<u>Methodology part of</u>
<u>Farm Management Handbook of Kenya (revised)</u>

Crop yield simulation models and ENSO approach

1. Calculation of agrohumid periods (AHP) and yield potentials by using crop-simulation model and ENSO

1.1 Introduction and general structure of the model

Agro-ecological zonation as a concept of sustainable land use planning in the tropics has to contain different methodological approaches for allowing tempo-spatial recommendations for different stakeholders. An important constraint for farmers, for instance, is the need of information about yield expectations of annual and perennial crops –probably before the onset of the rainy seasons-, so that they are able to provide themselves with seed material and cultivate crops adapted to the expected/forecasted performance of the coming rainy season. According to Penning de Vries (1990; cited in: Hornetz, 1997) "…crop modelling can support farming indirectly by being a source from which guidelines, diagrams and extension service advice can be derived, and by enabling explicit alternatives for agricultural development to be drawn up". Ritchie (1991; cited in: Hornetz, 1997) believes that crop simulation modelling opens the possibility to avoid resource consuming trial and error experimentation for forecasting tempo-spatial distribution of crop yields. Good models should be calibrated and validated as well be able to

- delineate the stage-specific development of crops/plants (including yield sensitive aspects);
- estimate/calculate morphological development of plant parts (e.g. roots, LAI);
- estimate/calculate yield parameters in correlation to soil water balances (being most important in particular in tropical dry lands).

In Kenya crop simulation models have been successfully used in the interpretation of research results in complex and highly variable cropping systems (Shisanya, 1996). Crop modelling has also been applied for evaluating soil and water conservation measures for improved crop production (e.g. Kiome, 1992; Rötter, 1993; all cited in: Shisanya, 1996).

However, sophisticated models of soil-water-dynamics like WOFOST or CERES including all climatic, soil-hydraulic and plant physiological parameters show a very limited success in forecasting yield potentials on a regional level (Rötter, 1989; Hornetz, 1997). The detailed parameters -which they need for calculating- are usually only available at selected stations, mostly with a limited regional representativeness.

The model presented above has been calibrated and validated for different areas and regions (e.g. Kenya, Ethiopia, Zimbabwe, Paraguay; Hornetz, 1997; Hornetz et al., 2001, 2006; Shisanya, 1996). The structure of the model is made up of several parts:

1. A super ordinate controlling part processes the climatic data of daily rainfall in Kenya since 1926 and calculated figures of evapotranspiration (according to Woodhead, 1968; cited in: Shisanya, 1996) as well as the various crop scenarios with characteristic crop coefficients, leaf and root development characteristics, yield and stress physiological parameters (see e.g. Hornetz, 1991; Shisanya, 1996).
2. In a first simulation approach (WATBAL 2003) lengths and intensities of the agrohumid periods (AHP; see Jätzold & Schmidt, 1982) are calculated on a decadc (10 days) data base for defined sites. This enables stakeholders to decide whether it is possible to cultivate certain crop varieties on particular soils within a growing period.
3. By means of the yield simulation programme MARCROP (e.g. Hornetz et al., 2001) yield probabilities –as defined by Jätzold & Schmidt (1982)- are calculated site specifically for defined crop varieties on particular soils (using a daily data base).
4. Farmer (1988), Ogallo (1988) and Willems (1993) have shown that the *El Niño Southern Oscillation (ENSO)* phenomenon has a significant influence on the performance of the rains (in particular the short rains) in the southern, eastern and northern parts of Kenya. Here, the Southern Oscillation Index (SOI) was used as a discriminating criterion for each individual rainy season (into ENSO, Anti-ENSO and Normal conditions); thus being able to forecast rainfall conditions of the short rains almost 2 months before the onset of the rains (Willems, 1993; Hornetz et al., 2001).
5. The statistical combination of calculated yield potentials (by MARCROP) with the ENSO approach leads to a configuration of detailed temporal patterns of the yield performances. This allows stakeholders to decide which kind of crop and crop variety can be cultivated during the coming season. Such temporal patterns of yield potentials are delineated spatially by using the subzones of the AEZ which are representing the agroecological units.

1.2 Approaches and programmes

1.2.1 Calculation and configuration of agrohumid periods (AHP) by using simulation programme *WATBAL 2003*

The input data for the determination of the beginning, end, lengths and intensities of the AHP's were decadic rainfall (P) and potential evapotranspiration (PET; according to the modified PENMAN approach; Woodhead, 1968; cited in: Shisanya, 1996) (see Figure 1.1). The programme calculates per double year the length of different independent growing periods (bimodal and trimodal patterns; see Jätzold & Schmidt, 1982) at maximum. The length of the growing period is defined as the period between the beginning of vegetation activities (initial period) and the attainment of physical maturity of annual crops. The corresponding decades are designated as TI and TE.

In the algorithm the following parameters which can be totally varied to describe all possible combinations of plant physiological parameters of an agronomic location are found:

- The crop physiologically yet justifiable minimum water requirements, expressed as KC-values of the first and last three (to four) can be expressed empirically by combining these figures by progressive addition (Hornetz, 1991). Thus

$$ISUM = KC/min_1 + 2\ KC/min_2 + KC/min_3$$
$$ESUM = KC/min_{n-2} + 2\ KC/min_{n-1} + KC/min_n$$

