SIMWASER
A numerical model on soil water balance and plant growth

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Preface:

This number of the "Petzenkirchen Report" is at the same time the final report of the Project 2239 of the Austrian Federal Agency on Water Resources, by which the further development of the model and practical experiences that have taken place since the last publication of the model description (STENITZER 1998) are documented. Taking into account that the basic model had been developed about 30 years ago (WOLKEWITZ & STENITZER 1976) this latest version of SIMWASER represents a lot of practical experience but still needs further refinement for example on assessment of preferential flow. This problem is becoming more important in connection with the transport of harmful substances into the ground water and besides the respective changes of the model formulations of SIMWASER more detailed information on the rain intensity will be needed.

None the less the current version of SIMWASER is a valuable tool in treating practical problems on soil water management as is exemplary shown by the reprints and articles compiled in this volume of the "Petzenkirchen Report".

There also the complete source code of SIMWASER is enclosed together with a glossary so the interested reader might be able to check the model formulations into detail. The source code also is available for use but because the model at the moment is not very comfortable for a new user, close contact to us will be necessary at least during a test period. The following articles also were produced within the frame of the project but are written in German language; they are available on request:

STENITZER, E. (2000): SIMWASER – Ein physikalisches Kompartimentmodell zum Bodenwasserhaushalt. Aus: "Methoden der Sickerwassermodellierung – Theorie und Praxis". GSF-Bericht 18/00 des Institutes für Hydrologie, S. 29-34

STENITZER, E. (2002): Erfassung der Grundwasserneubildung aus infiltrierenden Niederschlägen über die Bodenwasserhaushaltsmodellierung. - Vortrag.

STENITZER, E, (2002): Eignung von Feldlysimetern zur Eichung von SIMWASER. - Schriftenreihe BAW, Bd. 16, 67-82

STENITZER, E. und J. HÖSCH (2003): Extrapolation von Lysimeter-Ergebnissen mit Simulationsmodellen: Auswirkung einer Zwischenbegrünung auf den Wasserhaushalt und den Ertrag im Marchfeld. - Bericht über die 10. Lysimetertagung am 29. und 30. April 2003, in Gumpenstein 111-114.

STENITZER, E. & G. SCHMID (2003): Einfluss des Flurabstandes auf die Saugspannung im Wurzelbereich in einem Niedermoor. - Manuskript, Institut für Kulturtechnik und Bodenwasserhaushalt, A-3252 Petzenkirchen

WOLKEWITZ, H. & E. STENITZER (1976): Der Salztransport in mit Wassergesättigten Böden. Bericht an die Deutsche Forschungsgesellschaft, Bonn

Prof. Dr. E. Klaghofer

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Summary

This volume of the “Petzenkirchen Reports” in the first chapter gives an overall impression on the model SIMWASER by describing it’s outlines and the input and output data and formats as well. No further information is given on preparing the relevant soil, plant, weather and groundwater data from different data sources; this will be performed within the frame of a user handbook, which then should complete the general information given here.

The next four chapters consist of descriptions of case studies performed with SIMWASER on assessment of deep percolation of flood plain soil based on the Austrian Soil Map, on the impact of soil compaction on Maize yields on a heavy soil in Austria and irrigated sandy soil in SW Spain and at last on the impact of afforestation on natural ground water recharge in a dry region of Eastern Austria.

So a rather broad field of application is used to demonstrate the use of this model, where by high value was set on the verification of the model’s output by extensive field data.

The complete source code and a glossary of the most important variables are supplementing this introduction to the SIMWASER model.

1 Modelling features

Elmar Stenitzer

The deterministic simulation model SIMWASER (STENITZER 1988) describes the one dimensional vertical water flux within a soil profile, neglecting interflow and preferential flow. The water balance and the growth of plants is interrelated by the physiological interaction between transpiration and assimilation: accumulation of plant material depends on the amount of CO_2 incorporated via the stomata, by which at the same time water vapour is lost from the saturated vacuole into the unsaturated ambient air. Potential assimilation and therefore potential growth is only possible as long as the water supply towards the stomata can meet the potential transpiration loss. If this is not the case stomata will close and formation of plant material will be restricted. All these processes depend on the respective plant development stage as for example the partition of the daily assimilates between leaves, stem and roots. SIMWASER calculates the actual development stage by dividing the currently accumulated growing degree days by the sum of growing degree days necessary for ripeness of the respective crop: a growing degree day corresponds to the mean daily temperature minus a base temperature which is specific to that crop.

Actual plant growth is derived from potential plant growth, which depends mainly on air temperature and global radiation by the proportion of the actual transpiration to the potential one (eq. 1):

$$P_{act} = P_{pot} * T_{act} / T_{pot} \qquad (1)$$

P_{act}, P_{pot}	actual & potential plant growth (kg CH_2O/m^2,d)
T_{act}, T_{pot}	actual & potential transpiration (mm/d)

Potential evapotranspiration PET is calculated according to Penman-Monteith

$$PET = (ft*Q+0.864*H0/r_{air})/(ft+rcrop/r_{air}) \qquad (2)$$

PET	potential evapotranspiration (mm/d)
ft	weighing factor depending on temperature
Q	evaporation equivalent of available energy (mm/d)
0.864	Factor converting (g H_2O/m^3)/(s/cm) into (mm/d)
H0	saturation deficit of air (g H_2O/m^3 air)
r_{air}	aerodynamic resistance (s/cm)
rcrop	crop resistance (s/cm)

Both r_{air} and r_{crop} are variables depending on weather as well as on actual plant development stage. Potential transpiration T_{pot} is deduced from PET proportional to the global energy absorbed by the leaves of the crop stand:

$$T_{pot} = PET * (1.0 - \exp(-0.6*totlai)) \tag{3}$$

totlai total leaf area per unit soil surface (m^2/m^2)
exp exponent

Actual transpiration T_{act} is determined by comparison of potential transpiration T_{pot} to the amount of water SUMWUR which can be withdrawn by the roots from the soil. If SUMWUR is larger than T_{pot} then $T_{act} = T_{pot}$ otherwise T_{act} = SUMWUR, which will be the larger the deeper the roots are growing into the soil profile. Actual rooting depth depends on the respective crop as well as on the penetration resistance of the soil and is calculated at each day.

When calculating the soil water flux within the soil profile (s. fig. 1) one must take into account if it may be influenced by the ground water level or not: in latter case it may be assumed that there exists no capillary rise from the coarse aquifer, whereas in the former case the variable ground water level will form the lower boundary of the profile.

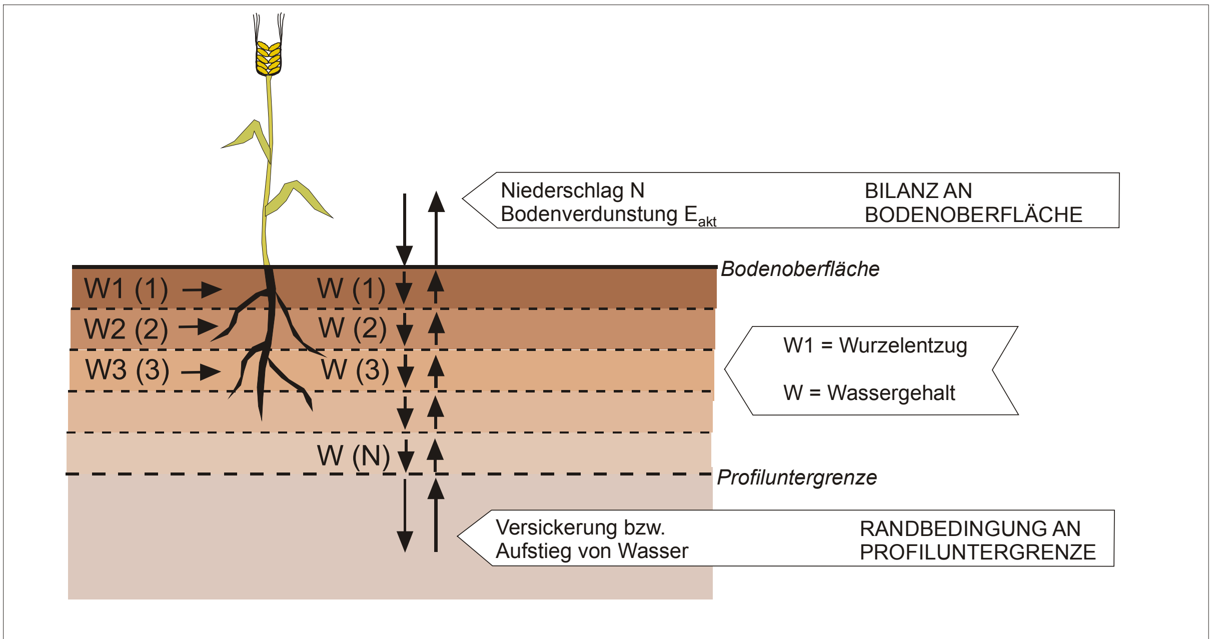

Fig.1: Schematic illustration of the soil water flux taken into account by SIMWASER

Water flux between the soil layers is calculated according to DARCY's law as function of the capillary conductivity and the gradient of the matric potential using small but variable time steps which restrict changes of water content to 0.1 Vol%. Filter velocity at the lower end of a soil layer V_i is calculated according to equation 4:

$$V_i = \frac{(K_i + K_{i+1})}{2} \cdot \left(\frac{\Psi_{i+1} - \Psi_i}{Z_i} + 1\right) \quad (4)$$

V_i	Filter velocity
K_i, K_{i+1}	capillary conductivity of layers i, i+1
ψ_i, ψ_{i+1}	matric potential of layers i, i+1
Z_i	distance from centre of layer i to centre of layer i+1

The filter velocity V_i of the water flowing out of the bottom of layer i is at the same time the filter velocity of the water flowing at the top of the next layer i+1 into it.

The soil profile model may be divided into 50 layers maximum, each 5 – 10 cm thick and must reach down to a depth which is outside the range of plant roots. A soil profile influenced by ground water must be deeper than the deepest ground water level at that site.

1.1 Input data

There are five main groups of input data:
general information
description of the soil profile
hydraulic soil parameters
physiologic plant parameters
weather data and ground water data

General information on the simulation scenario: name of the site (STANDORT) and name and listing of the crop rotation (FRUCHTFOLGE) to be simulated (s. tab. 1)

Tab. 1: Information on name of project and crop rotation

```
STANDORT :Obersiebenbrunn\Messpunkt_OBG
FRUCHTFOLGE:Fruchtfolge_1996_1999
............................FRUCHTFOLGE.......................
 ELEMENT        KENNUNG BEGINN    ENDE
 Brache             0 19951015 19951121
 Winterweizen       1 19951122 19960717
 Brache             0 19960718 19960725
 Winterweizen       1 19960726 19960930
 Brache             0 19961001 19961003
 Wintergerste       3 19961004 19970719
 Brache             0 19970720 19980420
 Mais400            9 19980421 19980930
 Brache             0 19981001 19990320
 Sommergerste       4 19990321 19990715
 Brache             0 19990716 19990731
```

Information on soil profile:

Name of the site (STANDORT) and it's elevation (GELAENDEHOEHE) given in meters above sea level; name of the relevant weather station (WETTERSTATION) and (in case of a site influenced by ground water) name of the relevant ground water gauge (GRUNDWASSERSONDE), the elevation of it (GELAENDEHOEHE) given in meters above sea level and the difference in elevation (DELTAGW) between the ground water level at the gauging site and the simulation site given in m and being positive if the simulation site is upstream of the gauge.

Number of the layer (Bilanz-Schicht) at which the soil water balance will be calculated; number of last soil layer of the profile

Depth and thickness of the soil layers, soil type in each of the layer, pore volume (vol%) and soil water content at the begin of the simulation.

Tab. 2: Informations on the simulation site and the soil profile

```
STANDORT:Obersiebenbrunn.obg
GELAENDEHOEHE       : 147.00 M U.A.
WETTERSTATIONSNR.   : Obersiebenbrunn
GRUNDWASSERSONDE    :
GELAENDEHOEHE       :
DELTAGW.            :
Bilanz-Schicht      : 24
ANZAHL DER SCHICHTEN: 25
```

	TIEFE(DM)	BODENART	PV%	CODE	W(V%)
01	0.0- 0.2	obg_010	45	1	31.5
02	0.2- 0.5	obg_010	45	1	31.5
03	0.5- 1.5	obg_010	45	1	32.0
04	1.5- 2.5	obg_020	47	2	32.5
05	2.5- 3.5	obg_030	42	3	30.5
06	3.5- 4.0	obg_040	42	4	30.0
07	4.0- 4.5	obg_040	42	4	30.0
08	4.5- 5.0	obg_050	40	5	33.0
09	5.0- 5.5	obg_050	40	5	33.0
10	5.5- 6.5	obg_060	40	6	34.0
11	6.5- 7.5	obg_070	43	7	34.5
12	7.5- 8.0	obg_080	41	8	35.0
13	8.0- 8.5	obg_080	41	8	36.0
14	8.5- 9.5	obg_090	30	9	18.5
15	9.5-10.5	obg_100	28	10	9.5
16	10.5-11.5	obg_110	28	11	6.5
17	11.5-12.5	obg_120	30	12	6.5
18	12.5-13.5	obg_130	28	13	4.5
19	13.5-14.5	obg_140	29	14	5.0
20	14.5-15.0	obg_150	28	15	5.5
21	15.0-15.5	obg_160	28	16	5.0
22	15.5-15.7	obg_160	28	16	4.5
23	15.7-15.9	obg_160	28	16	4.0
24	15.9-16.0	obg_160	28	16	3.5
25	16.0-16.1	obg_160	28	16	3.1

Information on soil

For each of the 16 different soil types (BODENART; e.g. obg_10, see tab. 2) the hydraulic parameters must be given in tabulated form (s. tab.3 below): the first line is the name of the file which at the same time is the name of the respective soil (e.g. obg_10); the second line gives the number of curves (ANZAHL DER STANDARDKURVEN) within that file; the third line gives the pore volume (PORENVOLUMEN DER KURVE) of the curve; the next three lines are text lines containing the headings of the four columns of the table:

column PSI: soil water tension (kPa)
column W: soil water content (vol%)
column K: capillary conductivity (mm/d)
column PE: penetration resistance (MPa)

Tab. 3: "Hydraulic soil parameters" of soil type obg_10 in the uppermost soil layer of the profile OBERSIEBENBRUNN.OBG

```
obg_010(Obersiebenbrunn OBG)
ANZAHL DER STANDARDKURVEN:     1
PORENVOLUMEN DER KURVE  1:    45
             PV=45
 PSI    W     K      PE
 kPa    V%   mm/d    Mpa
1.0E-2 45.0 1.3E+03  1.6
1.0E-1 44.6 6.2E+02  1.7
2.0E-1 44.3 3.7E+02  1.7
4.0E-1 43.2 1.7E+02  1.7
1.0E+0 40.2 3.2E+01  1.8
2.0E+0 37.4 5.2E+00  1.8
4.0E+0 35.2 1.1E+00  1.9
1.0E+1 32.7 1.3E-01  2.0
2.0E+1 30.5 3.0E-02  2.1
4.0E+1 29.2 8.1E-03  2.2
1.0E+2 27.2 1.1E-03  2.3
2.0E+2 26.0 3.5E-04  2.5
4.0E+2 23.6 9.5E-05  2.8
1.0E+3 19.4 1.7E-05  3.3
2.0E+3 15.7 3.6E-06  3.9
4.0E+3 12.2 5.9E-07  4.8
1.0E+4  8.5 4.7E-08  6.2
4.0E+4  4.9 1.0E-09 10.9
1.0E+5  3.3 1.1E-10 18.0
1.0E+6  0.1 1.0E-12 99.9
```

1.1.1 Plant parameters

For each of the cropping elements to be simulated in the respective project (see tab. 1) the typical physiological plant parameters must be given in tabulated format; as bare soil (BRACHE) also is a cropping element, it’s soil resistance is also given formally, while all other ‘physiological’ parameters are set to zero.

