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# ASPECTS AND CRITERIA OF THE AGRO-ECOLOGICAL ZONING APPROACH OF FAO

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## 1. *INTRODUCTION*

Agro-ecological zoning involves the inventory, characterization and classification of the physical environmental resources, which are meaningful for an assessment of the potential of agricultural production systems. These physical resources include components of climate, soils and landform, basic for the supply of water, energy, nutrients and physical support.

Bioclimatic zoning approaches rely on the processing of vast amount of climatic data with the objective of reflecting apparent distribution patterns as climatic zones. The natural vegetation distribution is hereby assumed to reflect the overall effect of climate which is acting on plant growth. Most bioclimatic classification at global level have therefore used the occurrence of natural vegetation types to define boundaries for various climatic zones (e.g. Köppen, Thornthwaite, Papadakis, Holdridge).

Since all living organisms require heat, light and water in varying amount, their distribution (in space and time) is governed by these climatic elements. Temperature and water (in combination with solar radiation) are the key climatic parameters in both bioclimatic and agro-ecological zoning. These 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 individual plant species. In the agro-ecological zoning approach of FAO data on climatic requirements for crop growth, development and production is an essential prerequisite for the compilation of a climatic inventory needed to assess the agro-climatic suitability of crops. Therefore, growth, development and production attributes of crops must be characterized for their thermal and moisture adaptability. Crops have specific temperature requirements for growth and development, and prevailing temperatures condition the crop performance when moisture requirements are met. Vice versa one can state that, when temperature requirements are met, the growth of a crop is largely dependent on how well the length of its growth cycle fits within the period when water is available. This has led to the concept of the length-of-growing period which is basic for the agro-ecological zoning approach of FAO. The length-of-growing period is defined as the period in days during the year in which water availability and prevailing temperature permit growth.

Crop performance depends as well on the availability of nutrients in the soil, the capacity to store water, and on mechanical support. Agro-ecological zoning also involves an assessment of the soils and landform. It is therefore also essential to assess the soil requirements of the crops under study. Soil characteristics meaningful for agricultural production can be listed in order to determine the suitability of the soil for specific crops. For the soils inventory the FAO/Unesco soil map of the world (FAO, 1971-81) was used as the source of soil data. This map quantifies the location and extent of 106 soil units, mapped as soil associations.

In the final step, the climatic inventory with its various major climatic divisions and delineation of various length-of-growing periods was superimposed on the world soil map. The resultant map then creates unique land units with clearly defined climatic and soil conditions. In this presentation the agroclimatic suitability will be discussed only. The FAO approach to characterize

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and delineate agroclimatic homogeneous zones will be summarized; for a complete discussion, reference is made to the reports on the agro-ecological zones project (FAO, 1978-1980).

## 2. *THE CLIMATIC INVENTORY*

Since the FAO study assesses rainfed crop production only, the climatic inventory include the following steps.

1. Differentiation of the continents of the earth into major climatic regions which reflect the geographical and seasonal distribution of major food crops. This differentiation is mainly based on thermal requirements of crops under consideration.
2. Quantification of the length of time available for rainfed crop production. This quantification is based on a water balance approach to determine to which extent moisture requirements of crops will be met.

Although not discussed here, the next step in the assessment involves the calculation of constraint free climatically potential crop yields with data on temperature and radiation. Finally, crop-specific agroclimatic constraints are applied - e.g. rainfall variability, moisture deficits or excesses, insects, diseases, workability - as they are related to various environmental conditions. This then ultimately leads to agro-climatically attainable yields.