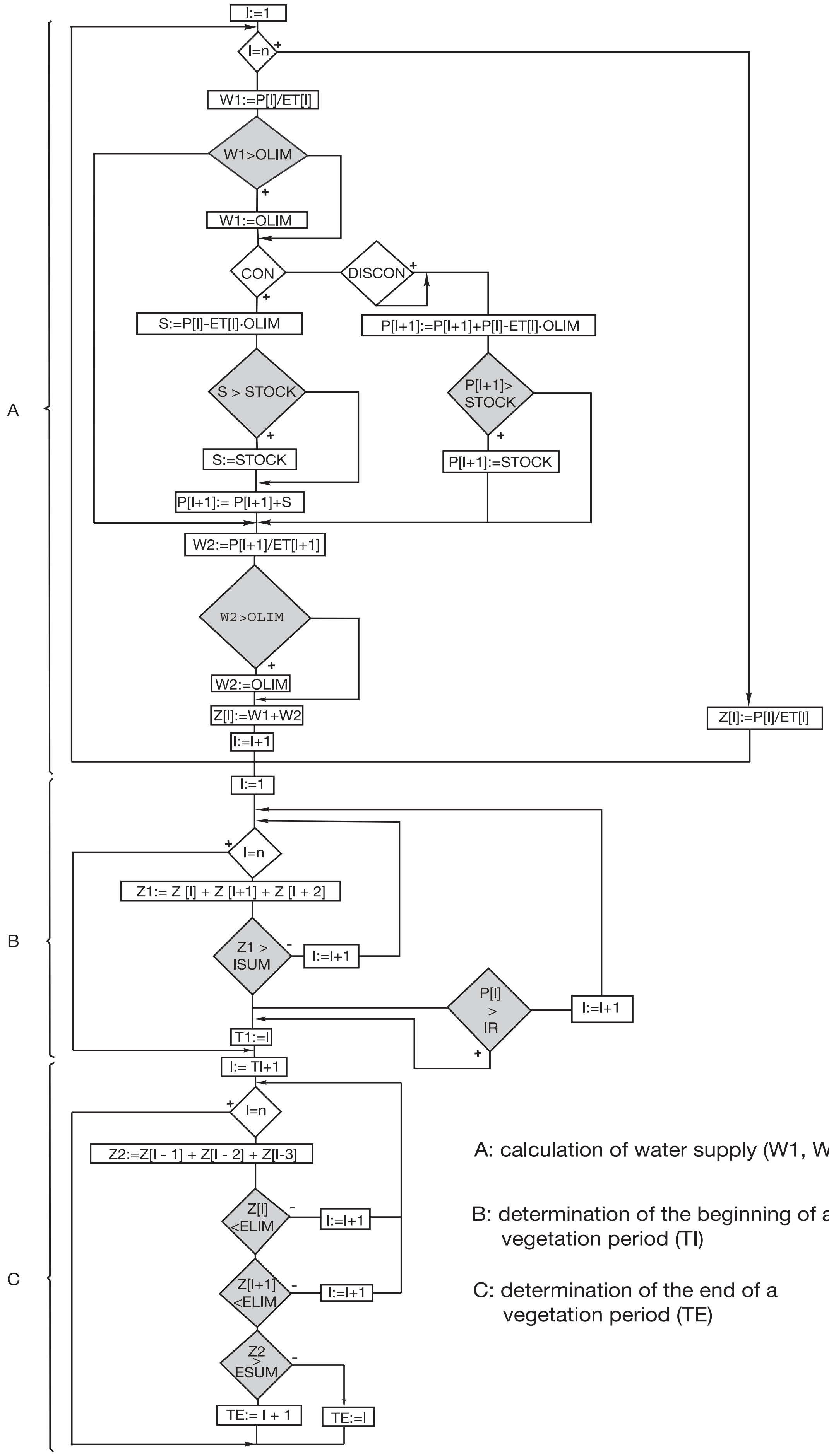
  If calculated water supply of any sequence of three (or four) decades exceeds the value for ISUM (as a virtual sum), given in the defined scenario, the beginning of the growing period (TI) is found.

- The short-term absolute minimum water requirement within the growing period (e.g. dry spells) is represented by the virtual sum ELIM; according to Kutsch & Schuh (1983) this is a period of 2 decades in general for annual crops. Therefore

$$ELIM = KC/min_i + KC/min_{i+1}$$

  This means that if the calculated water supply lies below this threshold for not more than 20 days, it can be a assumed an intermediate short dry period but not yet the end of the growing period; whereas, these dry conditions during one month at least cannot generally support the crop and therefore, the end of the growing period (TE) will have been reached.

Figure 1.1: Flow chart of *WATBAL 2003* (source: Müller, 2003)



A: calculation of water supply (W1, W2)

B: determination of the beginning of a vegetation period (TI)

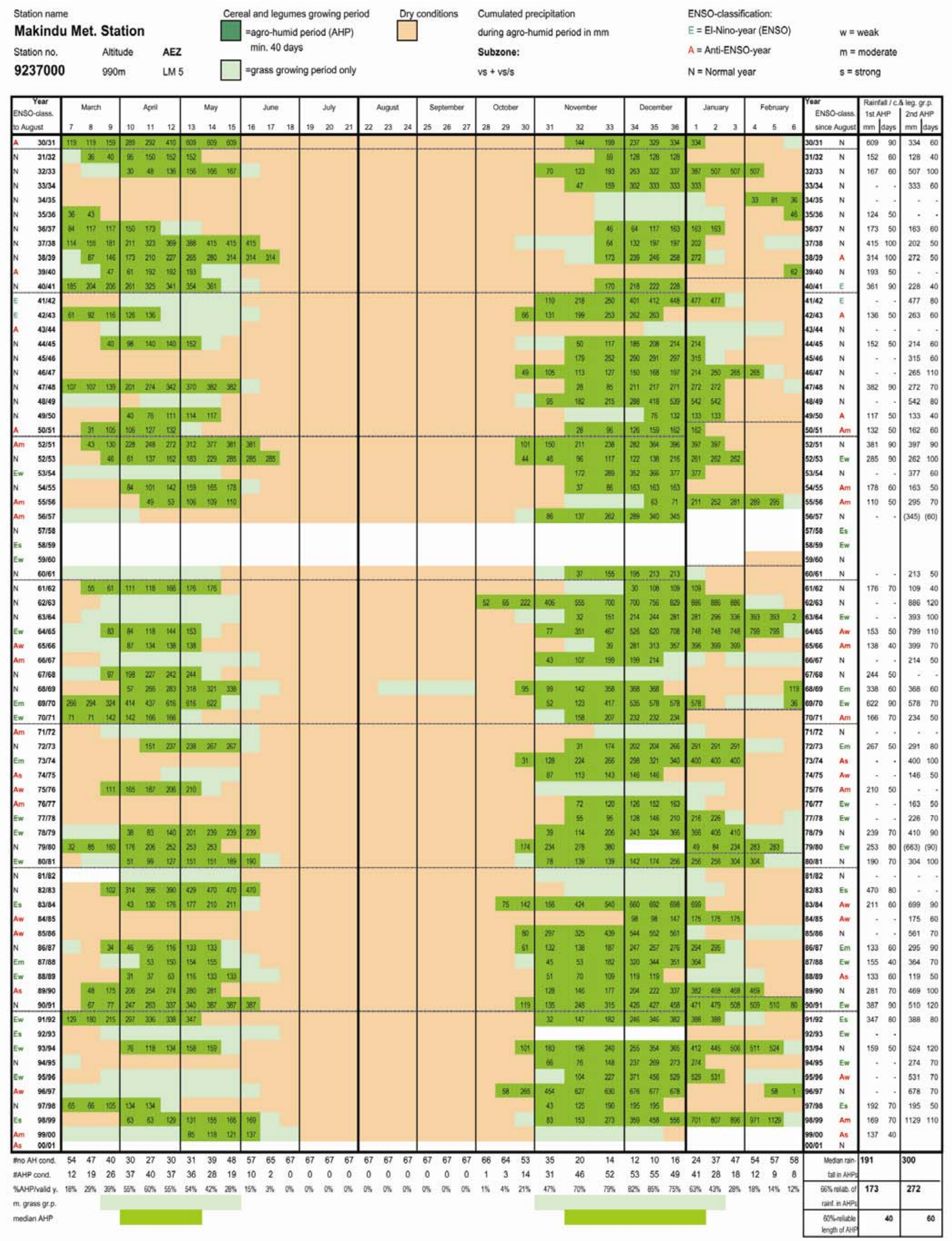
C: determination of the end of a vegetation period (TE)

The combination of this convention with the scenario variable ESUM leads to an unequivocal estimation of the end of a growing period. A further refinement is achieved by the fact that the end decade TE is determined whether the water supply of the last three (or four) decades lay below or above the value for ESUM.

