World Soil Resources Reports 71/3
ISSN 0532-0488

AGRO-ECOLOGICAL LAND RESOURCES ASSESSMENT FOR AGRICULTURAL DEVELOPMENT PLANNING

A CASE STUDY OF KENYA

RESOURCES DATA BASE AND LAND PRODUCTIVITY

Technical Annex 3

AGRO-CLIMATIC AND AGRO-EDAPHIC SUITABILITIES FOR BARLEY, OAT, COWPEA, GREEN GRAM AND PIGEONPEA

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS

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Agro-climatic and Agro-edaphic Suitabilities for Barley, Oat, Cowpea, Green Gram and Pigeonpea

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
1991

The FAO/AEZ system permits the user to organize and apply available primary and secondary information in the formulation of agro-climatic and agro-edaphic suitabilities for computer processing of land suitability. The suitabilities may be reviewed and updated at any time in the light of additional information and/or specific requirements.

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ISBN 92-5-03307-2

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Chapter 1
Introduction

The 'Agro-ecological Land Resources Assessment for Agricultural Development Planning' is a case 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 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 main report is supported by technical annexes which deal with details.

In Part I of the crop productivity assessment model (Technical Annex 4), agro-climatic suitability is assessed first. The agro-climatic suitability is then modified by the application of soil and landform limitation ratings (agro-edaphic suitability).

Basic agro-climatic and agro-edaphic suitabilities with input specific attainable yield are available through earlier work for all crops in Table 1.1 (FAO 1978 and 1980) except for crops of barley, oat, cowpea, green gram and pigeonpea.

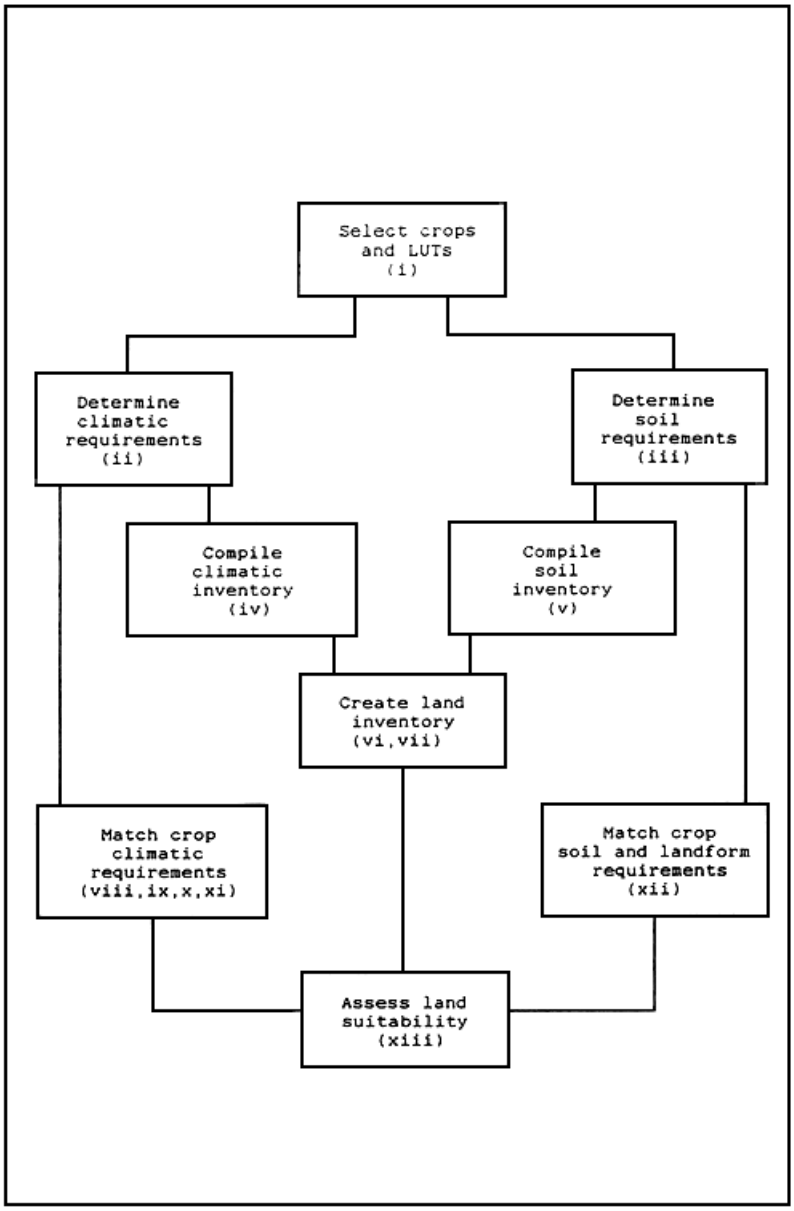
This report presents the basic agro-climatic and agro-edaphic suitability classifications for these five crops for rainfed conditions in Kenya.

TABLE 1.1
List of crops for rainfed productivity assessment

Crop and Type	Scientific Name
Cereal:	
Barley	*Hordeum vulgare*
Maize-Lowland	*Zea mays*
Maize-Highland	*Zea mays*
Oat	*Avena sativa*
Pearl millet	*Pennisetum*
Rice-Dryland	*Oryza sativa*
Rice-Wetland	*Oryza sativa*
Sorghum-Lowland	*Sorghum bicolor*
Sorghum-Highland	*Sorghum bicolor*
Wheat	*Triticum aesth/um*
Legume:	
Cowpea	*Vigna ungulculata*
Green gram	*Vigna radiata*
Groundnut	*Arachis hypogaea*
Phaseolus bean[1]	*Phaseolus* spp.
Pigeonpea	*Cajanus cajan*
Soybean	*Giycin max*
Root and Tuber:	
Cassava	*Manihot esculenta*
Sweet potato	*Ipomoea batatas*
White potato	*Solarium tuberosum*
Other:	
Banana	*Musa* spp.
Oil palm	*Elaeis guineensis*
Sugarcane	*Saccharum officinarum*

[1] Includes common bean *(Phaseolus vulgaris),* lima bean (*Phaseolus lunatus).* runner bean *[Phaseolus occineus)* and tepary bean *[Phaseolus acutifolius).*

FIGURE 2.1
Schematic presentation of the methodology (numbers in parenthesis refer to the activities described in the text)



Chapter 2
Methodology

The methodology of assessing land suitability for rainfed production, developed by the FAO Agro-ecological Zones Project is described in FAO (1978-81), and is summarized in Figure 2.1. It comprises of the following activities:

(i) Selection and definition of land utilization types (e.g. crop type, produce, production system, input level).

(ii) Determination of climatic requirements of crops.

(iii) Determination of soil and landform requirements of crop.

(iv) Compilation of a quantitative climatic resources inventory characterizing thermal regimes (thermal zones) moisture regimes (length of growing period zones and historical pattern of number of growing periods per year).

(v) Assemblage of a soil resources inventory, providing information on soil type, texture, stoniness, phase (if any) and slope.

(vi) Compilation of a land resources inventory, by overlaying the climatic inventory on the soil inventory, and measurement of resultant climate-soil land units.

(vii) Calculation (from iv, v and vi) of extents of soil units (by slope class, texture class, stoniness and phase) by thermal zone, length of growing period zone and pattern of growing period zone.

(viii) Matching the thermal zones of the climatic inventory (iv) with temperature requirements of crops, and where these requirements are met, computation of constraint-free crop yields by length of growing period zones.

(ix) Compilation of the agro-climatic constraints to crop production by length of growing period zones and thermal zones.

(x) Application of the agro-climatic constraints (ix) to the constraint-free crop yields (viii) to derive agronomically attainable crop yields, by growing period zones.

(xi) Agro-climatic suitability classification of each growing period zone according to anticipated crop yields (x)

(xii) Matching the soil requirements of crops (iii) with the soil types,texture classes, stoniness, phases and slope classes of the soil inventory, by rating soil limitations (agro-edaphic suitability classification').

(xiii) Computer application of the soil limitation ratings (agro-edaphic suitability classification) on the agro-climatic suitability classification of each growing period zone, to arrive at the land suitability classification, i.e. extents of land variously suited to production of the crop at each input level.

According to the methodology outlined above, the agro-climatic suitability classification involves activities (i), (ii), (iv), (viii), (ix), (x) and (xi), and the agro-edaphic suitability classification involves activities (i), (iii), (v) and (xii)

Chapter 3
Land resources

The land resources data base contains several layers of physical environmental resources which allow the creation of unique ecological land units (agro-ecological cells) within which soil, landform and climatic conditions are quantified. This information, compiled at the national level by province and district, constitutes the inventory of the physical land resources.

The climatic resources part consist of three seperate thematic layers: the thermal zones layer, the length of growing period zones layer and the pattern of number of growing period zones layer. The climatic resources inventory is described in Section 5.2.

The soil resources layer includes information on soils, landform and geology/parent materials. The soil resources inventory is described in Section 6.2.

Additional layers on land uses and administrative subdivisions have been added. These layers contain cash crop zones, forest zones, parkland areas, irrigated areas, tse-tse infestation areas, and province and district boundaries.

