Vertical hydrological balance and its one-dimensional simulation by the model "DAIR"

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Content

Abstract

A vertical hydrological balance and its simulation by use of the mathematical model, DAIR (DAily supplementary IRrigation estimation), is described.

Potential (comparable) evapotranspiration is evaluated according to the Budyko method, a complex set of nomographs (computerized by VÚVH) for monthly potential evapotranspiration-saturation deficit relationships. Optimal crop evapotranspiration can be computed by use of FAO's crop coefficient data. Actual evapotranspiration depends on the ratio between actual available soil moisture and readily available soil moisture. Runoff evaluation is based on empirical relationship between groundwater depth and measured discharge. Furthermore, soil moisture content and depth of groundwater table are calculated step by step on a daily basis using a water balance method and, if required, supplementary irrigation amounts are administered.

A set of parameters on soil physics data, runoff 'coefficients', crop development characteristics and irrigation boundary conditions for 3 - 8 crop types is required.

In this case-study for the Hupselse Beek watershed the Budyko method had been empirically adjusted to the potential evapotranspiration data obtained by Thom and Oliver method.

All the simulations were conducted by use of daily input data on air temperature, air humidity and precipitation.

Acknowledgement

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All the work was done in close cooperation with Ir. J.N.M. Stricker, who can be accredited with the successful performance of the study.

Also the author expresses his thanks to Mrs. Karin Anspach-Oosterhuis, Ir. Piet Warmerdam, Mr. Jacques Kole, Mr. Jim Field and all the colleagues not mentioned here, whose personal assistance has been beneficial to the work done while spending four unforgettable months in The Netherlands.

1. Introduction

Mathematical model DAIR has been developed by the Department of mathematical modelling in hydrology - Water Research Institute (VÚVH), Bratislava (Czechoslovakia).

The model has been built to study vertical hydrological balance with an application in agricultural irrigation systems, for design and operation. Originally, the model has been calibrated for semi-fine textured soils in the south Slovakian region with the input of Žiharec research station observation data and, additionally, experimentally applied in the east Slovakian region with fine textured soils.

The necessity for certain improvements in the model became evident since there were some difficulties in modelling the real course of capillary rise from the groundwater reservoir upwards to the root zone and, secondly, in modelling 'short-circuiting' in case of infiltration.

In this internal report the latest version of the model, results obtained for 'Hupselse Beek' and brief information on Žiharec experimental station are summarized.

During the author's stay with the Agricultural University some subroutines of the model have been changed with the leadership and assistance of Ir. J.N.M. Stricker.
The improved version of the model has been calibrated for Hupselse Beek experimental basin data. The model is intended to be applied to the east Slovakian region, for which a new project of 80,000 ha (mostly fine textured soil) of arable land shall be prepared for supplementary irrigation.

2. Potential (reference crop) evapotranspiration.

Potential evapotranspiration represents the first indirectly estimated input in the simulated data.
Of all the potential methods, there is not a single method that is recognized as the best for use in an any given climatological condition.

In cooperation with FAO (ref. 1) a mathematical program has been developed by Gupta, S.K., Pruitt, W.O., Lonczak, J. and Tanji, K.K. For use in this program the following methods are possible: radiation, Blaney Criddle, Penman, corrected Penman and pan (based on Class-A evaporation measurement) method.
The mentioned program was used to compare recommended methods of FAO with the Budyko-complex method used for potential evapotranspiration estimation in the U.S.S.R. (ref. 2). Comparison of the 6 methods for Žiharec research station in the year 1978 ($\lambda = 17^{o}54'E$, $\varphi = 48^{o}04'N$, h = 111m a.s.l. and meteorological indicative number is IIiii = 11820) can be seen in Fig. 1 (a - budyko, b - radiation, c - Blaney - Criddle, d - Penman, e - corrected Penman, f - pan evaporation - based in our case from computed free water evaporation data - method).

It is difficult to chosse only one 'adequate' method without checking all of them. We have tried to do that by means of grass evaporation lysimetric measurement during the 1978 growing season in real local, microclimatological conditions and usual harvesting. The course of evapotranspiration measured (double line g, harvesting is signed by arrow) and computed according to the same method as given in Fig. 1 can be seen in Fig. 2. All values are in relative units (computed free water evaporation for the same time period is equal to 1).

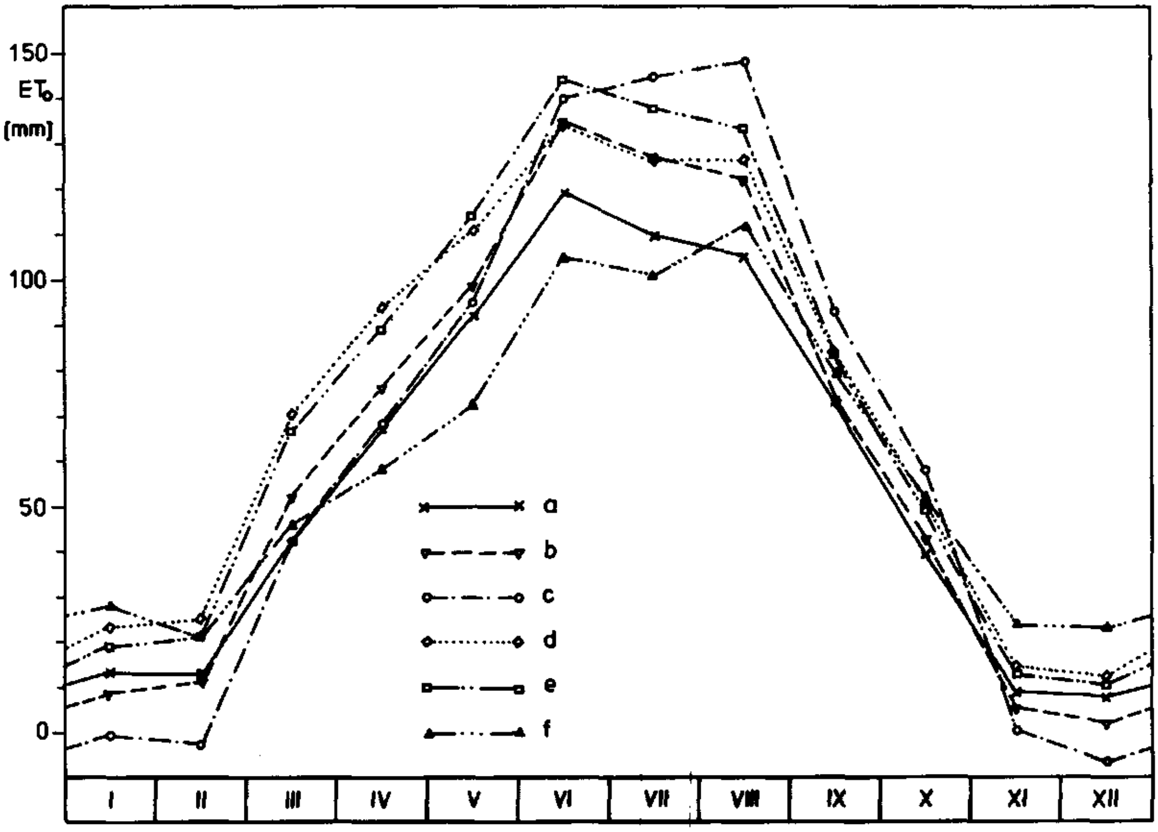

Fig. 1. Potential evapotranspiration in 1978 at Žiharec.

