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Adoption of agroclimatograms for assisting species selection in the tropics

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Abstract. Agroclimatograms are presented for assisting species selection in the tropics by analyzing agroclimatological factors and similarities. The diagrams include data for temperature, precipitation, water budget and potential evapotranspiration (PET). A computer program to calculate the PET is provided and *Adansonia digitata* L. (baobab) is used as an illustrative example.

1. Introduction

The selection of appropriate species for both intensive and low external input land-management systems may play a decisive part in the success or failure of development projects, e.g. tree introduction programmes. This article is dedicated to one of the major factors in site assessment procedures, the climate: For the analysis of agroclimatological factors, enhanced climatograms have been created which may assist trained academic and the non-academic expertise in species selection for the field.

2. Background

Based on proposals by various earlier authors, Walter and Lieth [1960] published a world atlas of climatograms compiled to a standard layout. Because these climatograms were initially developed for temperate climates, the additional associated informations centred on the period of time when frost might occur (months with average daily minimum temperature < 0 °C and months with absolute minimum temperature < 0 °C). This reflected the importance of low temperature as the major climatological factor determining plant growth for most temperate climatic zones. In most of tropical climates, however, low temperatures play only a marginal role. (Tropical highlands and desert climates are the main exceptions.) It is drought periods that are the primary concern for land use practice in seasonal tropical climates.

Drought periods are visually approximated in the original form of climatogram by the intervals of time when the temperature line raises above the rainfall line. However, more informative and more reliable, is the calculation of a water budget, because in most of the tropical environments potential evapotranspiration exceeds by far the actual precipitation. Thus, the duration of drought period and severity are not accurately delimited or are even completely omitted in the original form of climatogram. The modification proposed here, therefore, includes a graph of the potential evapotranspiration and the water budget into each climatogram.

To simplify comparison of macroclimates at different sites standard climatograms are convenient, and an extension of these to reveal evapotranspiration and information on the water budget, as well as temperature and rainfall patterns, has been devised. It is hoped that the new form will encourage more people to make use of published agroclimatological data of the tropics [4, 5, 6]. Like conventional climatograms [11, 12] the enhanced agroclimatograms allow quick interpretation of important features of the climate and can be rapidly produced.

3. The layout of agroclimatograms

Time is shown on the X-axis scale and two differently calibrated Y-axis scales are used. Intervals on the Y1-scale represent *temperature* (**Temp**) by 10 °C and those on the Y2-scale 20 mm of *precipitation* (**P**), *potential evapotranspiration* (**PET**) and *water deficit* (**WD**). For values of these which exceed 100 mm each scale interval represents 200 mm, thus saving space. Black and white shading patterns are in accordance to Walter and Lieth [1960] and an additional shaded area is shown as necessary, when WD > 100 mm.

Supplementary information is displayed as follows:

- ≫ X-axis: moisture availability
- ≫ Y1-axis: temperature and sunshine
- ≫ Y2-axis: water budget and a resulting index
- ≫ head of graph: location and summary
- ≫ figures: see Fig. 1.

For display purposes, key features can be given more emphasis if a coloured pattern is used or the black and white patterned areas are additionally coloured, for example:

≫ 100 mm > P over line of Temp:	**blue**	(water is available)
≫ P > 100 mm (by convention):	**black**	(water surplus)
≫ Temp over line of P:	**orange**	(drought periods)
≫ WD > 100 mm:	**red**	(severe drought periods, fire risk)
≫ area below single bold bar — showing the growing season:	**green**	(vegetative period)

The values for the PET were adopted from FAO [1984, 1985, 1987] and the figures for water deficit and indices were computed according to Thornthwaite [1948]. This computation also generates figures for soil water storage, maximum water deficit, total water deficit and total water surplus. The soil water storage estimates assume a full capacity of 100 mm, as used by FAO [1984, 1985, 1987], to determine the length of the growing season and the humid period.