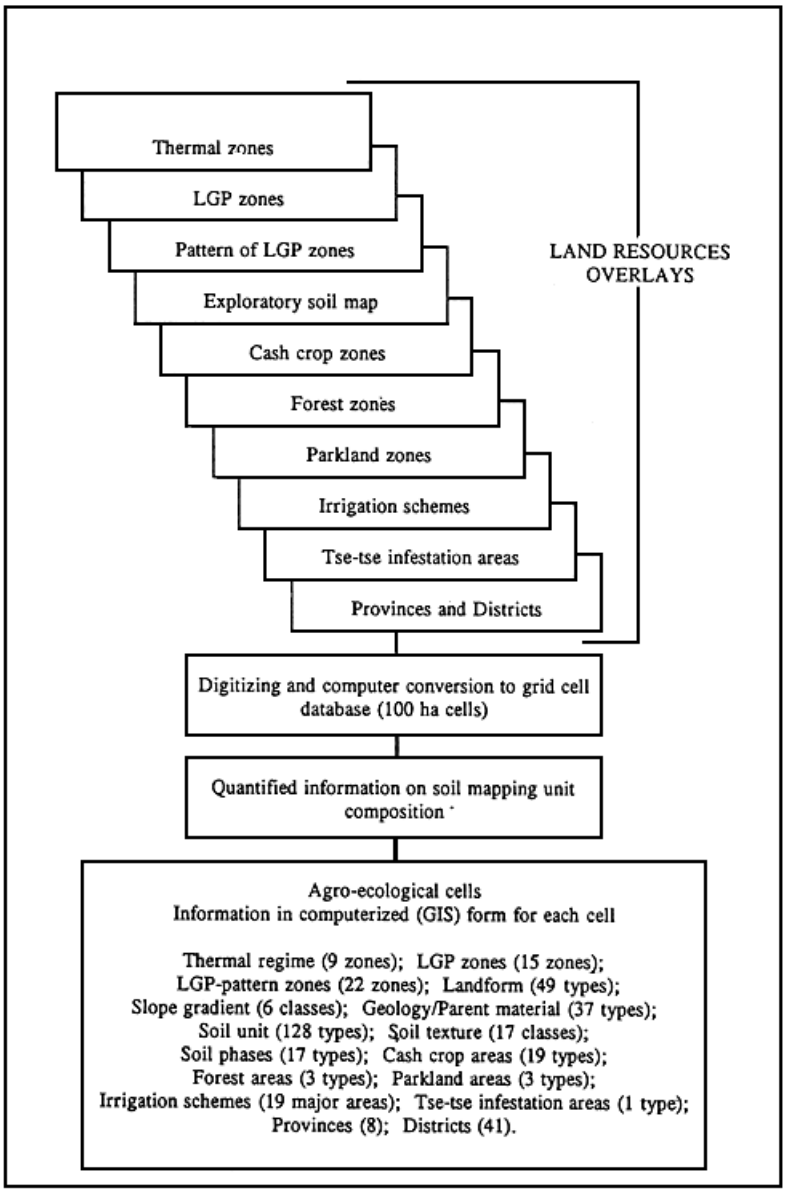
The individual layers have been digitized. The digitized information derived from the individual layers has been converted to a data base of 576,072 grid cells. Each grid cell (one millimeter square) corresponds to 100 ha.

Subsequent to digitizing, the soil map unit composition of each mapping unit and the associated edaphic conditions have been incorporated.

The make-up of the national land resources data base is schematically presented in Figure 3.1. The computerized land resources data base for Kenya records total extents of about 91 000 unique agro-ecological cells. Each cell contains information on:

- Sequence number (NUM) Province (PRV)
- District (DIST)
- Thermal Zone (TZ)
- Length of Growing Period Zone (LGP)
- Pattern of Length of Growing Period Zone (PAT)
- Soil Mapping Unit (MPU)
- Landform (LNDFM)
- Geology/Parent Material (GEO)
- Soil Unit (SOIL)
- Soil Texture (TXT)
- Soil Phases (PHASES)
- Cash Crop Zone (CROP)
- Forest Zone (FOR)
- Irrigation Scheme (IRR)
- Tse-tse Infestation Areas (TSE)
- Parkland Area (PARK)
- Extent in hectares (EXTENT).

FIGURE 3.1
Make-up of land resource data base



The land resources data base is available in the form of a grid based geographic information system (GIS). For details, reference should be made to Technical Annex 7.

Chapter 4
Crops and land utilization types

The following conditions apply to the five crops considered:

(a) Barley is grown for dry grain production from day-length neutral cultivars.

(b) Oat is grown from dry grain production from day-length neutral cultivars.

(c) Cowpea is grown for dry grain production from early to medium duration cultivars of determinate growth habit (i.e. upright and semi-upright or bunch types).

(d) Green gram is grown for dry grain production.

(e) Pigeonpea is grown for dry grain production from medium duration cultivars in the range 130 to 190 days to maturity.

The crops are considered at three levels of inputs, a low an intermediate and a high. The attributes of the two input level production circumstances are listed in Table 4.1, and form the basis of the definition of the land utilization types employed in the assessment of the agro-climatic and agro-edaphic suitabilities.

TABLE 4.1
Attributes of land utilization types

Attribute	Low inputs	Intermediate inputs	High inputs
Produce and production	Rainfed cultivation of barley, maize, oat, pearl millet, dryland rice, wetland rice, sorghum, wheat, cowpea, green gram, groundnut, *Phaseolus* bean, pigeon pea, soybean, cassava, sweet potato, white potato, banana, oil palm and sugarcane. Sole and multiple cropping of crops only in appropriate cropping patterns and rotations.		
Market orientation	Subsistence production	Subsistence production plus commercial sale of surplus	Commercial production
Capital intensity	Low	Intermediate with High credit on accessible terms	
Labour intensity	High, including uncosted family labour	Medium, including uncosted family labour	Low, family costed if used
Power source	Manual labour with animal traction with	Manual labour with hand tools hand tools and/o rimproved implements; some mechanization	Complete mechanization including harvesting
Technology	Traditional cultivars. No fertilizer or chemical pest, disease and weed control. Fallow periods Minimum conservation measures	Improved cultivars as available.Appropriate extension packages including some fertilizer application.nd some chemical pest, disease and weedcontrol. Some fallow periods and some conservation measures	High yielding cultivars including hybrids. Optimum fertilizer application. Chemical pest, disease and weed control.Full conservation measures
Infrastructure	Market accessibility not necessary Inadequate advisory services	Some market accessibility necessary with access to demonstration plots and services	Market accessibility essential. High level of advisory services land application of research findings
Land holding	Small, fragmented	Small, sometimes fragmented	Large, consolidated
Income level	Low	Moderate	High

Note No production involving irrigation or other techniques using additional water. No flood control measures.

Chapter 5
Agro-climatic suitability classification

The agro-climatic suitability classification is based on:

(i) matching the attributes of temperature regimes in each thermal zone to crop temperature requirements for photosynthesis and phenology, and determining whether the crop qualifies for further consideration in the matching exercise;

(ii) computation of constraint-free yield of the qualifying crop for each length of growing period zone;

(iii) computation of agronomically attainable yields for each crop in each length of growing period, taking into account yield losses that occur due to agro-climatic constraints of temperature and moisture stress, pests and diseases, and workability.

To enable crops to be matched to climatic conditions, the climatic inventory of Kenya was compiled to permit the interpretation of the climatic resources in terms of their suitability for production of crops. The appropriate climatic adaptability attributes of the crop dictate what parameters need to be taken into account in the compilation of the climatic inventory. The climatic adaptability attributes of crops form the basis of defining the crop climatic requirements, and are outlined in the next section. The climatic resources inventory of Kenya is decribed in Technical Annex 1, and is briefly outlined in Section 5.2.

5.1 Crop Climatic Adaptability

Crops have climatic requirements for photosynthesis and phenology both of which bear a relationship to yield. The rate of crop photosynthesis and growth are related to the assimilation pathway and its response to temperature and radiation. However, the phenological climatic requirements, which must be met, are not specific to a photosynthetic pathway.

In the FAO Agro-ecological Zones methodology (Kassam, Kowal and Sarraf, 1977), crops are classified into climatic adaptability groups according to their fairly distinct photosynthesis characteristics. Each group comprises crops of 'similar ability' in relation to potential photosynthesis, and the differences between and within groups in the response of photosynthesis to temperature and radiation determine crop-specific biomass productivity when climatic phenological requirements are met.

TABLE 5.1
Average photosynthetic response of Individual leaves of four groups of crops to radiation and Temperature

Characteristics	Crop adaptability group[1]			
	I	II	III	IV
Photosynthetic pathway	C3	C3	C4	C4
Rate of photosynthesis at lightsaturation at optimum temperature (mg $CO_2 dm^{-2} h^{-1}$)	20–30	40–50	> 70	> 70
Optimum temperature (°C)	15–20	25–30	30–35	20–30
Radiation intensity of maximum photosynthesis (cal $cm^{-2} min^{-1}$)	0.2–0.6	0.3–0.8	>1.0	> 1.0
Crops included in the Kenya assessment	Barley Oat Wheat *Phaseolus* bean White potato	Cowpea Green gram Pigeon pea *Phaseolus* bean Rice Soybean Groundnut Sweet potato Cassava Banana Oil palm	Pearl millet Sorghum Maize Sugarcane	Sorghum Maize

[1] For further information on crop adaptability groups see Tables 3.1 to 3.5 in FAO (1978).