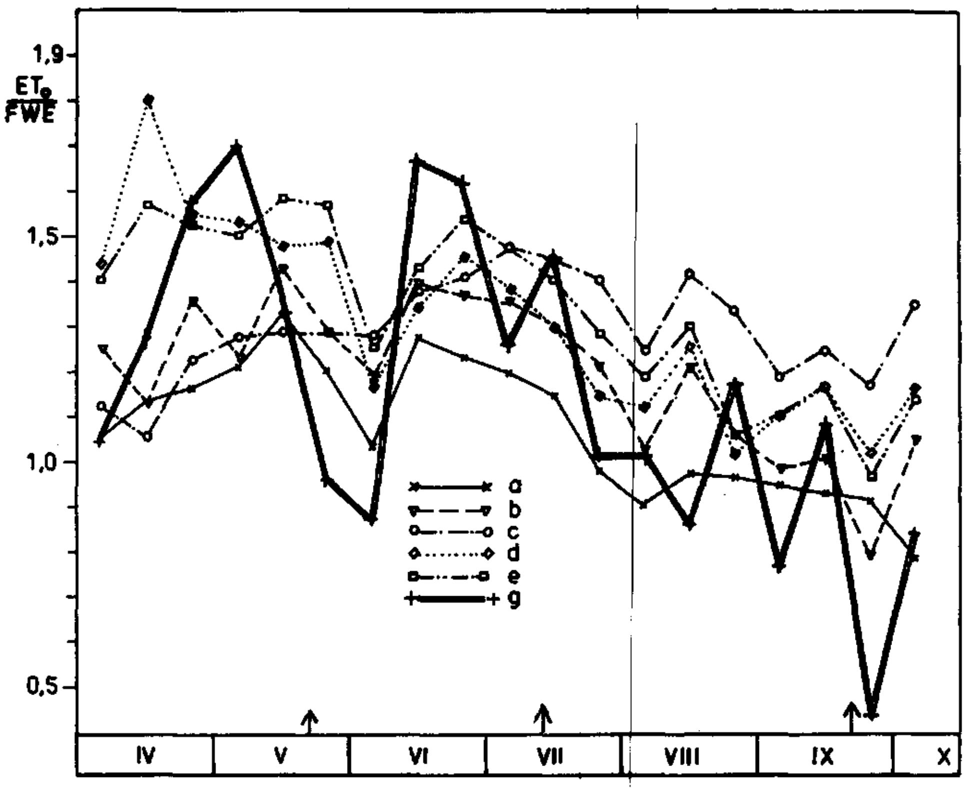

Fig. 2. Computed and measured evapotranspiration.

Comparison of respective methods gives for the growing season total evapotranspiration (in the same sequence): a - 587 mm (- 5,8 %), b - 658 (+ 5,6 %), c - 720 (+ 15,6 %), d - 706 (+ 15,3 %), e - 730 (+ 17,3 %), f - 553 mm (- 11,2 %) and g - 623 mm (the base for %).
It has been shown by author (ref. 3) that the radiation method can be used as an upper approximation and the Budyko method as a lower approximation to the measured data. The Budyko method has been chosen for further computation due to its good fittness and simple input, for which mean temperature and mean air humidity is needed.
The alignment chart, published in the Budyko recommendations (Fig. 3), was tabulated into the by computer usable form and the subroutine for evaluation of daily data has been developed.
By the refinement of the DAIR model with the Hupselse Beek experimental data, as a base for potential evapotranspiration, the data obtained from the Thom and Oliver method were used (ref. 4). To obtain potential evapotranspiration close enough to Thom and Oliver data, the Budyko method was adjusted. Computations for 3 various geobotanical zones was evaluated and none data set were found which could be used directly with a deviation less than 10 - 15%.

An iterative method for fitting monthly 'Thom and Oliver data', PETTHO, (ref.4) from 'Budyko data', PETBUD, was used and for computation the following expression is used:

$$\text{PETTHO} = (.0005055 * \text{PETMON} + .9809) * \text{PETMON} -,733 \qquad (1)$$

where

$$\text{PETMON} = \text{PETREC(MONTH)} * \text{PETBUD} \ [\text{mm/month}] \qquad (2)$$

and values for monthly coefficients MONCO (MONTH) for each month are .955, .892, .962, .804, .781, .735, .797, .782, .747, .713, .944, .876 respectively.

By fitting daily data, it is necessary to recompute all coefficients (but there is not the same number of days in each month), or to multiply daily value from Budyko method by the number of days in a given month and after use of eq. (1) and (2) to divide it again by the same number. Results of this second approach can be seen in columns POT in table 1.

3. Estimation of potential (optimal) evapotranspiration of an individual crop:

So called 'biological coefficient k_b of water consumption curves' method has been standardized in Czechoslovakia (ref. 5) for evaluation of crop optimal evapotranspiration in irrigation practice.

The method is as simple as possible and the saturation deficit and the vegetation phase is taken as an input for the basic equation:

$$CPE = k_b * \Sigma SD \qquad (3)$$

where CPE is potential (optimal) crop evapotranspiration for the same time for which the sum of saturation deficit SD is given. Coefficient k_b depends on the vegetation phase (expressed step by step like a value belonging to the respective interval of positive temperature sums) and its values can be found in tables published by agricultural authorities, e.g. by SLÅMA/1978/(ref. 6).

A different approach to this problem is done by FAO (ref. 1) where a simplified crop coefficient curve is used (Fig. 4.).

Crop potential evapotranspiration (CPE) is a function of crop coefficient CROPCO and potential (comparable) evapotranspiration PE as follows:

$$CPE = CROPCO * PE \qquad (4)$$

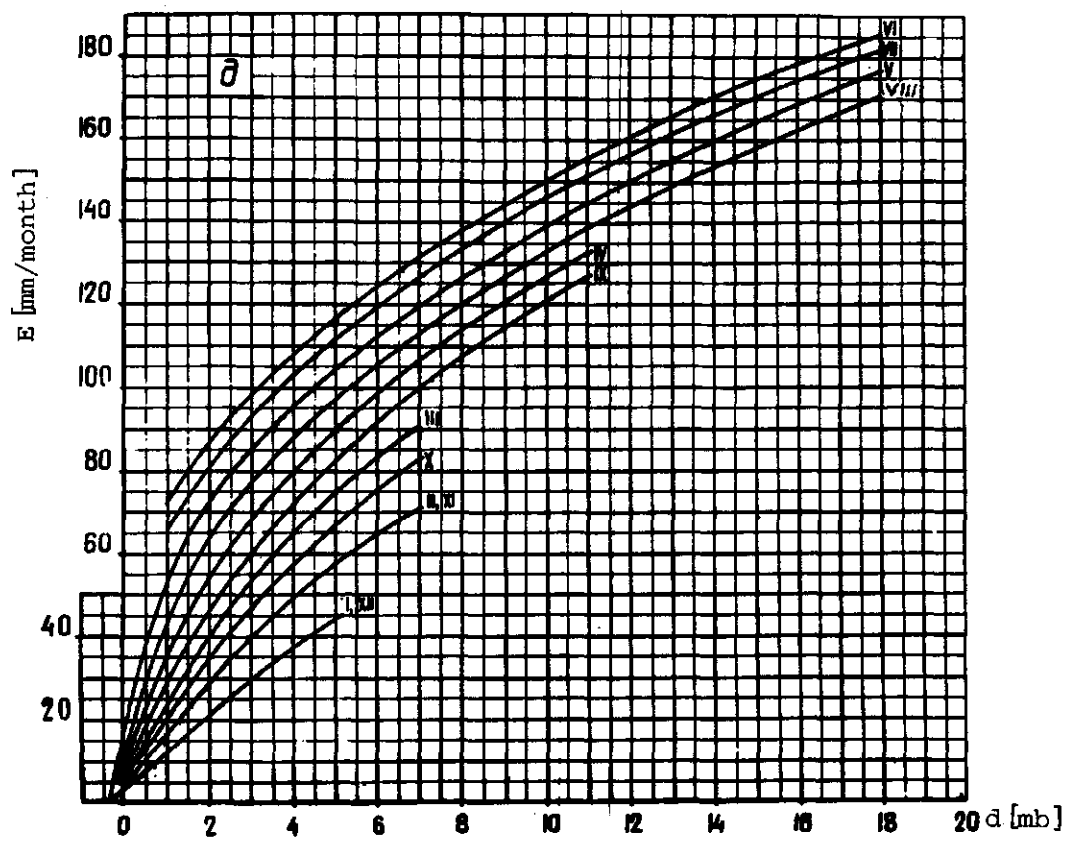

Fig. 3. Potential evapotranspiration in mm/month as a function of saturation deficit d in mb and time (month) of a year for geogr.region 5 "forest-steppe".