### 2.1 The Thermal Regimes

Photosynthesis produces the sources of assimilates which plants use for growth and development. The rate of photosynthesis is influenced by temperature and radiation. However, plants also have an obligatory development in time, which must be met if the photosynthetic assimilates are to be converted into economically useful yields of satisfactory quantity and quality. This developmental sequence of crop growth in relation to the crop phenology is influenced by temperature (and day-length in case of photosensitive crops). Therefore the temperature regime and the photoperiodic regime govern the selection of the crop to be cultivated. In some cases temperature may determine whether a particular development process will be initiated or not (e.g. chilling requirements for initiation of flower buds). Low temperatures can also delay flowering and fruit setting. Day-length in photosensitive cultivars plays an important role in determining the time of flowering. Many soybean varieties are photoperiod sensitive and will not flower under equatorial conditions. Deep-water rice will only flower after the dark period has exceeded a certain length, which coincides with the end of the rainy season in Southeast Asia.

The evolutionary changes that have occurred in the biochemical and physical characteristics of photosynthesis have resulted in a large variation between crops in both their optimum temperature requirements and the responses of photosynthesis to changes in temperature and radiation. These responses depend on the nature of the photosynthetic pathway. In general the C3 pathway of assimilation is adapted to operate at optimum rates under lower temperature conditions than the C4 assimilation pathway. However breeding and selection (both natural and under human influence) have changed the temperature responses of photosynthesis in some C3 and C4 species. It is therefore possible to make a division of the major food crops according to their assimilation pathway and corresponding temperature requirements. Four groups have been recognized:

Group I: C3 species adapted to low temperatures (e.g. wheat, potatoes)
Group II: C3 species adapted to higher temperatures (e.g. soybean, rice, cassava)
Group III: C4 species adapted to high temperatures (e.g. millet, sorghum, maize, sugar cane)
Group IV: C4 species adapted to lower temperatures (e.g. millet, sorghum, maize).

Figure 1 illustrates for each group the effect of temperature on the maximum leaf photosynthesis rate.

The various temperature requirements for specific groups of crops were used to identify major climatic divisions. For convenience 5 degree Centigrade intervals were chosen to define warm climates (mean temperature during the growing period is more than 20 °C), moderately cool climates (mean temperature ranges from 15° to 20 °C), cool climates (5°-15 °C) and cold climates (less than 5 °C). Since moderately cool to cold climates may occur at any latitude, depending on the elevation above sea level, the major climatic divisions were in first instance separated on the basis of the seasonal temperature conditions reduced to sea level temperatures. It is assumed that the temperature decreases with 0.6 °C for each 100 m increase in elevation (e.g. a mean monthly temperature of 10 °C at an elevation of 2000 m is equivalent to a monthly temperature of 22 °C at sea level (10 °C + 0.6 × 20).