Crop adaptability groups and their characteristic average photosynthesis response to temperature and radiation are presented in Table 5.1. Barley and oat have a C3 photosynthesis pathway. They belong to group I and are adapted to operate under cool conditions (<20°C mean daily temperature). Cowpea, green gram and pigeonpea have a C3 photosynthesis pathway. They belong to group II and are adapted to operate under warm conditions (>20°C) with a potential rate of photosynthesis that is greater than in group I crops. Crops in group III (e.g. pearl millet, sugarcane) have a C4 photosynthesis pathway. They are adapted to operate under warm conditions (>20°C) but with a potential rate of photosynthesis that is greater than in group II crops. Crops in group IV (e.g. highland maize) have a C4 photosynthesis pathway. They are adapted to operate under cool conditions (<20°C) with a potential rate of photosynthesis that is similar to that in group III crops.

The time required to form yield depends on the phenological constraints on the

use of time available in the growing period, and the location of yield in the plant (e.g. seed, leaf, stem, root) has an important influence. Temperature has a rate controlling/limiting effect on growth, and it may influence the growth of a specific part and the accumulation of yield if located therein. For example, in barley and oat, cool night temperatures are required for tillering but the optimum temperatures at the time of flowering and subsequent yield formation are higher. Similarly, optimum temperatures for growth in sugarcane are greater than 20°C but during the ripening period, and because the yield is located in the stem, a lower temperature in the range 10-20°C is required for concentration in the cane of sugar of the right kind. On the other hand, optimum temperatures for growth, development and yield formation in cowpea, green gram and pigeonpea are greater than 20°C and most of the specific temperature requirements are also met when temperatures are optimum for photosynthesis and growth.

TABLE 5.2
Climatic adaptability attributes of crops

Attributes	Barley	Oat	Cowpea	Green gram	Pigeon pea
Species	*Hordeum vulgare*	*Avene sativa*	*Vlgna ungidculata*	*Vigna radiala*	*Cqjanus cqjan*
Photosynthetic pathway	C3	C3	C3	C3	C3
Crop adaptability group	I	I	II	II	II
Days to maturity	90–120[1]	90–120[1]	80–100[4]	60–80[4]	130–150[4]
	120–150[2]	120–150[2]	100–140[4]	80–100[4]	150–170[4]
	150–180[3]	150–180[3]			170–190[4]
Harvested part	Seed	Seed	Seed	Seed	Seed
Main product	Grain (C)	Grain (C)	Grain (L)	Grain (L)	Grain (L)
Growth habit	Determinate	Determinate	Indeterminate	Indeterminate	Indeterminate
Life-span					
- Natural	Annual	Annual	Annual	Annual	Short-term perennial
- Cultivated	Annual	Annual	Annual	Annual	Annual/Biennial
Yield: Cultivated	TI	TI	LI	LI	LI
Formation period	LT	LT	ME	ME	ME
Thermal zone for consideration	3, 4, 5, 6, 7	3, 4, 5, 6, 7	1, 2, 3	1, 2, 3	1, 2, 3

C - Cereal
L - Legume
TI - Terminal inflorescence
LI - Lateral inflorescence
LT - Last one third of growth cycle
ME - Middle to end period of growth cycle

Thermal zones:
1 - >25.0 °C
2 - 22.5-25.0
3 - 20.0-22.5
4 - 17.5-20.0
5 - 15.0-17.5
6 - 12.5-15.0
7 - 10.0-12.5

[1] thermal zones 3 & 4
[2] thermal zone 5
[3] thermal zones 6 & 7
[4] thermal zones 1,2 & 3

The attributes that are helpful in assessing the climatic adaptability of the crops in the matching exercise are given in Table 5.2.

Barley and oat (C_3-species, group I) are annuals with a botanically determinate growth habit. Their yield is located in terminal inflorescences in seeds, and the crop yield formation period is the last one-third of their growth cycle. Their climatic adaptability attributes qualify them to be considered for matching in areas with mean daily temperatures less than 22.5 °C and more than 10°C (i.e. thermal zones 3, 4, 5, 6 and 7).

Cowpea (C_3-species, group II) is an annual with botanically indeterminate growth habit, offering cultivars that may be morphologically determinate (bunch types) or indeterminate (spreading types). Its yield is located in the lateral inflorescences in seeds, and the crop yield formation period is from the middle to the end of its growth cycle. Its climatic adaptability attributes qualify it to be considered for matching in areas with mean daily temperatures greater than 20°C (i.e. thermal zones 1, 2 and 3).

TABLE 5.3
Thermal zones

Thermal zone code	Temperature class (°C)	Altitude (m)	Crop group suitable for consideration			
1	> 25.0	< 800	II	III		
2	22.5 - 25.0	800-1200	II	III		
3	20.0 - 22.5	1200- 1550		II	III	
4	17.5-20.0	1550-1950		II	III	IV
5	15.0- 17.5	1950-2350		IV		
6	12.5- 15.0	2350 - 2700		IV		
7	10.0- 12.5	2700-3100				
8	5.0- 10.0	3100-3900				
9	< 5.0	> 3900				

Green gram (C3-species, group II) is an annual with botanically indeterminate growth habit, offering cultivars that may be morphologically determinate in growth and stature. Its yield is located in the lateral inflorescences in seeds, and the crop yield formation period is from the middle to the end of its growth cycle. Its climatic adaptability attributes qualify it to be considered for matching in areas with mean daily temperatures greater than 20°C (i.e. thermal zones 1, 2 and 3).

Pigeonpea (C3-species, group II) is a short-term perennial with botanically indeterminate but morphologically determinate growth habit. Its yield is located in the lateral inflorescences in seeds, and the crop yield formation period is from the middle to the end of its annual cultivated life-span. Its climatic adaptability attributes qualify it to be considered for matching in areas with mean daily temperatures greater than 20°C (i.e. thermal zones 1, 2 and 3).

5.2 Climatic Inventory

The climatic resources inventory of Kenya (Technical Annex 1.1) quantifies both heat and moisture conditions.

Quantification of heat attributes has been achieved by defining **reference thermal zones** representing the prevailing temperature regimes[1]. Temperature seasonality effects of latitude are minor due to the equatorial position of Kenya.

[1] The following equation closely represents the relationship between average daily temperature in degree Celcius (T) and altitude in metres (A): T = 30.2 - 6.496(A/1000).

To cater for differences in temperature adaptability between nine thermal zones (based on 2.5 °C intervals) are distinguished in the climatic inventory of Kenya (Table 5.3). The temperature threshold used in these definitions accord with those differentiating the four temperature adaptability groups of crops as described above.

Quantification of moisture conditions was achieved through the concept of **reference length of growing period (LGP)** being defined as the duration (in days) when moisture supply can permit crop growth. A moisture supply from rainfall of half, or more than half, potential evapotranspiration has been considered to permit crop growth. The following main concepts, definitions and methods form the basis of the quantification of moisture conditions in the climatic inventory.

The growing period is the time when moisture supply from rainfall exceeds half potential evapotranspiration. It includes the time required to evapotranspire up to 100 mm of stored moisture from the soil profile. A 'normal' growing period has a humid phase, i.e. a period when moisture supply is greater than full potential evapotranspiration. When there is no humid period, the growing period is defined as 'intermediate'.

The quantification of moisture regime is based on the analysis of the length of growing period for each year separately and the computation of:

a) number of separate lengths of growing periods per year, summerized as a historical profile of **pattern of number of growing periods per year (referred to as LGP-Pattern);**

(b) length of each growing period and its various moisture periods, summarized as mean total dominant length, first associated length and second associated length, and the ean individual dominant and associated lengths making up the total lengths;

(c) the quality of moisture conditions during the growing period and its various moisture periods;

(d) year-to-year-variability (frequency distribution) of each length of growing period and the associated moisture condition.

Twenty two LGP-Pattems are recognized, and these with their composition are presented in Table 5.4. The LGP-Pattern code represents the number of growing periods per year in order of frequency of occurrence, e.g. in the pattern coded 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

TABLE 5.4
Patterns of growing periods (LGP-pattems) – historical profiles of occurrence of number of growing periods per year

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).

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 LGP-Pattern type, 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 lengths are again correlated to the former total length. These relationships are presented in Tables 5.5 and 5.6.

TABLE 5.5
Relationships between mean total dominant and mean total associated lengths of growing period

LGP- Pattem	Relationship
1 -2	L2 = 80.40 + 0.75 L1
1 -2-H	
1 -H-2	
1 -2-3	L2 = 71.56 + 0.77 L1
1 -3-2	L3 = 77.14 + 0.66 L1
1 -2-D	
1 -2-D	
2- 1	L1 = -86.09 + 1.28 L2
2- 1 -H	L3 = 25.29 + 0.82 L2
2-1 -3	
2- 1 -D	
2-3	L3 = 30.11 + 0.83 L2
2-3-1	L1 = -98.72 + 1.35 L2
2-3-4	L4 = 114.54 + 0.58 L2
3-2	L2 = 45.05 + 0.80 L3
3-2- 1	L1 = -9.86 + 0.88 L3

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.

In the climatic inventory of Kenya, only the mean total dominant length has been inventoried on the map as 14 LGP zones. The boundary or isoline values used are 0, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, 365^{-} and 365^{+} days respectively delineating the mean total dominant length of growing period zones of 0, 1-29, 30-59, 60-89, 90-119, 120-149, 150-179, 180-209, 210-239, 240-269, 270-299, 300-329, 330-364, 365" and 365^{+} days[2].

[2] 365' - year-round growing period but not humid year-round; 365^{+} - year-round humid growing period

Additionally, the LGP-Pattern zones have been inventoried. Consequently, the relationships in Tables 5.5 and 5.6 together with the map of dominant LGP zones and the LGP-Pattern zones provide the historical profile of any mean total dominant length of growing period in any of the 22 LGP-Pattern zones.