- The KC value determining the optimum crop water requirement in terms of full water supply is called OLIM. With this parameter all soil water surplus (above OLIM) in the water balance of the crop stand can be evaluated whether it will be stored or drained.
- The mean water holding capacity of the soil within the main rooting zone is expressed in the scenario as STOCK (in mm). This parameter allows estimating roughly the influence of the soil storage on the length of the AHP.
- The parameter DUR defines the minimum length of a growing period (which should be given out by the programme).
- RE refers to "effective rainfall" (acc. to FAO, 1975; cited in: Hornetz, 1991), i.e. the fraction of rainfall (X/100) which penetrates into the rooting zone.
- The parameter IR (= initial rain) is used for defining the minimum amount of rainfall (in mm) required for an expected beginning of a growing period; this value is defined due to the amount of soil water which is necessary to stimulate the growth of defined plants (e.g. 10 mm for pasture and xerophytic plants; 20 mm for mesophytic plants).

Müller (2003) has integrated the calculation procedures as well as the input and output tables of WATBAL 2003 into an EXCEL databank (for more details; see: Müller, 2005). The results of the AHP calculations are configured into diagrams showing different physiological scenarios (crop and grass growing conditions coloured with dark and light green; see Figure 1.2) as well as periods without growing conditions. Figures of the cumulated precipitation during the crop growing periods are integrated into the decades of the AHP's; thus allowing a quick overview of the amount of rainfall accumulating during the running AHP. Additionally, rainfall amounts as well as number of days during the AHP's are listed in a table at the right side of the diagram differentiated into ENSO, Anti-ENSO and Normal conditions. Finally, the programme is calculating descriptive statistics, giving information on median and 2/3 probability of rainfall and lengths of AHP's as well as probabilities for the occurrence of conditions for AHP's within the decades of the year (on the bottom of the diagram).

Figure 1.2: **Growing periods in AEZ *LM 5 vu + vs/s* *(= with a very uncertain first growing period and a very short to short second one)* at 9237000 Makindu (acc. to calculations with *WATBAL 2003*)**



1.2.2 Calculation and configuration of yield potentials by using crop simulation programme *MARCROP*

1.2.2.1 Crop Water Requirements (CWR)

The potential evapotranspiration (ET_0) is normally used as the reference in the calculation of potential evapotranspiration from a crop stand (ET_{crop}). This is done by using plant and time specific correction factors referred to as KC-values. The determination of crop water requirements is generally given by Doorenbos & Pruitt (1977):

$$ET_{crop} = KC * ET_0$$

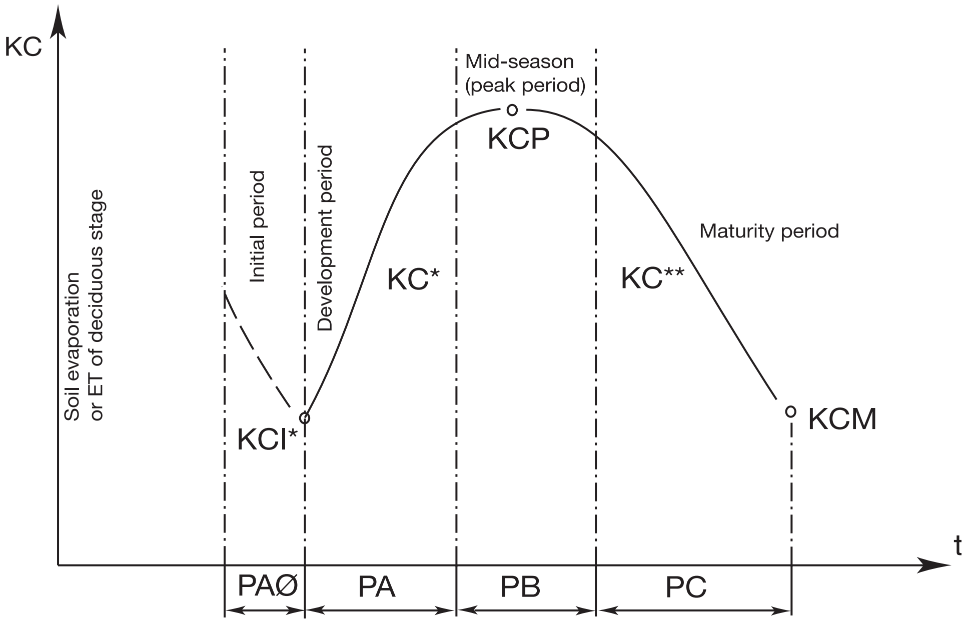
Various KC-values for different crops have been given by Doorenbos & Pruitt (1977) and Achtnich (1980). In a series of laboratory and field experiments, Hornetz (1991), Shisanya (1996), Hornetz (1993), Hornetz et al. (2001), Hornetz et al. (2006) have calculated a number of crop water requirement coefficients for different crops and crop varieties.

The daily measurements of these values are highly correlated with the mathematical approach/formula developed by Kutsch & Schuh (1980) which is based on an e-function. The following parameters are necessary for the computation of the water requirements:

a) the duration of the different vegetation phases (initial, vegetative, generative, ripening);
b) the water requirement coefficients for the initial period, peak period and the period of physical maturity.

The accuracy of the mathematical function was tested by e.g. Hornetz et al. (1992) and Hornetz et al. (2001) for different crops in the climatological laboratory of the University of Trier. They found very high significant correlations (r = 0.86 - 0.99) between the actual KC-values (measured as daily water consumption data by a weighing lysimeter) and those estimated from the mathematical approach of Kutsch & Schuh (1980).