4. Three agroclimatograms as examples — the distribution of the baobab tree

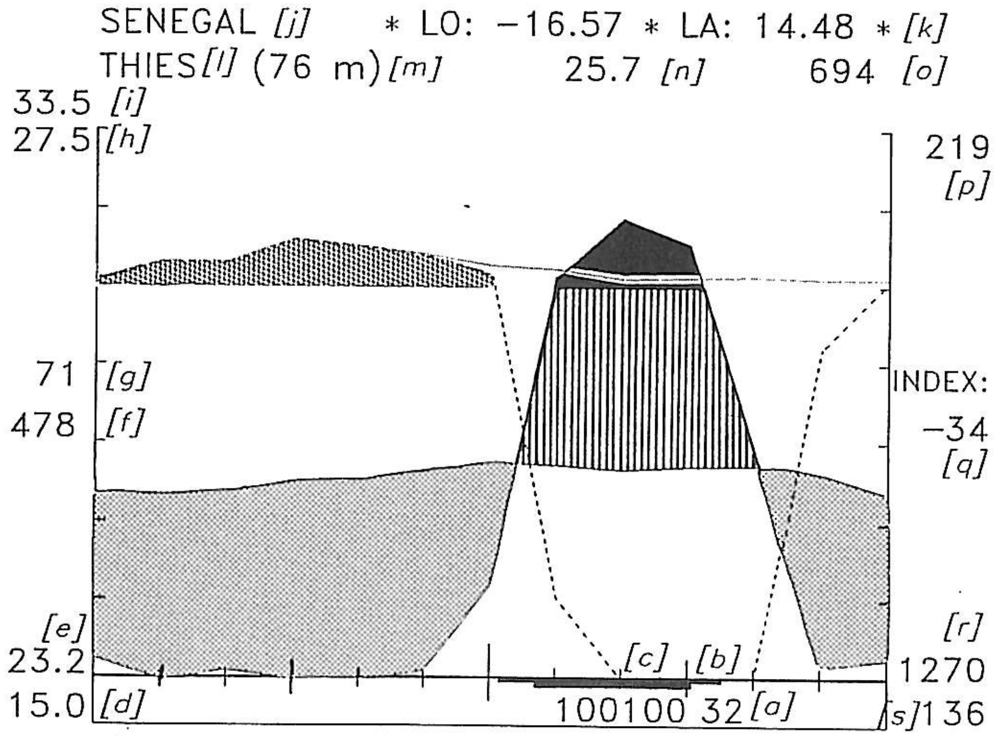
Three agroclimatograms are presented, typical for a range of climatic conditions: from per-humid to very arid. Figure 1 shows an agroclimatogram which represents climatic conditions for an area where baobab (*Adansonia digitata* L.) forms naturally almost closed stands [7]. This is a semi-arid environment and, because the dry-and rainy seasons are well defined, some rain surplus occurs during September and October. Temperature maxima and minima are relatively high. In this environment *A. digitata* can be expected to respond to favourable growing conditions by accumulating water in the soft tissue of the trunk during the relatively short rainy season.

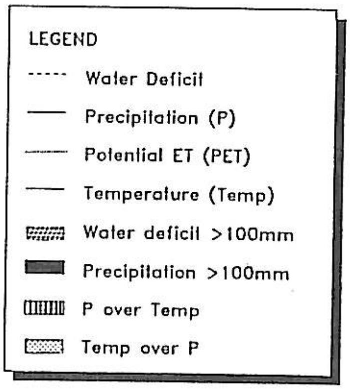
Baobab is a much valued perennial with multipurpose use and is widely planted and protected by man. When restrictive natural conditions are removed baobab, like any other plant, may grow much better than in the natural range under conditions of competition with other species.

The agroclimatograms for Libreville and Khartoum (Figs. 2 and 3) represent climatic extremes with respect to the water budget. In Libreville, *A. digitata* has been introduced as an ornamental tree [10]. Libreville is subject to a per-humid climate with a very short dry season, little water stress and little deviation in temperature (Fig. 2).

At the other extreme is Khartoum (Fig. 3), representing a very arid climate where baobab still occurs along the Nile [13], and where it has certainly been introduced. Under this climate perennials like the baobab are dependent on trapping ground-water. Maxima and minima temperatures are relatively high, indicating high tolerance of baobab with respect to temperature fluctuations and water stress.