Tab. 4: Plant parameters

```
1=winterwheat,2=summerwheat,3=winterbarley,4=summerbarley,5=winterrye,6=oats,7=maize_early,8=maize_
9=maize_late,10=maize_seed,11=pea,12=soybean,13=sugarbeet,14=potato,15=grassland,16=mustard,17=bean
18=winterrape,19=sunflower,20=lawn,21=alalfa-grass,
.........................................................................................
ext= extinction coefficient; bfgew= leaf area weight; hgt= plant height; rs= stomatal resistance;
ass= assimilation; ft= temperature class;rlg= root length ;rd= rooting density; rr= root strength c
lfw= leaf width; ripe= ripeness; lai0= LAI at emergence; amin= minimum air volume; cdayl= critcal d
-----------------------------------------------------------------------------------------
Plant type     CODE  ext  bfgew hgt rs  ass  ft rlg rdf rr lfw ripe lai0 amin cdayl
...............................................................................
 Brache            0 0.00,.0000,0.0,0.8,00.0,0,00.,0.0,0,00.0,0000.,.000,00.0,00.0
 Winterweizen      1 0.40,.0030,1.0,1.0,25.0,1,25.,6.0,1,01.0,2000.,.100,05.0,09.0
 Winterweizenaufl  1 0.40,.0030,1.0,1.0,25.0,1,25.,6.0,1,01.0,2000.,.050,05.0,09.0
 Wintergerste      3 0.40,.0020,1.0,1.0,20.0,1,20.,5.0,1,00.5,2200.,.100,05.0,10.0
 Wintergersteaufl  3 0.40,.0020,1.0,1.0,20.0,1,20.,5.0,1,00.5,2200.,.050,05.0,10.0
 Sommergerste      4 0.45,.0025,0.8,2.0,20.0,1,20.,6.0,2,00.5,1450.,.100,05.0,10.0
 Mais400           9 0.50,.0020,2.5,2.0,40.0,3,30.,6.0,1,05.0,1500.,.010,05.0,10.0

Brache            bare soil
Winterweizen      winter wheat
Winterweizenaufl  regerminating losses of the winter wheat main crop
Wintergerste      winter barley
Wintergersteaufl  regerminating losses of the winter barley main crop
Sommergerste      summer barley
Mais400           late riping maize (FAO 400 type)
```

1.1.2 Weather data

Daily weather data are given as **binary file** stored in a master file called “WETTERDATEI” on the computer disc (see Installation Instructions) named after the weather station (e.g. tab. 2: obersiebenbrunn) where they had been measured. The data must be converted from ASCII or EXCEL tables, an excerpt of which is shown in tab. 5 below.

Tab. 5: Excerpt of weather data (ASCII-Format)

Date	DYL	T_max	T_min	T_07	T_14	T_19	RH07	RH14	RH19	MRH	SD_07	SD_14	SD_19	MSD	wind	rain	glob
1996-11-01	96	127	9	37	123	108	96	70	89	85	25	326	109	153	23	4	251
1996-11-02	95	158	96	106	157	102	88	53	74	72	117	630	248	332	30	1	744
1996-11-03	95	176	52	108	170	109	84	55	84	74	158	653	159	323	14	0	719
1996-11-04	94	164	24	31	160	100	97	65	89	84	18	478	104	200	8	1	787
1996-11-05	94	134	34	41	125	88	98	76	94	89	13	264	52	110	14	0	549
1996-11-06	93	150	47	56	141	90	86	52	82	73	99	584	159	281	12	0	713
1996-11-07	93	154	87	90	152	124	78	69	78	75	194	403	241	279	16	3	567
1996-11-08	92	123	63	81	118	67	85	55	83	74	125	475	129	243	38	0	663
1996-11-09	92	134	18	38	130	46	98	45	80	74	13	625	133	257	11	0	750
1996-11-10	91	109	15	33	104	86	98	63	76	79	12	357	207	192	16	1	542
1996-11-11	91	164	69	89	148	153	94	61	66	74	53	495	445	331	27	1	498
1996-11-12	90	194	134	153	189	154	57	50	52	53	563	812	632	669	30	0	395
1996-11-13	90	184	120	161	182	133	56	52	70	59	605	748	347	567	26	0	284
1996-11-14	89	121	45	86	58	47	96	96	96	96	34	29	27	30	28	97	44
1996-11-15	89	105	44	47	68	71	96	96	96	96	27	31	31	30	8	21	101
1996-11-16	89	106	64	71	77	67	96	96	96	96	31	32	30	31	18	0	149
1996-11-17	88	127	61	97	123	73	96	94	96	95	37	65	32	45	18	2	208
1996-11-18	88	147	62	116	136	124	96	85	91	91	42	177	99	106	23	3	228
1996-11-19	87	103	52	66	89	61	72	60	80	71	212	351	146	236	13	0	264
1996-11-20	87	107	63	71	103	71	87	76	93	85	102	230	55	129	23	5	145
1996-11-21	87	80	25	44	69	42	81	70	71	74	124	231	187	181	30	1	312
1996-11-22	86	47	-1	34	35	7	76	92	98	89	147	49	10	69	13	2	189
1996-11-23	86	50	-44	-43	48	3	97	68	94	86	11	215	30	85	10	1	599
1996-11-24	86	39	-12	-8	39	25	89	68	72	76	50	202	161	138	48	7	232
1996-11-25	85	46	-25	-24	42	5	91	47	69	69	37	342	156	178	22	0	580
1996-11-26	85	16	0	3	9	5	97	97	97	97	15	15	15	15	10	46	144
1996-11-27	85	45	-13	5	43	21	97	90	89	92	15	65	62	47	8	1	219
1996-11-28	84	20	-10	5	17	10	95	96	94	95	25	22	31	26	14	0	92
1996-11-29	84	42	-2	4	42	4	87	62	84	78	65	245	80	130	24	0	489
1996-11-30	84	13	-2	-1	12	6	88	91	95	91	58	47	25	43	16	3	192

DYL day length (h*10)
T_max maximum temperature (°C*10)
T_min minimum temperature (°C*10)
T_07 temperature at 07.00 hours (°C*10)
T_14 temperature at 14.00 hours (°C*10)
T_19 temperature at 19.00 hours (°C*10)
RH07 relative humidity at 07.00 hours (%)
RH14 relative humidity at 14.00 hours (%)
RH19 relative humidity at 19.00 hours (%)
MRH mean relative humidity
SD_07 saturation deficit at 07.00 hours (g/m^3 *100)
SD_14 saturation deficit at 14.00 hours (g/m^3 *100)
SD_19 saturation deficit at 19.00 hours (g/m^3 *100)
MSD mean saturation deficit (g/m^3 *100)
Wind wind velocity at 2 m height (m/s*10)
Rain precipitation (mm*10)
Glob global radiation sum (J/cm^2,d)

In case of ground water influence daily depths to groundwater (given in cm) must also be stored in **binary format** within a separate master file "GRUNDWASSERDATEI" on the computer disc (see Installation Instructions) named after the gauging station (e.g. tab. 2: obersiebenbrunn) where they had been measured. The data must be converted from ASCII or EXCEL tables, an excerpt of which is shown in fig. 2 below.

date	GW_depth
1996-11-01	237.5
1996-11-02	237.5
1996-11-03	237.6
1996-11-04	237.0
1996-11-05	236.0
1996-11-06	236.6
1996-11-07	237.2
1996-11-08	237.7
1996-11-09	238.0
1996-11-10	237.0
1996-11-11	236.4
1996-11-12	236.0
1996-11-13	235.7
1996-11-14	235.7
1996-11-15	235.9
1996-11-16	236.2
1996-11-17	236.5
1996-11-18	236.7
1996-11-19	236.9
1996-11-20	237.0
1996-11-21	237.2
1996-11-22	237.4
1996-11-23	237.6
1996-11-24	237.7
1996-11-25	237.8
1996-11-26	238.0
1996-11-27	238.1
1996-11-28	238.2
1996-11-29	238.3
1996-11-30	238.5

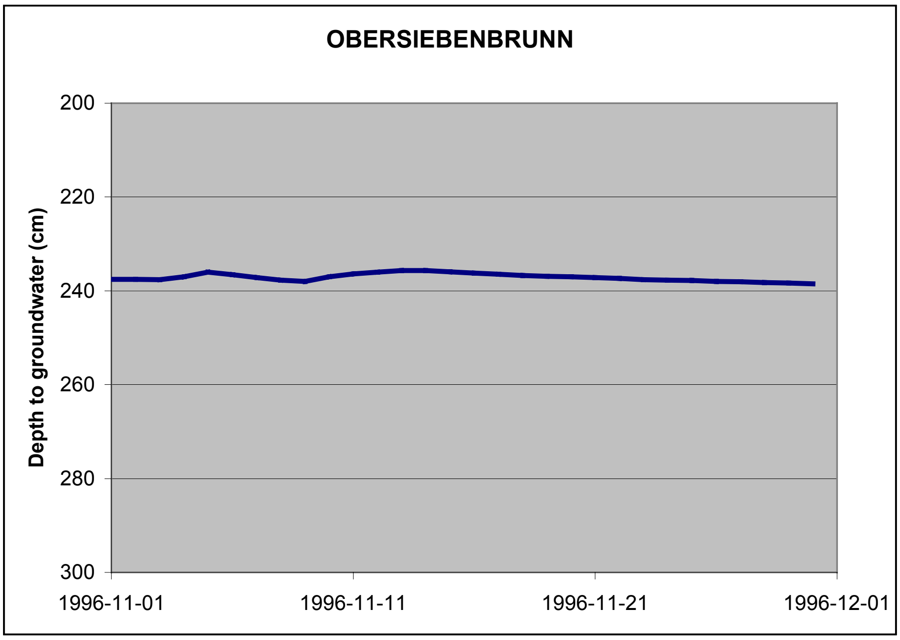

Fig. 2: Excerpt of groundwater data (ASCII format) at Obersiebenbrunn

1.2 Output data

Simulation results are given in general form for each cropping element (s. tab. 6) and in more detail for each simulated day, which format is helpful in calibrating and validating the model.

Tab. 6: General results (File "WLAYER")

C:\SIMWASER_COMPACTION\MODELLSTANDORTE\Obersiebenbrunn\Messpunkt_OBG

Datum	SWG	STRS	SETA	SEI	GWR	RAIN	SGWN	IRR	ROFF	FSS	SGT	RDM
19951121	368.	0.	16.	0.	0.	48.	0.	0.	0.	0.	0.	0.
19960717	237.	265.	398.	37.	0.	464.	196.	0.	0.	1.	16252.	3309.
19960725	237.	0.	2.	0.	0.	2.	0.	0.	0.	0.	0.	0.
19960930	287.	50.	94.	12.	0.	144.	0.	0.	0.	1.	6016.	1888.
19961003	286.	0.	3.	0.	0.	1.	0.	0.	0.	0.	0.	0.
19970719	361.	251.	391.	53.	0.	470.	3.	0.	0.	1.	14122.	3324.
19980420	352.	0.	204.	0.	0.	294.	98.	0.	0.	0.	0.	0.
19980930	323.	239.	404.	48.	0.	352.	30.	52.	0.	1.	23852.	3134.
19990320	368.	0.	86.	0.	0.	230.	99.	0.	0.	0.	0.	0.
19990715	340.	195.	283.	37.	0.	281.	26.	0.	0.	1.	9533.	2034.
19990731	337.	0.	17.	0.	0.	14.	0.	0.	0.	0.	0.	0.
19990801	339.	0.	1.	0.	0.	2.	0.	0.	0.	0.	0.	0.

SWG	Profilwassergehalt (mm)	SGWN	Summe Grundwasserneubildung (mm)
STRS	Summe Transpiration (mm)	IRR	Summe Bewässerungen (mm)
SETA	Summe aktuelle Evapotranspiration mm)	ROFF	Summe Oberflächenabfluss (mm)
SEI	Summe Interzeption (mm)	FSS	Stressfaktor
GWR	Summe kapillaren Aufstieges (mm)	SGT	Gesamttrockenmasse (kg/ha)
RAIN	akkumulierter Niederschlag (mm)	RDM	Wurzeltrockenmasse (kg/ha)

Tab. 7: Excerpt of daily results (File "RESULT")

Datum	SUMWG	SRAIN	SETA	SGWN	GWR	SROFF	ETA	RAIN	FXGW	GLAI	SGTM	ROOT
19960501	377.1	290.5	91.8	189.4	0.0	0.0	1.7	0.0	0.2	1.8	842.3	50.7
19960502	373.2	290.5	95.6	189.6	0.0	0.0	3.8	0.0	0.2	2.2	1020.9	55.0
19960503	372.1	292.8	98.7	189.9	0.0	0.0	3.1	1.5	0.3	2.5	1217.2	59.3
19960504	368.5	292.8	102.0	190.1	0.0	0.0	3.3	0.0	0.3	2.9	1446.9	62.6
19960505	366.2	293.6	104.8	190.4	0.0	0.0	2.8	0.5	0.3	3.3	1659.6	66.4
19960506	361.3	293.6	109.4	190.7	0.0	0.0	4.6	0.0	0.2	3.8	1938.0	71.4
19960507	356.6	293.6	113.9	190.9	0.0	0.0	4.5	0.0	0.2	4.2	2218.1	77.9
19960508	359.9	298.8	115.6	191.1	0.0	0.0	1.7	3.6	0.2	4.5	2358.1	84.0
19960509	372.5	313.0	117.0	191.3	0.0	0.0	1.4	12.9	0.2	4.7	2510.9	89.2
19960510	370.7	313.0	118.7	191.5	0.0	0.0	1.6	0.0	0.2	5.0	2691.6	91.1
19960511	368.3	313.0	120.8	191.7	0.0	0.0	2.2	0.0	0.2	5.3	2905.8	93.6
19960512	372.8	319.7	122.9	191.9	0.0	0.0	2.0	4.8	0.1	5.5	3056.1	96.4
19960513	381.9	329.4	123.3	192.0	0.0	0.0	0.5	9.3	0.1	5.6	3128.9	96.4
19960514	382.4	330.3	123.7	192.0	0.0	0.0	0.4	0.6	0.1	5.7	3175.5	96.4
19960515	380.9	330.3	125.1	192.1	0.0	0.0	1.4	0.0	0.1	5.8	3307.7	96.4

