of the mean lengths of growing periods is computed at 10-day intervals with the corresponding ratio of moisture supply to potential evapotranspiration (P100/ET) and excess moisture supply. These are presented in the form of frequency distribution tables, one for each individual mean length of growing period. The group of years with one length thus has one frequency distribution table whereas the group of years with two growing periods per year has two frequency distribution tables.

For Lamu, the mean length of 125.6 days, for the group of years with one length per year represents a variation from 60 to 186 days. The mean length of 132.4 days for length 1 in the group of years with two lengths per year, represents a variation of 67 to 195 days. Similarly, the mean length of 44 days, for length 2 in the same group of years, represents a variation of 9 to 118 days.

FIGURE 4.1
Schematic presentation of types of growing periods

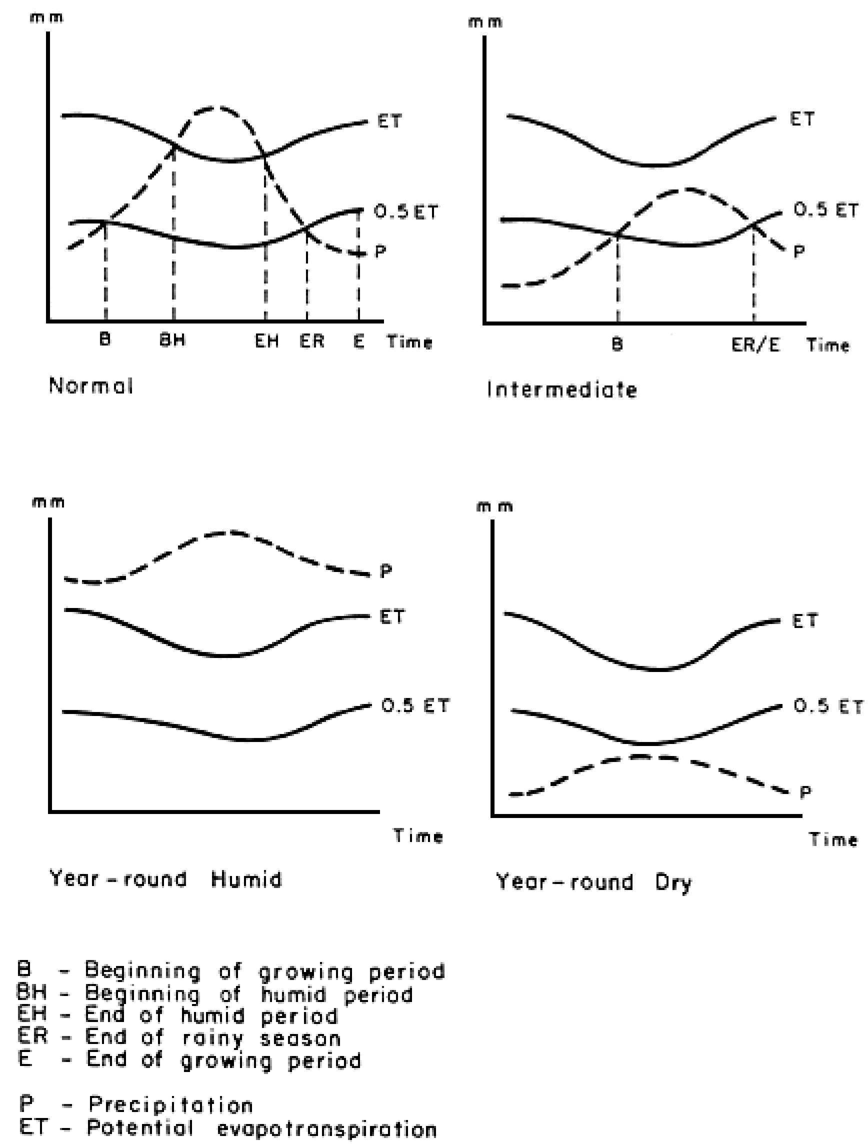
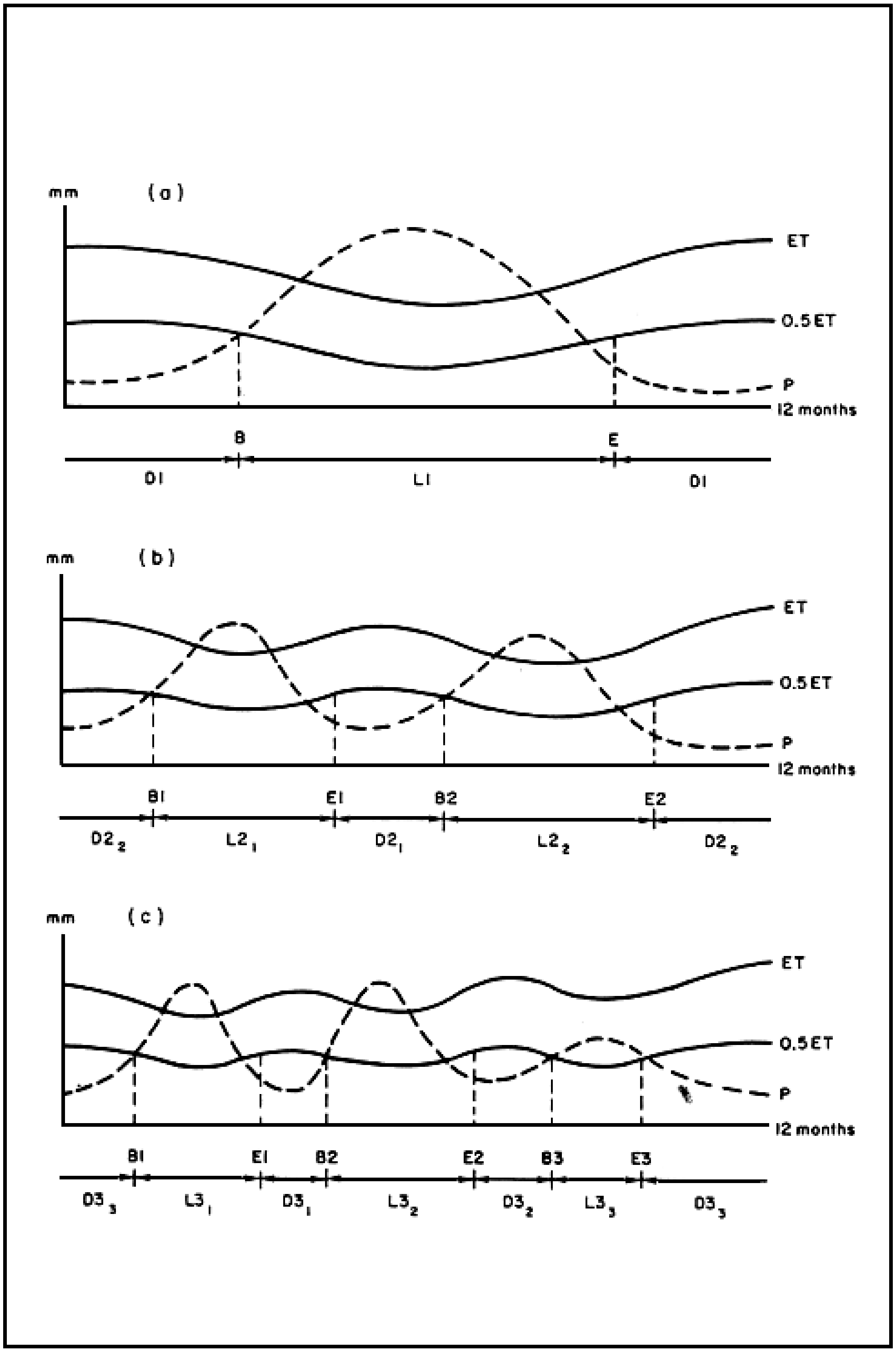


FIGURE 5.1
Number of growing periods and dry periods per year



Chapter 5

Growing period zones

The definitions and model used to quantify the length of growing period have been described in Section 4. The reference growing period is the time period when moisture supply exceeds half potential evapotranspiration; it includes the time required to evapotranspire up to 100 mm of soil moisture storage. The calculation of the reference growing period is based on a water balance model, comparing rainfall with potential evapotranspiration. The length of growing period and the number of growing periods and dry periods per year from a climatic viewpoint alone, and independent of crop, soil and landform, is therefore quantified in a reference manner (Figure 5.1).