<u>Figure 1.3</u>: General crop water requirement curve and related crop coefficients (after: Doorenbos & Pruitt, 1977; Kutsch & Schuh, 1980)



KC* : $KCP-(KCP-KCI^{*})\sqrt{1-\frac{e^{t/100}-1}{e^{PA/100}-1}}$

KC** : $KCP-(KCP-KCM)\sqrt{1+\frac{e^{-(PA+PB+PC)/100}-e^{-t/100}}{e^{-(PA+PB)/100}-e^{-(PA+PB+PC)/100}}}$

PAØ : initial phase
PA : vegetative phase
PB : phase of maximum water requirement
PC : ripening phase
t : day within vegetation period

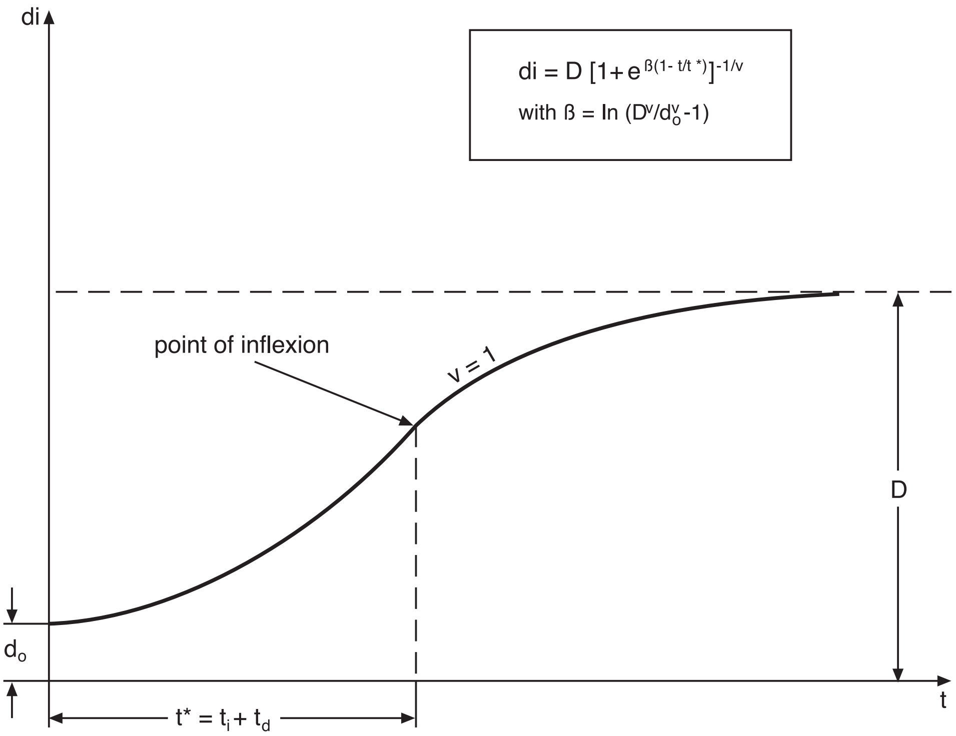
1.2.2.2 Theoretical root development and Leaf Area Index (LAI)

The importance of plant roots influencing the effectiveness of the plant to extract soil water cannot be underestimated. Causton & Venus (1981) introduced the RICHARD's function into plant growth analysis. They found that this function gives trends sufficiently sensible from a biological viewpoint due to the fact that the function is based on a biologically realistic model and the function is a bounded monotonic one (Kutsch & Schuh, 1983). The basis of modelling using this function offers the empirical observation (= linear allometry) of different parts of the plant (Causton &

and Venus, 1981). Under allometry, the growth of some parts of the plant proceeds at a rate faster than the others and then later on retrogresses.

In the program the algorithm of a straight forward simple linear allometric relationship between leaf growth (using LAI) and root growth was employed. The estimation of the theoretical root development (d_i) was done in the algorithm following the RICHARD's function (see Figure 1.4).

<u>Figure 1.4</u>: Model for the root development of a plant according to the RICHARD's function (source: Hornetz, 1991)



t* : day within the vegetation period when the point of inflexion is attained
D : maximum depth of the root complex
d_i : theoretical root length
ß : parameter determining the temporal position of the sigmoid function
v : parameter describing the position of the point of inflexion

The same algorithm was used for calculating the temporal development of the Leaf Area Index (LAI).

1.2.2.3 Actual root development and Leaf Area Index

The theoretical values for root and LAI development must be converted into actual ones. This was done by assuming a linear allometric relationship between foliage growth and root development (Causton & Venus, 1981). As parameters for this purpose, the actual water supply and the relative yield reduction coefficient (KY) as defined by Doorenbos & Kassam (1979) were used. Thus the theoretical (d_i) and actual (d_i*) root length/LAI were linked according to Kutsch & Schuh (1983).