SWG	Profilwassergehalt (mm)	ETA	aktuelle Evapotranspiration(mm/d)
SRAIN	akkumulierter Niederschlag (mm)	RAIN	Niederschlag (mm/d)
SETA	Summe aktuelle Evapotranspiration mm)	FXGW	Sickerwasserfluss (mm/d)
SGWN	Summe Grundwasserneubildung (mm)	GLAI	Blattflächenindex (m^2/m^2)
GWR	Summe kapillarer Aufstieg (mm)	SGTM	Gesamttrockenmasse (kg/ha)
SROFF	Summe Oberflächenabfluss (mm)	ROOT	Wurzeltrockenmasse (kg/ha)

Tab. 8: Excerpt of calculated daily water content within the soil layers

Datum	0-2cm	2-5cm	5-15cm	15-25cm	25-35cm	35-40cm	40-45cm	45-50cm
19960501	31.40	32.12	33.20	31.64	35.15	36.69	36.71	34.46
19960502	27.90	29.72	32.03	30.85	34.51	36.29	36.37	34.20
19960503	31.31	31.18	31.82	30.55	34.07	35.94	35.97	33.88
19960504	29.29	30.11	31.57	30.27	33.72	35.58	35.57	33.57
19960505	29.93	30.30	31.24	29.95	33.44	35.28	35.27	33.35
19960506	28.05	29.32	30.78	29.66	33.10	34.90	34.82	32.90
19960507	27.67	28.92	30.37	29.25	32.69	34.47	34.32	32.50
19960508	34.28	33.61	31.20	29.13	32.46	34.27	34.20	32.56
19960509	38.25	37.96	36.63	32.30	33.93	34.86	34.50	32.72
19960510	33.90	34.03	34.20	32.09	35.11	36.20	35.82	33.52
19960511	32.78	32.99	33.36	31.46	34.65	35.99	35.78	33.58
19960512	36.18	35.88	34.80	31.86	34.69	36.00	35.84	33.70
19960513	37.77	37.58	36.63	33.79	36.48	37.20	36.86	34.32
19960514	34.85	34.88	34.87	33.03	36.47	37.57	37.55	35.06
19960515	33.58	33.73	34.05	32.37	35.86	37.16	37.18	34.82

Tab. 9: Excerpt of the calculated daily soil water tensions within the soil layers

Datum	0-2cm	2-5cm	5-15cm	15-25cm	25-35cm	35-40cm	40-45cm	45-
19960501	152.32	120.54	84.17	72.07	64.89	63.57	63.02	61.95
19960502	734.41	310.29	123.57	95.92	81.83	77.06	74.18	71.22
19960503	156.48	162.72	132.77	109.29	94.45	89.66	87.96	87.10
19960504	387.15	251.04	144.72	121.25	110.68	108.40	108.82	110.11
19960505	272.65	234.08	159.67	136.07	125.23	123.50	124.48	126.14
19960506	679.36	382.30	190.96	156.13	142.72	145.81	152.52	163.62
19960507	836.80	458.01	227.41	183.41	172.08	179.23	191.44	210.16
19960508	56.83	72.76	161.74	191.42	190.09	195.18	200.79	203.55
19960509	16.28	17.44	25.78	56.43	100.11	148.87	176.71	184.51
19960510	64.90	61.58	58.37	60.31	65.69	80.00	95.98	113.70
19960511	97.13	90.00	79.80	77.03	77.89	87.15	98.13	109.29
19960512	29.59	32.53	46.87	65.96	76.75	86.41	94.59	100.34
19960513	18.47	19.52	25.79	34.40	40.00	48.85	57.95	66.87
19960514	45.86	45.38	45.58	42.70	40.26	40.27	40.67	41.21
19960515	73.66	69.42	61.07	54.99	50.52	49.62	49.34	49.09

1.3 Calibration and Validation

Calibration of the model SIMWASER normally is restricted to the soil and plant parameters. Mostly there exist only rough estimations of the capillary conductivity or the laboratory measurements of it are scattering to high degree, so calibrations are necessary. This is done using measurements during times when the soil is bare.

Plant parameters to be calibrated mostly are the stomatal resistance (by which potential water demand of the crop is determined) and the sum of growing degree day necessary for ripeness as well as the potential root length, which may strongly deviate from the typical value given by the standard values depending on the respective species of a given crop! These calibrations should be done with measurements during periods with unrestricted crop growth.

Validation of the model is the comparison of measured with simulated data using those states and processes which are most relevant for the problem to be studied by the simulation: in case of water balance and ground water recharge research these will be the water storage of the soil profile as well as the accumulated sums of evapotranspiration and deep percolation, keeping in mind the accumulated amount of precipitation. There is good agreement between measured and simulated time course of water storage shown in fig. 3 below, with a mean deviation of ± 20 mm which amounts to ± 6% of the mean water storage.

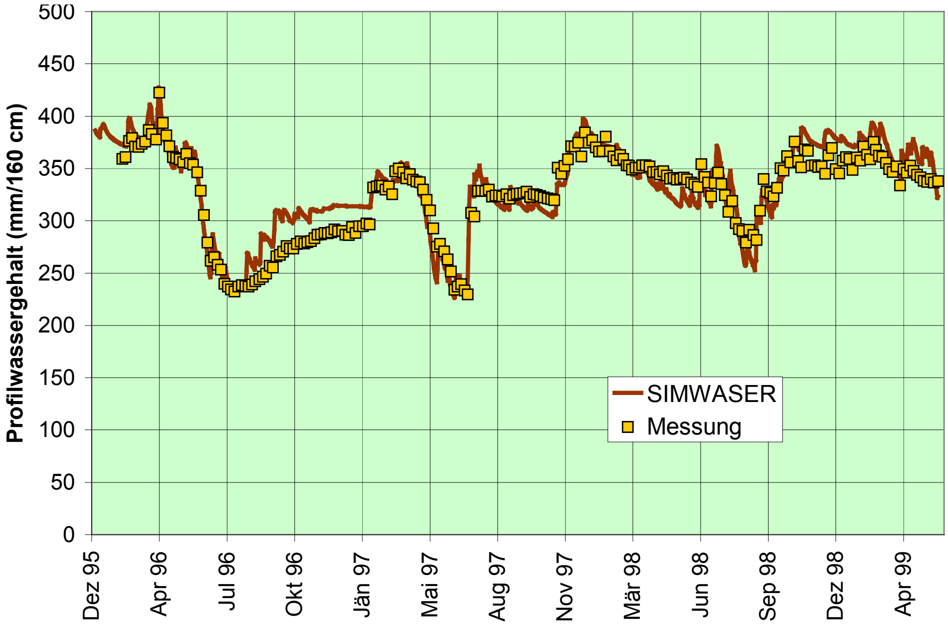

Fig. 3: Comparison of simulated and measured soil water storage

As shown in fig 4 a very good conformity exists between simulated and measured evapotranspiration and ground water recharge, therefore one may suppose that SIMWASER is able to reproduce the water balance and the ground water recharge of the investigated site in a very realistic manner.

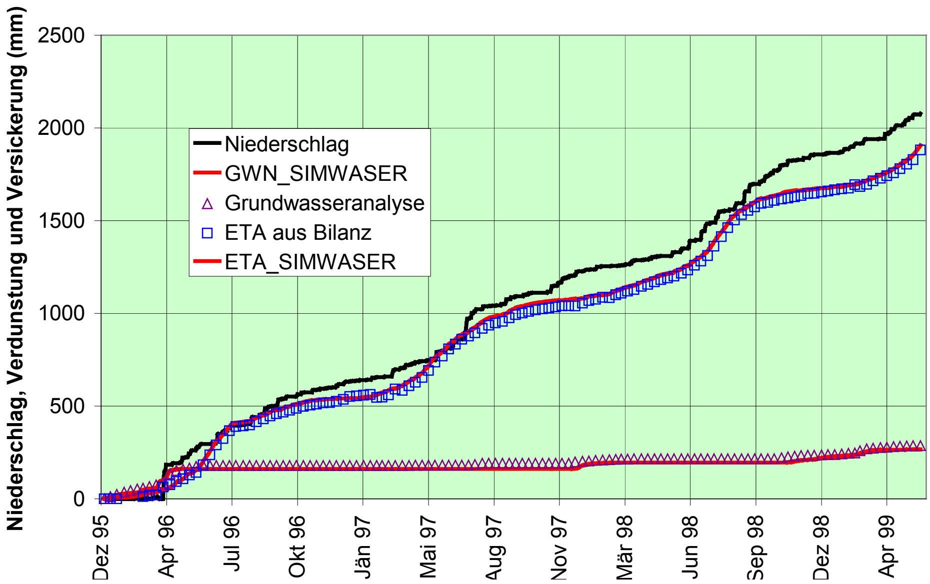

Fig. 4: Comparison of simulated and measured Evapotranspiration and groundwater recharge at Obersiebenbrunn

2 Assessment of deep percolation into a gravely aquifer: Simulation and Experimental Verification

by
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2.1 **Introduction**

In dealing with practical problems concerning groundwater recharge as well as groundwater pollution the Institute for Soil Water Management is routinely developing and testing methods appropriate for assessing of the soil water balance of typical soil units in some important agricultural areas in Eastern Austria. Thereby deep percolation of water and solutes is measured directly using different types of simple lysimeters at the field sites (FEICHTINGER 1992, MURER 1997). Lysimeters disturb natural soil water movement and transport processes (KLAGHOFER 1991) and the measurements may be erroneous. KASTANEK (1995) states, that systematic monitoring of soil water content and soil water potential would be more suitable to quantify undisturbed soil water movement and transport processes from such measurements by applying soil physical concepts. Yet another promising method is the use of simulation models: this paper presents the application of a simulation model in quantifying deep percolation, the model itself using hydraulic soil parameters derived from intensive soil water monitoring by modern non-destructive methods.

2.2 Materials and Methods.

2.2.1 Field Experiment

The experimental site is situated on the farmland of the Agricultural School in Obersiebenbrunn (48° N, 16° E), about 30 km east of Vienna, in the centre of the so called "Marchfeld". The soil profile at the measuring point represents a wide spread soil unit of this area: a schematic illustration of the installation pattern and of the different soil horizons is given in Fig. l. Soil moisture was measured by the TDR (Time Domain Reflectrometry) method, while soil water tension was determined by Granular Matrix Sensors and Gypsum Blocks down to a depth of 1.60 m below soil surface. The sensors were connected by cables to the dataloggers about 20 m apart, which automatica1ly measured the soil water content eight times a day, while the soil water suction sensors were interrogated each hour. During installation undisturbed soil samples had been taken for determination of the soil moisture characteristic and the unsaturated hydraulic conductivity of the representative soil horizons. Ground water level was monitored at about 40 m distance by a ground water stage recorder and weather data were collected at the same place by an automatic weather station. During the observation period (November 1995 - March 1997) winter wheat and winter barley were grown at the experimental site.

2.2.2 Assessment of Groundwater Recharge and Evapotranspiration.

Recharge of groundwater by deep percolation may be determined from groundwater fluctuations if the magnitude of the so called "Storage Coefficient" is known (BURRE 1960). For this purpose groundwater records of the years 1985 -1997 were analysed for distinct periods of groundwater rise at the end of winter and were correlated to the corresponding amounts of rain and snow: the slope of the 1inear regression function corresponds to the mean va1ue of the Storage Coefficient of the aquifer within the upper and lower boundary of the observed fluctuations of the groundwater table. Soil water ba1ance equation then can be solved on daily base for the unknown evapotranspiration.

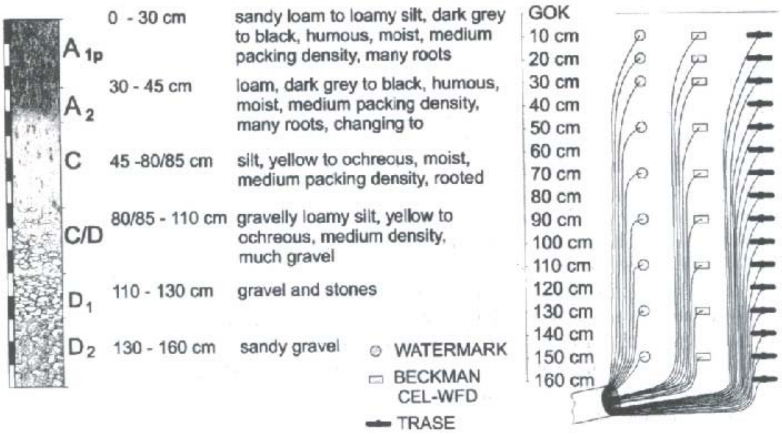

Fig. 1: Soil profile and installation pattern of sensors

2.2.3 Simulation Model

The numeric model SIMWASER (STENITZER 1988) simulates the water balance and the crop yield for any number of crop rotations and years, provided that daily weather records (air temperature, humidity of air, global radiation, wind and precipitation) are available. The soil profile to be simulated is divided into a number of layers, usually 5-10 cm thick, down to a depth, where seasonal change of the water content is believed to have minor impact upon the soil water regime. In case of capillary rise from groundwater the "model soil profile" is extended to the deepest groundwater level that is measured within the simulated period, and the daily course of groundwater level is included into the model calculations.

2.3 Results and Discussion

Daily precipitation, amount of soil water within the soil profi1e down to 1.65 m depth, and the well hydrograph are shown together in Fig. 2: from December to end of April the whole soil profi1e is at field capacity, and due to the low evaporative demand of the cold and humid atmosphere most of the precipitation is percolating down to the groundwater, causing the groundwater table to rise by about 130 cm. From the begin of May increasing evapotranspiration of the rapid growing winter wheat is exhausting the soil water storage to a great degree; at the same time, deep percolation ceases and the groundwater table even is lowered temporarily by limited local pumping. During winter 1996/97 soil-water storage subsequently is replenished by rains and snowmelt, but full field capacity of the whole soil profi1e is not yet reached at the end of March 1997. Under these circumstances no deep percolation was possible at the measuring site; therefore the recorded slight increase of the groundwater level is supposed to be caused by recharge from bare and less deep soil units nearby.