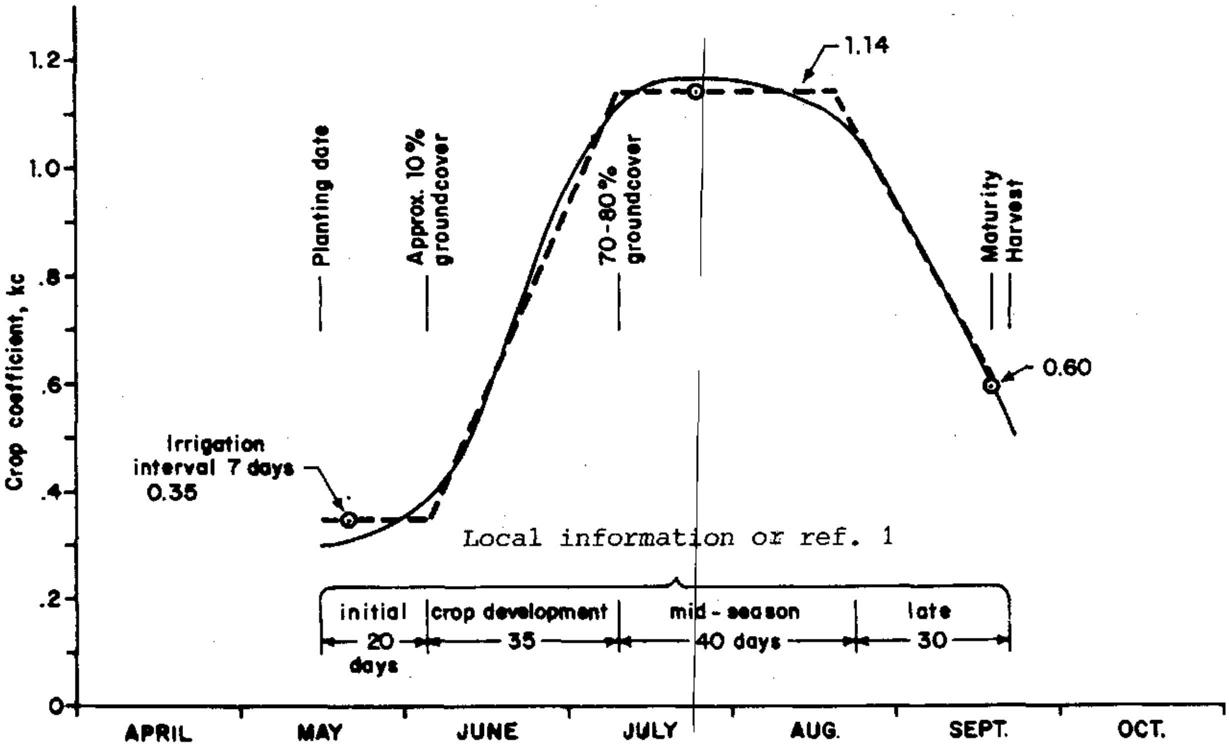

Fig. 4. Example of crop coefficient curve (ref.1).

Table 1. Comparison of evapotranspiration data estimated according to adjust Budyko-complex method and according to mathematical model DAIR with the data distributed by J.N.M. Stricker for intercomparison of the Dutch's evapotranspiration models - Hupsel experimental area.

Period	1976				1977				1978				ϕ (1976-1978)			
Evapo-transp.	POT		ACT		POT		ACT		POT		ACT		POT		ACT	
Method	THO	BU	COM	DAIR	THO	BU	COM	DAIR	THO	BU	COM	DAIR	THO	BU	COM	DAIR
I					3.8	5.2	3.8	5.2	15.8	13.0	15.8	13.0	[9.8]	[9.1]	[9.8]	[9.1]
II					12.4	11.1	12.4	11.0	15.3	10.0	15.3	10.8	[13.8]	[11.0]	[13.8]	[10.9]
III	39.6	37.1	39.6	36.2	33.2	33.8	33.2	33.7	31.4	33.3	31.4	33.2	34.7	34.7	34.7	34.4
IV	53.6	52.2	43.1	45.6	37.6	38.8	38.7	38.7	48.6	48.7	44.0	46.7	46.6	46.6	41.9	43.7
V	77.0	77.4	63.0	60.6	79.0	72.4	73.1	70.4	61.5	67.8	56.1	62.4	72.5	72.5	64.1	64.5
VI	107.1	95.0	73.6	67.3	60.8	71.1	64.8	69.4	76.4	78.2	75.6	66.1	81.4	81.4	71.3	67.6
VII	115.3	103.3	64.1	54.5	78.8	80.7	70.6	77.5	70.3	80.2	75.9	79.9	88.1	88.1	70.2	70.6
VIII	94.5	84.8	56.9	47.5	51.7	58.2	49.0	58.2	57.3	60.6	62.1	60.6	67.8	67.9	56.0	55.4
IX	40.6	41.8	37.5	31.7	40.7	41.4	38.6	41.3	38.6	36.8	39.1	36.7	40.0	40.0	38.4	36.6
X	22.9	22.3	22.9	22.2	24.7	24.1	24.7	24.0	19.2	20.6	19.2	20.6	22.3	22.3	22.3	22.3
XI	8.5	12.4	8.5	12.4	25.5	20.6	25.5	20.5	16.8	16.4	16.8	16.3	16.9	16.5	16.9	16,4
XII	6.0	6.5	6.0	6.5	11.0	10.2	11.0	10.2	11.2	7.7	11.2	7.6	9.4	8.1	9.4	8.0
Σ	565.1	532.8	415.2	384.5	459.2	467.6	445.4	460.1	462.4	474.2	462.5	453.9	503.3	498.2	448.8	439.5

[ ] - 1977 - 1978 only

The crop coefficient CROPCO can be found in FAO tables (ref. 1).

The values depend on vegetation phase and this dependency can be fit by upper boundary of trapezium for which all significant apexes are given by their dates (mean agricultural terms and/or duration) and values. Because of significant variability of agricultural terms from year to year, we have used as a time parameter the sum of positive temperature instead of date, which is more close to the actual situation. In our study three crops were analysed: alfalfa (medicago sativa), sugar beet (beta vulgaris alt.) and winter wheat (Triticum aestivum).

Comparison of the theoretical method with the lysimetric obtained data was done for Žiharec research station based on meteorological measurement within the period 1972 - 1980.
Results are presented in Fig. 5 (line-FAO, □-Sláma, + - 1972, 0 - 1973, * - 1974, x - 1975, ● - 1976, ∇ - 1977, Δ - 1978, ▼ - 1979, ▲ - 1980). It can be seen, that the 'theoretical' data by FAO and SLÁMA are acceptably the same and that the measured data have greater scattering and they give higher values than computed ones.

CROPCO, for use in computation, is given for each particular time period by 4 numbers (2 points in cummulative temperature - CROPCO values coordinates system), maximum 10 periods can be used.

In this case-study (for grassland Hupselse Beek area) it was assumed that the surface represents the ideal surface for potential evapotranspiration and subsequently CROPCO = 1 was used for the entire year.