The three agroclimatograms presented show one possible application of this form of describing climatic conditions for a certain species. A similar approach may be practicable to describe the occurrence of other species elsewhere, which would give the potential range of a species over differing climatic conditions. However, agroclimatograms also may be correlated with satisfactory plant growth: All those climatic conditions where a species proved unsatisfactory would be disregarded and agroclimatograms would display the range of climatic environments where this species can be expected to be introduced successfully (and probably conditions just outside this range). On this basis, by comparing the similarities of climatic environ-





Figures:

≫ **X-axis** (moisture availability):
- **a** = soil water storage in mm
- **b** = growing season
- **c** = humid period

≫ **Y1-axis** (Temp and sunshine intensity):
- **d** = lowest Temp mean min in °C
- **e** = lowest Temp average in °C
- **f** = mean radiation in cal/cm^2/day
- **g** = sunshine in %
- **h** = highest Temp average in °C
- **i** = highest Temp mean max in °C

≫ **head of graph** (location and summary):
- **j** = name of the country
- **k** = longitude & lat. in degree & minute
- **l** = name of the station
- **m** = altitude in m
- **n** = temperature average in °C
- **o** = total precipitation in mm

≫ **Y2-axis** (water budget and index):
- **p** = water deficit max in mm
- **q** = climatic index (here: Thornthwaite)
- **r** = total water deficit in mm
- **s** = total water surplus in mm

Graphs:

≫ **X-axis** (calibration intervals: 1 month):
time

≫ **Y1-axis** (calibration intervals: 10 °C):
temperature (**Temp**)

≫ **Y2-axis** (calibration intervals:
20 mm — for values till 100 mm — and
200 mm — for values exceeding 100 mm)
precipitation (**P**)
water deficit (**WD**)
potential evapotranspiration (**PET**)

Fig. 1. Agroclimatogram for Thies, Senegal: A typical semi-arid climate type.