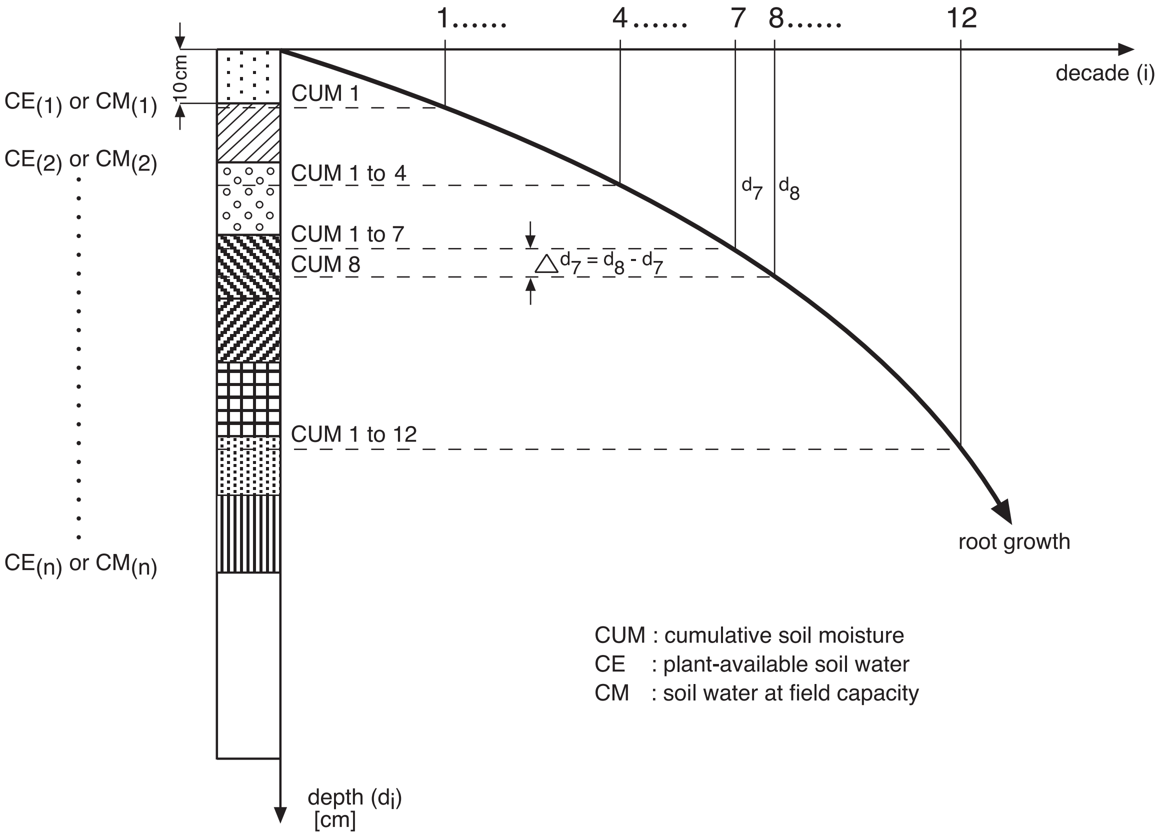
1.2.2.4 Actual soil water storage

The estimation of actual soil moisture storage in the present study was based on the multi-strata soil moisture model of Koitzsch (1977; cited in: Shisanya, 1996). As in the model, the following factors were taken into account:

- With optimum water supply the plants take water mainly from the soil strata near the surface.
- When water becomes short in supply, the water drawn from every sub-stratum is proportional to the amount of water in the sub-stratum which can still be used by the plants.
- After heavy rainfall the water requirements are initially met from the filled sub-strata.
- During the infiltration process the infiltrated water can be used by the plants for as long as it is within the rooting zone.

In the algorithm the thickness of the different soil moisture strata is obtained simultaneously with the growing length of the root complex. For the daily water balancing (see Figure 1.6) the cumulative water holding capacity (CUM; see Figure 1.5) of all previous strata is evaluated if there will be any surplus water above the corresponding water holding capacity. Amounts below this threshold are directly moved to the next day. An eventual surplus is drained into the next lower stratum where it can be tapped together with additional capillary water (K) by further advancing roots. This model is refined by the fact that for each ten centimetre of soil layer a representative value should be given for the maximum (CM; i.e. field capacity) and the effective, i.e. the plant-available water holding capacity (CE).

<u>Figure 1.5</u>: Multi-strata soil moisture model (source: Hornetz, 1991)



1.2.2.5 Stress physiological patterns

The above described model was further refined by Hornetz (1991) considering the following parameters of stress physiology with relevance to yield:

- threshold values of hydrature depending on certain amounts of actual soil moisture;
- adaptation of transpiration rates and consumptive water use to the decreasing soil water reserves;
- drought resisting mechanisms (morphological and physiological responses) and retardation of the permanent plant-specific wilting point, increasing the amount of plant-available water.

Therefore, the concept of “hydrature phases” of Kreeb (1958; cited in: Hornetz, 1991) and soil related parameters that are important in yield assessment were introduced. Based on experimental results, the adaptation of transpiration rates and consumptive water use to decreasing soil water reserves was confirmed. In this connection, the validity of the traditionally fixing of the permanent wilting point (PWP) at pF = 4.2 was questioned, in particular in the case of drought resistant/adapted plants. In the new algorithm the actual water balance, experimentally defined, is the difference between the plant available water in the moist soil and the new crop depended plant available water in the rooting zone (CE). A new parameter in MARCROP algorithm was introduced, denoted by KC* (= ecophysiologically adapted KC-values). This parameter reflects the reactions of drought resistant plants to stress, e.g. osmotic adjustment, parahelionastic response, stomatal closure etc. These morphological and physiological plant responses were correlated to the hydrature classes.

This methodological approach is permitting the combination of ecophysiological observations and measurements with agronomic factors. It is, for example, essential to distinguish the optimum hydrature period (hydrature period 1, “*Optimumphase*”) from the post-optimum hydrature period hydrature period 2, “*Nachotimumphase*”) because this decrease in hydrature –which is measurable as a significant drop in the water potential (Hornetz, 1991)- is related to relative highest yield. The ending hydrature period (hydrature period 4, “*Endphase*”) possesses equal relevance due to the delay of transpiration and photosynthesis. Using the occurrence frequency of each hydrature class during each of the different yield sensitive phenological phases, agroecological types (AET) are defined. These types provide the possibility of evaluating the yield potential during a given agrohumid period. According to Jätzold & Schmidt (1982) as well as FAO (1986) AET are defined as

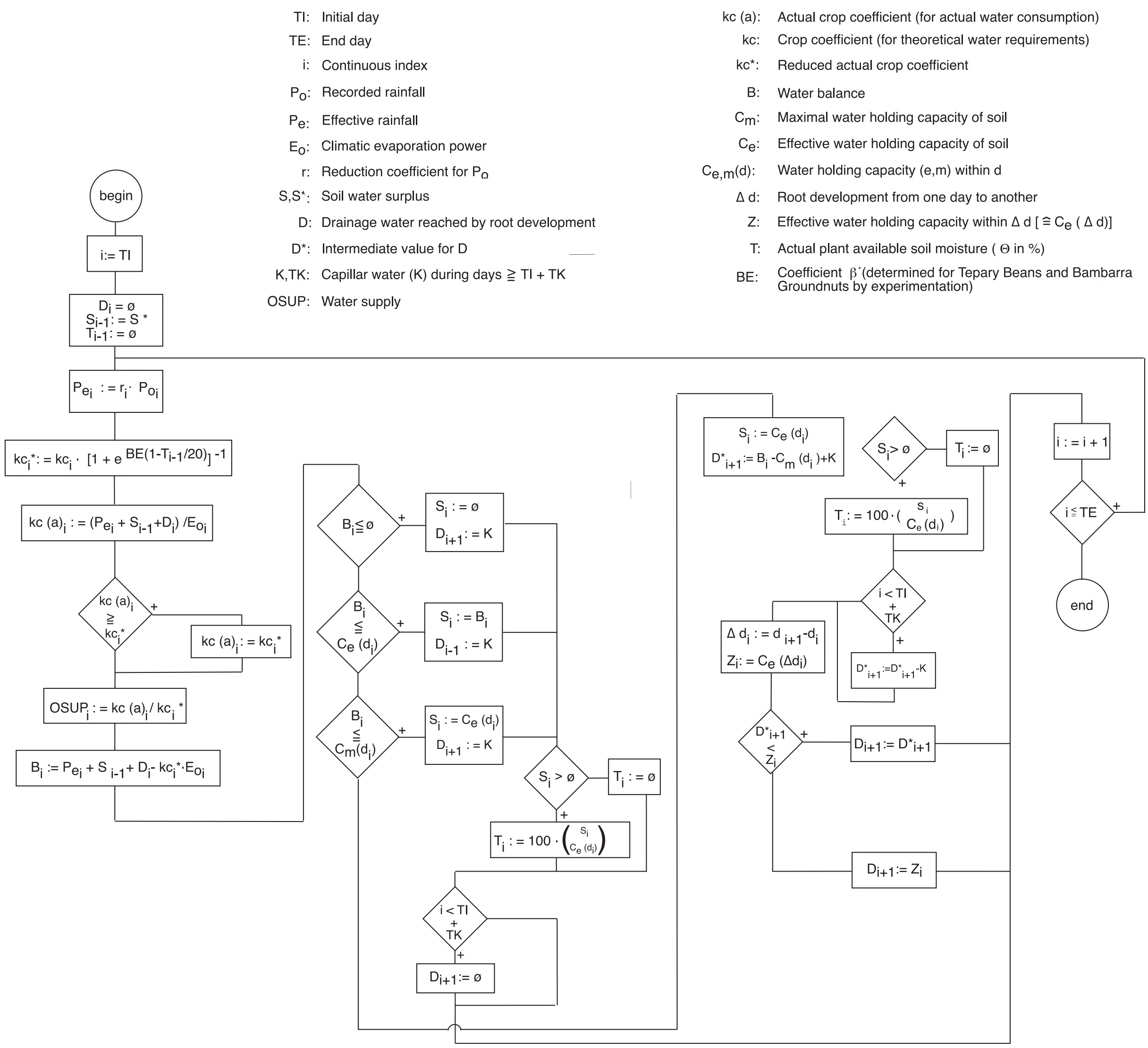
AET 1	: optimum/very good (80 – 100 % of potential yield)
AET 2	: sub-optimum/good (60 – 80 % of potential yield)
AET 3	: average/fair (40 – 60 % of potential yield)
AET 4 & 5	: marginal/poor (20 – 40 % of potential yield)
AET 6a	: minimum (10 – 20 % of potential yield)
AET 6b-d	: Total Crop Failure