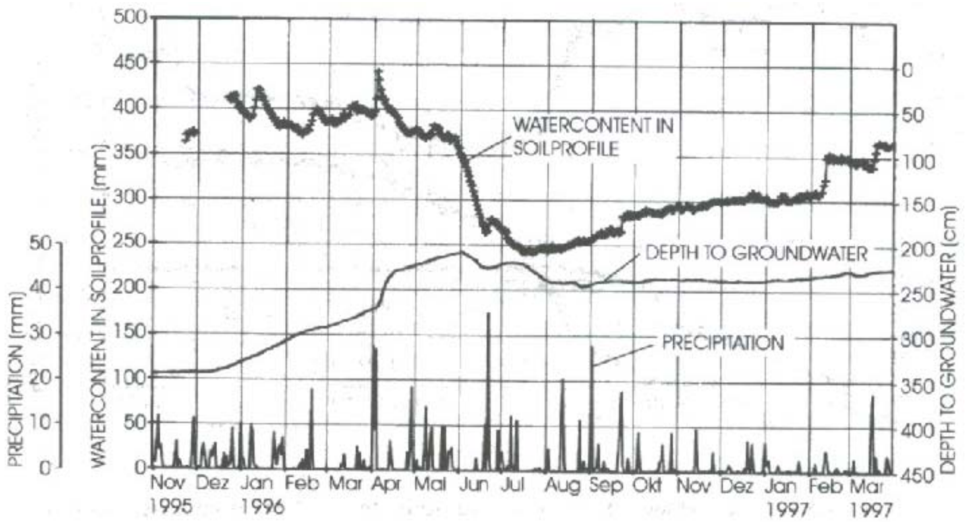

Fig. 2: Water content of the whole soil-profile, groundwater level and daily precipitation at the study site

The value of the Storage Coefficient as derived from the slope of the empirical regression at the study site ("SUMRAIN" = 72.5 + 0.175 "GROUNDWATER RISE") was assumed to be 0.18; the corresponding deep percolation due to the measured groundwater rise during winter 1995/96 amounted to 245 mm, including some seepage from shallow soils near to the observation well. No recharge by seepage from soil at the study site was assumed for the rest of the period until end of March 1997. At this time the precipitation had accumulated to 785 mm; soil water content at begin and at end of the measurements was practically the same: actual evapotranspiration during the whole period therefore amounts to 785 -245 = 540 mm.

Comparison of simulated soil-water content, evapotranspiration and deep percolation with their corresponding amounts derived from measurements is shown in Fig. 3: while the simulated and measured water contents are full in line, there exists some difference between simulated and observed deep percolation due to the above mentioned problems in assessing the groundwater recharge from the observation well. Accordingly the same difference is to be seen between simulated and "observed" evapotranspiration, the latter of which being derived from the water budget equation, wherein the amount of the deep percolation is uncertain at least for the period from mid of April to mid of May 1996. Considering the natural inhomogenities at field scale these deviations must be accepted in case of the given experimental setup.

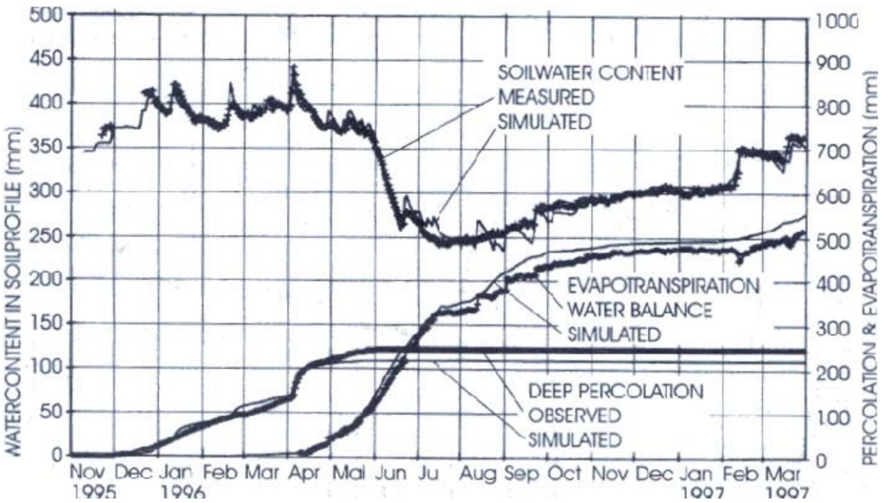

Fig. 3: Comparison of simulated and observed soil-water content, deep percolation and evapotranspiration

2.4 **Conclusions**

Deep percolation may be assessed successfully by simulation, provided that representative soil hydraulic parameters are available.

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3 Impact of soil compaction upon soil water balance and maize yield estimated by the SIMWASER model

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Abstract

A field experiment on the influence of soil compaction by wheel pressure upon soil structure, water regime and plant growth was used to test the capability of the soil water balance model SIMWASER to predict the impact of soil compaction upon the yield of maize (*Zea mays* L.). The experimental site was located on an Eutric Cambisol with loamy silt soil texture at an elevation of 260 m in the northern, semi-humid sub-alpine zone of Austria. Within the experimental field a 7 m wide strip was compacted by a tractor driven trailer just before planting maize in May 1988. Compression effects due to trailer traffic resulted in marked differences of physical and mechanical soil parameters in comparison with the uncompressed experimental plots down to a depth of about 30 cm: bulk density and penetration resistance at field capacity were increased from 1.45 g/cm³ to 1.85 g/cm³, and from 0.8-1.5 MPa respectively, while air filled pore space as well as infiltration rate were appreciable lowered from about 0.08-0.02 cm³/cm³ and from 50 to 0.5 cm³/day respectively. The overall effect was a clear depression of the dry matter grain yield from 7184 kg/ha of the non-compacted plot to 5272 kg/ha in the compacted field strip. The deterministic and functional model SIMWASER simulates the water balance and the crop yield for any number of crop rotations and years, provided that daily weather records (air temperature, humidity of air, global radiation, wind and precipitation) are available. Crop growth and soil water regime are coupled together by the physiological processes of transpiration and assimilation, which take place at the same time through the stomata of the plant leaves and are both reacting in the same direction to changes in the soil water availability within the rooting zone. The water availability during rainless seasons depends on the hydraulic properties of the soil profile within the rooting depth and on rooting density. Rooting depth and density are affected by both the type of the crop and the penetration resistance of the soil, which depends on the soil moisture status and may be strongly increased by soil compaction. The model SIMWASER was able to simulate these effects as shown by the calculated grain yields, which amounted in the non-compacted plot to 7512 and to 5558 kg dry matter/ha in the compacted plot.

Keywords: Soil compaction; Field experiment; Maize yield; Root length density; Soil water model

3.1 Introduction

Subsoil compaction due to long-term changes in soil management, especially due to increasing wheel loads has become a serious problem in the main agricultural areas of Austria, especially on heavy soil with loamy texture. Besides decreasing crop production subsoil compaction also deteriorates soil water balance by decreasing deep percolation to the groundwater and - at the same time – by increasing surface runoff, thus promoting erosion and pollution of surface waters with soil, nutrients and pesticides. Simulation models may help to understand the processes mentioned above and to extrapolate the findings of field experiments on soil compaction in a certain region to an other one, thus enabling to choose the appropriate measures for prevention of further increase of the compaction process. According to CONNOLLY (1998) only two of 11 reviewed deterministic models on water balance and crop growth used some explicit procedure to take into account the impact of mechanical soil resistance upon root growth. The one was the GOSSYM-model of BAKER et al. (1988) which is especially designed as cotton growth model and expert system, and the other is the water balance and growth model for wheat of JAKOBSEN and DEXTER (1987), which was developed for the climate of South Australia, using empirical water use efficiency factors when calculating dry matter production. The SIBIL model (SIMOTA et al. 2000) is based upon that of JAKOBSEN and DEXTER and also estimates dry matter production from the relation of actual to potential transpiration and potential water use efficiency of the simulated crop. None of these models is explicitly taking into account the effects of poor aeration upon physiological growth processes (VORHEES et al. 1975). LIPIEC et al. (2001) in their review on crop growth models found, that 'soil aeration compared to soil strength was much less frequently represented in crop growth models'.

The model SIMWASER (STENITZER 1988: SIMWASER – A numeric model for simulating soil water balance and crop yield. Internal report (in German), Institut für Kulturtechnik, A-3252 Petzenkirchen) was developed to simulate the soil water balance as well as the crop growth, taking into account the above mentioned effects of soil compaction upon water movement and plant growth. The objectives of this paper were (i) to present and describe this model and (ii) to evaluate it's suitability to estimate the impact of soil compaction on crop growth and soil water balance, using the experimental results from a demonstration field test on the influence of wheel traffic upon soil structure, water regime and plant growth (MURER 1998).

3.2 Material and Methods

3.2.1 Field experiment

Influence of soil compaction by wheel pressure upon soil structure, water regime and plant growth was investigated on an Eutric Cambisol, with loamy silt soil texture (Tab. 1) near Wieselburg (15°08' E, 48°10' N) at an elevation of 260 m in the semi-humid northern sub alpine zone of Austria. Mean air temperature is 8.6 °C and mean annual rainfall is 708 mm.

Tab. 1: Soil characteristic of the experimental field

Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Organic Matter (%)	CaCO3 (%)	PH (H2O)
00-35 (n=8)	20.2 ± 0.6	56.0 ± 2.5	23.8 ± 1.9	2.1 ± 0.3	34.2 ± 6.0	7.8 ± 0.0
35-45 (n=2)	19.0 ± 2.0	50.0 ± 1.0	31.0 ± 3.0	1.8 ± 0.1	46.0	7.9
45-55 (n=2)	15.0 ± 2.0	44.5 ± 1.5	40.5 ± 0.5	n.m.*	46.0	7.9

**) not measured*

The whole field was ploughed in autumn 1987; mineral fertiliser (215 kg/ha N, 48 kg/ha P and 48 kg/ha K) was broadcast in early spring 1988 and pre-emergence herbicide was applied after preparing the seedbed at end of April. At begin of May, when soil was at field capacity, a 7 m wide strip within the field was uniformly compacted by a tractor driven trailer, which had a load on tire of 33 kN and a pressure in tire of 0.5 MPa. The type of the tire was a Trelleborg 400 - 15.5 (tire width 400 mm and rim diameter 394 mm). Maize 'LG 11' was planted on May 5th at a density of 70 000 plants per ha and harvested by combine at begin of November 1988; grain yield was measured by hand harvesting eight rows of 4.0 m length on 17th October 1988. During the early vegetation period in May and June rainfall was about 30 % lower than the long-term mean, while from July to September precipitation was about the long-term mean.

Compaction effects were investigated by comparison of soil physical properties and plant growth (grain weight) of a compacted and a non-compacted plot. In the laboratory saturated hydraulic conductivity was measured on each five undisturbed soil samples of 200 cm³ size taken from six consecutive soil layers down to 60 cm in the field. Three of these samples form each layer were separated from determination of the soil water characteristic with the pressure plate apparatus at pressures of 1, 6, 10, 30 and 1500 kPa. At last, bulk density and total pore volume was determined on all five samples per soil layer. In the field penetration resistance was measured in the field by a hand held electronically recording BUSH Penetrometer (ANDERSON et al. 1980) at several times throughout the experimental period each 3.5 cm down to a depth of 50 cm using 11 strokes per "measurement plot", using a 10 cm grid-jig. Furthermore roots were sampled by soil cores (260 cm³) taken every 10 cm down to 100 cm depth within the plant rows at different growth stages of the maize. No replication were made during the growth period, but three replications of the root samples were mat at about the harvest of the maize crop. The root length density was determined after washing according to SMUCKER et al. (1982) and automatically counting (AMBLER and YOUNG 1977). During the period from July to end of September soil water suction was measured in 10, 20, 30, 40, 50 and 70 cm depth in the compacted and the non-compacted plot by means of gypsum blocks, which had been calibrated in the laboratory (STENITZER 1993); soil water storage was calculated from estimated water content which had been derived from the measured soil water suctions and the soil moisture characteristic of the respective soil horizons.

Compression effects due to trailer traffic resulted in marked differences of physical and mechanical soil parameters in comparison with the uncompressed experimental plots down to a depth of about 30 cm: bulk density as well as penetration resistance clearly increased, while air filled pore space and infiltration rate were appreciable lower than in the non trafficed soil (Figure 1):

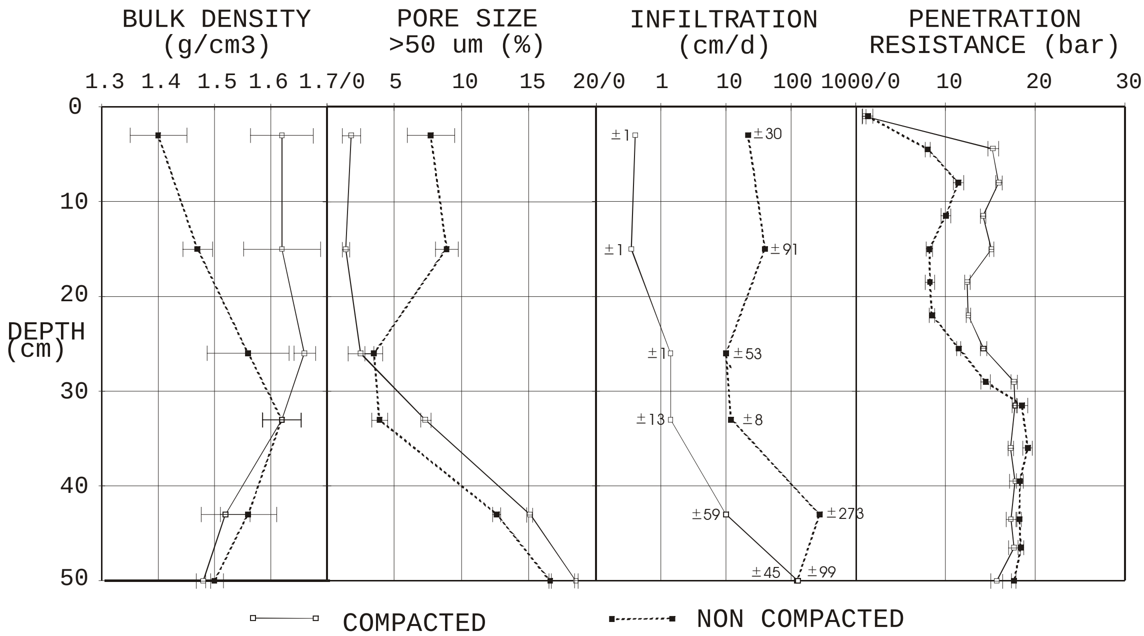

Fig. 1: Soil physical and mechanical parameters of the compacted and non-compacted experimental plots

Soil water characteristic within the compacted layer was changed as shown exemplary in Fig. 2 for the depth of 15 cm.