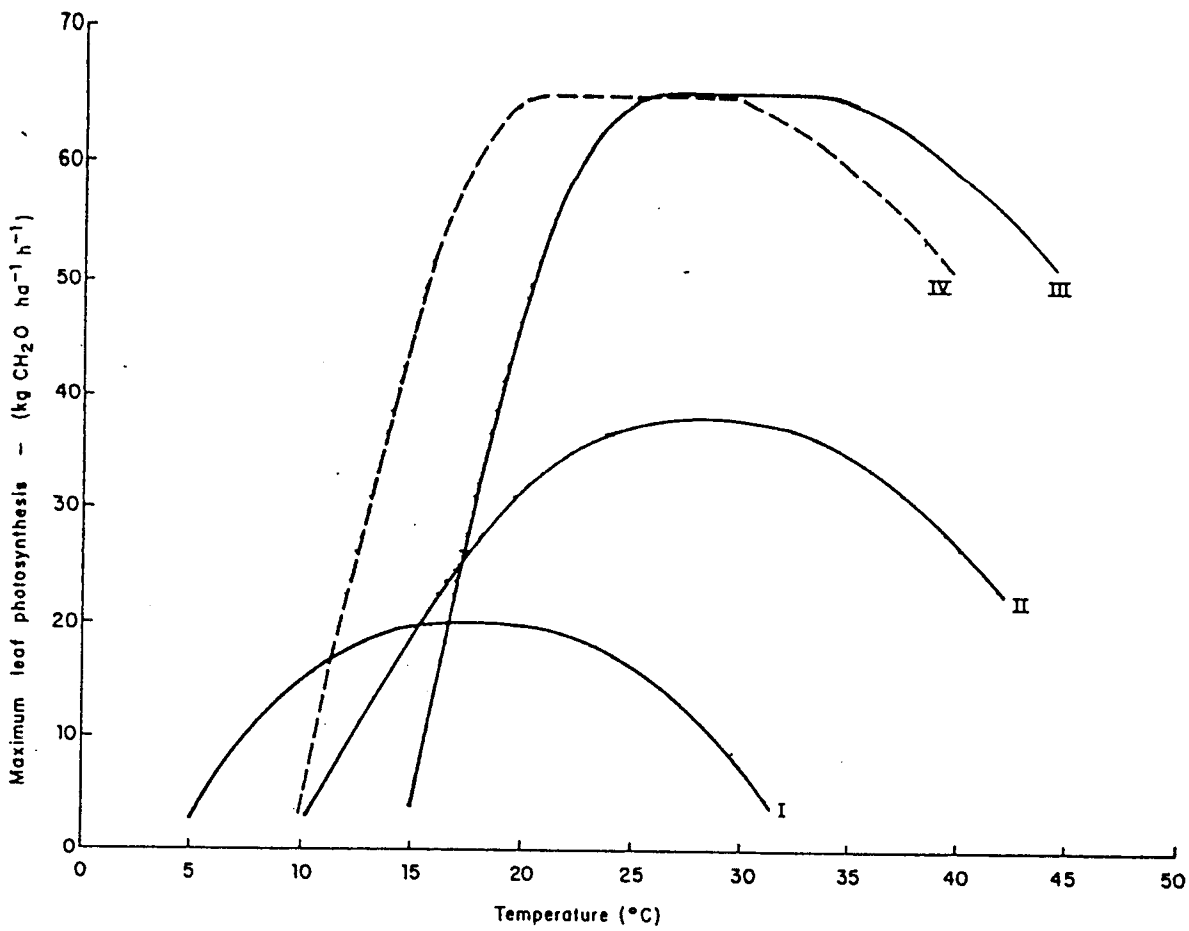


Fig. 1: Average relationship between maximum leaf photosynthesis rate ($P_m$) and temperature for crop groups I, II, III and IV. (Source: FAO, 1978-1981).

The major climates of the world are defined as follows:

Tropics: Geographical areas where the mean monthly temperature for all months corrected to sea level temperature is more than 18 °C.

Subtropics: Geographical areas where the mean monthly temperature during the year, corrected to sea level temperature, is between 5 °C and 18 °C.

Temperate: Geographical areas with at least one month having a mean monthly temperature corrected to sea level below 5 °C.

The subtropics were further subdivided on the basis of concentration of rainfall in the winter season or in the summer season. It should be realized that the subtropics with summer rainfall may have two major climates if the water availability period is sufficiently long and extends towards the cooler part of the year. The onset of the growing period may have a warm subtropic climate, while the end of the growing period may experience a moderately cool subtropic climate. In total 14 different thermal zones are recognized (Table 1).

Table 1 Characteristics of major climates during the growing period for the regions Africa, South and Central America, Southwest Asia and Southeast Asia. (Source: FAO 1978-1981).

| Climate | Major Climates during Growing Period | | 24-hr Mean (daily Temperature (C) Regime during the Growing Period | Suitable for Consideration during the Growing Period for Crop Group |
|---|---|---|---|---|
| | No | Descriptive Name | | |
| Tropics<br>All months with monthly mean temperatures, corrected to sea level, above 18°C | 1 | Warm tropics | More than 20 | II and III |
| | 2 | Moderately cool tropics | 15 - 20 | I and IV |
| | 3 | Cool tropics | 5 - 15 | I |
| | 4 | Cold tropics | Less than 5 | Not suitable |
| Sub-tropics<br>One or more months with monthly mean temperatures, corrected to sea level, Below 18°C but all months above 5°C. | 5 | Warm/moderately cool sub-tropics (summer rainfall) | More than 20 | II an III |
| | 6 | Warm/Moderately cool sub-tropics (summer rainfall) | 15 - 20 | I an IV |
| | 7 | Warm sub-tropics (summer rainfall) | More than 20 | II and III |
| | 8 | Moderately cool sub-tropics (summer rainfall) | 15 - 20 | I and IV |
| | 9 | Cool sub-tropics (summer rainfall) | 5 - 15 | I |
| | 10 | Cold sub-tropics (summer rainfall) | Less than 5 | Not suitable |
| | 11 | Cool sub-tropics (winter rainfall) | 5 - 20 | I |
| | 12 | Cold sub-tropics (winter rainfall) | Less than 5 | Not suitable |
| Temperate<br>One or more months with monthly mean temperatures, corrected to sea level, below 5°C | 13 | Cool temperate | 5 - 20 | I |
| | 14 | Cold temperate | Less than 5 | Not suitable |