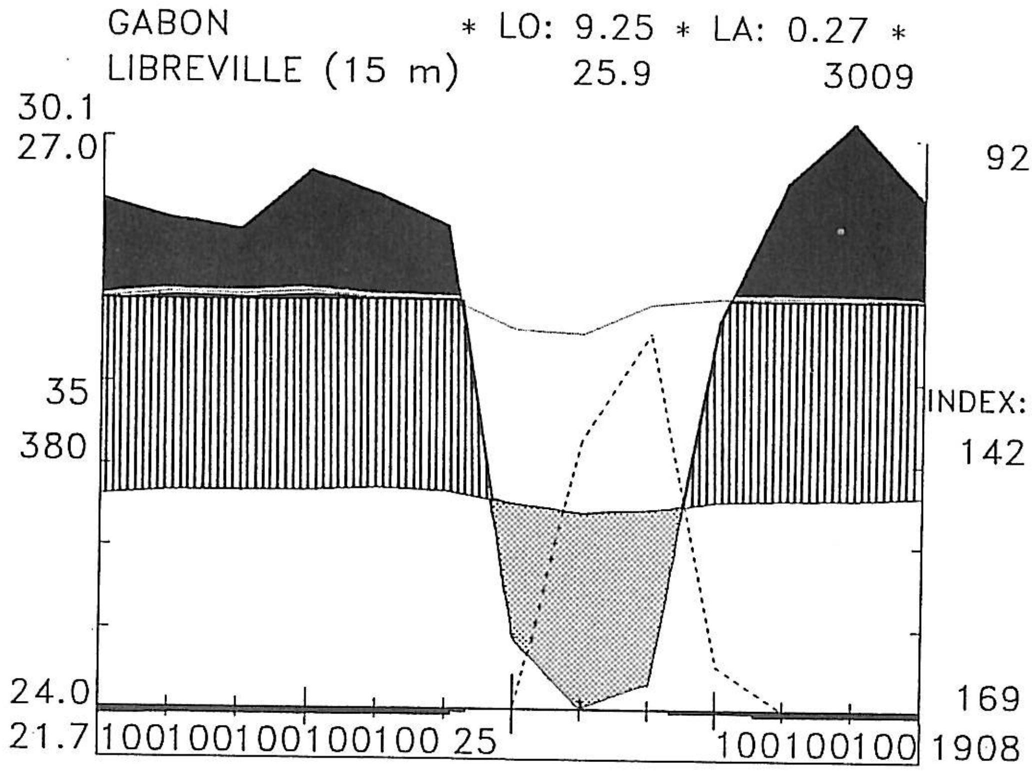


Fig. 2. Agroclimatogram for Libreville, Gabon: A per-humid climate type.

ments, sensible decisions can be made to include or exclude certain species in on-going programmes.

5. Use and shortcomings of the agroclimatograms

In an increasing number of situations agroclimatograms — particularly those presented on a monthly basis — offer too rough a summary of climatic conditions, and a strong subjective element still remains in decision-making about appropriate land use options and their scheduling. Lately considerable effort has been made to analyse agroclimatological factors for species selection with advanced technology [1, 2]. Computerized analyses of agroclimatological factors, however, rely on preliminary subjective selection of convenient criteria. For example, in assessing the severity of drought periods, the mean temperature and mean precipitation of the driest quarter (3 months) can be used [2]. However, because a computer compares and counts numbers only, though very rapidly, the results of even advanced dynamic programmes remain relatively static, although the output may take a form enabling the interpreter to ascertain climatological similarities on a multivariate basis [2].

The use of computerized climatological data in species selection may help

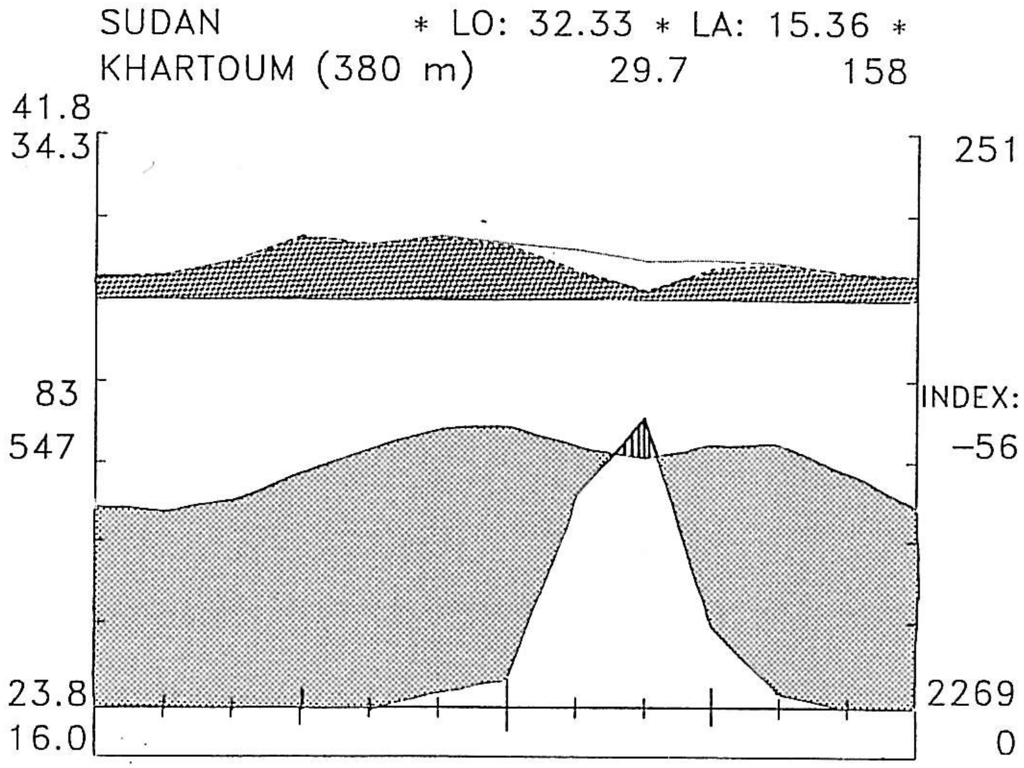


Fig. 3. Agroclimatogram for Khartoum, Sudan: A very arid climate type.

indicate suitable species, but it will never replace individual judgement. On the other hand comparison of climatological similarities by agroclimatograms is extremely convenient: they are relatively easy to produce using standard climatological summaries and flexible in interpretation.