5.1 Length of Growing Period (LGP)

The mean length of growing period for each individual group of years has been computed. Where there are more than one length of growing period per year, the total mean length as well as the individual mean lengths (e.g. two, three) are calculated.

For a group of years with one length of growing period, the length is designated to the code L1, and the dry period is coded D1 (Figure 5.1a). For a group of years with two lengths of growing periods per year, the lengths are coded $L2_1$ and $L2_2$, and the first length ($L2_1$) is followed by the first dry period ($D2_1$) and the second length ($L2_2$) by the second dry period ($D2_2$) (Figure 5.1b) The sum of lengths $L2_l$ and $L2_2$ is coded L2. For a group of years with three lengths of growing periods per year, the lengths are coded $L3_1$, $L3_2$ and $L3_3$, and there are dry periods in between ($D3_1$, $D3_2$, $D3_3$) (Figure 5.1c). The sum of lengths $L3_l$, $L3_2$, $L3_3$ is coded L3.

5.2 Pattern of Length of Growing Period (LGP-Pattern)

To inventory the year-to-year variation in the number of lengths of growing periods per year, a historical profile is compiled showing groups of years each with a different number of growing periods per year. The proportional representation of each group in the total historical series is computed.

This information represents the pattern of growing period. Twenty two patterns are recognized in the climatic resources inventory. The patterns of growing period and their composition are presented in Table 5.1.

The pattern of growing period code represents the number of growing periods per year in order of frequency of occurrence, e.g. in the pattern coded as 2-1-3, the numeral 2 represents the number of lengths of growing periods per year (i.e. two) that occur in the majority of the years (i.e. 55 percent) - the dominant length number; the numeral 1 represents number of lengths of growing periods per year (i.e. one) that has the next most commonly occurring frequency (i.e. 25 percent) - the first associated length number; and the numeral 3 represents number of lengths of growing periods per year (i.e. three) that has the smallest occurrence (i.e. 20 percent) - the second associated length number.

For each pattern of growing period, the mean total length of the dominant number is correlated with the mean total length of the associated numbers. Also, when the mean total length is a summation of more than one mean length, the latter are again correlated with the former. These relationships are presented in Tables 5.2 and 5.3.

In the climatic inventory map of Kenya, only the mean total dominant length has been inventoried on the map. The relationships in Table 5.2 are further presented in terms of length of growing period zones in the Appendix 5.1, giving the mean total dominant (mapped) and the corresponding mean total associated (unmapped) lengths of growing periods. Similarly the relationships in Table 5.3 are further presented in terms of length of growing period zones in the Appendix 5.2 giving the mean total length of growing period zones and the corresponding individual component lengths of growing periods.

TABLE 5.1
Patterns of growing periods - historical profiles of occurrence of number of length of growing periods per year (LGP-patterns)

Code	LGP-Pattern	Proportion (%)
1	1	100
2	H - 1	60:40
3	1 - H	70: 30
4	1 - H - 2	65:20: 15
5	1 - 2 - H	65: 20: 15
6	1 - 2	65:35
7	1 – 2 - 3	50: 35: 15
8	1- 3 - 2	50 : 30 : 20
9	1 – 2 - D	40 : 35 : 25
10	1 – D - 2	40 : 35 : 25
11	1 - D	60:40
12	2	100
13	2 - 1	70: 30
14	2 - 1 - H	55: 30:15
15	2 – 1 - 3	55 : 25 : 20
16	2 - 3	75: 25
17	2 – 3 - 1	60:25: 15
18	2 – 3 - 4	60 : 30 : 10
19	2 - 1 - D	70: 15 : 15
20	3 - 2	60:40
21	3 – 2 - 1	50:35 : 15
22	D	100

H = 365^{+} days (i.e. year-round humid)
D = zero days (i.e. year-round dry)

5.3 Variability of Length of Growing Period

In addition to the frequency distribution tables described in Section 4.5.3, coefficient of variation was calculated to allow a comparison of the variability in the mean length of growing period, and to take into account the likely losses in crop production.