4. Soil physical and crop parameters.

A simplified approach to the deterministic water movement in unsaturated and saturated layers was used. The parameters used in computation are:

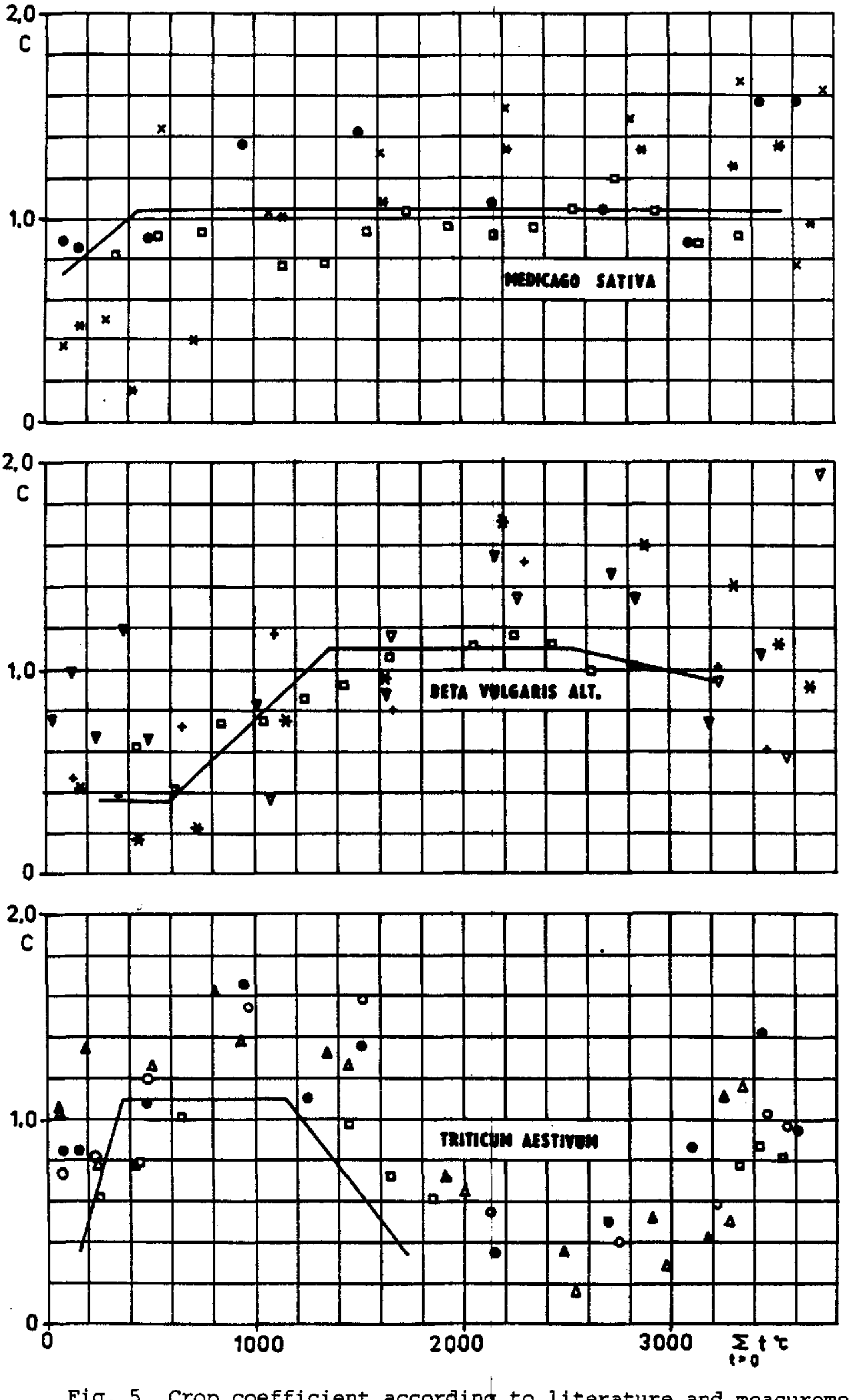

Fig. 5. Crop coefficient according to literature and measurement.

WLTNG - wilting point - soil moisture in ‰ (or in mm of water in 1 m of soil), which represents the amount of water that cannot be used by vegetative cover;

SFFC - (Soil) Full (Field) Capacity is the amount of water, which can be held by soil in equilibrium against gravitation in ordinary local conditions (in mm/m or ‰);

AVSOMO = SFFC - WLTNG is AVailable SOil MOisture for plant water use. The withdrawal of soil water is not uniform within the whole range of soil moisture contents; and

SMCO - 'Soil Moisture Content Optimal' as a lower boundary for readily available soil moisture is introduced. Optimal content of soil moisture depends largely on type of crop and on its vegetative phase. The value of SMCO is also the lower boundary of soil moisture at which actual evapotranspiration is still equal to the potential one. The value of SMCO within a growing season is dependent on the variable PCAST as follows:

$$\mathrm{SMCO} = \mathrm{WLTNG} + \mathrm{AVSOMO} * \mathrm{PCAST}/100 \qquad (5)$$

where, the value PCAST (readily available soil moisture in % of available soil moisture) for a given day (given cummulative sum of daily temperature CUMTCP) is evaluated from input data by the same interpolation method used for CROPCO. Data of PCAST are currently used in Czechoslovakian irrigation practice and have been published (ref. 5). By vertical balance evaluation it seems to be useful to keep in mind that data for PCAST in part expresses also the depth of root zone development (discussed later). During the fitting process for the studied region it was acceptable not to follow exactly the prescribed data for PCAST but this parameter could be used as one of the few adjustable parameters in our model. The value, DEROZO - DEpth of ROot ZOne, is taken as a depth at which the majority of the soil moisture is consumed by the plant transpiration, it was inputed similarly as CROPCO.

A basic relationship (transformed to the time-temperature scale) was used (ref. 7)

$$\text{DEROZO} = \frac{n_d}{n_t} * \text{DRZMAX} \tag{6}$$

where: n_d is a current day of crop development;

n_t is total (longterm mean) amount of days needed for the full development of roots in the root zone;

DRZMAX is maximal (fullt developed) depth of roots 'standardized' in ČSSR (ref. 5).

It was assumed that DEROZO $\geq$ 0.2 m.

PENCO-represents a type of storage coefficient which gives the change in the groundwater table position in m after 1 mm of water percolates or is consumed by plants or transported by runoff. In the present version of the model it is assumed that PENCO may be used as a constant.

Capillary rise occurs when the groundwater table is close enough to the root zone. It is assumed that in dry soil conditions the maximum possible capillary rise is expressable by the equation:

$$\text{QFLOWM} = \text{EXP(QFLC01-QFLC02*ALOG(DEPTH))} \tag{7}$$

where; QFLC01 and QFLC02 are coefficients depending only on soil type. They may be estimated from local pF-Θ relationship and from hydraulic conductivity, and DEPTH=UWL-DEROZO is the distance between the groundwater level UWL and the major part of root zone DEROZO.

In fine texture soil conditions, the rate of capillary rise (and also seepage and bypassing) depends on swelling and cracking characteristics of particular soils (ref. 8-14). According to Wösten (ref. 15) for heavy soils capillary rise decreases at pF = 2.0. For our model we can assume that the equation (7) can be used and the only changed values are for the variables QFLC01 and QFLC01.

Equation (7) has to be used for 'dry' soil conditions. In practice a relative 'dryness' parameter RELDRY is used:

$$\text{RELDRY} = \text{(SFFC - SMC)/AVSOMO} \tag{8}$$

where; SFFC and AVSOMO are as previously described and SMC is the actual soil moisture content.

Role of capillary rise under real soil moisture conditions used in our model was as follows:

QFLOW = RELDRY * QFLOWM [mm/day] (9)

with the condition QFLOW ≤ CRISEL (Capillary RISE Limit).

All soil parameters for the original version of model DAIR for Žiharec research station were determined by Institute of Hydrology and Hydraulics, Slovak Academy of Sciences (J. Šútor) according to Benetin method (ref. 16).

For this case-study and for the improvements model all parameters have been computed by J.N.M. Stricker and the following values have been used:

WLTNG = 41‰ (at pF = 4.2) for upper 1 m layer
WLTNG = 62‰ (at pF = 4.2) for upper 0,5 m layer
SFFC = 160‰ (at pF = 2.0) for upper 1 m layer
SFFC = 190‰ (at pF = 2.0) for upper 0.5 m layer

PCAST was used as a tuning parameters and it is given by following points for interpolation:

for upper 1 m	for upper 0.5 m	CUMTCP range
[0.,90.] [580.,90.]	[0.,90.],[580.,90.]	< 0., 580.>
[580.,90.],[2500.,50.]	[580.,90],[2500.,20.]	< 580., 2500.>
[2500.,50.],[5000.,90.]	[2500.,20.] [5000.,90.]	< 2500., 5000.>

PENCO was approached by calibration and the value 0.013 was used for both thicknesses, 1 m and 0.5 m, of analysed soil;

QFLCO1 = 0.5324, QFLCO2 = 1.9754 were derived from pF curve by J.N.M. Stricker.