1.2.2.6 Structure and algorithms of the MARCROP programme

Figure 1.6 is reflecting structure and algorithms of MARCROP. Different parameters have been additionally integrated into the model in order to take into consideration agroecologically important aspects and developments: e.g.

- reduction coefficients for effective rainfall (as influenced by evaporation, interception, runoff, land use techniques etc.);
- stored soil moisture at the beginning of an agrohumid period;
- capillary soil water rising from deeper soil layers or ground water table;
- coefficients and thresholds (of plant-available soil water) for describing wilting points and hydrature classes of defined crops.

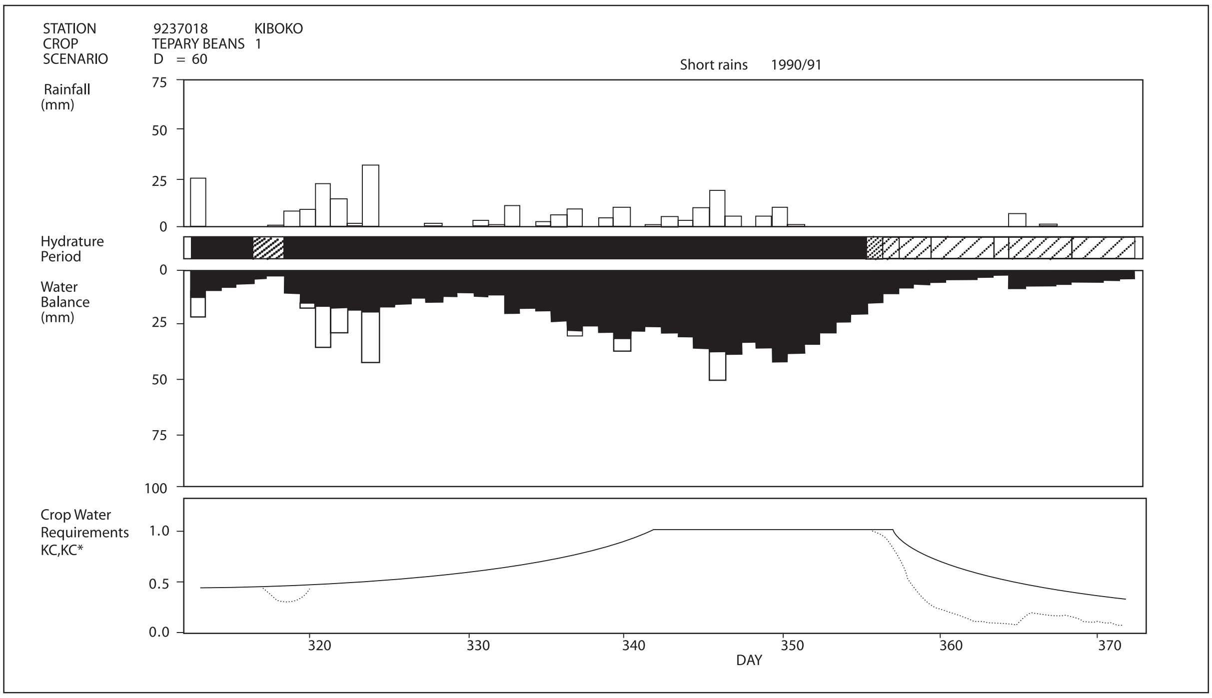
<u>Figure 1.6</u>: Structure and algorithms of MARCROP (source: Hornetz, 1991)



1.2.2.7 Results of calculations with MARCROP

MARCROP results are not only given out in tabular form (see e.g. Table 1.1) but also graphically, which reflects the daily trend of the important parameter inputs (see Figure 1.7).

<u>Figure 1.7</u>: Optimum agroecological type (AET 1) for tepary beans at KARI/NRRC/ICRISAT Kiboko (Short rains 1990) (source: Hornetz, 1997)



For estimating yield potentials and expectations the calculated agroecological types (AET) are annually listed within the simulation programme and can be statistically evaluated according to the different crop and soil scenarios. After that, mean AET figures are used to calculate *Total Crop Failures* (TCF; out of 10 years) and yield expectations (see Hornetz et al., 2001) as well as mean potential yields (in kg/ha) – as a combination of mean AET and optimum yields of defined crops according to experimental results (see Table 1.1). These results are listed in tables and enable us to understand properly the land use possibilities. Table 1.1.and 1.2 are reflecting the results of the crop yield simulation for different soil types; yield expectations on Ferralsols (Table 1.1) are about 10-20 % higher than on less fertile Acrisols and Luvisols (Table 1.2).