Reference tables relating the mean total dominant LGPs (mapped) and the corresponding mean total associated LGPs (unmapped) are presented in Technical Annex 1, together with generalized coefficients of variation of mean LGPs, and frequency of occurrence of intermediate LGPs.

5.3 Matching of Crops to Thermal Zones

The initial step in the matching process is comparison of the temperature requirements of individual crops with the identified thermal zones. This step indicates the crops which should be considered from a temperature/growth and phenology viewpoint, in each thermal zone

.

Crop/thermal zone suitability ratings for each crop and zone are presented in Table 5.7. Five suitability classes are employed (i.e. S1, S2, S3, S4, and N), and the ratings apply to both levels of inputs: where requirements are fully met, the zone is adjusted S1: where requirements are sub-optimal, the zone is adjudged S2, S3 or S4; where requirements are not met, the zone is adjudged as N (not suitable).

A rating of S1 indicates that the temperature conditions for growth and yield physiology, and phenology development are optimal and that it is possible to achieve the maximum attainable agro-genetic yield potential, if there are no additional climatic or edaphic limitations. Ratings of S2, S3 and S4 indicate that temperature conditions for growth and development are sub-optimal and that there would be a suppression of yield potential in the order of 25, 50 and 75 percent respectively. A rating of N indicates that the thermal requirements are not met and the zone is not suitable for father consideration.

TABLE 5.6
Relationship between individual component mean length and mean total length of growing period

LGP-Pattern	Relationship
2	L2, = -1.11 + 0.55 L2
1 -2	$L2_1$ = 4.94 + 0.62 L2
1 -2-H	
1 -H-2	
1 -2-3	$L2_1$ = 5.87 + 0.64 L2
1 -3-2	$L3_1$ = 22.12 + 0.39 L3
1 -2-D	$L3_2$ = 1.58 +0.32 L3
1 -D-2	
2- 1	L2, = -5.48 + 0.64 L2
2- 1 -H	L3, = 0.14 + 0.46 L3
2- 1 -3	$L3_2$ - -0.98 + 0.33 L3
2-1 -D	
2- 3	$L2_1$ = -3.05 + 0.61 L2
2-3-1	L3, = 1.68 + 0.43 L3
2-3-4	$L3_2$ = -3.00 + 0.34 L3
	L4, = 26.35 + 0.34 L4
	$L4_2$ = -20.88 + 0.38 L4
	$L4_3$ = -17.66 + 0.27 L4
3- 2	L2, = -2.33 + 0.63 L2
3-2-1	$L3_1$ = 5.62 + 0.45 L3
	$L3_2$ = 1.25 + 0.31 L3

$L2_1$ = 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.

5.4 Matching of Crops to Growing Period Zones

Matching of crops to growing period zones is according to the following procedure:

(i) assessment of net biomass and constraint-free crop yields by individual lengths of growing period zones, assuming optimum temperature conditions for production (i.e. S1 crop/thermal zone rating);
(ii) inventory of agro-climatic constraints for each length of growing period zone by crop and by input level;
(iii) application of the thermal zone suitability ratings (Table 5.7) and agro-climatic constraints (ii) to the constraint-free yields (i) to determine (agro-climatically attainable) crop yields by individual lengths of growing period zones in each thermal zone.

TABLE 5.7
Thermal zones suitability ratings

Crop	Growth cycle (days)	Thermal zones								
		T1	T2	T3	T4	T5	T6	T7	T8	T9
Barley	90-120	N	N	S3	S1	na	na	na	N	N
Barley	120-150	N	N	na	na	S1	na	na	N	N
Barley	150-180	N	N	na	na	na	S2	S4	N	N
Oat	90-120	N	N	S4	S2	na	na	na	N	N
Oat	120-150	N	N	na	na	S1	na	na	N	N
Oat	150-180	N	N	na	na	na	S2	S4	N	N
Cowpea	80-100	S1	S1	S3	N	N	N	N	N	N
Cowpea	100-140	S1	S1	S3	N	N	N	N	N	N
Green gram	60-80	S1	S2	S4	N	N	N	N	N	N
Green gram	80-100	S1	S2	S4	N	N	N	N	N	N
Pigeonpea	130-150	S1	S1	S3	N	N	N	N	N	N
Pigeonpea	150-170	S1	S1	S3	N	N	N	N	N	N
Pigeonpea	170-190	S1	S1	S3	N	N	N	N	N	N

The above matching exercise results in a basic agro-climatic suitability classification of each length of growing period zone by thermal zone only. From this, the agro-climatic suitability classification of each mean total dominant growing period zone (inventoried) can be derived for each crop according to agro-climatically attainable yields by thermal zone and by pattern zone. This is achieved by computing agro-climatically attainable yields as affected by year-to-year variability (i.e. LGP-Pattern) from the basic agro-climatic suitability classification of each length of growing period. Agro-climatic suitability by LGP-Pattern zone is not attempted in this annex but is considered in a separate annex (Technical Annex 1.4) dealing with crop productivity potential of each length of growing period by thermal zone and by LGP-Pattern zone.

5.4.1 Potential net biomass and yield

The methodology for the calculation of net biomass and constraint-free yields by suitable thermal zone is according to Kassam (1977), and is presented in this section.

Net total biomass (Bn) is calculated from the equation:

$$Bn = (0.36\ bgm \times L)' / (1/N + 0.25\ Ct) \qquad (5.1)$$

where:

bgm = maximum rate of gross biomass production at leaf area index (LAI) of 5

L = maximum growth ratio, equal to the ratio of bgm at actual LAI to bgm at LAI of 5. (L at LAI 1, 2, 3, 4 and 5 is 0.4, 0.6, 0.8, 0.9 and 1.0 respectively)

N = length of crop growth cycle

Ct = maintenance respiration, dependent on both crop and temperature; given by the relation:

$$Ct = C30\ (0.0044 + 0.0019\ T + 0.0010\ T^2)$$

At 30 °C, C = 0.0283 for a legume crop and 0.0108 for a non-legume crop. Constraint-free yield (By) is calculated from net biomass (Bn) from the equation:

$$By = Hi \times Bn \qquad (5.2)$$

where: Hi = Harvest index (i.e. proportion of the net biomass of the crop that is economically useful**).**

The maximum rate of gross biomass production (bgm) is dependent on the maximum rate photosynthesis (Pm) which is dependent on temperature and photosynthesis pathway of the crop. Maximum rates of photosynthesis (Pm) for the five crops by temperature is presented in Table 5.8.

TABLE 5.8
Maximum rate of photosynthesis (Pm in kg CH_20 ha'^{1} hr*^{1})

Crops	Average day-time temperature (°C)				
	10	15	20	25	30
Barley and oat	15	20	20	15	5
Cowpea, green gram and pigeonpea	0	15	32.5	35	35

For Pm = 20 kg CH_20 ha^{-1} hr^{-1} and LAI of 5, bgm is calculated from the equation:

$$bgm = F \times bo + (1\text{-}F)\ bc \qquad (5.3)$$

where:

F = fraction of the daytime the sky is clouded:

F = (Ac - 0.5 Rg)/(0.8 Ac) where Ac is the maximum active incoming shortwave radiation on clear days in cal cm^{-2} day^{-1} (Table 5.9) and Rg is the incoming shortwave radiation in cal cm^{-2} day^{-1}

Bo = gross dry matter production rate of a standard crop for a given location on a completely overcast day, kg CH2O ha^{-1} day^{-1} (Table 5.9)

Bc = gross dry matter production rate of standard crop for a given location on a clear (cloudless) day, kg CH_2O ha^{-1} day^{-1} (Table 5.9).

When Pm is greater than 20 kg CH_2O ha^{-1} hr^{-1}, bgm is given by the equation:

$$bgm = F(0.8 + 0.01\ Pm)bo + (1 - F)(0.5 + 0.025Pm)bc. \qquad (5.4)$$

When Pm is less than 20 kg CH_2O ha^{-1} hr^{-1}, bgm is given by the equation:

$$bgm = F(0.5 + 0.025Pm)bo + (1 - F)(0.05Pm)bc. \qquad (5.5)$$

An example calculation of net total biomass and yield of cowpea for Lamu, is presented below.