### 2.2 The Moisture Regimes

The quantification of moisture conditions during the year is achieved through the concept of the reference length of the growing period, the type of growing period and its seasonality. These three characteristics determine by and large whether the water requirements for specific crops are met.

### 2.2.1 *Length of the growing period.*

The length of the growing period is defined as *'that period (in days) during the year when precipitation (P) exceeds half the potential evapotranspiration (PET) plus a period required to evapotranspire up to 100 mm of water from excess precipitation assumed stored in the soil profile'*. A normal growing period must exhibit a period when precipitation exceeds potential evapotranspiration. Any interval during the growing period with temperatures too low for growth is excluded.

The start of the growing period is obviously based on the start of the rainy season. Farmer's cropping strategies are undoubtedly influenced by the variability they have experienced in the onset of the rainy season. In general, they will plant or dry seed their crop when a certain amount of rainfall has accumulated and sufficiently moistened the top soil. The start of the growing period is therefore entirely dependent on the amount and frequency distribution of these early rains. Based on an experience of FAO in Africa, Asia and South America the reliability of precipitation of these early rains increases considerably once the monthly precipitation equals or exceeds half the potential evapotranspiration. Since the amount of moisture required to sustain growth of germinating crops is much below the full evapotranspiration demand of crops at maximum canopy cover 0.5 PET is considered sufficient to meet water requirements for an establishing crop.

The end of the growing period is determined by the end of the rainy season — the moment in time when precipitation is less than 0.5 PET — if there are no accumulated moisture reserves in the soil. If however the growing period exhibits period when precipitation exceeds potential evapotranspiration, the end of the growing period is determined by the time that precipitation is less than full potential evapotranspiration plus a period needed to evapotranspire an assumed 100 mm storage water in the soil at full rates of evapotranspiration.

Obviously the figure of 100 mm is a reference value. The amount of water stored in the soil profile can never be more than the amount that has been accumulated during the period when rainfall exceeds full evapotranspiration. Secondly the water storage capacity of the soil profile has to be considered. This depends on soil physical characteristics, soil profile characteristics, the rootable depth of the soil profile, the rooting pattern of the crop, etc. The choice of 100 mm is based on experimental evidence from Africa, Asia and South America, which indicated that the major food crops can utilize stored moisture in the range of 75 to 125 mm by the time of harvest.

The length of the growing period, thus defined, can be calculated on the basis of precipitation and potential evapotranspiration. The original set of data are monthly records. The dates where P and PET intersect are interpolated. The potential evapotranspiration is calculated by using a modified version of Penman (Frère and Popov, 1978). The next step in the climatic inventory is the plotting of individual station values of the lengths of growing period and the construction of isolines of growing periods with values of 0, 75, 120, 150, 180, 210, 240, 270, 300, 330, and 365 days, which then delineate length of growing period zones of 0-74 days, 75-119 days, 120-149 days, etc.

### 2.2.2 *Types of growing periods*

It is important to characterize the growing period in terms of excess precipitation over potential evapotranspiration.