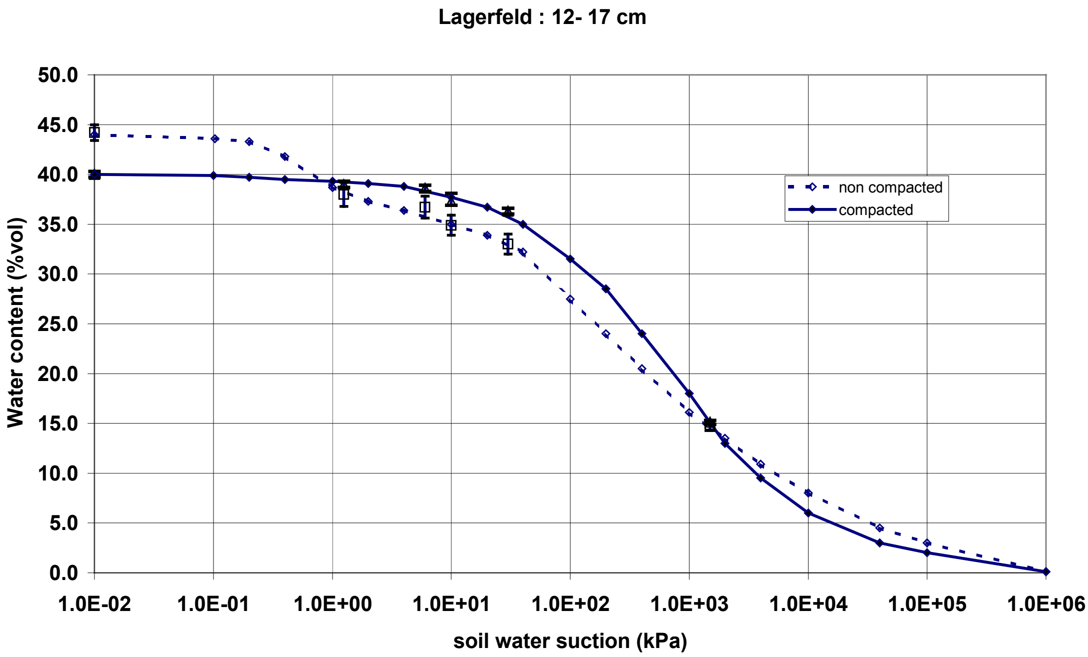

Fig. 2: Typical change of the soil moisture characteristic within 0-30 cm depth

Although both figures show distinct differences in the physical soil parameters of both the non compacted and the compacted plot, there were only small differences in rooting depth (non compacted: 105 cm, compacted: 100 cm) as well as in root length density of both plots at the end of cropping season (Tab. 2).

Tab. 2: Root length density (cm/cm³) of the non compacted and at the compacted plot

Depth	Non compacted*	Compacted*
0 - 10 cm	4.98 ± 0.41	5.79 ± 1.95
10 - 20 cm	1.50 ± 0.60	1.17 ± 0.72
20 - 30 cm	0.98 ± 0.17	1.33 ± 0.90
30 - 40 cm	0.63 ± 0.32	0.61 ± 0.25
40 - 50 cm	0.27 ± 0.16	0.65 ± 0.21
50 - 60 cm	0.28 ± 0.10	0.54 ± 0.07
60 - 70 cm	0.28 ± 0.17	0.56 ± 0.13
70 - 80 cm	0.25 ± 0.16	0.46 ± 0.20
80 - 90 cm	0.15 ± 0.10	0.31 ± 0.17
90 -100 cm	0.08 ± 0.07	0.08 ± 0.09

* (three replications)

Soil water tension (Fig.3) and depletion (Fig. 4) down to 70 cm depth from late July to end of September, as estimated from gypsum block measurements, also showed no great differences: in the non compacted plot the maize crop was able to extract only 13 mm more than in the compacted plot.

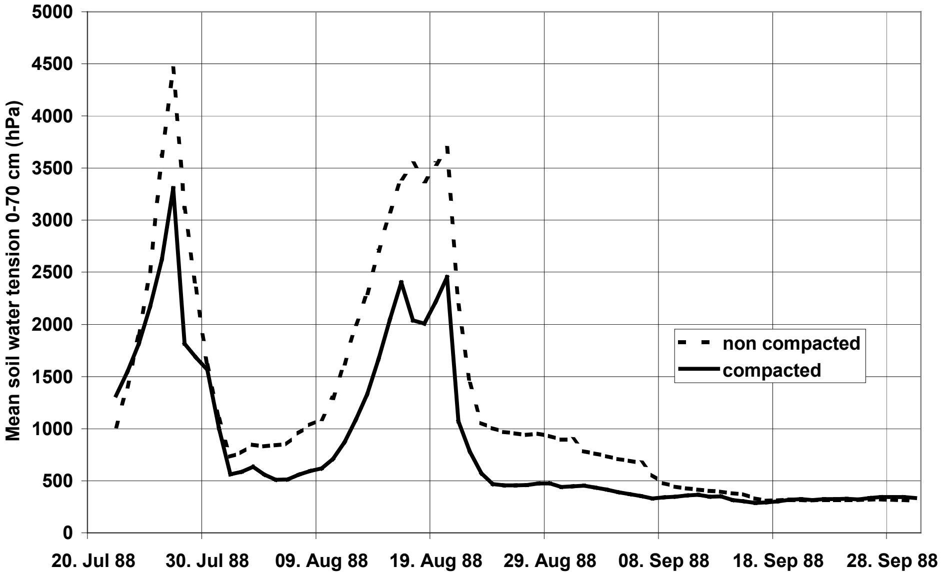

Fig. 3: Measured soil water tension (0-70 cm) in the non compacted and the compacted plot

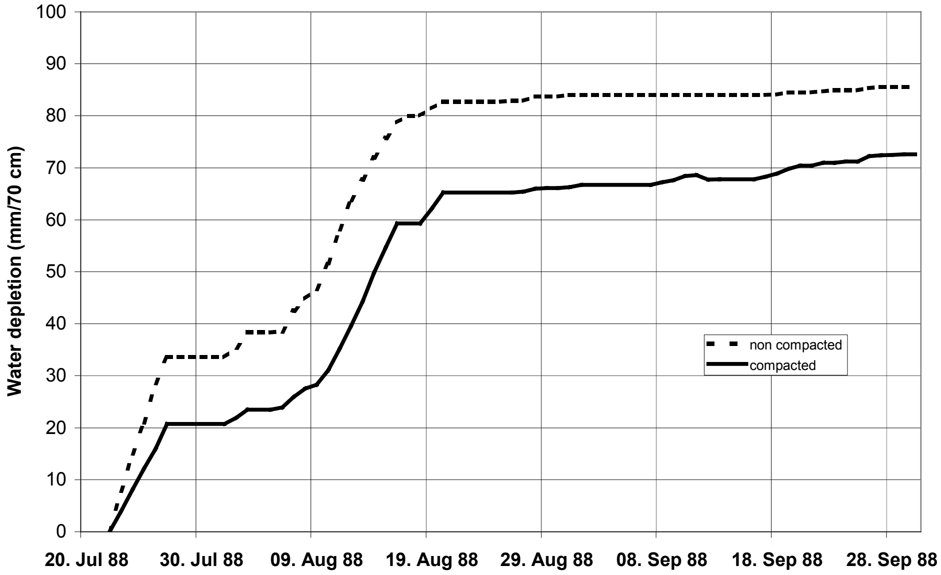

Fig. 4: Measured soil water depletion (0 – 70 cm) in the non compacted and the compacted plot

Nevertheless, these rather small differences in water stress and water availability do not explain the high yield depression (Tab. 3) within the compacted field strip.

Tab. 3: Grain yield (kg/ha dry matter)

non-compacted	7187* +/- 567
compacted	5277* +/- 418

* mean of nine replications

3.2.2 Simulation model

3.2.2.1 General features

The functional and deterministic model SIMWASER is designed to describe one-dimensional, vertical flow of water in a soil profile; interflow and preferential flow are neglected. Water balance and plant growth are linked together by the physiological interaction of assimilation and transpiration. The increase of dry matter production depends on taking in carbon dioxide from the air via the stomata, during which process water vapour is lost from inside of the plant to the unsaturated air. As long as the delivery of water to the stomata can satisfy potential transpiration, potential assimilation and potential plant growth take place, otherwise stomata will close and dry matter accumulation will be restricted. All the above mentioned processes are influenced by the respective development phase of the plant, e.g. the partition of the daily assimilated plant dry matter between leaves, stem and roots. SIMWASER defines the current development stage as quotient of the current accumulated 'growing degree days' divided by the sum of growing degree days necessary for plant growth from sowing to ripeness. A 'growing degree day' is defined by the mean daily air temperature minus a base temperature typically for the respective crop.

The actual plant growth is calculated from the potential production rate as the proportion of actual transpiration to potential transpiration (eq.1).

$$Pact = \frac{P_{Pot} x T_{act}}{T_{POT}} \tag{1}$$

P_{act}, P_{pot}	actual and potential plant production (kg CH2O/m²,d)
T_{act}, T_{pot}	actual and potential transpiration (mm/d)

Potential evapotranspiration PET is calculated according to the well known 'Penman-Monteith - formula" (eq. 2):

$$PET = \frac{ft\ x\ Q\ +\ 0.864\ x\ H_0/R_{air}}{ft\ +\ 1\ +\ R_{crop}/R_{air}} \tag{2}$$

PET	potential Evapotranspiration (mm/d)
ft	weighing factor, depending on air temperature
Q	evaporation equivalent of available energy (mm/d)
0.864	factor converting ((g H2O/m³)/(s/cm)) to (mm/d)
H0	saturation deficit of air (g H2O/m³ air)
R_{air}	aerodynamic resistance against water vapor exchange (s/cm)
R_{crop}	crop resistance against water vapor exchange (s/cm)

Both R_{air} and R_{crop} are variable, depending on the weather situation as well as on the current development stage of the crop. Potential transpiration T_{pot} is derived from PET proportionate to the energy absorbed by all leaves within the stand:

$$T_{pot} = PET*(1-exp(-0.6*tot_{lai})) \quad (3)$$

tot_{lai}	total leaf area of the stand per unit soil surface (m²/m²)
exp	exponent

3.2.2.2 Root and plant growth

Actual transpiration T_{act} is assessed by checking if the water demand of potential transpiration may be met by water extraction of the plant roots. At first an estimate of the 'maximum possible' amount of the water extraction by the roots in every rooted soil layer is made with the following simplifying assumptions:

$$WUR(i) = \frac{P_P - P_S}{R_P + R_S} xRLD(i)xH(i) \quad (4)$$

WUR	maximum possible water uptake by roots within a soil layer i (mm)
Pp	plant water potential (MPa)
Ps	soil water potential (MPa)
Rp	plant resistance (MPa/mm)
Rs	soil resistance (MPa/mm)
RLD(i)	root length density within the soil layer (cm/cm²)
H(i)	thickness of the soil layer (cm)

SIMWASER assumes plant water potential P_P to be 1.5 MPa and the plant resistance Rp to vary between 100 and 2000 MPa/mm depending on development stage. Soil resistance Rs is assessed by the numerical value of 1day/Ku, where Ku is the unsaturated (capillary) conductivity at the current matric potential Ps. If the sum of the potential water extraction SUMWUR of all current rooted soil layers is smaller than the potential transpiration Tp, then

$$T_{act} = T_{pot} \quad (5)$$

otherwise the actual transpiration

$$T_{act} = SUMWUR \quad 6)$$

The amount of water uptake by roots will be higher the deeper the roots are able to grow into the soil. The current rooting depth depends both on the type of the crop and on the penetration resistance of the soil. For each crop the values of the 'potential root length' ROOTLG and of the sum of 'growing degree days' from seeding to ripening of the crop RIPING must be given in the model's data set on plant parameters (see below). From these information in a first step mean rate of root length growth RROTG in optimal conditions is estimated by

$$PROTG = \frac{1}{0.3xRIPING} \qquad (7)$$

RROTG	rate of root length growth (dm/°C)
RIPING	Sum of photo-thermal units from seeding to ripening (°C)

Even with optimal conditions "current" potential root length growth rate RRLG will deviate from the mean root growth rate RROTG, depending on the development stage by the factor FRROTG, the value of which is estimated to vary from 0.1 at begin of the root development to 2.5 at full root growth stage:

$$RRLG = FRROTG\ x\ RROTG \qquad (8)$$

RRLG	actual root growth rate (dm/°C)
FRROTG	relative root growth rate factor (dimensionless)
RROTG	mean root length growth rate (dm/°C)

Daily gain of 'potential' root length PGRL is calculated according to Eq. (9):

$$PGRL=RRLG\ x\ PTU\ x\ ROOTLG\ x\ FROOT \qquad (9)$$

PGRL	current possible gain of root length (dm)
RRLG	potential rate of root length growth in optimal conditions (dm/d,°C)
PTU	photo-thermal unit (°C)
ROOTLG	potential root length (dm)
FROOT	root growth factor (dimensionless)

To estimate the actual gain of root length (AGRL) from its potential value, two more reduction factors are introduced:

$$AGRL = PGRL*RF*FWLOG \qquad (10)$$

RF	reduction factor due to penetration resistance (dimensionless)
FWLOG	reduction factor due to water logging (dimensionless)

The current value of RF depends on the current magnitude of the mechanical soil resistance against root growth in the deepest of all the rooted soil layers as well as on the type of the crop. This resistance is expressed by the penetrometer resistance PE, which is supposed to be a soil physical parameter depending on soil texture, bulk density and water content (CANARACHE 1990). In the present version of SIMWASER three different curves of RF are prepared for three typical classes of 'root density' (Fig. 5) which were deduced from Fig. 4 in BENGOUGH and MULLINS (1990).