5. Seepage, bypassing and runoff

Amount of precipitation PREC falling on the soil surface is assumed to be liquid at air temperatures TEMP $\geq 0\ ^{o}C$.
It is assumed, that there is no direct surface runoff (i.e. studied area does not have any significant slope, otherwise surface runoff coefficient SURRCO should be used). The amount of precipitation, SII, not exceeding FILLIM can infiltrate in 24 hours. The remainer:

$$SSP_{i+1} = SSP_i + PREC - SII \qquad (10)$$

is processed in the next time step as a surface storage of precipitation. Value SII is used as an input for evaluation of actual evapotranspiration and soil moisture SMCN2 at the end of the time step. If this soil moisture is higher than field capacity, SFFC, amount of seepage:

$$SEN = SMCN2 - SFFC \qquad (11)$$

is evaluated and the corresponding increase of the groundwater table PENCO * SEN is calculated. The starting soil moisture for the next time step cannot be higher than SFFC.

In the case of negative air temperature it is assumed that precipitation is falling as snow and that it is stored at the soil surface as a WSP (Winter Stored Precipitation). For the whole nonvegetative period there is a checking of WSP and, if it is positive, snow evaporation (see later) is computed and if the air temperature is positive also, the snow-melt process is considered by a day-degree factor SNMEFA (ref. 17). Amount of melted water SNMELT is added to SSP and processed similarly as liquid precipitation.

Time distribution of rainfall is not homogenous and there can exist some shorter or longer periods of drought in which horizontal and vertical soil cracks can be developed due to soil shrinking. In such a situation a portion FPW of rain (and also of water originated by snow-melt) can under certain circumstances reach groundwater table without influencing soil moisture content. This phenomena, often called bypassing, depends in our model on following parameters:

NORALI - lower circuit of days since the last (significant = higher than 1 mm) precipitation after which some seepage through preferable ways can occur;

NORAPW - number of days without rain after which the fully developed cracks are to be expected;

FPW - factor expressing a portion of water filtrated through preferable ways in soil alyer;

YPWLIM - upper limit for daily amount of bypassed water (in mm).

The amount BYPASS of bypassed water depends also on amount of days NORAIN since the last rain and on the actual soil moisture content SMCN1 at the beginning of the calculated time step. The measure for dryness and cracking of soil is:

$$\mathrm{RELDRY} = \mathrm{MAX}\ (\mathrm{DRY1},\ \mathrm{DRY2}) \leq 1 \qquad (12)$$

where: DRY1 = NORAIN/NORAPW and DRY2 = WLTNG/SMCN1.
In model DAIR the following structure is used:

$$\mathrm{BYPASS} = \mathrm{RELDRY} * \mathrm{PREC} * \mathrm{FPW} \leq \mathrm{YPWLIM} \qquad (13)$$

if all the following conditions are fulfilled:

NORAIN > NORALI, PREC > 3.(and in input parameters NORAPW > 0, FPW > 0.001, YPWLIM > 0.).

For water melted from snow a 'direct' bypassing:

$$\mathrm{BYPASS} = \mathrm{SNMELT} * \mathrm{FPW} \qquad (14)$$

is calculated.
The change of groundwater table due to bypassing is reevaluated.

In an one dimensional (vertical) study we have some boundary conditions, where an interaction with the surrounding environment

is occuring. Let us define as 'runoff' the amount of water (in mm/day) which leaves our vertical column. In the case that we also have some inflow into our groundwater 'aquifer' (there is no horizontal movement of water at the soil surface and in its unsaturated layer), term runoff means positive contribution of our areal unit to the total runoff.
If we suppose that our areal unit is located in the point of gravity of a watershed, it is also possible to use measured discharge (in mm/day) as a boundary condition.

For the present version of DAIR two more or less complicated runoff subroutines have been developed. In this study there is a description of the version used only for the case-study, Hupselse Beek. Runoff is expressed by the equation:

$$RUNOFF = DISCHM*WATARC+COBAFL+RUNCO5*BRV+RUNCO6*YYY+YC*YY \quad (15)$$

where: DISCHM is measured discharge;
WATARC is WATershed ARea Coefficient, which is used for recomputation of measured discharge from any units into mm/day and can be used also for corrections of nonrepresentativeness of rainfall and/or discharge measurements;
COBAFL is COnstant BAse FLow, can be used for expressing some (low) outflow off the river chanel (bypassing runoff) due to hydrogeological conditions in the studied river basin.
RUNCO5, RUNCO6, YC are 'runoff' coefficients used for tuning the model;
BRV is runoff obtained from the relationship between groundwater table depth and measured (or calculated) discharge; YYY is an older variable for a groundwater depth - runoff relationship; YY is runoff obtained by use of antecedent precipitation index.

The choice for the coefficients WATARC, COBAFL, RUNCO5, RUNCO6, and YC determines also the choice for a particular runoff submodel.

Available possibilities are in details as follows:

$$BRV = RUNCO8*UWLN+RUNCO9 \quad (16)$$

where UWLN is depth of (computed) groundwater table and there

for UWLN in range [m] are	RUNCO8	RUNCO9
0.0 - 0.57	- 16.070	10.
0.57 - 0.68	- 4.909	3.638
0.68 - 0.87	- 0.737	0.801
0.87 - 1.74	- 0.182	0.318
1.74 and more	0.0	0.0

and/or

$$\mathrm{YYY = BRUNOF*EXP(-(UWLN-UWLMIN)/UWLAMP)} \tag{17}$$

where BRUNOF, UWLMIN and UWLAMP are tuning parameters and UWLN has been defined previously

and/or

$$\mathrm{YY = (1.-RUNCO1)*RUNCO2*API} \tag{18}$$

$$\mathrm{API}_{t+1}\mathrm{=API}_{t}\mathrm{*RUNCO1+RUNCO3*SSP}_{t-1}\mathrm{+(1-RUNCO3)*SSP}_{t} \tag{19}$$

where; RUNCO1, RUNCO2, RUNCO3 are tuning parameters, SSP is described above.

In the initial version of DAIR for Žiharec research station the equations (17) and (18) have been used (meaning RUNCO6 $\neq$ 0 and YC $\neq$ 0, but there is also some surface runoff with SRY < 5% of PREC, which was applied). For the case-study Hupselse Beek, the equation (16) was applied (RUNCO5 $\neq$ 0). Values of RUNCO8 and RUNCO9 had been estimated by Ir. J.M.S. Overmars and for groundwater table less than 0.68 m they were approached by tuning of the model.
To complete the runoff description it is necessary to add, that in the program DAIR there is a possibility to model a 'hard drainage' system, which limits the groundwater table from the top by a parameter UWLMIN (or from the soil surface, if UWLMIN = 0). If the computed groundwater table should be higher than the mentioned UWLMIN, then supplementary 'drained runoff-DRRUN' is evaluated. Cumulative value of DRRUN gives also information about amount of water needed to be pumped out for keeping 'our field' in 'wanted' boundaries.

6. Actual evapotranspiration and soil moisture

Actual evapotranspiration is usually taken as a function of crop optimal evapotranspiration and soil moisture, unless we are speaking of phytological approach and phenomena modelling. Water withdrawal from the point of view of soil moisture availability and the actual to potential evapotranspiration ratio is discussed by a group of authors working with Agricultural Canada (ref. 18): 'Typical relationship between available soil moisture and AE:PE ratio are shown in Figure 6. Baier (1969 - ref.19) discussed these relationships in detail and demonstrated that the soil-moisture estimates from the versatile budget differed significantly when extreme type (e.g. C and F) were used, whereas those error was probably within the precision of most methods for soil-moisture determination. The decision as to which type to use can be based on comparisons between observed and estimated soil moisture by testing different relationships in each computer run or on existing knowledge of moisture retention characteristics of soils (Salter and Williams 1965 - Ref. 20)'.
In model DAIR, Type G(C,H) was used with a movable boundary for readily available soil moisture, SMCO, at which the reduction starts so that, instead of using the set of tables (ref. 18) for obtaining wanted ratio, then only the yearly course of parameters PCAST for the eq. (5) is needed.