TABLE 5.9
The photosynthetically active radiation on very clear days (Ac) in cal cm^{-2} day^{-1} and the dally gross photosynthesis rate of crop canopies on very clear (bc) and overcast (bo) days in kg CH_2O $ha^{-1}day^{-1}$for Pm = 20 kg $CH_2$0 kg ha^{-1} hr^{-1} (from de Wit 1965)

Lat. North		Jan	Fob	Mar	Apr	May	Jun	Jul	Aug	Sop	Oct	Nov	Dee
Lat. South		Jul	Aug	Sop	Oct	Nov	Doe	Jan	Fob	Mar	Apr	May	Jun
0°	Ac	343	360	388	364	348	337	342	367	368	365	348	337
	bc	413	424	428	426	417	410	413	422	428	427	418	410
	bo	219	228	230	228	221	216	218	226	230	228	222	216
10°	Ac	288	332	368	376	377	374	376	377	369	346	311	281
	bo	376	401	422	437	440	440	440	438	431	411	386	370
	bo	187	212	226	234	236	236	236	236	230	218	203	183

Climate

Station : Lamu, Kenya
Location : 2° 16' S and 40° 54' E
Altitude : 30 m
Growing period : 140 days
Start growing period : 5 April
End growing period : 25 August
Average radiation (Rg) : 471 cal cm^{-2} day^{-1}
Average day-time temperature : 26.5 °C
Average 24hr mean temperature : 25.3 °C

Crop

Crop : Cowpea
Growth cycle : 100 days
Leaf area index at maximum growth rate : 4
Harvest index : 0.30
Crop adaptability : Photosynthesis pathway C3, group II

Calculation of daily rate of gross biomass production fbgm)

Photosynthesis rate Pm at 26.5 °C : 35 kg CH_2 ha^{-1} hr^{-1}.
Difference in Pm relative to Pm = 20 kg CH_2O ha^{-1} hr^{-1}: 75%.
Average photosynthetically active radiation on clear days (Ac) : 351 cal cm^{-2} day^{-1} (Table 5.9).
Fraction of the day-time when the sky is overcast (F): 0.41 (from equation F = (Ac -0.5Rg)/0.8Ac).
Average rate of gross biomass production for perfectly clear days at Pm = 20 kg CH_2O ha^{-1} hr^{-1} (be) : 418 kg CH_2O ha^{-1} day^{-1} (Table 5.9).
Average rate of gross biomass production for totally overcast days at Pm = 20 kg CH_2O ha^{-1} hr^{-1} (bo) : 222 kg CH_2O ha^{-1} day^{-1} (Table 5.9).

TABLE 5.10
Crop characteristics considered in the potential biomass and yield computations

Crap characteristics	Barley	Oat	Cowpea	Green gram	Pigeonpea
Length of normal growth cycle (days	90–180[1]	90–180[1]	80–140	60–100	130–190
Yield formation period (days)	30–60	30–60	40–70	30–50	65–95
LAI at maximum growth rate	3.5–4.5	3.5–4.0	3.0–4.0	3.0–4.0	3.0–4.0
Harvest index	0.4	0.35	0.3	0.3	0.25

[1] Days to maturity of barley and oat assumed to increase by 6 days for each 0.5 °C decrease in mean temperature from 20 °C.

Rate of gross biomass production at Pm = 20 kg CH_2O ha^{-1} hr^{-1} at LAI of 5 : 338 kg CH_2O ha-1- day^{-1} (from equation 5.3).

Rate of gross biomass production at Pm = 35 kg CH_2O ha^{-1} hr^{-1} at LAI of 5 (bgm) : 444 **kg** CH_2O ha^{-1} day^{-1} (from equations 5.3 and 5.4).

Calculation of total net biomass production (Bn) and Yield (By)

Maintenance respiration coefficient at 30 °C : 0.0283 (for legume crop).

Maintenance respiration coefficient at 24.4 °C (Ct): 0.017 (from equation $Ct = C_{30} (0.0044 + 0.0019 T + 0.0010 T^2)$).

Net total biomass (Bn) : 10.3 t/ha (equation 5.1). Yield (By) : 3.1 t/ha (equation 5.2).

Crop characteristics considered in the biomass and yield calculations are presented in Table 5.10. The constraint-free net biomass and yield values are presented in Table 5.11. In Tables 5.10 and 5.11, values apply to the respective component length of growing period under which they appear in the tables. For a growing period range, the values continue to apply as stated as long as the largest growing period value in the range is equal to or shorter than the longest growth cycle or days of active growth considered. For any growing period range, the lower yield figure refers to the shortest crop growth period considered in the range.

The yield formation period has been assumed to be the end one-third of the growth cycle in barley and oat, and the second half of the growth cycle in cowpea, green gram and pigeonpea. Within the growth cycle range considered, leaf area index (LAI) of the shorter duration crop has been reduced proportionately relative to the LAI of the longer duration crop. Where the growth cycle is curtailed due to the growing period being shorter (e.g. 100-day cowpea at 75 days growing period), LAI has been reduced proportionately relative to the LAI for the normal growth cycle considered.

TABLE 5.11
Constraint-free potential net blomass (Bn) and yield (By) In t/ha dry weight

Crop		Length of growing period (days)									Mean tempera-ture range (°C)	Ther-mal zone
		30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	>270		
Barley	Bn	1.7-4.9	4.9-8.1	8.6-12.6	9.4-13.1	9.6-13.2	9.3-12.8	9.3-12.8	9.2-12.6	9.1-12.6	17.5-20.0	4
	By	0.0	0.0-3.2	3.4-5.0	3.8-5.2	3.7-5.3	3.7-5.1	3.7-5.1	3.7-5.0	3.7-5.0	20.0-22.5	3
	By	0.0	0.0-3.2	3.4-5.0	3.8-5.2	3.8-5.3	3.7-5.1	3.7-5.1	3.7-5.0	3.7-5.0	17.5-20.0	4
	By	0.0	0.0	0.0-3.2	3.4-5.0	3.8-5.2	3.8-5.3	3.7-5.1	3.7-5.1	3.7-5.0	15.0-17.5	5
	By	0.0	0.0	0.0	0.0-3.2	3.4-5.0	3.8-5.2	3.8-5.3	3.7-5.1	3.7-5.0	12.5-15.0	6
	By	0.0	0.0	0.0	0.0	0.0-3.2	3.4-5.0	3.8-5.3	3.8-5.3	3.7-5.0	10.0-12.0	7
Oat	Bn	1.7-4.9	4.9-8.1	8.6-12.6	9.4-13.1	9.6-13.2	9.3-12.8	9.3-12.8	9.2-12.6	9.1-12.6	17.5-20.0	4
	By	0.0	0.0-2.8	3.0-4.4	3.6-4.6	3.4-4.6	3.3-4.5	3.3-4.5	3.2-4.3	3.2-4.3	20.0-22.5	3
	By	0.0	0.0-2.8	3.0-4.4	3.6-4.6	3.4-4.6	3.4-4.5	3.3-4.5	3.3-4.5	3.2-4.3	17.5-20.0	4
	By	0.0	0.0	0.0-2.8	3.0-4.4	3.6-4.6	3.6-4.6	3.4-4.5	3.3-4.5	3.2-4.3	15.0-17.5	5
	By	0.0	0.0	0.0	0.0-2.8	3.0-4.4	3.6-4.6	3.4-4.6	3.3-4.5	3.2-4.3	12.5-15.0	6
	By	0.0	0.0	0.0	0.0	0.0-2.8	3.0-4.4	3.0-4.4	3.4-4.6	3.3-4.5	10.0-12.0	7
Cowpea	Bn	1.7-4.9	4.9-8.1	8.3-11.5	8.2-11.2	8.1-11.2	8.2-11.1	7.8-11.0	7.8-11.0	7.5-10.4	>20.0	1,2,3
	By	0.0-0.3	0.3-2.3	2.5-3.4	2.6-3.4	2.4-3.4	2.4-3.3	2.3-3.3	2.3-3.3	2.2-3.1	>20.0	1,2,3
Green	Bn	1.7-4.9	4.9-8.1	6.4-8.3	6.4-8.2	6.4-8.2	6.4-8.2	6.1-7.8	6.1-7.8	5.8-7.4	>20.0	1,2,3
gram	By	0.0-1.0	1.0-2.4	1.9-2.5	1.9-2.5	1.9-2.5	1.9-2.5	1.8-2.5	1.8-2.5	1.7-2.2	>20.0	1,2.3
Pigeon-	Bn	1.7-4.9	4.9-8.1	8.3-11.5	11.2-13.1	13.1-15.0	13.0-14.8	12.8-14.7	12.8-14.7	12.3-13.9	>20.0	1.2,3
pea	By	0.0	0.0-0.6	0.6-2.0	2.0-3.3	3.3-3.8	3.3-3.7	3.3-3.7	3.2-3.7	3.1-3.5	>20.0	1,2.3

When the yield formation period is curtailed due to growing period being shorter, harvest index (Hi) has been reduced proportionately in relation to the Hi for the normal yield formation period considered.

Values for barley and oat (group I) apply to areas where mean temperatures during the growing period are less than 22.5 °C but greater than 10°C (thermal zones 3,4,5,6,7). Values for the remaining crops (groups II) apply to areas where the mean temperature during the growing period is greater than 20°C (thermal zones 1,2,3).

5.4.2 Agro-climatic constraints

The methodology for matching the climatic inventory with the crop adaptability groups, and for the calculation of net biomass and yield of crops provides quantification of yields that can be anticipated under conditions that are essentially free from soil constraints but also from agro-climatic constraints to production within the growing period.

To complete an agro-climatic suitability classification, yield losses likely to occur due to the agro-climatic constraints must be deducted from the constraint-free yields in Table 5.11.

Agro-climatic constraints have their origin primarily due to the prevailing climate, and cause direct or indirect losses in yield and quality of produce as follows:

(a) yield losses due to water stress constraints on crop growth;

(b) yield losses due to the effects of pest, disease and weed constraints on crop growth;

(c) yield losses due to water stress, and pest and disease constraints on yield components, yield formation and quality of produce; and

(d) yield losses due to workability constraints.

The assessment of the severity of the four sets of constraints by crops, growing period zones and levels of inputs is presented in Table 5.12. The severity of constraints are rated as follows:

Rating 0 - no (or only slight), resulting in no significant yield losses;

Rating 1 - moderate, resulting in yield losses of the order of 25 percent

Rating 2 - severe, resulting in yield losses of the order of 50 percent

In general, the major agro-climatic constraint in the shorter growing period zones for all crops is water stress. The major agro-climatic constraints in the longer growing period zones for annual crops are those of pests, diseases and weeds, and workability.