Agroclimatograms therefore continue to offer an inspiring and somewhat dynamic approach to the appraisal of the climatic conditions of a site and how well it can meet the climatic prerequisites of a certain species. For example, by assessing the impact of a drought period, a period of time with little rainfall may be outweighed by relatively little potential evapotranspiration and a resulting low figure of water deficiency, particularly when perennial species are to be selected. On the other hand, a relatively short drought period in conjunction with high figures for potential evapotranspiration and the resulting water deficit, indicates a high water stress for this period of time, despite its brevity, and, additionally, risk of fire in many areas.

Like similar summaries of climatic conditions, agroclimatograms can only give a clue for the decision-maker. However, the better the tropical sites and their climatic conditions become known and summarized in agroclimatograms, the more reliable will be the interpretation of the climatic conditions of further sites.

6. Microclimatological factors

Agroclimatograms are well adapted for describing macroclimatic conditions. However, the urgency of taking microclimatological factors into account should also be stressed. Micro- and macroclimatic conditions both influence research sites and have major impacts on plant growth. An exposed hill site may be very different from a protected valley. In Kigoma, Tanzania, for example it was observed, that *Calliandra calothyrsus* Meissn. did well in places where the oil palm, *Elaeis guineensis* Jacq. was cultivated. The climatological station of Kigoma is exposed on a small hill site and not within the range of *E. guineensis*, but just one kilometre from the station microclimatological factors and ground water availability at some places create favourable conditions for this valuable crop.

A description of microclimatic conditions can be done by specifying the situation of the climatological station relative to the planting site and by observing changes of the natural and cultivated vegetation towards the planting site (which, in fact, also adds to a reliable picture of macroclimatic conditions). Moreover, the layout of the site should be fully characterized, particularly when tall trees are prominent in the immediate vicinity — frequent with agroforestry plantations — modifying the potential evapotranspiration through the reduction of wind velocity and, near individual trees, by providing shade. Information on groundwater availability also should be provided. Only when all this information is available, can decisions — for example, on species suitability in terms of climatic requirement — be made with confidence.

7. Calculation of the potential evapotranspiration

Agroclimatograms should be seen as one possible tool amongst others in assisting species selection. To analyse data for individual stations and for individual years, particularly for interpretation and analysis of climatic changes, the diagrams may be drawn on a weekly, or even daily basis, although trends become less pronounced when the smoothing effect of averaging by month is removed.