A normal growing period contains a period during the water availability season, when precipitation exceeds potential evapotranspiration. This period is called the humid period. Such a period not only meets the full evapotranspiration demands of rainfed upland crops at maximum canopy cover, but it also replenishes the moisture deficit of the soil profile. Although not in line with A.E.Z. logic, a minimum requirement of 200 mm precipitation per month is defined for the cultivation of bunded rice under rainfed conditions in the humid tropics (FAO, 1980). The concept of 200 mm for bunded rice under rainfed conditions was first applied in the agroclimatic survey of Indonesia (Oldeman, 1975).

An intermediate growing period is defined as a growing period that does not exhibit a humid period. Throughout the year monthly precipitation is always below the full rate of potential evapotranspiration, but there is a period when monthly precipitation is equal or greater than half the potential evapotranspiration. Under those conditions water availability does not meet the full water requirements of major food crops at maximum canopy cover.

All year round humid period. In this case the average monthly precipitation exceeds for every month of the year the full rate of average monthly potential evapotranspiration. The symbol for these agroclimatic zones is 365+, to distinguish them from areas with a year round growing period, which is not continuously humid (symbol 365-).

All year round dry period. In this case the average monthly precipitation is lower than half the potential evapotranspiration for every month of the year. These areas have the symbol 0.

### *2.2.3 Seasonality of the growing period*

A significant advantage of the regional agro-ecological zone approach of FAO, if compared with other global climatic inventories, is the fact that monthly instead of annual climatic values are used. This is essential for annual crops which are only cultivated during a certain period of the year, but recognition of the length of a humid period, the occurrence of cool periods during the year certainly has application for perennial vegetation patterns as well. Two particular cases which reflects the seasonality are discussed.

Occurrence of bimodal rainfall patterns. A rainfall distribution with two peaks of rainfall separated by a dry period. This may result in two growing periods. When the rainfall deficit during the drier period is less than 50 mm the water availability period is considered as being the continuous period over the two growing periods. If this water deficit is more than 50 mm, the two growing periods are separated and only the period with the longest growing season is included in the inventory. Even then certain long duration crops such as cassava and pigeon peas may survive.

Occurrence of a cold period during the growing period. When the water availability period occurs during the cool season, such as in the so-called Mediterranean climates, the period when the average monthly mean temperature is below 5 °C is subtracted from the water availability growing period. (During this cold spell there is no growth of the crop). For this reason the cool and cold subtropics are divided on the basis of occurrence of summer rains and winter rains.

## *3. RESULTS AND LIMITATIONS*

The climatic inventory has been prepared in the form of agroclimatic tables for specific locations as well as in the form of agroclimatic maps which indicate the major climatic divisions of the thermal regimes and the length of growing period zones. An example of the agroclimatic inventory for South America is illustrated in Figure 2 while an example of the agroclimatic tables is reproduced in Table 2. It should be noted that the original climatic inventory was constructed by plotting lengths and type of growing periods zones and major thermal regimes on the 1:5 million FAO/Unesco soils map, which was then reduced to a scale of 1:10 million. These maps have so far not yet been published. Area measurements of the various growing period zones, by major climatic division was originally achieved by undertaking a grid count on the original 1:5 million maps. At present these inventories are part of FAO's GIS database. Table 3 illustrates the percentage of the land surface of South America, Southeast Asia (not including China and Japan) and Africa covered by various lengths of normal growing periods.