5.4.3 Anticipated yields and agro-climatic suitability classification

Application of the appropriate reduction factors, according to the occurrence and severity of the temperature constraints (Table 5.7) and agro-climatic constraints of water stress, pests and diseases and workability (Table 5.12), to the constraint-free yields (Table 5.11), allows quantification of attainable yields with the agro-climatic constraints for the agro-climatic suitability assessment and classification. The reductions were made consecutively according to the presence or absence of the constraints and the severity of their occurrence in each growing period zone and at each level of inputs. The computation was made in the order of presentation of the four sets of constraints, i.e. group 'a' constraints applied first and group 'd' constraints applied last, after applying reductions due to temperature constraints.

TABLE 5.12
Agro-climatic constraints by crop

Crop	Barley and Oat					
Thermal zone	3,4		5		6,7	
Input Level	Low	High	Low	High	Low	High
Constraints	Ratings		Ratings		Ratings	
	abcd	abcd	abcd	abcd	abcd	abcd
Growing period zones (days)						
30 – 59	2 0 1 0	2 0 1 0	2 0 10	2 0 1 0	2 0 1 0	2 0 1 0
60 – 89	2 0 1 0	2 0 1 0	2 0 1 0	2 0 1 0	2 0 1 0	2 0 1 0
90 – 119	1 0 0 0	1 0 0 0	2 0 1 0	2 0 1 0	2 0 1 0	2 0 1 0
120 – 149	0 0 0 0	0 0 0 0	1 0 0 0	1 0 0 0	2 0 0 0	2 0 0 0
150 – 179	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	1 0 0 0	1 0 0 0
180 – 209	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0
210 – 239	0 1 1 0	0 0 1 1	0 1 00	0 1 0 1	0 0 0 0	0 0 0 0
240 – 269	0 1 1 1	0 1 1 1	0 1 1 0	0 1 1 1	0 1 1 0	0 1 1 1
270 – 299	0 2 2 1	0 2 2 2	0 2 2 1	0 2 2 2	0 2 1 1	0 2 1 2
300 – 329	0 2 2 1	0 2 2 2	0 2 2 1	0 2 2 2	0 2 2 1	0 2 2 2
330 – 364	0 2 2 2	0 2 2 2	0 2 2 2	0 2 2 2	0 2 2 2	0 2 2 2
365-	0 2 2 2	0 2 2 2	0 2 2 2	0 2 2 2	0 2 2 2	0 2 2 2
365+	0 2 2 2	0 2 2 2	0 2 2 2	0 2 2 2	0 2 2 2	0 2 2 2

Crop	Cowpea		Green gram		Pigeonpea	
Thermal zone	1.2.3		1.2.3		1.2.3	
Input Level	Low	High	Low	High	Low	High.
Constraints	Ratings		Ratings		Ratings	
	abcd	abcd	abcd	abcd	abcd	abcd
Growing period zones (days)						
30 – 59	2 0 2 0	2 0 2 0	2 0 2 0	2 0 2 0	2 0 2 0	2 0 2 0
60 – 89	2 0 2 0	2 0 2 0	2 0 2 0	2 0 2 0	2 0 2 0	2 0 2 0
90 – 119	2 0 1 0	2 0 1 0	2 0 0 0	2 0 0 0	2 0 2 0	2 0 2 0
120 – 149	1 0 1 0	1 0 1 0	1 0 0 0	1 0 0 0	1 0 1 0	1 0 1 0
150 – 179	0 0 1 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0
180 – 209	0 0 1 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0
210 -239	0 1 1 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0
240 – 269	0 1 1 0	0 0 0 1	0 1 1 0	0 0 0 1	0 0 1 0	0 0 0 1
270 – 299	0 1 1 0	0 0 0 1	0 1 1 0	0 0 0 1	0 1 1 0	0 0 0 1
300 – 329	0 1 1 0	0 1 0 1	0 1 1 1	0 1 0 2	0 1 1 0	0 1 0 1
330 – 364	0 1 1 1	0 1 1 2	0 2 1 1	0 1 1 2	0 2 1 1	0 1 1 2
365-	0 2 2 1	0 1 2 2	0 2 2 1	0 1 2 2	0 2 2 1	0 1 2 2
365+	0 2 2 2	0 2 2 2	0 2 2 2	0 2 2 2	0 2 2 2	0 2 2 2

Crop yields for representative growth cycles of each crop for the three input levels are presented in Tables 5.13, 5.14 and 5.15. Because of the yield reducing effects of low

soil fertility and management limitations inherent in the low input level conditions, the constraint-free yields for this level have been assumed as 25 percent of the constraint-free yields under high input conditions in Table 5.11. Anticipated yields at the intermediate level are taken to be half-way between the high and low level yields.

Anticipated yields at each level of inputs are also presented in Tables 5.16, 5.17, 5.18, 5,19 and 5.20 for barley, oat, cowpea, green gram and pigeonpea respectively. Further, in Tables 5.16-5.20 the anticipated yield for each growing period zone is shown as a percentage of the maximum yield attainable, i.e. in the case of barley with 90-120 days growth cycle at high input level, the maximum attainable yield is 4.55 t/ha grain dry weight in the 150-179 days zone. The yield of 3.10 t/ha from the 90-119 days zone is therefore as shown, 68 percent of the maximum.

The agro-climatic suitability classification is also presented in Tables 5.16-5.20 in terms of suitability bar charts. The basis of these charts is comparison of attainable crop yields in the different lengths of growing period zones, in terms of percentages of maximum attainable. If the yield of a crop from a particular zone is 80 percent or more of the maximum attainable, that zone is assessed as agro-climatically 'very suitable' (VS) for that crop. Zones with yields of 60 to less than 80 percent are classified as 'suitable' (S); 40 to less than 60 percent as 'moderately suitable' (MS); 20 to less than 40 percent as 'marginally suitable' (mS); and less than 20 percent as 'not suitable' (NS). On the bar charts, the dividing line between the agro-climatic suitability classes is located at the nearest 15-day position in relation to the growing period zones.

Suitabilities and yields in Tables 5.16-5.20 are matched to individual component length of growing periods, i.e. L1, $L2_1$, $L2_2$, $L3_1$, $L3_2$, $L3_3$, $L4_1$, $L4_2$, $L4_3$ and $L4_4$ in the land suitability assessment. The LGP-Pattern evaluation for each crop is achieved by taking into account all the constituent component lengths in each LGP-Pattern, thus providing a profile of variability in potential yields over time (e.g. average yield, maximum yield, minimum yield). From such information it is then possible to assess yield stability of crops. This stability assessment has been incorporated in the crop productivity model (Technical Annex 1.4).

Yields in Tables 5.13-5.20 apply to normal lengths of growing periods. For intermediate growing periods, yield reductions are of the order of 50% on all soils except Fluvisols and Gleysols. The percentage of occurrence of intermediate lengths of growing periods, in all LGP-Pattern zones combined, is 100% in zone 1-29 days; 65% in zone 30-59 days; 25% in zone 60-89 days; 10% in zone 90-119 days and 5% in zone 120-149 days.

An exception to the general methodology for agro-climatic suitability classification applies to Fluvisols because the length of growing period does not fully reflect their particular circumstances with regards to moisture regime.

TABLE 5.13
Crop yields (t/ha dry weight) for Individual lengths of growing periods at low level of Inputs

Crop	Growth cycle (days)	Maximum yield	Length of growing period (days)													
			0	1–29	30–69	60–89	90–119	120–149	150–179	160–209	210–239	240–269	270–299	300–329	330–364	365^{-}	365^{+}
Barley	90–120	1.15	0.00	0.00	0.00	0.15	0.76	1.16	1.16	1.10	0.60	0.45	0.20	0.20	0.15	0.15	0.15
	120–160	1.15	0.00	0.00	0.00	0.00.	0.00	0.76	1.16	1.16	0.86	0.65	0.20	0.20	0.16	0.16	0.15
	150–180	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.76	1.16	1.16	0.85	0.20	0.20	0.20	0.15	0.15
Oat	90–120	1.00	0.00	0.00	0.00	0.15	0.70	1.00	0.95	0.95	0.66	0.35	0.15	0.16	0.10	0.10	0.10
	120–150	1.00	0.00	0.00	0.00	0.00	0.00	0.70	1.00	0.95	0.95	0.55	0.15	0.16	0.10	0.10	0.10
	150–180	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.70	1.00	0.95	0.95	0.15	0.16	0.10	0.10	0.10
Cow-pea	80–100	0.60	0.00	0.00	0.00	0.05	0.10	0.20	0.40	0.60	0.50	0.30	0.30	0.30	0.20	0.20	0.20
	100–140	0.60	0.00	0.00	0.00	0.00	0.10	0.30	0.60	0.60	0.60	0.60	0.60	0.60	0.40	0.20	0.20
Green gram	60–80	0.50	0.00	0.00	0.02	0.07	0.20	0.40	0.60	0.60	0.60	0.20	0.20	0.20	0.10	0.10	0.10
	80–100	0.60	0.00	0.00	0.00	0.10	0.30	0.50	0.60	0.60	0.60	0.30	0.30	0.20	0.10	0.10	0.10
Pigeon opea	130–160	0.80	0.00	0.00	0.00	0.03	0.08	0.36	0.80	0.80	0.80	0.60	0.40	0.40	0.20	0.10	0.10
	160–170	1.00	0.00	0.00	0.00	0.00	0.00	0.40	1.00	0.90	0.90	0.70	0.50	0.50	0.20	0.20	0.10
	170–190	1.02	0.00	0.00	0.00	0.00	0.00	0.00	0.89	1.00	1.01	0.77	0.73	0.55	0.27	0.20	0.10