Our computation is proceeding step by step for every day and SMC is an arithmetical mean of the soil moisture values at the beginning SMC1 and at the end SMC2 of the analysed time stop.
A new day begins with the soil moisture content from the previous day. Soil moisture at the end can be expressed according to the Budyko method as follows:

$$\mathrm{SMC2=WLTNG}+\frac{(\mathrm{SMC1-WLTNG})*(1-\mathrm{CPE}/(2*(\mathrm{SMCO-WLTNG})))+\mathrm{SII}}{1+\mathrm{CPE}\;/\;(2*(\mathrm{SMCO}-\mathrm{WLTNG}))} \qquad (20)$$

where; all variables are previously defined.
If mean soil moisture, SMC, within the particular time step is

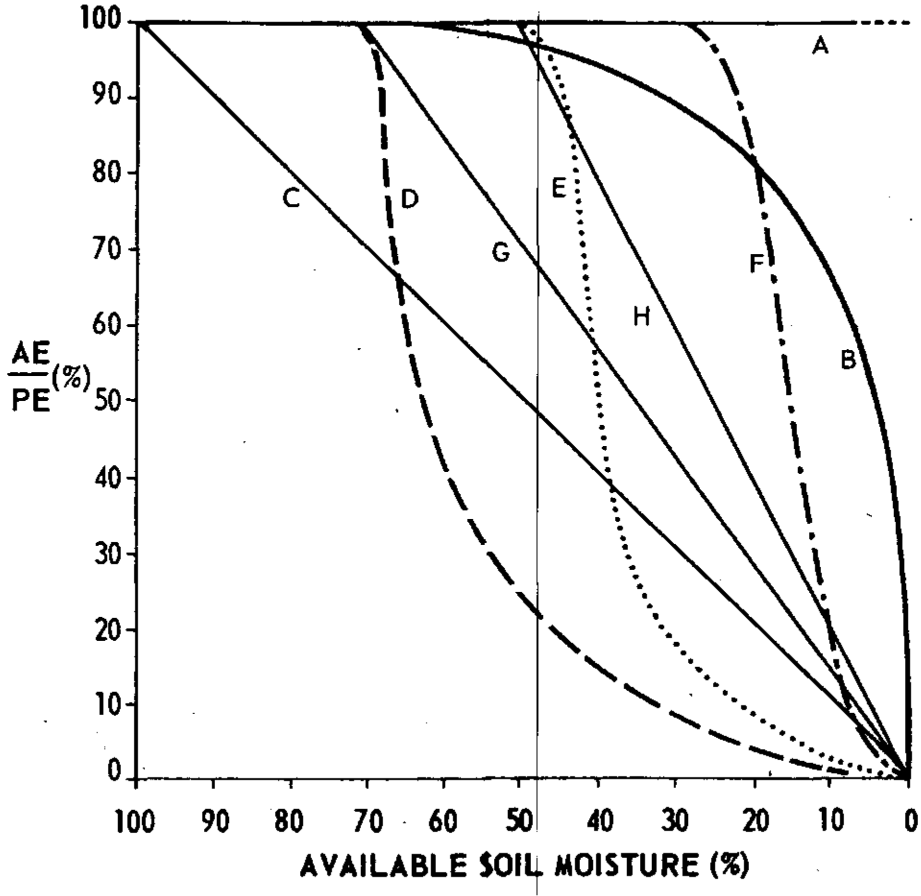

Fig. 6. Various proposals for the relationships between AE:PE ratio and available soil moisture (Baier and Robertson 1966 - ref. 21)

less than SMCO, actual evapotranspiration is given by the relationship:

$$ACET = CPE * SMC/SMCO \quad (21)$$

If mean soil moisture SMC is not less than SMCO, the following two equations should be applied:

$$ACET = CPE \quad (22)$$

$$SMC2 = SMC1 + SII - CPE \quad (23)$$

At the end of each time step there is a regular shifting of the boundary condition:

$$SMC1_{t+1} = SMC2_t \quad (24)$$

The DAIR model can work simultaneously for 3-8 crops under natural conditions and under irrigation, so that the letters N and I were introduced in variables SMCN1, SMCN2, SMCI1, SMCI2 respectively and the index ISCRPS = 1,2, ..., 8 was used.

In winter a simplified approach was used. If the air temperature is negative, it was assumed that the soil surface is frozen and no vertical transport of water is possible. In that case soil moisture content is kept constant and if there is no snow at the surface (WSP=0), actual evapotranspiration is set equal to zero.

If there is snow at the surface, snow evapotranspiration SNOWET is computed according to an empirical relationship (ref. 22) based on measurements done by Popov's evaporimeter (500 cm^2) at Žiharec research station.

$$\mathrm{SNOWET} = (-2810.+11.18*(273.16+\mathrm{TEMP}))*(\mathrm{SVPSST}-\mathrm{AHUM})/(273.16+\mathrm{TEMP}) \tag{25}$$

with the condition $0 \leq \mathrm{SNOWET} \leq \mathrm{WSP}$

where TEMP is air TEMPerature in mm Hg

AHUM is Air HUMidity in mm Hg

SVPSST is Saturated Vapour Pressure at Snow Surface Temperature, SSTEMP

and

$$\mathrm{SSTEMP} = -\ 0.6+0.82*\mathrm{TEMP} \tag{26}$$

with the condition $\mathrm{SSTEMP} \leq 0$ and

$$\mathrm{SVPSST} = 4.58*10**(9.5\ \mathrm{TEMP}/(\mathrm{TEMP}+265.5)) \tag{27}$$

(Remark: the last equation is valid for non positive TEMP only, it is saturated vapour pressure related to ice surface).

In days with WSP > 0 and TEMP > 0, both CPE(BUDYKO) according to adjust Budyko method and SNOWET according to eq. (25) are computed. If there is

$$\mathrm{CPE(BUDYKO)} \leq \mathrm{SNOWET} \leq \mathrm{WSP} \tag{28}$$

then

$$\mathrm{ACET} = \mathrm{SNOWET} \tag{29}$$

If there is a case with

$$\text{SNOWET} < \text{CPE(BUDYKO)} \tag{30}$$

then CPE(ETPLUS) = CPE(BUDYKO)-SNOWET (31)

is processed by a relevant subroutine according to eqs. (20) - (23) and for the actual evapotranspiration a value,

$$\text{ACET(TOTAL)} = \text{SNOWET} + \text{ACET(ETPLUS)}, \tag{32}$$

is used.

Daily and cummulative values within a calendar year are estimated and printed according to print rules given by corresponding parameter NDPRST.

7. Irrigation boundary conditions

The model DAIR computes simultaneously 'natural' and 'irrigated' yearly course of soil moisture, seepage, capillary rise, actual evapotranspiration and runoff for the full set of chosen crops (3-8) and, with certain conditions being fulfilled, then supplementary irrigation amount is evaluated. The day, in which there is a computed portion of water, is taken as an irrigation date and for the next time step it is assumed that the computed portion has been applied.