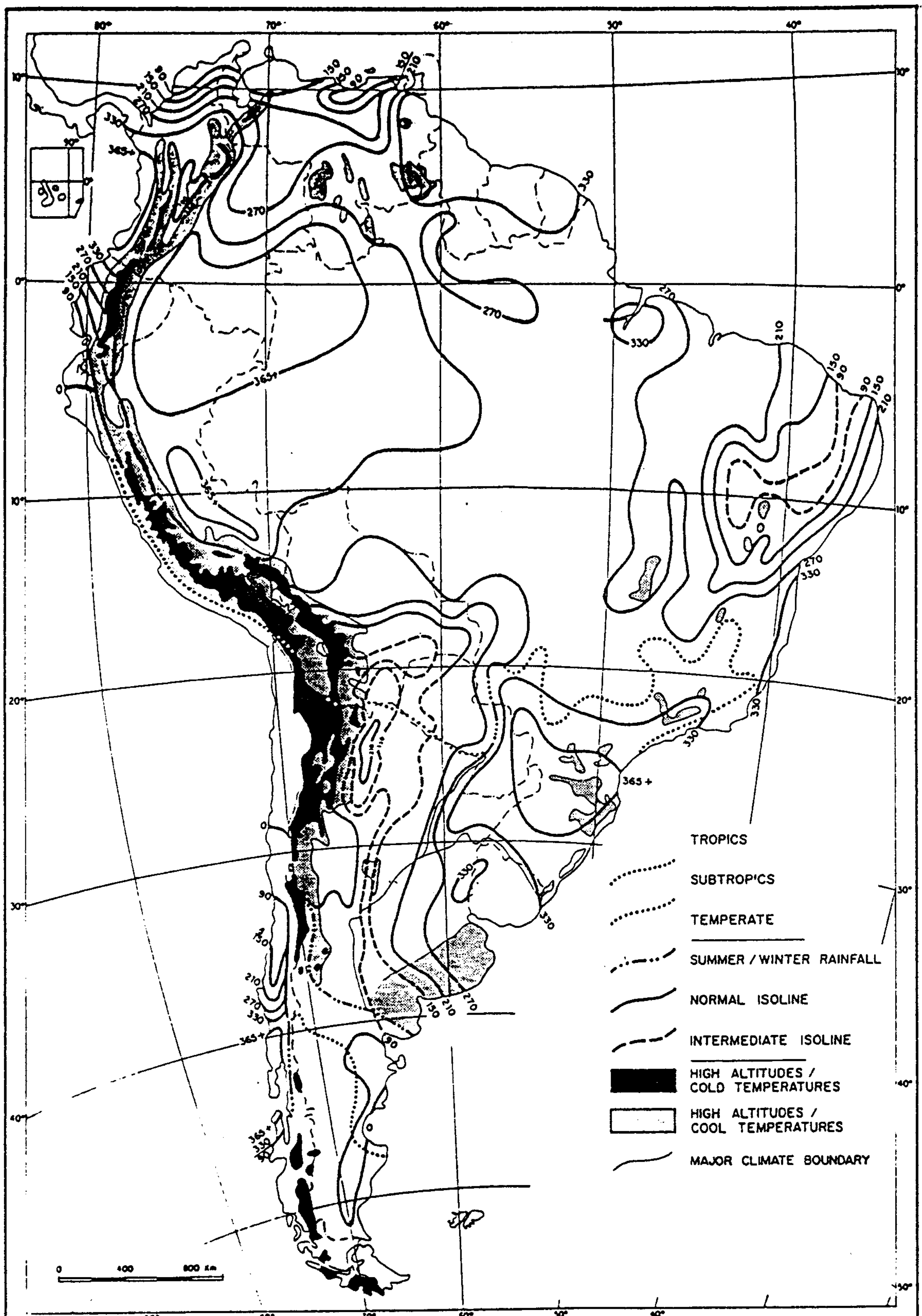


Fig. 2: Generalized climatic inventory for South America (Source FAO, 1981)

Table 2 Agroclimatic tables for two locations in Kenya. (Source: FAO, 1984)

COUNTRY : KENYA * STATION : GALOLE * NUMBER : 63750

* LATITUDE: -1.30 * LONGITUDE : 40.02 * ELEVATION : 100 MET.