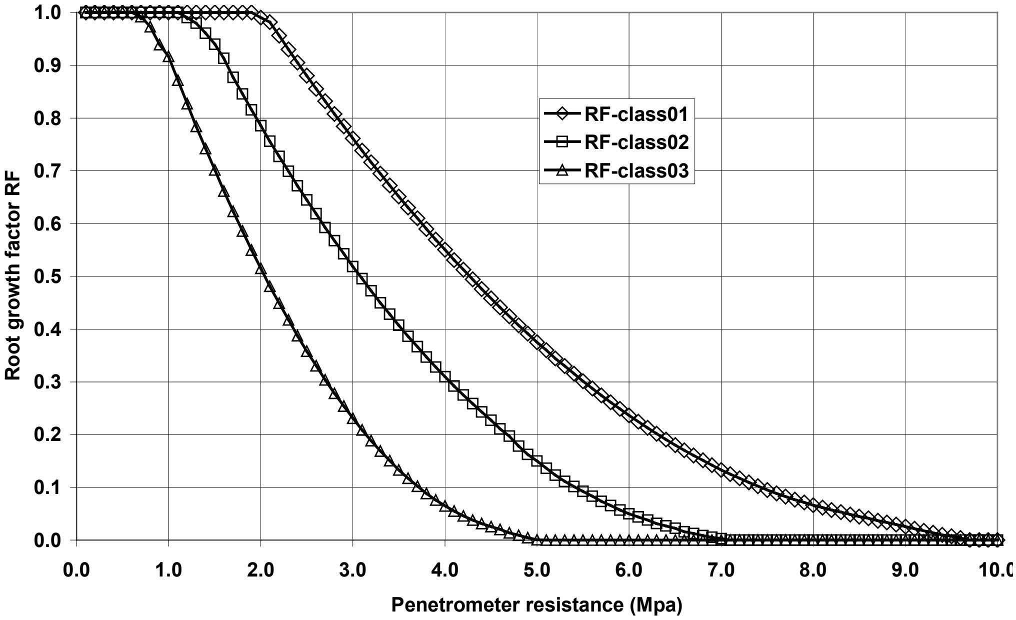

Fig. 5: Theoretical Root Growth Factor RF for different root types (Class 01: 'very dense' (root density RD > 20 cm/cm³); Class 02: 'medium' (RD=10 –20 cm/cm³); Class 03: 'weak' (RD<10 cm/cm³))

The class number of a crop must be defined in SIMWASER's data set on plant parameters: for example grasses will belong to root density class 1, small crops typically fall into root density class 2 and soybean or some high yielding maize breeds may have a rather weak root growth thus belonging to root density class 3. The current penetration resistance in that soil layer where the (vertical oriented) root tips grow in are estimated according to CANARACHE (1990) with the following basic formula:

$$RP = a \; x \; w^{m} \tag{11}$$

where RP is the penetrometer resistance (MPa), w the gravimetric water content (g/g) and a and m being shape factors depending on clay content and bulk density of the soil material. The calculation procedure (CANARACHE 1990) is shown below:

$$M = 0.055*(1.047^{C})*(BD^{7.53}) \tag{12}$$

$$RPs = -0.36*(1.0026^{C})*(BD^{1.27})*(BD^{(0.0267*C)}) \tag{13}$$

$$S = \frac{100(-0.38xBD)}{BD} \tag{14}$$

$$TP = 100(1-\frac{BD}{2.65}) \tag{15}$$

$$TPm = 44.9+0.163*C \tag{16}$$

$$dc = 100\frac{TP_m - TP}{TP_m} \tag{17}$$

$$f \quad = 0.875 + 0.0032 \; x \; dc \tag{18}$$

$$PR = PR_S\left(\left(\frac{2 \; x \; w}{S \; x \; f}\right)^M\right) \tag{19}$$

where M = constant m , C = clay(<0,002 mm)-content (wt.%), BD = bulk density (g/cm³), RP_S = standard resistance to penetration at moisture content 50% of quasi saturation (MPa), S = moisture content at saturation (wt.%), TP = total porosity (%.vol), TPm = minimally required total porosity (%.vol) , dc = degree of compaction (%), f = empirical factor.
Eqns. 12 to 19 yield the amount of penetrometer resistance for any soil water content (expressed as wt.%). This function is converted to a respective function based on soil water suction by multiplying gravimetric water contents by bulk density and deducing the respective soil water suction from the soil water characteristic. This 'converted' function of the penetrometer resistance is added then into the 'soil parameters' input data tables (see below), which have to be prepared for each distinct soil horizon within the simulated soil profile.

The 'water logging factor' FWLOG takes into account the influence of poor aeration on root growth: it's value depends on the current air volume in the soil layer, where the root tips are growing.

If w(i) = wsat(i) then FWLOG(i) =0.0 (20)

If w(i) < (wsat(i) – airmin) then FWLOG(i) = 1.0 (21)

Else $$FWLOG(i) = \frac{w_{sat}{}^{(i)} - w^{(i)}}{air_{\min}} \tag{22}$$

w(i)	soil water content (%vol) within soil layer (i)
wsat(i)	water content at saturation (%vol) of soil layer (i)
air_{min}	minimum air volume necessary for good plant growth

The minimum air volume air_{min} necessary for good plant growth depends upon crop type and is defined in the present model's version with 5 %.vol.

Besides the influence of the water logging factor upon root length growth SIMWASER assumes, that the assimilation process is influenced also by the reduction factor F_AERATION which is defined by the weighted mean of the water logging factors within the rooted profile:

$$F\_AERATION = \frac{(SUM(FWLOGF(i)xRL(i))}{SUMRL} \qquad (23)$$

FWLOG(i)	reduction factor (eqns. 20-22)
RDL(i)	root length within soil layer (i)
SUMRL	total root length

3.2.2.3 Water balance

The water balance on daily base is made at the soil surface with precipitation and irrigation as input and evaporation and transpiration as output. Interception is also taken into account. The water movement within the soil is calculated according Darcy's Law and the 'continuity equation'. The soil profile is divided into several soil layers (usually of 5-10 cm depth) down to a depth in which plant roots may not have any direct influence on the water movement. In case where capillary rise from shallow groundwater must be taken into account the deepest soil layer must reach below the deepest groundwater level. In such case the boundary condition at the lower end of the model profile is given by the current groundwater level, otherwise the lower boundary condition is defined by the capillary conductivity of the deepest soil layer at the current water content. The 'normal' time step of the model is the day, but water movement is calculated using variable time steps, which are limited by the condition, that the maximum change of water content within any of the soil layer during the time step is restricted to 0.001 cm^3/cm^3.

3.2.2.4 Input data

For running the model SIMWASER four general types of input data are necessary:
1) information on location, including the responsible weather and groundwater station, and on crop rotation , 2) plant parameters, 3) soil physical parameters and 4) weather data.

Tab. 4: Input parameters

Input data	Sources:
Weather & Irrigation Data	
air temperature, air humidity, wind velocity, global radiation, precipitation + irrigation	weather station near the experimental site
Soil parameters:	
moisture characteristic	experimental data
hydraulic conductivity	experimental data
penetrometer resistance	calculated according to CANARACHE (1990)
Plant parameters	
minimum stomatal resistance	calibrated
potential plant height	experimental data
potential rooting depth	mean value from literature
potential root length density	calibrated
growing degree days necessary for ripping	calibrated

The plant parameters also include the extinction coefficient of visible radiation, leaf area weight, an index for the 'temperature response' curve, an index for root 'strength' class, and leaf area index at end of emergence/begin of leaf growth stage. These plant parameters are more or less fixed after having been tested on the results of several field experiments. All other constants or tabulated functions (like the root growth factor RF shown in Fig. 5) are fixed within the source code.

The soil parameters cover the moisture characteristic, the hydraulic conductivity curve and the penetrometer resistance curve. They are shown in Figs. 6 – 8 for both the non-compacted plot and the compacted plot as well. The moisture characteristic is based on laboratory measurements of the total pore volume as well as on the water content at suctions of 1, 8, 30 and 1500 kPa, using undisturbed soil cores of 200 cm³ volume. Hydraulic conductivity was derived from saturated conductivity also measured on undisturbed soil cores and taking into account the shape of the moisture retention curve according to the method of Millington & Quirk (see: BOWER & JACKSON, 1974). The curve of the Penetrometer resistance was calculated according to eqns. 12-19.

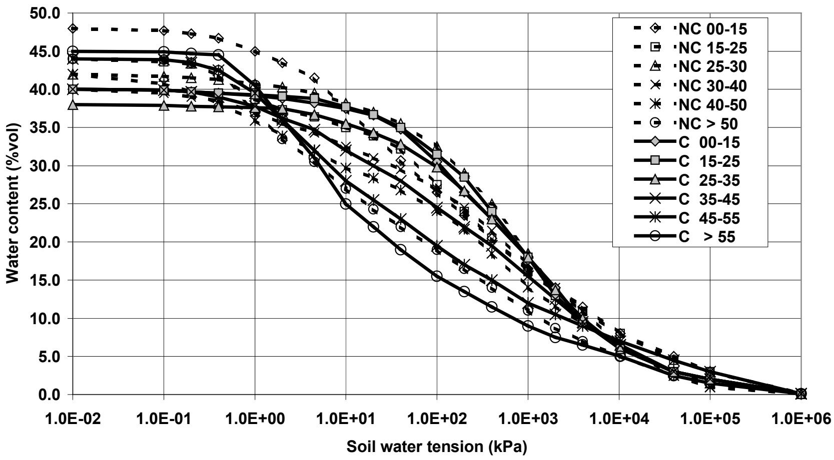

Fig. 6: Moisture characteristic of the different layers in the non compacted (NC) and the compacted (C) plot

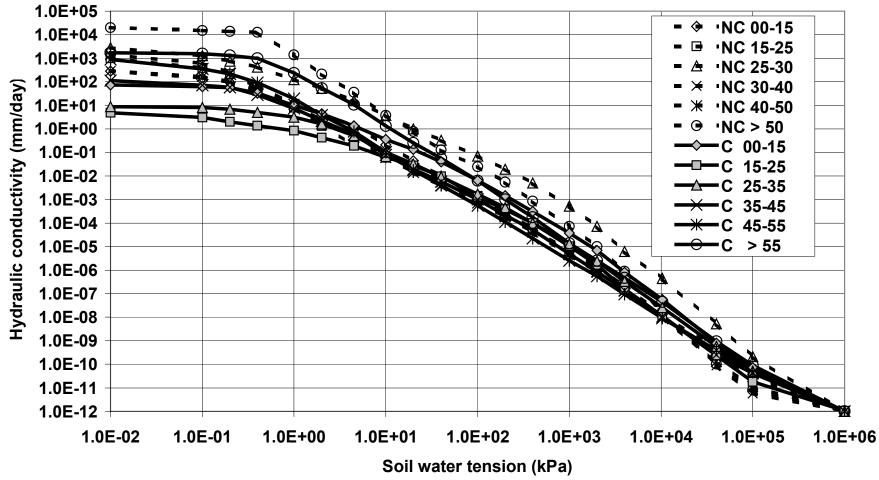

Fig. 7: Hydraulic conductivity of the different layers in the non compacted (NC) and the compacted (C) plot

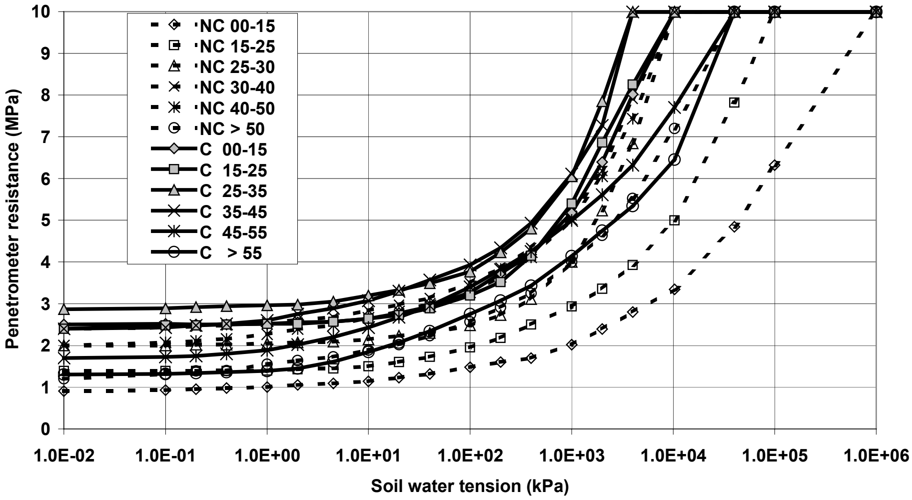

*Fig. 8: Penetrometer resistance of the different layers in the non compacted (NC) and the c*ompacted (C) plot

3.2.2.5 Output

According to the crop rotation defined in the input data, output of SIMWASER supplies the soil water balance as well as the crop yields, expressed as the above ground dry matter of the crop, from which grain yield may be deduced by an appropriate harvest index. There is also an output list available which contains the daily values of the above mentioned simulation results.

3.2.2.6 Calibration

Calibration process of the model SIMWASER normally is restricted to the soil and plant parameters. Calibration of soil parameters will not be necessary if they can be deduced from very intensively instrumented field measurements. In most cases some parameter estimations are unavoidable and periods with no plant growth must be used for calibration, which will consist of running the model with different but plausible soil parameter curves and of comparing the simulated results with measured ones. SIMWASER provides a plant parameter table for about 20 different crops grown in temperate climates, which may be used for rough estimations only. To get realistic results calibration of plant parameters will be necessary, mostly concerning the stomatal resistance, which is relevant for the water demand of the crop and may differ according to different varieties. Another rather variable parameters are the potential rooting depth and the sum of growing degree days necessary for ripeness.

In the special case of the compaction experiment none of the above mentioned calibrations could be made directly on experimental data. Plant parameters were calibrated using results from an experimental station with comparable climate and sufficient data. The results presented in Fig. 9 show that simulated soil water extraction of the maize crop is sufficiently corresponding to the measured one.

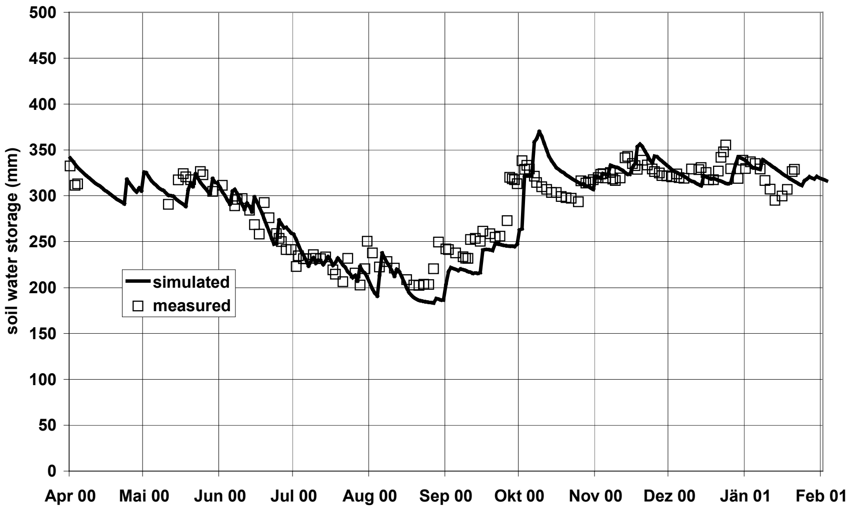

Fig. 9: Result of plant parameter calibration for the maize crop, using results from an experimental station with comparable climate (see text)

For calibration of the soil parameters data on soil water storage of the non compacted plot in the year 1990 (Fig. 10) were used:

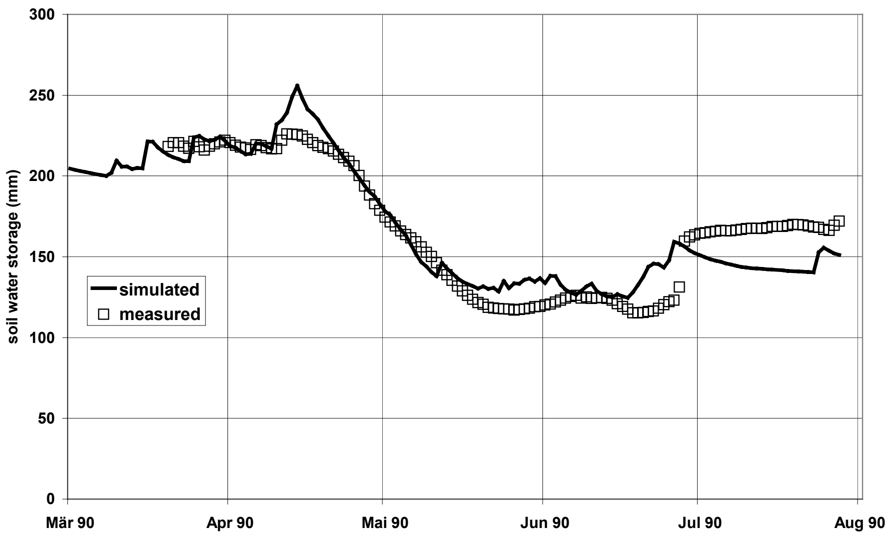

Fig. 10: Result of soil parameter calibration for the non compacted plot (see text)

3.3 Results and discussion

SIMWASER estimates the dry matter of the whole crop; the simulated crop yields shown in Tab. 5 therefore had to be multiplied by an empirical 'harvest index HI' for the maize crop at the experimental site to get grain yields which also are given in Table 5.