The formula for the calculation of the potential evapotranspiration incorporate numerous climatological parameters (see program) and the calculation is time consuming. In this case, use of computer facilities is very advantageous. The program provided is a simple calculation program, smooth to run on any IBM compatible machine with GWBASIC on MSDOS. Anyone familiar with micro-computer use, whether or not experienced in the use of Penman's formula, will be able to calculate the PET for a whole year on a daily basis using this program, faster than producing any result by hand! The program displays all relevant parameters four times on a standard screen to indicate the effects of changes in the values of variables (lines 100—140).

```
50  PRINT "** PROGRAM TO CALCULATE THE POTENTIAL EVA-
    POTRANSPIRATION *"
60  INPUT "REFLECTION COEFF.:(OPEN WATER:.05, GREEN
    CROPS:.25, FOREST:.15"; R
70  INPUT "NORTH-SOUTH (N-S)"; NS$:IF NS$ = "N"THEN B = -1
    ELSE IF NS$ = "S"THEN B = 1
80  INPUT "DEGREE N-S HEMISPHERE (0–50)"; C:IF C < 0 OR C
    > 50 THEN BEEP:GOTO 80
90  INPUT "MONTH OF YEAR (1–12)"; A%
100 INPUT "DAY OF MONTH"; A2%
110 INPUT "DRY-BULB TEMPERATURE (0 <= TD <= 50)"; TD
120 INPUT "WET-BULB TEMPERATURE (0 <= TW <= 40)"; TW
130 INPUT "SUNSHINE d/h (0 <= SN <= 17)"; S:S = S*60
140 INPUT "MILES WINDRUN/d (0 <= WR <= 1000)"; U
150 Z = ((A%-1)*30) + A2%:N = 737 + (3.3667*C + (3.333^-
    4)*C^3)*SIN((Z-80)/1.0139):D = B*C
160 IF A% = 1 GOTO 180 ELSE IF A% = 2 GOTO 190 ELSE IF A% =
    3 GOTO 200 ELSE IF A% = 4 GOTO 210 ELSE IF A% = 5 GOTO
    220 ELSE IF A% = 6 GOTO 230
170 IF A% = 7 GOTO 240 ELSE IF A% = 8 GOTO 250 ELSE IF A% =
    9 GOTO 260 ELSE IF A% = 10 GOTO 270 ELSE IF A% = 11
    GOTO 280 ELSE IF A% = 12 GOTO 290
180 RA = .5955 + .006*D-7.345E-05*D^2:GOTO 300
190 RA = .6155 + .0036*D-8.524E-05*D^2: GOTO 300
200 RA = .6224 + 6.071E-05*D-9.357001E-05*D^2: GOTO 300
210 RA = .602 - .0027*D-8.451999E-05*D^2:GOTO 300
220 RA = .5723 - .005*D-7.58E-05*D^2:GOTO 300
230 RA = .552 - .0062*D-6.869E-05*D^2:GOTO 300
240 RA = .5569 - .0058*D-6.821E-05*D^2:GOTO 300
250 RA = .5833 - .0039*D-8.071E-05*D^2:GOTO 300
260 RA = .6092 - .0009321*D-9.011999E-05*D^2:GOTO 300
270 RA = .6143 + .0025*D-8.939999E-05*D^2:GOTO 300
280 RA = .5977 + .0052*D-7.667001E-05*D^2:GOTO 300
290 RA = .5877 + .00663*D-7.167E-05*D^2
300 EA = 10^(((7.5*TD)/(237.3 + TD)) + .78571):ED = ((.76*EA)-
    (1.799*(TD-TW)))/.76
310 EAT = .35*(1 + U/100)*((EA-ED)*.76):ST4 = ((((TD + 273.2)^4)
    *5.67E-08) *2.0632)/59
320 RB = ST4*((.56) - (9.000001E-02)*(SQR(ED*.76)))*(.1 + .9 *(S/
    N)):RA1 = RA*1440/59
330 RI = ((RA*1440)/59)*(.18 + .55*(S/N)): HT = ((1-R)*RI)-RB:E1 =
    EA-ED:ND1 = S/N
340 PET = (((.3238 + .0757*TD + .0016*TD^2)*HT) + EAT)/ ((.3238 +
    .0757*TD + .0016*TD^2) + 1)
```

```
350 PRINT"-E1-------EAT----ST4------ND------RB-----RA-------RI------HT
    ------PET
360 PRINT USING "# #.# #---"; E1; EAT; ST4; ND1; RB; RA1; RI;
    HT; PET:GOTO 100
```

This is the core program with only one error trap (line 80). All relevant variables [8] are printed in line 340, PET = potential evapotranspiration. Hyphens in line 330 and 340 represent one space each, and should not be typed for programming. Some additional adjustments may be required [3], but they are easy to integrate into this short designed program. E.g., to use input data of relative humidity, change the second calculation in line 280 to ED = (EA*RH)/100; or if you measured the wind run in a different height than 2 m or in km/h, add an adjustment factor to the variable 'U' in line 140, as shown in line 130.

The water budget and climatological index [9] is much easier to calculate. Nevertheless, a computer program (too long to include here, available from the address above) is useful — and the results error free — when there is an appreciable volume of data to analyse.

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