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PRECIPITATION | 35 | 19 | 34 | 56 | 30 | 20 | 21 | 13 | 49 | 38 | 94 | 61 | 470 |
| TEMP. AVERAGE | 28.3 | 29.2 | 29.0 | 28.1 | 27.3 | 26.1 | 25.0 | 25.1 | 26.0 | 26.7 | 27.7 | 27.6 | 27.2 |
| TEMP MEAN MAX | 34.2 | 35.3 | 34.8 | 34.0 | 33.1 | 31.2 | 31.1 | 31.3 | 32.1 | 32.3 | 33.1 | 33.2 | 33.0 |
| TEMP MEAN MIN | 22.5 | 23.1 | 23.2 | 22.2 | 21.5 | 21.0 | 19.0 | 19.0 | 20.0 | 21.0 | 22.2 | 22.0 | 21.4 |
| TEMP MEAN DAY | 30.4 | 31.4 | 31.1 | 30.2 | 29.4 | 27.9 | 27.2 | 27.4 | 28.2 | 28.7 | 29.6 | 29.6 | 29.3 |
| TEMP MN NIGHT | 26.2 | 26.9 | 26.9 | 25.9 | 25.2 | 24.2 | 22.8 | 22.9 | 23.9 | 24.6 | 25.7 | 25.6 | 25.1 |
| VAPOUR PRESS. | 26.3 | 26.3 | 28.3 | 28.2 | 26.8 | 25.7 | 24.0 | 23.3 | 24.2 | 26.7 | 29.0 | 27.8 | 26.4 |
| WIND SPEED 2M | 1.4 | 1.4 | 1.5 | 2.0 | 2.7 | 2.9 | 3.2 | 3.0 | 3.1 | 2.4 | 1.5 | 1.3 | 2.2 |
| SUNSHINE % | 63 | 69 | 69 | 66 | 64 | 62 | 57 | 63 | 68 | 69 | 66 | 64 | 65 |
| TOT RADIATION | 516 | 560 | 569 | 515 | 483 | 434 | 436 | 443 | 458 | 497 | 524 | 532 | 497 |
| EVAPOTRANSP. | 144 | 145 | 157 | 142 | 140 | 124 | 129 | 141 | 153 | 149 | 135 | 135 | 1694 |

TYPE OF GROWING SEASON : INTERMEDIATE SEASON
DRY DAYS : 326 INTERM. DAYS : 39 WET DAYS : 0

SEASON NR : 1
SEASON BEGINS ON 31 OCT.
END OF SEASON ON 9 DEC.
TOTAL LENGTH OF SEASON IS 40 DAYS

COUNTRY : KENYA * STATION : MACHAKOS SCHOOL * NUMBER : 63759

* LATITUDE: -1.31 * LONGITUDE : 37.17 * ELEVATION : 1680 MET.

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PRECIPITATION | 49 | 53 | 124 | 210 | 76 | 12 | 5 | 6 | 9 | 53 | 189 | 122 | 908 |
| TEMP. AVERAGE | 20.3 | 20.7 | 20.6 | 20.0 | 19.0 | 18.0 | 17.0 | 17.5 | 19.0 | 19.7 | 19.7 | 19.5 | 19.3 |
| TEMP MEAN MAX | 26.2 | 27.6 | 26.7 | 25.3 | 24.2 | 23.2 | 22.5 | 22.7 | 24.8 | 26.1 | 25.0 | 24.2 | 24.9 |
| TEMP MEAN MIN | 13.6 | 13.7 | 14.5 | 14.7 | 14.2 | 12.7 | 11.6 | 12.2 | 12.5 | 13.3 | 14.5 | 14.3 | 13.5 |
| TEMP MEAN DAY | 22.2 | 23.1 | 22.8 | 21.9 | 21.0 | 19.8 | 19.0 | 19.3 | 20.9 | 22.0 | 21.6 | 21.0 | 21.2 |
| TEMP MN NIGHT | 17.6 | 18.1 | 18.4 | 18.1 | 17.4 | 16.0 | 15.1 | 15.5 | 16.4 | 17.4 | 17.9 | 17.5 | 17.1 |
| VAPOUR PRESS. | 17.2 | 17.1 | 18.2 | 18.8 | 18.0 | 15.6 | 15.1 | 15.0 | 15.1 | 16.2 | 17.8 | 17.6 | 16.8 |
| WIND SPEED 2M | 2.0 | 1.4 | 1.7 | 1.5 | 1.7 | 1.5 | 1.7 | 1.8 | 1.8 | 2.0 | 1.8 | 2.2 | 1.8 |
| SUNSHINE % | 94 | 93 | 82 | 69 | 67 | 67 | 50 | 39 | 65 | 75 | 70 | 76 | 70 |
| TOT RADIATION | 601 | 615 | 576 | 506 | 469 | 449 | 398 | 382 | 499 | 544 | 515 | 527 | 506 |
| EVAPOTRANSP. | 135 | 125 | 133 | 110 | 101 | 91 | 89 | 96 | 117 | 130 | 114 | 119 | 1360 |