Following determinant parameters are used:

DAVMIN minimum of applicable irrigation portion (from the point of view of technology, economy, etc.);

DAVMAX maximum of applicable irrigation portion;

SMLLCO (Soil Moisture Lower Limit COefficient) is a parameter for condition:

$$\text{SMCI2} < \text{SMLLCO} * \text{SMCO} \tag{33}$$

and, if it is valid, then the evaluation of all further conditions starts;

SMULCO (Soil Moisture Upper Limit COefficient) is a parameter for the computation of the irrigation portion, DAVKA. The parameter is used to prevent exceeding the final soil moisture, SMULCO * SFFC and

$$\text{DAVKA} = \text{SMULCO} * \text{SFFC} - \text{SMCI2} \tag{34}$$

IRSTEP (IRrigation STEP) is a limit in days expressing the shortest time period inbetween two consecutive application of irrigation (the highest frequency);
IRFD (IRrigation First Day) the first day (sequence number in year) in the irrigation period;
IRLD (IRrigation Last Day) the last day in the irrigation period.
Decision philosophy on wether or not to apply irrigation is focused in the fulfilment condition (33) and the following conditions:

$$\mathrm{ISAFTI} > \mathrm{IRSTEP} \tag{35}$$

$$\mathrm{IRFD} \leq \mathrm{NDAY} \leq \mathrm{IRLD} \tag{36}$$

$$\mathrm{DAVKA} \geq \mathrm{DAVMIN} \tag{37}$$

where; NDAY (an internal variable) is a sequence of particular time step in a year;
ISAFTI (an internal variable - IS AFTer Irrigation) is the number of days since the last irrigation of a particular crop type;
DAVKA is computed portion by eq. (34).

Before application, the computed portion DAVKA is compared with the limit DAVMAX and an amount not higher than DAVMAX is applied on a particular crop type.

8. Results and discussion

Results obtained from the model DAIR give a time series of studied elements. At present there is a possibility to 'tune' the model by use of actual evapotranspiration data estimated by a different method and/or only by comparison of simulated and measured course of groundwater table.

Simulated and measured groundwater table at Žiharec research station processed by the initial version of the model are compared in Fig. 7 (ref. 23).

For the improvement the model and case-study Hupselse Beek both

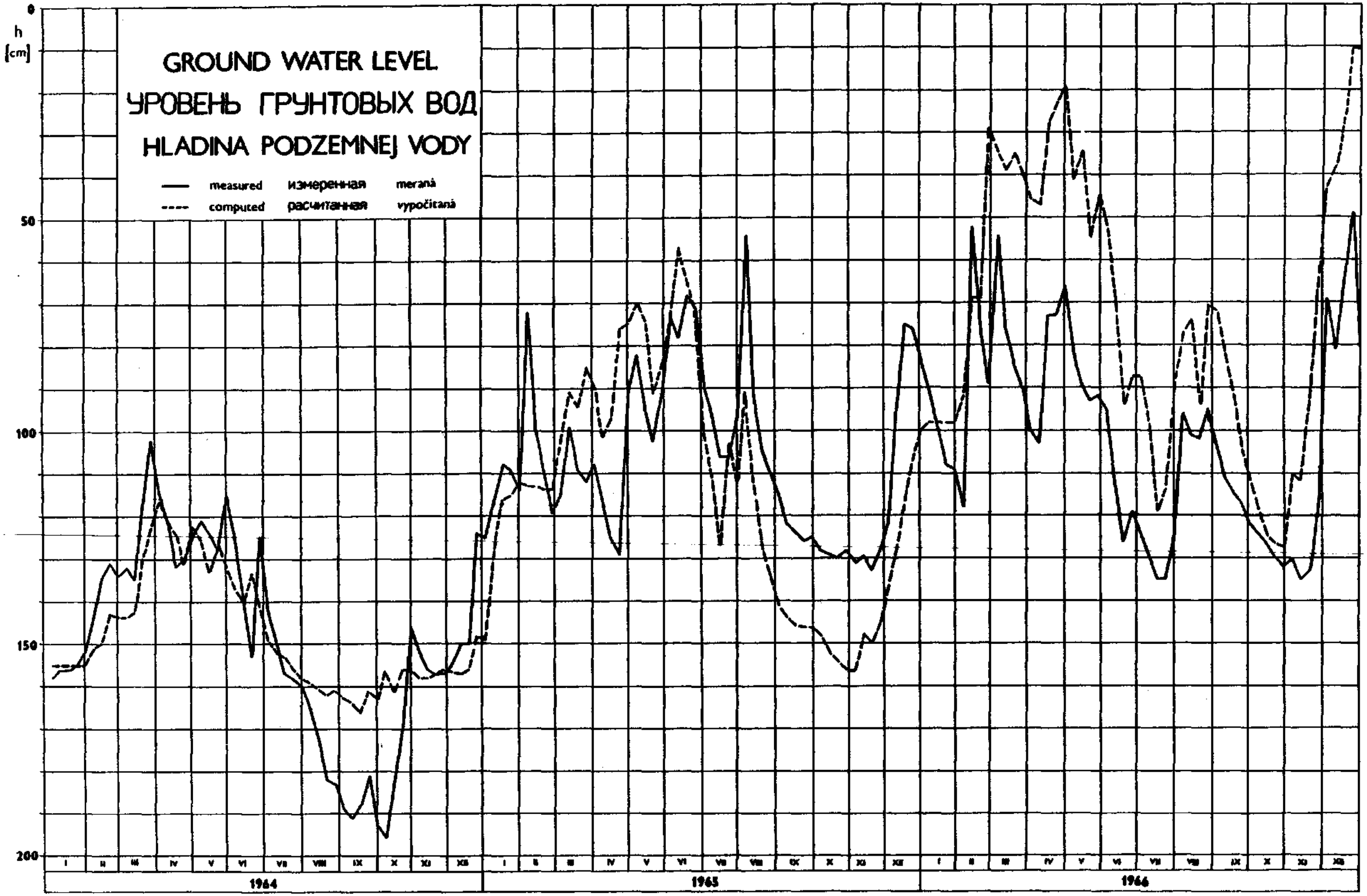

Fig. 7. Weekly data of groundwater level at Žiharec (full line - measured, dashed line - simulated by the initial version of the model DAIR).

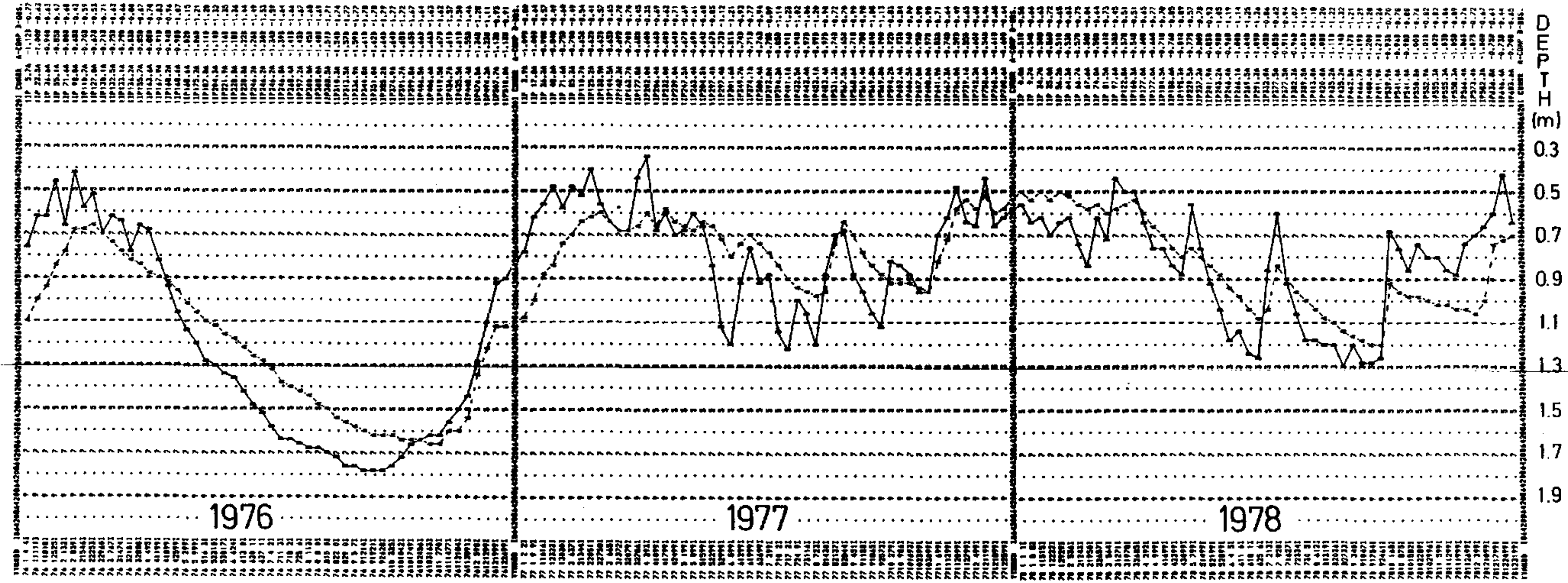

Fig. 8. Groundwater table variation at Hupselse Beek (full line-measured, dashed line-simulated by the initial version of the DAIR).