TABLE 5.14
Crop yields (t/ha dry weight) for Individual lengths of growing periods at intermediate level of Inputs

Crop	Growth cycle (days)	Maximum yield	Length of growing period (days)														
			0	1–29	30–59	60–89	90–119	120–149	150–179	180–209	210–239	240–269	270–299	300–329	330–364	365^{-}	365^{+}
Barley	90–120	2.85	0.00	0.00	0.00	0.38	1.93	2.83	2.85	2.75	1.55	1.15	0.38	0.38	0.35	0.35	0.35
	120–150	2.85	0.00	0.00	0.00	0.00	0.00	1.93	2.83	2.85	1.68	1.25	0.38	0.38	0.35	0.35	0.35
	150–180	2.85	0.00	0.00	0.00	0.00	0.00	0.00	1.93	2.83	2.85	1.35	0.38	0.38	0.35	0.35	0.35
Oat	90–120	2.55	0.00	0.00	0.00	0.33	1.75	2.55	2.48	2.43	1.38	0.98	0.30	0.30	0.28	0.28	0.20
	120–150	2.55	0.00	0.00	0.00	0.00	0.00	1.76	2.55	2.43	1.58	1.08	0.30	0.30	0.28	0.28	0.28
	150–180	2.55	0.00	0.00	0.00	0.00	0.00	0.00	1.75	2.55	2.48	1.28	0.30	0.30	0.28	0.28	0.28
Cow–pea	80–100	1.45	0.00	0.00	0.03	0 20	0.50	0.85	1.40	1.46	1.45	1.00	1.00	0.75	0.40	0.30	0.25
	100–140	1.95	0.00	0.00	0.00	0.00	0.60	1.11	1.95	1.95	1.95	1.50	1.45	1.10	0.65	0.40	0.30
Green gram	60–80	1.20	0.00	0.00	0.05	0.17	0.60	0.90	1.20	1.20	1.15	0.80	0.80	0.40	0.30	0.20	0.15
	80–100	1.55	0.00	0.00	0.00	0.25	0.80	1.20	1.55	1.55	1.55	1.10	1.00	0.50	0.35	0.25	0.20
Pigeon-pea	130–150	2.05	0.00	0.00	0.00	0.05	0.22	0.87	2.05	2.06	2.00	1.50	1.40	1.05	0.55	0.35	0.25
	150–170	2.40	0.00	0.00	0.00	0.00	0.00	0.95	2.40	2.30	2.30	1.75	1.60	1.25	0.60	0.45	0.25
	170–190	2.53	0.00	0.00	0.00	0.00	0.00	0.00	2.22	2.49	2.63	1.93	1.82	1.33	0.67	0.49	0.25

TABLE 5.15
Crop yields (t/ha dry weight) for Individual lengths of growing periods at high level of Inputs

Crop	Growth cycle (days)	Maximum yield	Length of growing period (days)													
			0	1–29	30–59	60–89	90–119	120–149	150–179	180–209	210–239	240–269	270–299	300–329	330–364	365^{-}	365^{+}
Barley	90-–20	4.55	0.00	0.00	0.00	0.60	3.10	4.60	4.55	4.40	2.60	1.85	0.65	0.65	0.65	0.55	0.65
	120–150	4.55	0.00	0.00	0.00	0.00	0.00	3.10	4.50	4.55	2.60	1.85	0.55	0.55	0.55	0.55	0.55
	150–180	4.55	0.00	0.00	0.00	0.00	0.00	0.00	3.10	4.50	4.55	1.85	0.66	0.55	0.55	0.55	0.55
Oat	90–120	4.10	0.00	0.00	0.00	0.50	2.80	4.10	4.00	3.90	2.20	1.60	0.45	0.45	0.45	0.45	0.45
	120–150	4.10	0.00	0.00	0.00	0.00	0.00	2.80	4.10	4.00	2.20	1.60	0.46	0.45	0.45	0.45	0.45
	150–180	4.10	0.00	0.00	0.00	0.00	0.00	0.00	2.80	4.10	4.00	1.60	0.46	0.45	0.45	0.45	0.45
Cow-pea	80–100	2.40	0.00	0.00	0.05	0.35	0.90	1.60	2.40	2.40	2.30	1.70	1.70	1.20	0.60	0.40	0.30
	100–140	3.40	0.00	0.00	0.00	0.00	1.10	1.92	3.40	3.30	3.30	2.60	2.40	1.70	0.90	0.60	0.40
Green gram	60–80	1.90	0.00	0.00	0.08	0.27	1.00	1.40	1.90	1.90	1.80	1.40	1.40	0.60	0.60	0.30	0.20
	80–100	2.50	0.00	0.00	0.00	0.40	1.30	1.90	2.60	2.60	2.50	1.90	1.70	0.80	0.60	0.40	0.30
Pigeon-pea	130–150	3.30	0.00	0.00	0.00	0.07	0.35	1.38	3.30	3.30	3.20	2.40	2.40	1.70	0.90	0.60	0.40
	150–170	3.80	0.00	0.00	0.00	0.00	0.00	1.60	3.80	3.70	3.70	2.80	2.70	2.00	1.00	0.70	0.40
	170–190	4.04	0.00	0.00	0.00	0.00	0.00	0.00	3.55	3.98	4.04	3.08	2.91	2.21	1.07	0.77	0.40

TABLE 5.16
Agro-climatic suitability classification and yields (with agro-climatic constraints) in t/ha dry weight for barley

LOW INPUTS

Growth cycle 90–120 days

LGP (days)	*60–89*	*90–119*	*120–149*	*150–179*	*180–209*	*210–239*	*240–269*	*270–299*	*300–329*	*330–364*	*365⁻*	*365⁺*
Yield [1]	*0.15*	*0.75*	*1.15*	*1.15*	*1.10*	*0.60*	*0.45*	*0.20*	*0.20*	*0.15*	*0.15*	*0.15*
Perc. of Max. [2]	*13*	*65*	*100*	*100*	*96*	*52*	*39*	*17*	*17*	*13*	*13*	*13*
Suitability[3]	*NS*	*MS*	*S*	*VS*		*S*	*MS*	*nS*	*NS*			

INTERMEDIATE INPUTS

Growth cycle 90–120 days

LGP (days)	*60–89*	*90–119*	*120–149*	*150–179*	*180–209*	*210–239*	*240–269*	*270–299*	*300–329*	*330–364*	*365⁻*	*365⁺*
Yield [1]	*0.38*	*1.93*	*2.83*	*2.85*	*2.75*	*1.55*	*1.15*	*0.38*	*0.38*	*0.35*	*0.35*	*0.35*
Perc. of Max. [2]	*13*	*68*	*99*	*100*	*96*	*54*	*40*	*13*	*13*	*12*	*12*	*12*
Suitability[3]	*NS*	*MS*	*S*	*VS*		*S*	*MS*	*nS*	*NS*			

HIGH INPUTS

Growth cycle .90–120 days

LGP (days)	*60–89*	*90–119*	*120–149*	*150–179*	*180–209*	*210–239*	*240–269*	*270–299*	*300–329*	*330–364*	*365⁻*	*365⁺*
Yield[1]	*0.60*	*3.10*	*4.50*	*4.55*	*4.40*	*2.50*	*1.85*	*0.55*	*0.55*	*0.55*	*0.55*	*0.55*
Perc. of Max.[2]	*13*	*68*	*99*	*100*	*97*	*55*	*41*	*12*	*12*	*12*	*12*	*12*
Suitability[3]	*NS*	*MS*	*S*	*VS*		*S*	*MS*	*nS*	*NS*			

[1] Agronomically attainable yield

[2] Perc. of Max refers to the yields of the respective gromting periods expressed as a percentage of the maximus yield attainable from any groming period without permanent constraints

[3] Suitability		Very suitable (VS)	Suitable (S)	Moderately suitable (MS)	Marginally suitable (mS)	Hot suitable (NS)
Yield (t/ha) :	low inputs	1.15–0.92	0.92–0.69	0.69–0.46	0.46–0.23	0.23–0.00
	int. inputs	2.85–2.28	2.28–2.71	1.71–1.14	1.14–1.57	0.57–0.00
	high inputs	4.55–3.64	3.64–2.73	2.73–1.82	1.82–0.91	0.91–0.00

LOW INPUTS

Growth cycle 120–150 days

LGP (days)	*60–89*	*90–119*	*120–149*	*150–179*	*180–209*	*210–239*	*240–269*	*270–299*	*300–329*	*330–364*	*365-*	*365+*
Yield [1]	*0.00*	*0.00*	*0.75*	*1.15*	*1.15*	*0.85*	*0.65*	*0.20*	*0.20*	*0.15*	*0.15*	*0.15*
Perc. of Max. [2]	*0*	*0*	*65*	*100*	*100*	*74*	*56*	*17*	*17*	*13*	*13*	*13*
Suitability[3]	*NS*		*MS*	*S*	*VS*		*S*	*MS*		*NS*		