TYPE OF GROWING SEASON : NORMAL GROWING SEASON (WITH DRY PERIOD)
DRY DAYS : 200 INTERM. DAYS : 68 WET DAYS : 97

SEASON NR : 1
SEASON BEGINS ON 22 FEB.
BEGIN HUMID ON 19 MAR.
HUMID PERIOD ( 50 DAYS) ENDS ON 7 MAY
END OF SEASON ON 23 MAY
TOTAL LENGTH OF SEASON IS 91 DAYS
SEASON NR : 2
SEASON BEGINS ON 20 OCT.
BEGIN HUMID ON 30 OCT.
HUMID PERIOD ( 49 DAYS) ENDS ON 17 DEC.
END OF SEASON ON 3 JAN.
TOTAL LENGTH OF SEASON IS 76 DAYS

Table 3 Land areas of various lengths of normal growing period zones in South America, Southeast Asia (excl. China and Japan) and Africa, expressed as percentage of total land surface

| | South America | Southeast Asia | Africa |
|---|---|---|---|
| 9-12 months Normal | 49 % | 34 % | 15 % |
| 3-9 months Normal | 26 % | 49 % | 32 % |
| less than 3 months Normal | 10 % | 12 % | 44 % |
| Intermediate growing period 3-9 months | 12 % | - | 9 % |
| Cold | 3 % | 5 % | + |

South America has the largest area (almost half of the continent) with normal growing periods of more than 270 days, while in Southeast Asia almost 50 % of the area is characterized by a three to nine months growing period, which clearly illustrates that large parts of Southeast Asia are subject to a monsoonal climate with dry and wet seasons. The largest part of the African continent is characterized by a growing period of less than 90 days. This obviously includes the Sahara desert. Almost 30 % of Africa has a year round dry period.

The FAO studies did not cover temperate and cold regions outside Latin America, Africa and Asia. In these zones (USA-Canada, Europe-Asian part of USSR, Australia-New Zealand) the day-length and number of sunshine hours comes to the fore (the seasonal distribution and its exposition on polar facing slopes versus equator facing slopes) as well as the occurrence of permafrost or intermittent permafrost soil conditions. These factors have been taken into account at a recent agroclimatic zoning exercise by a FAO-Chinese team for Northern China while also Canada (Dumanski) has worked with them. The methodology for the cool and cold zones of higher latitudes still requires some refinement.

Once man-induced Climatic Change scenarios are sufficiently precise and non-disputed as regards changes in rainfall and temperature regimes at the *regional and local level* rather than the global level, then the agro-ecological zoning approach of FAO can also be applied to predict crop-growth changes (and natural vegetation changes as well) with its regional socio-economical implications.

## *4. CONCLUSIONS*

The agroclimatic inventories as prepared by FAO contain a major source of climatic information, which can be utilized in various ways. By superimposing the climatic inventory on the soils inventory of the world - the FAO/Unesco soil map of the world - it is possible to identify land areas with unique climate and soil characteristics. Because the climatic inventory also contains information on maximum and minimum temperatures, radiation, humidity, and wind speed, it is possible to calculate agroclimatic constraint - free potential crop yields. Application of agroclimatic and soil constraints then ultimately leads to an assessment of the agro-ecological suitability. The quantification, and delineation of major climates and lengths of growing periods in tables and on maps can also be used for the characterization of climatic parameters for major vegetation types if the zones are superimposed on vegetation maps.

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