Table 1.1: Climatic yield potentials of seasonal crops[1] in AEZ *LM 5 vu + vs/s* (calc. for 9237000 Makindu Met. St. with loc. dominating Ferralsols)

	First rainy season **(start end of March till end of April)**			***Second rainy season*** **(start end of October till end of November)**		
Yield Potential (in % of Opti-mum)	**Crop variety**	**Estim. average yield (kg/ha)[2]**	**Total crop failures out of 10 seasons**	**Crop variety**	**Estim. average yield (kg/ha)[2]**	**Total crop failures out of 10 seasons**
Very good (80 - 100 %)						
Good (60 – 80 %)				Foxtail millet (Jodhpur) Grams (KVR 26)	1080 650	0 0
Fair (40 – 60 %)				Maize (DLC) Maize (KCB) Finger millet (Kat/FM 1) Pearl millet (Kat/PM1, PM2) Pearl millet (Kat/PM 3) Proso millet (Kat Pro 1) Bulrush millet (Serere Comp. II) Foxtail millet (Ise 285) Sorghum (Seredo) Sorghum (KARI Mtama-1) Tepary beans Katheka beans (Kat/Bean 1) Katheka beans (Kat X 56) Cowpeas (HB48/10E) Cowpeas (MTW 63; MTW 610) Cowpeas (K 80) Moth beans (Jodhpur) Green grams Black grams Grams (Kat Dengu 26) Dolichos beans (Kat/DL-1) Chickpeas Soybeans (Nyala) Bambarra groundnuts (N-Cameroon)	1360 1530 430 1160 910 910 1700 1690 1230 1540 630 620 660 630 760 850 880 530 730 580 970 770 1425 540	0 0 0 0 0 0 0 0 0 0 1 2 2 2 2 2 1 3 1 0 1 1 1 2
Poor (20 – 40 %)	Proso millet (Serere I) Foxtail millet (Jodhpur) Foxtail millet (Ise 285) Hog millet (Jodhpur) Moth beans (Jodhpur) Grams (KVR 26) Grams (Kat Dengu 26)	940 580 790 500 410 380 250	2 2 2 2 3 2 3	Finger millet (Ekalakala) Foxtail millet (Kat/Fox-1) Sorghum (IS 8595) Sorghum (Serena) Sorghum (IS 76) Beans (Mwitemania) Beans (Mwezi moja) Beans (Rosecoco) Beans (New Mwezi moja) Groundnuts (Makulu Red)	930 520 1260 1160 690 410 430 570 270 730	2 2 2 2 2 3 3 3 3 3

[1] Only crops listed with total crop failures (TCF) generally less than 33 % (acc. to yield calculations with MARCROP model of Hornetz et al., 2001).
[2] Well manured, fertilized and protected. Water loss as surface runoff is stopped by contour ridges, calculated with MARCROP.

Table 1.2: Climatic yield potentials of seasonal crops[1] in AEZ *LM 5 vu + vs/s* (calc. for 9237000 Makindu Met. St. with loc. occurring Luvi-/Acrisols)

	First rainy season **(start end of March till end of April)**			***Second rainy season*** **(start end of October till end of November)**		
Yield Potential (in % of Optimum)	**Crop variety**	**Estim. average yield (kg/ha)[2]**	**Total crop failures out of 10 seasons**	**Crop variety**	**Estim. average yield (kg/ha)[2]**	**Total crop failures out of 10 seasons**
Very good (80 - 100 %)						
Good (60 – 80 %)						
Fair (40 – 60 %)				Maize (DLC) Foxtail millet (Jodhpur) Foxtail millet (Ise 285) Tepary beans Katheka beans (Kat/Bean 1) Cowpeas (HB48/10E) Cowpeas (MTW 63; MTW 610) Moth beans (Jodhpur) Grams (KVR 26) Grams (Kat Dengu 26) Soybeans (Nyala) Bambarra groundnuts (N-Cameroon)	1070 930 840 510 480 480 600 690 530 480 **1110** 410	1 0 0 2 2 2 2 2 1 2 2 2
Poor (20 – 40 %)	Proso millet (Serere 1) Foxtail millet (Jodhpur) Foxtail millet (Ise 285) Hog millet (Jodhpur) Grams (KVR 26)	740 420 600 390 340	3 3 3 3 2	Maize (KCB) Finger millet (Ekalakala) Finger millet (Kat/FM 1) Pearl millet (Kat/PM1, PM2) Pearl millet (Kat/PM 3) Proso millet (Kat Pro 1) Bulrush millet (Serere Comp. II) Foxtail millet (Kat/Fox-1) Sorghum (Serena) Sorghum (IS 8595) Sorghum (IS 76) Sorghum (Seredo) Sorghum (KARI/Mtama-1) Katheka beans (Kat X 56) Cowpeas (K 80) Green grams Black grams Dolichos beans (Kat/DL-1) Chickpeas	1160 680 370 900 700 700 1480 420 850 920 560 960 1210 540 680 450 560 740 580	1 3 2 2 2 2 2 3 3 3 3 1 1 3 3 3 1 1 1

[1] Only crops listed with total crop failures (TCF) generally less than 33 % (acc. to yield calculations with MARCROP model of Hornetz et al., 2001).

[2] Well manured, fertilized and protected. Water loss as surface runoff is stopped by contour ridges, calculated with MARCROP.

1.2.3 The ENSO concept

The research results on the influence of the ENSO phenomenon in Kenya (e.g. Farmer, 1988; Ogallo, 1988; Shisanya, 1996) open the possibility to forecast the intensity of most rainy seasons before they start, due to the air pressure differences between the eastern and western parts of the Pacific Ocean (Tahiti and Darwin/Australia) –resulting in worldwide teleconnection processes. One or two months before the onset of a rainy season a small difference (Southern Oscillation Index SOI < 1.05) is already indicating an ENSO season with more rain, a high air pressure difference (SOI > 2.33) an Anti-ENSO season with less rain, especially for the 2^{nd} rainy season (see Table 1.3). This enables farmers to choose the probable right seed variety and plant density to avoid risks or increase chances for successful cropping as Shisanya (1996) has shown. It is now to the Government to organize the flow of this vital information from the *Meteorological Department* to the media. These information should be reachable by the local authorities and farmers in time so that they can follow the advice given e.g. in the *Farm Management Handbook* which should be transmitted finally by the Field Officers. It may also be a sophisticated method of drought warning that farmers sell part of their livestock before the animals loose weight and the prices drop.

But this transfer of information has to be well organized so that the right seed is available at the right place in the right time; and farmers may have the chance to get a credit after a bad season for new seed and livestock.

The analysis of Makindu (Table 1.3, 1.4) –a typical location for the semi-arid areas of SE-Kenya- shows some general aspects of the influence of the ENSO phenomenon: The frequency of the predominantly good ENSO years has significantly increased during the last 4 decades of the 20^{th} century, probably a positive effect of the global warming. Fortunately, the frequency of the predominantly bad Anti-ENSO years has not significantly increased (Table 1.3).