Tab. 5: Simulated and measured crop yields (kg dry matter/ha)

	total crop	HI	simulated grain yield	Measured grain yield
non-compacted	18 780	0.40	7 512	7 187
compacted	13 896	0.40	5558	5 277

Simulated and measured grain yields of the maize crop were about the same level for both the non compacted and the compacted plot. There was also good conformity of the simulated and measured root length densities as shown in Figs. 11 and 12.

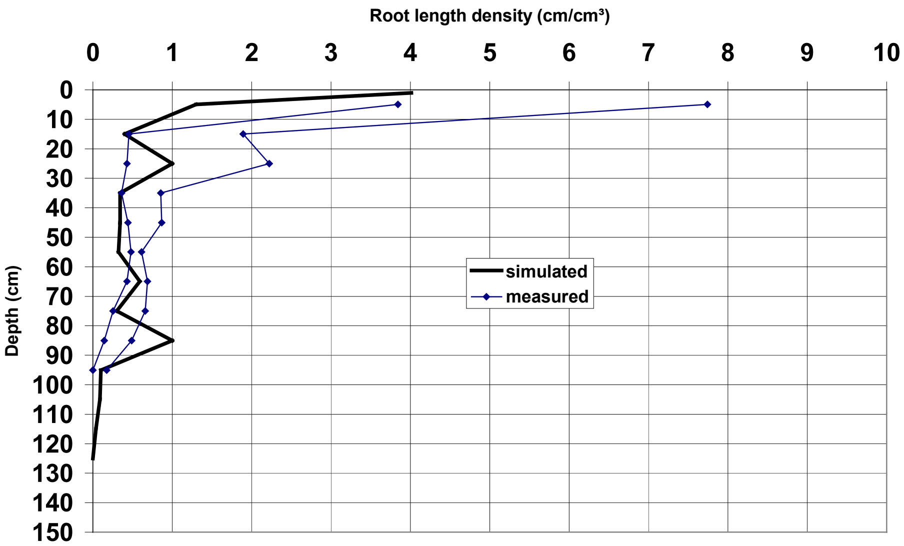

Figure 11: Simulated root length density in the compacted plot at harvest time

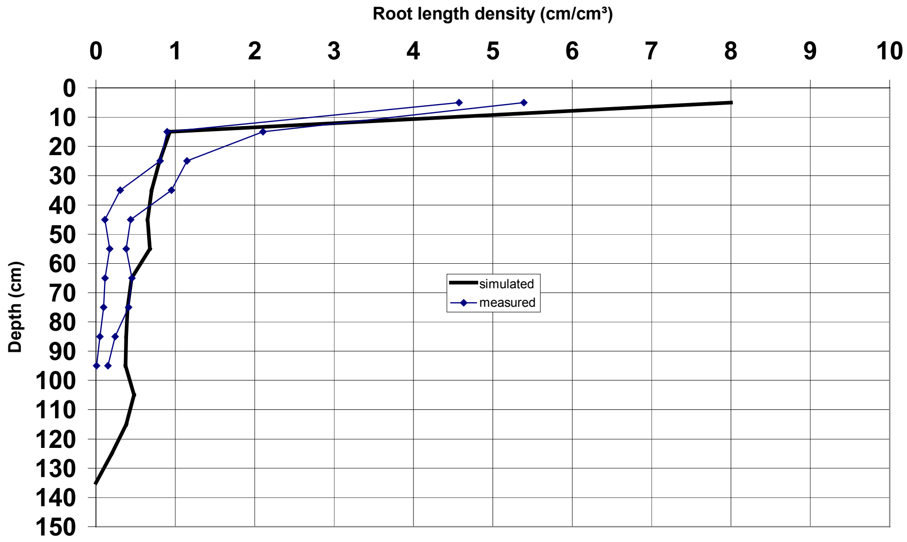

Figure 12: Simulated root length density in the non compacted plot at harvest time

Tab. 6 indicates the causality of the model's concepts concerning the effects of soil compaction on the water balance and yield of the maize crop. As described above, SIMWASER takes into account the increase of penetrometer resistance as well as the decrease of air-filled pore volume in simulating root and crop growth. To find out, which one of both modelling concepts had the most effect upon the rather good results, we made two additional simulation runs, the one of it not taking into account the increase of penetrometer resistance, the other not allowing a decrease of dry matter production due to the 'aeration factor'.

Tab. 6: Simulated soil water balance (mm) and yield

	Rain	Actual evapo-transpiration	Percolation	Run off	Soil water storage	Total dry matter (kg/ha)
Non compacted	363	437	22	0	-96	18780
Compacted	363	332	6	90	-66	13896
Compacted*	363	332	10	76	-57	14394
Compacted**	363	411	9	37	-94	18842

* assuming no increase of penetrometer resistance
** assuming no aeration factor (eqn. 23) effective

Under the given circumstances neglecting the increase of penetration resistance had minor influence upon the crop yield, while reduced air-filled pore space effected almost all of the simulated yield reduction.

3.4 Conclusion

The simulation model SIMWASER was able to estimate fairly good the observed maize yield reduction within the compacted strip of the experimental field. The model assumptions in principle seem to enable realistic modelling of impact of soil compaction upon the interrelationship between soil water balance and plant growth. But it must be remembered that some essential model parameters were fitted according to the circumstances of the case study and may not be effective in other cases! For example, choice of the appropriate 'root growth factor' (s. Fig. 2) of the crop on the one hand and setting a realistic 'minimum air volume necessary for good plant growth' (s. eq. 22) on the other hand are of great importance for good simulation results. Another very important point is, that in case of fine textured soils with low percentage of air filled pores the model output is very sensitive to the hydraulic soil parameters determined in the laboratory, which in fact do not take into account aeration effects due to shrinking under field conditions. As far as the SIMWASER model is concerned, experimental data on these parameters are still missing to a great extend.

3.5 References

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4 Simulation of the impact of subsoil compaction on soil water balance and crop yield of irrigated maize on a loamy sand soil in SW Spain

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Abstract
Irrigation of crops in Mediterranean countries can produce some conditions that favour soil compaction processes. The SIMWASER model takes into account the effects of sub-soil compaction on water balance and crop yield. The objectives of this paper were: (I) to test the mentioned model using the data set collected, during three years (1991-1993), from irrigation experiments with maize *(Zea mays* L., cv. Prisma) on a sandy soil (CAMBISOLS (FAO, 1990) or XEROCREPTS (USDA, 1998)) in SW Spain and (II) to estimate the influence of sub-soil compaction on soil water balance and crop yield assuring long lasting heavy sub-soil compaction that may be developed under irrigation for the SW Spain conditions. The model was run *tb* simulate soil water content, evapotranspiration, drainage below the root zone, and crop yield for the same period in which the experiment was carried out. Results of simulation were compared with the experimental results in order to know the agreement between them. The results obtained show a fairly good agreement between simulated and measured values for most of the parameters considered. For the scenario in which subsoil compaction is developed under irrigation, the results simulated by the model indicate a reduction of the rooting depth. However, the effects on water balance and crop yield in this sandy soil were not relevant under the SW Spain conditions.

Keywords: Subsoil compaction; Simulation model; Irrigation; Water balance; Maize; Root length density

4.1 Introduction

The increase of process modelling of water ba1ance in tillage experiments has imposed a demand of accurate measurements of soil physica1 properties, crop development, and crop yield (MORENO et a1., 1997). For given climatic conditions, and a particular soil-plant system, both the method of tillage and the system of irrigation can, however, alter the soil structure (MESSING and JARVIS, 1993). For cultivated soils, the transport properties of the soil top layer can change during the growing season and

thus to affect the water balance. Simulation models may be valuable tools in agricultural water management, if they are able to describe the processes, which are the most relevant for a given problem. In case of sub-soil compaction, for example, the influence of soil strength upon effective rooting depth is very important for the amount of soil water storage which is available for crop water use.
The change from rainfed crops to irrigated crops can produce some conditions that favour soil compaction processes. MORENO et al. (1986) reported, for a sandy loam soil of the Seville province (SW Spain), that after the change of a rainfed olive orchard into an irrigated annua1 cropping area the soil bulk density decreased. This change did not last very long and bu1k density started to increase after the first irrigated crop (sunflower). This increase of bulk density was considerable in the soil-layer at the depth of 0.2 - 0.4 m. This indicate that the soil water content at the mentioned depth, due to irrigation, remained at a level favouring sub-soil compaction. This phenomenon was a1so observed at the depth of 0.4 - 0.6 m. The increase of bu1k density continued during the successive crop seasons of the experiment. These authors also observed a reduction in porosity.
The objectives of this paper were: (I) to test the simulation model SIMWASER (STENITZER and MURER, 2003), by which this effect is accounted for, on the extensive data from irrigation experiments with maize on a sandy soil in SW Spain (MORENO et a1., 1996) and (II) to estimate the influence of subsoil compaction upon soil water ba1ance as well as upon crop yield assuming fictive long lasting heavy subsoil compactions that may develop under irrigation of these soils.

Table 1

Soil properties [a]

Depth (cm)	Soil particle size (µm) (g per 100 g)			Organic matter (g per 100 g)	Bulk density (Mg m^{-3})
	>20	20-2	<2		
0-40	77.6 (4.9)	8.9 (1.8)	13.5 (2.2)	0.88 (0.15)	1.52 (0.04)
40-100	75.4 (4.6)	8.3 (2.1)	16.4 (1.9)	0.55 (0.09)	1.65 (0.03)

[a] Numbers in brackets are standard deviations.

4.2 Material and methods

4.2.1 Experimental site

The irrigation experiments were conducted at the experimenta1 farm of the Instituto de Recursos Natura1esy Agrobiologia de Sevilla (IRNAS, CSIC) 10-cated at Coria del Rio close Seville city in SW Spain (37°17'N, 6°3'W). The climate is typica11y Mediterranean, with mild rainy winters and very hot, dry summers. The average annual rainfall (1971-1992) is 550 mm and most falls between October and May. The soil is a Xerochrept of sandy texture (Table 1), developed on limey sandstone of the Aljarafe Miocene, with a depth of more than 3 m.
The field experiment consisted of two fertilisation treatments and is fully described by MORENO et al. (1996) and FERNANDEZ et al. (1996). Both subplots of each 450 m^2

were cropped with maize *(Zea mays* L., cv. Prisma) during three consecutive years from 1991 to 1993. The crop was irrigated by furrow with some sprinkler irrigations applied between planting and the establishment of the furrows. Tillage operations consisted of mouldboard ploughing to 25-30cm depth after harvesting of maize crop, harrowing 15 cm deep (twice crossing the field) before sowing and application of the cultivator (15-20 cm depth) between crop row as secondary tillage. The land surrounding the experimental plots was cropped every year with furrow or sprinkler irrigated maize or cotton to minimise advection effects. The soil of the plot was kept bare during the period between the harvest and the beginning of the next crop season.
Within both subplots, each was installed with three measuring sites consisting of one access tube for the neutron probe down to a measuring depth of 2.3 m and five mercury tensiometers at 0.3, 0.5, 0.7, 0.9, and 1.1 m depth in each site. Soil water content was monitored every 5 or 7 days during the crop period. During the bare soil period, these measurements were carried out every 2 weeks, and always after a rainfall. Tensiometer readings were recorded daily during the crop season, and one or two times per week during the bare soil period. Rainfall and meteorological data (air temperature, air humidity, wind and global radiation) were obtained from a meteorological station situated within the experimental farm, 200 m away from the plot.
The water balance was calculated from the mass-conservation equation:

$$\Delta S = R + I - D - AET \qquad (1)$$

where ΔS is the change in water storage (mm), *R* the rainfall (mm), *I* the depth of irrigation (mm), *D* the drainage (mm), and AET the actual evapotranspiration (mm). Surface runoff was neglected because it was practically nil at this site. The drainage component *D* was estimated by Darcy's law:

$$D = q\Delta = -K(\Theta)\, grad\, H \Delta t \qquad (2)$$

where *q* is the mean volumetric flux density (mm per day) during *~t, ~t* the time (day) and gradH is the hydraulic head gradient at the end of the soil profile. *K(e)* is the hydraulic conductivity (mm per day) as a function of the water content *e* at the end of the soil profile. The *K(Θ)* relationship was determined by the internal drainage method (HILLEL et al., 1972) to be

$$K = 0.00000749 exp(63.5\, \Theta) \text{ and } r = 0.84 \qquad (3)$$

Despite of different nitrogen fertilisation treatments of the two experimenta1 plots, no significant differences in crop yield and crop water use were found (MORENO et al., 1996). Therefore the measurement results of both subplots were used for model calibration and verification.

4.2.2 The simulation model SIMWASER

The model SIMWASER (STENITZER and MURER, 2003) is deterministic and mechanistic model designed to describe the relationship between soil water balance and plant growth. Both processes are linked together by the physiological interaction of assimilation and transpiration, the latter depending on atmospheric demand as well as on soil water available to the plant roots. Soil compaction directly affects crop growth by restricting root growth due to higher soil resistance. Soil compaction also reduces air filled pore volume of the rooted soil layers and thus reduces plant growth processes. Furthermore, compacted soil-layers decrease hydraulic conductivity and therefore may cause moisture levels too high for optimal crop growth. All these effects are taken into consideration by the model SIMWASER, which is described in detail by STENITZER and MURER (2003) in this issue.

SIMWASER is not designed to predict soil compaction itself but to estimate the effects of it upon crop yield and water balance. Therefore, the soil parameters relevant

Table 2

Model input data

Input data	Source
Weather and irrigation data	
Air temperature, air humidity, wind velocity, global radiation and precipitation	Weather station at the experimental site
Irrigation	Experimental data
Soil parameters	
Moisture characteristic	Experimental data
Hydraulic conductivity	Experimental data
Penetration resistance	Calculated according to CANARACHE (1990)
Plant parameters	
Minimum stomatal resistance	Calibrated
Potential Effective plant height	Mean value from literature
Potential effective rooting depth	Mean value from literature
Growing degree days necessary for ripening	Calibrated

for describing soil compactness must be known beforehand: these are the moisture characteristic, the hydraulic conductivity, and the penetration resistance of each soil-layer as functions of soil water potential. In case of the present study, soil moisture characteristic and hydraulic conductivity functions are known from the extensive data of the irrigation experiments (MORENO, personal communication). The penetration resistance function of the different soil-layers were estimated according to CANARACHE (1990) with the following basic formula:

$$PR = awm \tag{4}$$

where PR is the penetration resistance (MPa), w the gravimetric water content (g g^{-1}), and a and m being shape factors depending on clay content and bulk density of the soil. The calculation procedure is described in detail by STENITZER and MURER (2003) in this issue. The other input data, that must be known for running SIMWASER, are shown in Table 2, together with the data sources.