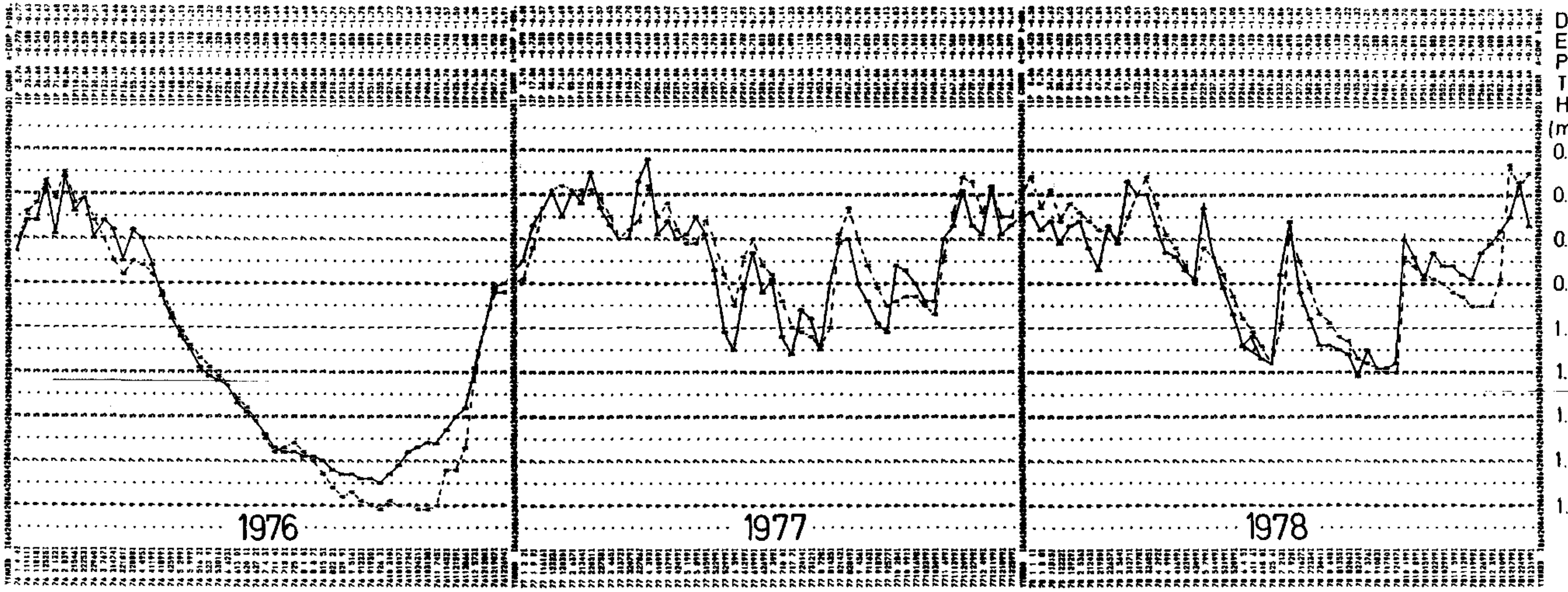

Fig. 9. Groundwater table variation at Hupselse Beek (full line-measured, dashed line-simulated by the improved version of DAIR).

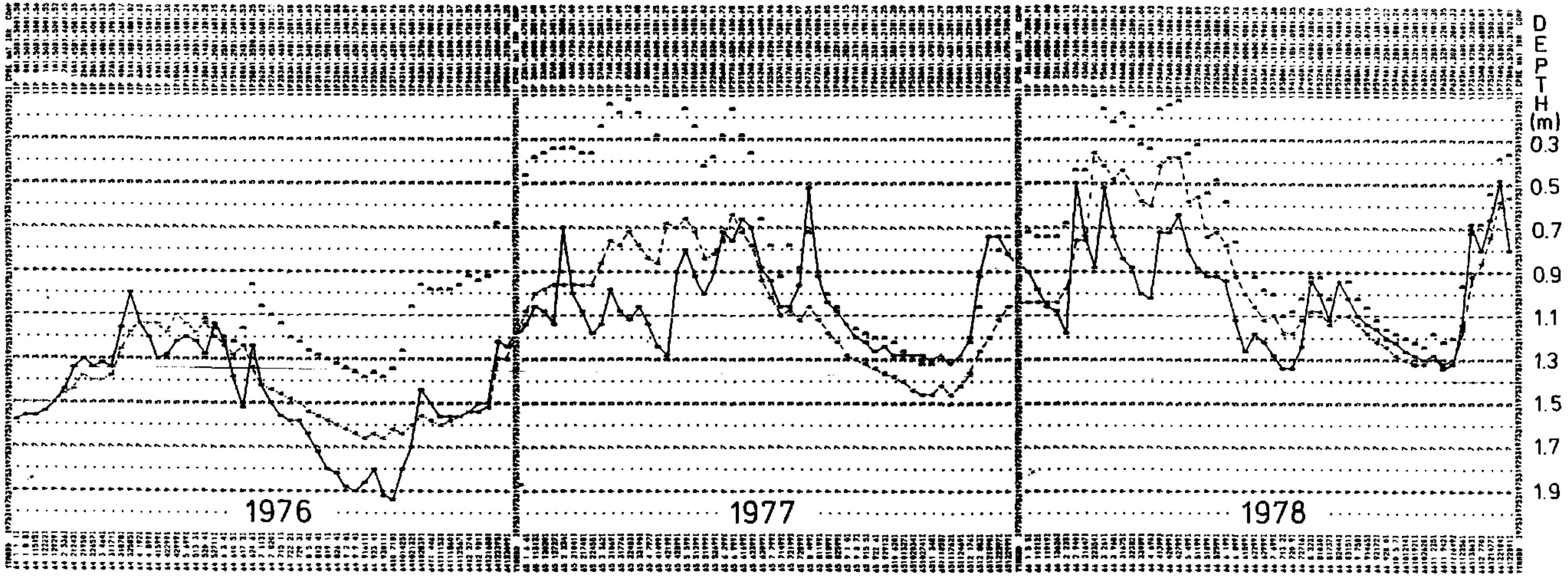

Fig. 10. Groundwater table variation at Žiharec (full line-simulated by the improved version of DAIR,dashed line-measured).

possibilities have been used. 'Tuned' simulated groundwater table by the initial version of the model is compared with the measured one in Fig. 8. Results ontained by the improved version of the model are shown in Fig. 9. Actual evapotranspiration according to improved DAIR is compared with data evaluated by J.N.M. Stricker based on heat balance COM and given in columns ACT in tab. 1.

Simulated and observed groundwater level for Žiharec station , obtained by the improved version, are shown in Fig. 10.

Presented results show that improved 'tuned' version of the model DAIR gives a better approach and acceptable coincidence between measured and simulated data.

The only daily inputs needed for computation are data on air temperature, air humidity and total precipitation.
The program was developed for the computer ROBOTRON ES 1040 (compatible with IBM 360/40) and for the improvement of the model DAIR and for this case-study the DECSYSTEM 10 - computer at the Agricultural University Wageningen had been used.
A run for 3 types of crop and for 3 years needs 16 sec. CPU time.

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10. List of figures