INTERMEDIATE INPUTS

Growth cycle 120–150 days

LGP (days)	*60–89*	*90–119*	*120–149*	*150–179*	*180–209*	*210–239*	*240–269*	*270–299*	*300–329*	*330–364*	*365-*	*365+*
Yield 1	*0.00*	*0.00*	*1.93*	*2.83*	*2.85*	*1.68*	*1.25*	*0.38*	*0.38*	*0.35*	*0.35*	*0.35*
Perc. of Max. 2	*0*	*0*	*68*	*99*	*100*	*59*	*44*	*13*	*13*	*12*	*12*	*12*
Suitability3	*NS*		*MS*	*S*	*VS*		*S*	*MS*		*NS*		

HIGH INPUTS

Growth cycle 120–150 days

LGP (days)	*60–89*	*90–119*	*120–149*	*150–179*	*180–209*	*210–239*	*240–269*	*270–299*	*300–329*	*330–364*	*365-*	*365+*
Yield [1]	*0.00*	*0.00*	*3.10*	*4.50*	*4.55*	*2.50*	*1.85*	*0.55*	*0.55*	*0.55*	*0.55*	*0.55*
Perc. of Max. [2]	*0*	*0*	*68*	*99*	*100*	*55*	*41*	*12*	*12*	*12*	*12*	*12*
Suitability[3]	*NS*		*MS*	*S*	*VS*		*S*	*MS*		*NS*		

LOW INPUTS

Growth cycle 150–180 days

LGP (days)	*60–89*	*90–119*	*120–149*	*150–179*	*180–209*	*210–239*	*240–269*	*270–299*	*300–329*	*330–364*	*365-*	*365+*
Yield [1]	*0.00*	*0.00*	*0.00*	*0.75*	*1.15*	*1.15*	*0.85*	*0.20*	*0.20*	*0.15*	*0.15*	*0.15*
Perc. of Max. [2]	*0*	*0*	*0*	*65*	*100*	*100*	*74*	*17*	*17*	*13*	*13*	*13*
Suitability[3]	*NS*		*MS*	*S*	*VS*		*S*	*MS*	*nS*	*NS*		

INTERMEDIATE INPUTS

Growth cycle 150–180 days

LGP (days)	60–89	90–119	120–149	150–179	180–209	210–239	240–269	270–299	300–329	330–364	365⁻	365⁺
Yield [1]	0.00	0.00	0.00	1.93	2.83	2.85	1.35	0.38	0.38	0.35	0.35	0.35
Perc. of Max. [2]	0	0	0	68	99	100	47	13	13	12	12	12
Suitability[3]	NS			MS	S	VS		MS		NS		

HIGH INPUTS

Growth cycle 150–180 days

LGP (days)	60–89	90–119	120–149	150–179	180–209	210–239	240–269	270–299	300–329	330–364	365⁻	365⁺
Yield [1]	0.00	0.00	0.00	3.10	4.50	4.55	1.85	0.55	0.55	0.55	0.55	0.55
Perc. of Max. [2]	0	0	0	68	99	100	41	12	12	12	12	12
Suitability[3]	NS			MS	S	VS		MS	nS	NS		

[1] *Agronomically attainable yield*

[2] *Perc. of Max refers to the yields of the respective gromting periods expressed as a percentage of the maximus yield attainable from any groming period without permanent constraints*

[3] Suitability		Very suitable (VS)	Suitable (S)	Moderately suitable (MS)	Marginally suitable (mS)	Hot suitable (NS)
Yield (t/ha) :	low inputs	1.15–0.92	0.92–0.69	0.69–0.46	0.46–0.23	0.23–0.00
	int. inputs	2.85–2.28	2.28–2.71	1.71–1.14	1.14–1.57	0.57–0.00
	high inputs	4.55–3.64	3.64–2.73	2.73–1.82	1.82–0.91	0.91–0.00

TABLE 5.17
Agro-climatic suitability classification and yields (with agro-climatic constraints) in t/ha dry weight for oat

LOW INPUTS

Growth cycle 90–120 days

LGP (days)	*60–89*	*90–119*	*120–149*	*150–179*	*180–209*	*210–239*	*240–269*	*270–299*	*300–329*	*330–364*	*365⁻*	*365⁺*
Yield [1]	*0.15*	*0.70*	*1.10*	*0.95*	*0.95*	*0.55*	*0.35*	*0.15*	*0.15*	*0.10*	*0.10*	*0.10*
Perc. of Max. [2]	*15*	*70*	*100*	*95*	*95*	*55*	*35*	*15*	*15*	*10*	*10*	*10*
Suitability[3]	NS	S	VS			S	MS	nS	NS			

INTERMEDIATE INPUTS

Growth cycle 90–120 days

LGP (days)	*60–89*	*90–119*	*120–149*	*150–179*	*180–209*	*210–239*	*240–269*	*270–299*	*300–329*	*330–364*	*365-*	*365+*
Yield 1	*0.33*	*1.75*	*2.55*	*2.48*	*2.43*	*1.38*	*0.98*	*0.30*	*0.30*	*0.28*	*0.28*	*0.28*
Perc. of Max. 2	*13*	*69*	*100*	*97*	*95*	*54*	*38*	*12*	*12*	*11*	*11*	*11*
Suitability3	*NS*	*S*	*VS*			*S*	*MS*	*nS*	*NS*			

HIGH INPUTS

Growth cycle 90-120 days

LGP (days)	*60–89*	*90–119*	*120–149*	*150–179*	*180–209*	*210–239*	*240–269*	*270–299*	*300–329*	*330–364*	*365⁻*	*365⁺*
Yield [1]	*0.50*	*2.80*	*4.10*	*4.00*	*3.90*	*2.20*	*1.60*	*0.45*	*0.45*	*0.45*	*0.45*	*0.45*
Perc. of Max. [2]	*12*	*68*	*100*	*98*	*95*	*54*	*39*	*11*	*11*	*11*	*11*	*11*
Suitability[3]	*NS*	*S*	*VS*			*S*	*MS*	*nS*	*NS*			

[1] Agronomically attainable yield

[2] Perc. of Max refers to the yields of the respective gromting periods expressed as a percentage of the maximus yield attainable from any groming period without permanent constraints

[3] Suitability		*Very suitable (VS)*	*Suitable (S)*	*Moderately suitable (MS)*	*Marginally suitable (mS)*	*Hot suitable (NS)*
Yield (t/ha) :	*low inputs*	*1.15–0.92*	*0.92–0.69*	*0.69–0.46*	*0.46–0.23*	*0.23–0.00*
	int. inputs	*2.85–2.28*	*2.28–2.71*	*1.71–1.14*	*1.14–1.57*	*0.57–0.00*
	high inputs	*4.55–3.64*	*3.64–2.73*	*2.73–1.82*	*1.82–0.91*	*0.91–0.00*

LOW INPUTS

Growth cycle 120–150 days

LGP (days)	*60–89*	*90–119*	*120–149*	*150–179*	*180–209*	*210–239*	*240–269*	*270–299*	*300–329*	*330–364*	*365⁻*	*365⁺*
Yield [1]	*0.00*	*0.00*	*0.70*	*1.00*	*0.95*	*0.95*	*0.55*	*0.15*	*0.15*	*0.10*	*0.10*	*0.10*
Perc. of Max. [2]	*0*	*0*	*70*	*100*	*95*	*95*	*55*	*15*	*15*	*10*	*10*	*10*
Suitability[3]	*NS*		*S*		*VS*		*S*	*MS*		*NS*		

INTERMEDIATE INPUTS

Growth cycle 120–150 days

LGP (days)	*60–89*	*90–119*	*120–149*	*150–179*	*180–209*	*210–239*	*240–269*	*270–299*	*300–329*	*330–364*	*365⁻*	*365⁺*
Yield [1]	*0.00*	*0.00*	*1.75*	*2.55*	*2.43*	*1.58*	*1.08*	*0.30*	*0.30*	*0.28*	*0.28*	*0.28*
Perc. of Max. [2]	*0*	*0*	*69*	*100*	*95*	*62*	*42*	*12*	*12*	*11*	*11*	*11*
Suitability[3]	*NS*		*S*		*VS*		*S*	*MS*	*nS*	*NS*		

HIGH INPUTS

Growth cycle 120–150 days

LGP (days)	*60–89*	*90–119*	*120–149*	*150–179*	*180–209*	*210–239*	*240–269*	*270–299*	*300–329*	*330–364*	*365⁻*	*365⁺*
Yield [1]	*0.00*	*0.00*	*2.80*	*4.10*	*4.00*	*2.20*	*1.60*	*0.45*	*0.45*	*0.45*	*0.45*	*0.45*
Perc. of Max. [2]	*0*	*0*	*68*	*100*	*98*	*54*	*39*	*11*	*11*	*11*	*11*	*11*
Suitability[3]	*NS*		*S*		*VS*		*MS*	*nS*		*NS*		

[1] Agronomically attainable yield

[2] Perc. of Max refers to the yields of the respective gromting periods expressed as a percentage of the maximus yield attainable from any groming period without permanent constraints

[3] Suitability		*Very suitable (VS)*	*Suitable (S)*	*Moderately suitable (MS)*	*Marginally suitable (mS)*	*Hot suitable (NS)*
Yield (t/ha) :	*low inputs*	*1.15–0.92*	*0.92–0.69*	*0.69–0.46*	*0.46–0.23*	*0.23–0.00*
	int. inputs	*2.85–2.28*	*2.28–2.71*	*1.71–1.14*	*1.14–1.57*	*0.57–0.00*
	high inputs	*4.55–3.64*	*3.64–2.73*	*2.73–1.82*	*1.82–0.91*	*0.91–0.00*