The relationship between individual length of growing period and coefficient of variation was obtained by plotting all values provided by the climatic analysis, and an aggregate relationship is given at right.

Mean length of growing period (days)	Coefficient of variation (%)
< 30	> 50
30 -59	50
60- 89	40
90- 119	40
120-149	35
150- 179	30
180-209	25
210-239	20
240 - 269	15
270 - 299	10
> 299	< 10

TABLE 5.2
Relationships between mean total dominant and mean total associated lengths of growing period

LGP-Pattern	Relationship	r
1 -2	L2 = 80.40 + 0.75 L1	0.89
1 -2-H		
1 -H-2		
1 -2-3	L2 = 71.56 + 0.77 L1	0.90
1 -3-2	L3 = 77.14 + 0.66 L1	0.80
1 -2-D		
1 -2-D		
2 - 1	L1 = -86.09 + 1.28 L2	0.94
2-1 -H	L3 = 25.29 + 0.82 L2	0.78
2-1 -3		
2-1 -D		
2 - 3	L3 = 30.11 + 0.83 L2	0.83
2-3-1	L1 = -98.72 + 1.35 L2	0.85
2-3-4	L4 = 114.54 + 0.58 L2	0.71
3 - 2	L2 = 45.05 + 0.80 L3	0.68
3-2-1	L1 = -9.86 + 0.88 L3	0.62

L1 = Total length of one growing period per year
L2 = Total length of two growing periods per year
L3 = Total length of three growing periods per year
L4 = Total length of four growing periods per year

5.4 Intermediate Lengths of Growing Periods

From the frequency distribution tables (Section 4.5.3) occurrence of intermediate lengths of growing periods was quantified by relating P/ET ratio and moisture excess values with length of growing period.

The P/ET ratio for the intermediate lengths of growing periods of less than 150 days corresponds to values in the range 0.70-0.75.

Mean length of growing period (days)	Occurrence of intermediate periods (%)
< 30	100
30- 30	65
60- 89	25
90-119	10
120-149	5
> 149	< 1

The relationship between the individual length of growing period and occurrence of intermediate periods is shown above.

TABLE 5.3
Relationship between individual component mean length and mean total length of growing period

LGP-Pattern	Relationship		r
2	$L2_1$ = -1.11 +	0.55 L2	0.95
1 -2	$L2_1$ = 4.94 +	0.62 L2	0.77
1 -2-H			
1 -H-2			
1-2-3	$L2_1$ = 5.87 +	0.64 L2	0.91
1-3-2	$L3_1$ = 22.12 +	0.39 L3	0.78
1 -2-D	$L3_2$ = 1.58 +	0.32 L3	0.85
1 -D-2			
2-1	$L2_1$ = -5.48 +	0.64 L2	0.93
2- 1 -H	$L3_1$ = 0.14 +	0.46 L3	0.78
2-1 -3	$L3_2$ = -0.98 +	0.33 L3	0.85
2-1 -D			
2-3	$L2_1$ = -3.05 +	0.61 L2	0.89
2-3-1	$L3_1$ = 1.68 +	0.43 L3	0.79
2-3-4	$L3_2$ = -3.00 +	0.34 L3	0.84
	$L4_1$ = 26.35 +	0.34 L4	0.62
	$L4_4$ = -20.88 +	0.38 L4	0.86
	$L4_3$ = -17.66 +	0.27 L4	0.89
3-2	$L2_1$ = -2.33 +	0.63 L2	0.90
3-2-1	$L3_1$ = 5.62 +	0.45 L3	0.88
	$L3_2$ = 1.25 +	0.31 L3	0.93

$L2_1$ = First length of the two growing periods per year
$L3_1$ = First length of the three growing periods per year
$L3_2$ = Second length of the three growing periods per year
$L4_1$ = First length of the four growing periods per year
$L4_2$ = Second length of the four growing periods per year
$L4_3$ = Third length of the four growing periods per year