Table 1.3: Rainfall and growing periods in Normal, ENSO and Anti-ENSO seasons at 9237000 Makindu, Makueni District/SE-Kenya (acc. to calculations with *WATBAL 2003*)

	First Rainy Season			Second Rainy Season		
	Normal	ENSO	Anti-ENSO	Normal	ENSO	Anti-ENSO
Occurring 1930 - 2000	32 out of 71 = 45 %	20 out of 71 = 28 %	19 out of 71 = 27 %	30 out of 70 = 43 %	17 out of 70 = 24 %	18 out of 70 = 26 %
Occurring 1961 - 2000	13 out of 40 = 32 %	15 out of 40 = 38 %	12 out of 40 = 30 %	13 out of 40 = 32 %	15 out of 40 = 38 %	12 out of 40 = 30 %
Median rainfall in growing period	168 mm	155 mm	100 mm	265 mm	285 mm	190 mm
Median length of growing period	50 days	50 days	35 days	60 days	72 days	50 days

In the first rainy season, the effect of an ENSO year is almost zero because then the influence is already coming to its end after starting in August. Rainfall is not higher than in normal seasons (in the sample it is accidentally even a bit less), and also the length of the agrohumid growing period is the same. However, the influence of an Anti-ENSO year is much more evident and important in the first rainy season: The median rainfall and the length of the growing period drop at Makindu in 3 out of 4 seasons below the minimum for the least demanding crops (minor millets).

In the second rainy season the positive effect of an ENSO situation is visible here: Although the increase of the median rainfall is small (8 %) and just 11 out of 17 seasons got more than the median of the normal ones, the length of the growing period is 20 % longer, here 72 compared to 60 days. This is an important difference in the Livestock-Millet Zone 5, because then maize (DLC) has a good chance, it is the higher yielding and more preferred food crop.

The negative influence of an Anti-ENSO situation is more significant than in the first rainy season. The median rainfall drops at Makindu to 190 mm only and the length of growing period to 50 days. But according to the probability it is better to plant minor millet then instead of expecting a crop failure with maize.

Table 1.4: **Climatic yield potentials of seasonal crops[1] in ENSO, Normal and Anti-ENSO years (second rainy season) [2] in AEZ *LM 5 vu + vs/s* (calc. for 9237000 Makindu Met. St. with different soils [3])**

Crop Variety	Soil	Total crop failures out of 10 years			Estimated average yield (in kg/ha)		
		ENSO	Normal	Anti-ENSO	ENSO	Normal	Anti-ENSO
Maize	Ferralsol	0	0	0	1580	1380	1050
(Dryland Comp.)	Luvi-/Acrisol	0	1	1	1130	1100	700
Bulrush millet	Ferralsol	1	1	1	1960	1920	1320
(Serere Comp. II)	Luvi-/Acrisol	1	2	3	1720	1640	1080
Sorghum	Ferralsol	0	0	0	1670	1640	1050
(KARI/Mtama-1)	Luvi-/Acrisol	0	1	1	1470	1430	920
Tepary beans	Ferralsol	1	1	1	780	670	560
	Luvi-/Acrisol	1	2	3	750	550	400
Beans	Ferralsol	2	4	5	720	540	470
(Rosecoco)	Luvi-/Acrisol	3	4	7	530	340	230
Cowpeas	Ferralsol	1	2	4	1060	900	590
(K 80)	Luvi-/Acrisols	1	3	4	880	650	520
Soybeans	Ferralsol	0	1	1	1680	1500	1030
(Nyala)	Luvi-/Acrisol	1	2	2	1330	1250	900
Groundnuts	Ferralsol	1	4	5	750	750	500
(Makulu Red)	Luvi-/Acrisol	3	4	6	620	680	460

[1] Crops listed acc. to yield calculations with MARCROP model of Hornetz et al. (2001).
[2] 15 ENSO seasons, 10 Normal seasons and 10 Anti-ENSO were calculated and configured from 1961 till 1997.
[3] Well manured, fertilized and protected. Water loss as surface runoff is stopped by contour ridges calculated with MARCROP.

Table 1.4 shows that at Makindu estimated average yields in Anti-ENSO seasons are 30-40 % lower for all crops (also for soybean) on different soils than under ENSO conditions; for Normal seasons yield results are about 10-20 % lower.

On less fertile Luvi-/Acrisols Total Crop Failures are generally 10-20 % higher than on the dominating Ferralsols; yield results show similar patterns under the different rainfall conditions, however, on a lower level resulting by a general decrease of about 10-20 %.

Similar observations were made with different leguminous crops like drought-resistant tepary beans and green grams as well as drought-susceptible mwezi moja beans at NRRC Kiboko near Makindu (AEZ: LM 5- 6): Calculations with the crop simulation model MARCROP from 1959 till 1991 showed that Total Crop Failures (TCF) for the fast growing tepary beans occurred in 13-14 % of the second rainy seasons under normal and Anti-ENSO conditions, but none in ENSO seasons; for green grams this risk is about 21 % under normal, 38 % under Anti-ENSO and only 11 % under ENSO conditions. For the high yielding and fast growing mwezi moja beans there is a risk for TCF of about 57 % under normal and 62 % under Anti-ENSO conditions – however, only 22 % in ENSO seasons (Hornetz et al., 2001).

2. Configuration of agro-ecological zones and crop potentials by using the EDP search programme *DBS Makindu*

Within his masters' thesis Thorsten Schorn (Schorn, 2006) has elaborated a ***data bank system (DBS)*** called ***Makindu*** consisting of

- a data bank management system (DBMS) and
- a data bank (DB)

by using MS ACCESS software.

The DB contains a number of data files for 4 district groups in Eastern Province (Meru North & Tharaka, Meru Central & Meru South, Embu & Mbeere, Machakos & Makueni) concerning e.g.

a) tables of

- temperature and rainfall conditions as well as altitudes of 85 AEZ and 171 subzones during growing (= agrohumid) periods
- lengths of growing periods within the AEZ and subzones
- about 700 selected perennial and annual crop varieties and their growing periods (days to maturity)

b) 144 maps of
- AEZ
- Subzones

The main advantage of the ***DBS Makindu*** is that the files of the data bank can be linked together by means of a DBMS, so that crop varieties can be selected within defined agro-ecological units (AEZ or even subzones) and growing periods (long rains and short rains) according to their climatological requirements and vice versa. So lists of crop varieties are automatically produced and printed. Maps are showing the distribution potentials of these plants within the agro-ecological units; thus enabling stakeholders to gain a quick overview of agronomic potentials.

DBS Makindu can be supplemented by adding additional crop varieties, AEZ, subzones and districts, even soils and yield potentials as calculated by crop simulation model MARCROP and taking into consideration forecasting approaches like the ENSO concept.

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