With the soil parameters (Fig. 1) the soil water ba1ance and crop yield of maize was simulated for the period from the beginning of the year 1992 to harvest time in 1993 and the model was calibrated and va1idated by comparison of the simulated output with the respective experimental results. Calibration was restricted to variation of two 'plant parameters' of the maize crop (Table 2) within their values known from literature.

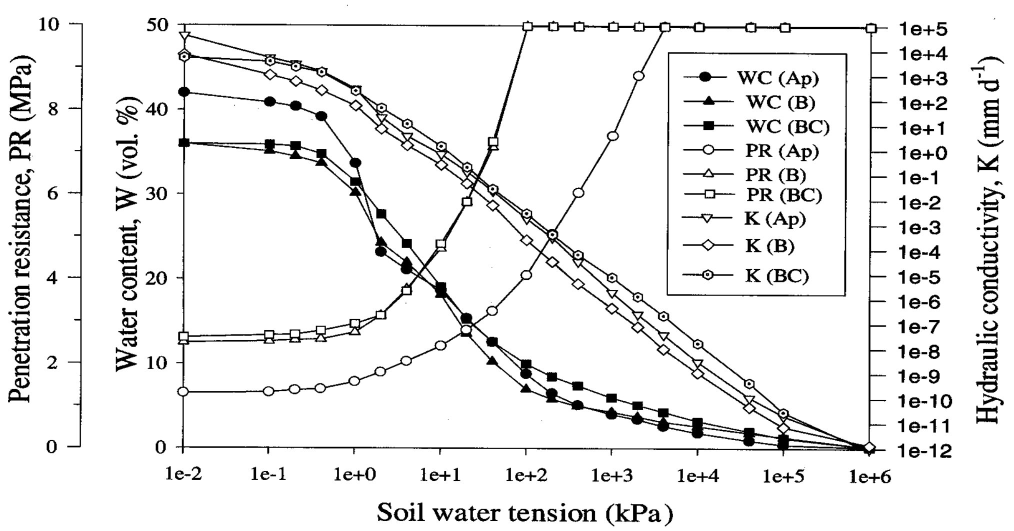

Fig. 1: Soil parameter functions (soil water characteristic (WC), hydraulic conductivity (K), and penetration resistance (PR)) of Ap-, B-, and BC-horizons.

4.2.3 Case study

For estimation of the influence of possible subsoil compaction upon soil water balance and crop yield, a second simulation run was made for the same time period with changed soil parameters supposing a dramatic increase of the bulk density below ploughing depth and a respective change of the soil parameter functions as shown in Fig. 2.

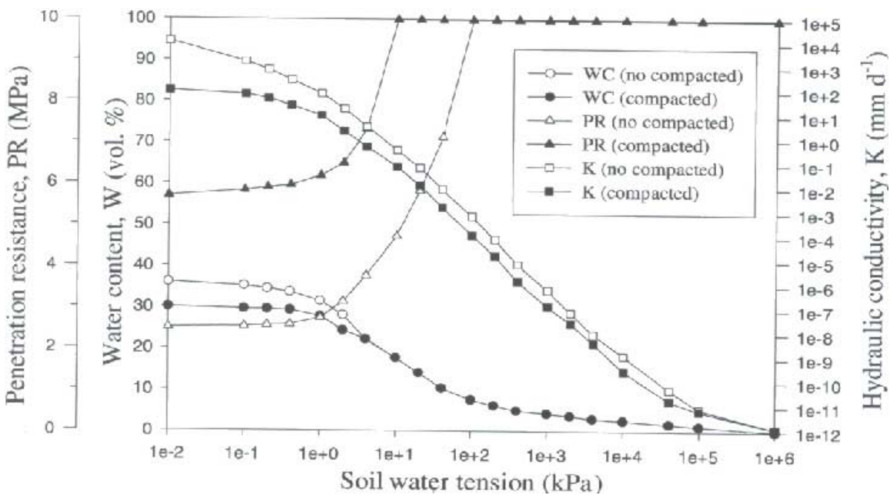

Fig. 2. Changes of the soil parameters (soil water characteristic (WC), *hydraulic conductivity* (K), *and penetration resistance (PR)) in the hypothetical plough pan.*

4.3 Results and discussion

4.3.1 Model calibration

Results of the calibration run shows, that the simulated accumulated values of actual evatranspiration and of drainage (Fig. 3) agree fairly good with the measured values in both years.

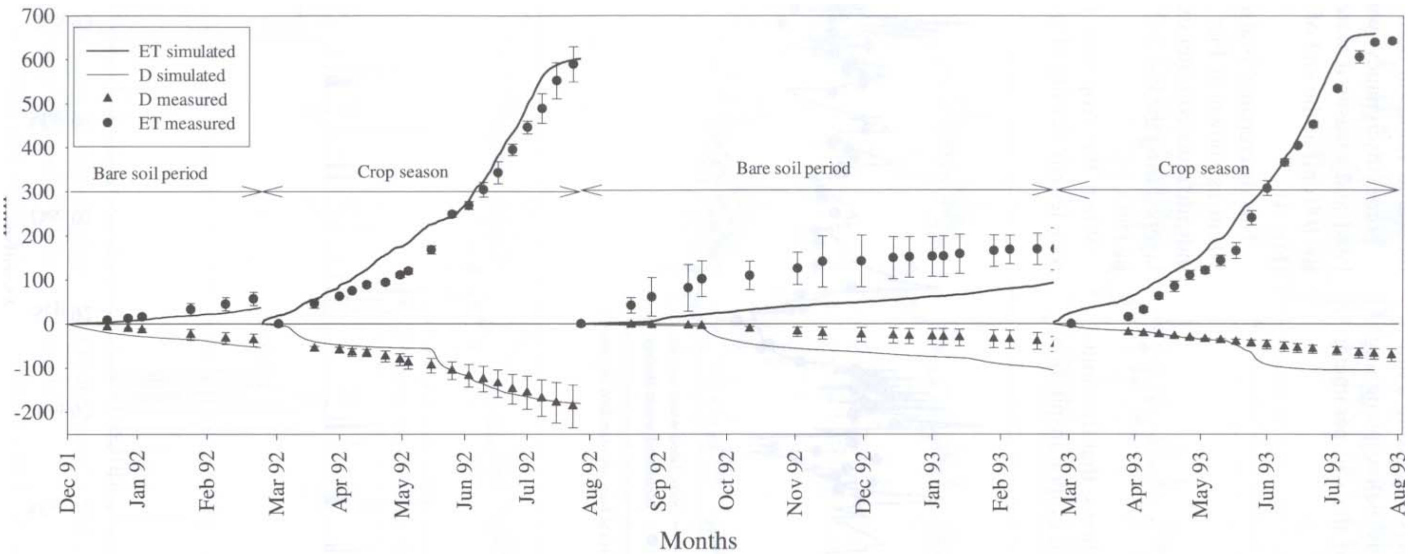

Fig. 3. Comparison of simulated and measured expotranspiration and drainage

Some discrepancy was observed between simulated and measured water storage in the soil profile (0-100 cm) at the end of the cropping season of 1993 (Fig. 4)

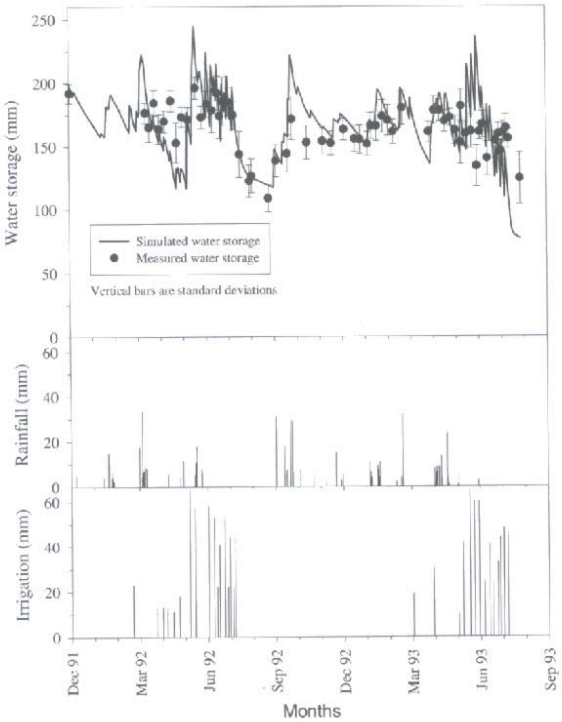

Fig. 4. Simulated water storage (0-100 cm) compared to measured water storage, rains, and irrigation

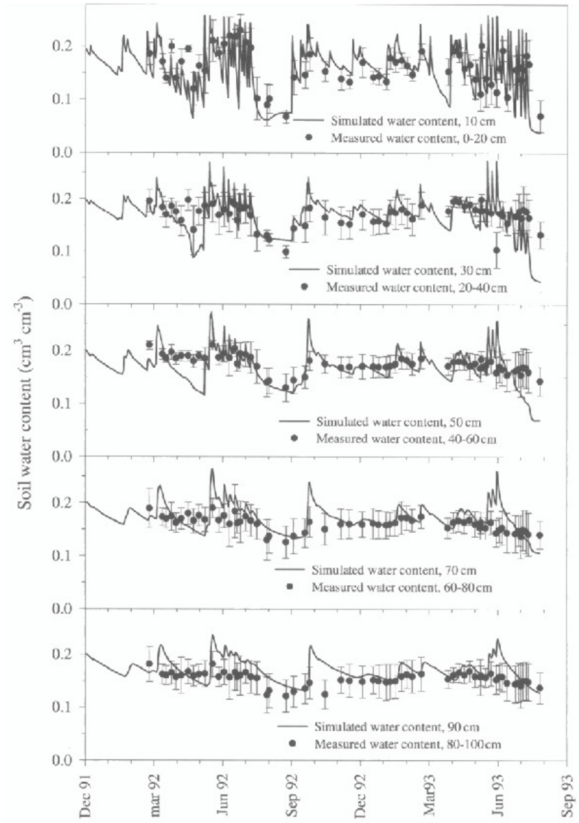

Fig. 5. Simulated and measured soil water content in different soil-layers of the profile

This discrepancy is also seen at the depths of 30 and 50 cm as shown in Fig. 5. Measured water contents indicate reduced water extraction by the roots of these layers during the last 2-3 weeks of crop growth period in 1993.

When the crop was fully developed, the highest root length density (Fig. 6) was found between 10 and 50 cm depth. Simulated root length density at the depths of 10 and 20 cm was about three times higher than the measured root length density (CAYUELA, 1996), but from 30 to 90 cm depth, measured and simulated root length density were very similar (Fig. 6) (CAYUELA, 1996). However, at the depth of 0-30cm in some sites of the same experimental plot, FERNANDEZ et al. (1996) found similar values to those simulated by the model.

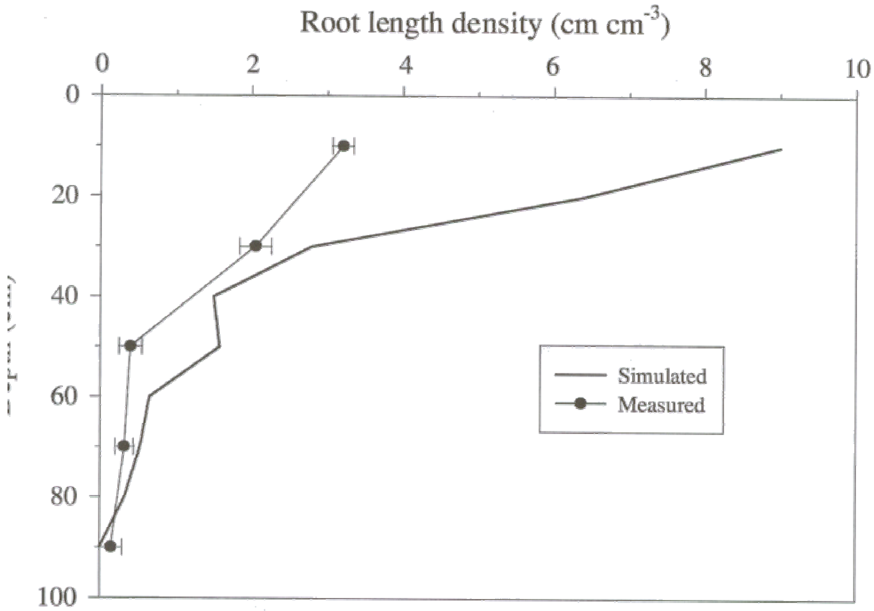

Fig. 6. Root length density on 6 July 1993. Horizontal bars are standard errors.

Maize yields as well as plant height and leaf area index also show a distinct depression in 1993 (Table 3), which may be caused by reduced water extraction as measured, but the reason for this reduction could not be explained by the simulation model.

Table 3 Simulated and measured crop yield, plant height, and leaf area index[a]

Year	Parameter	Simulated[b]	Measured	
1992	Grain yield (Mg ha^{-1})	12.00	12.50	(0.32)
1993		12.16	9.70	(0.26)
1992	Plant height (m)	2.80	2.27	(0.15)
1993		2.80	1.83	(0.31)
1992	Leaf area index (m^2m^{-2})	4.60	3.79	(0.22)
1993		5.50	3.08	(0.33)

a Numbers in brackets are standard deviations.

b Simulated grain yield is estimated from simulated total plant dry matter multiplied by a harvest index of 0.5, and simulated leaf area index includes green stem area.

When judging the applicability of the model SIMWASER to predict the effects of subsoil compaction upon soil water ba1ance and crop yield by comparing simulated and measured results as done above, one has to take into account, that on1y rainfall, irrigations and change of soil water storage were directly measured terms of the water ba1ance equation. The drainage term was ca1culated from measured water contents and soil water suctions (Eqs. (2) and (3)) at a selected site of the experimenta1 plot (MORENO et al., 1996). The evapotranspiration term then was ca1culated according to Eq. (2). The experimenta1 results furthermore are based on the assumption on even1y distributed irrigation water, which may not be the case especially with furrow irrigation. Despite the above mentioned shortcomings of the simulation results, in some details the performance of the model under the conditions of Southern Spain seems to be sufficient for assessment of the influence of subsoil compaction upon soil water balance and crop yield.

Table 4 Comparison of simulated evapotranspiration, drainage, and grain yield of the non-compacted and compacted cases.

Case	Evapotranspiration (mm)		Drainage (mm)		Grain yield (Mg ha^{-1})	
	1992	1993	1992	1993	1992	1993
Non-compacted	604	659	181	104	12.00	12.16
Compacted	603	634	181	107	12.00	11.93

4.3.2 Case study

The development of a heavily compacted plough layer at 35-45 cm depth in this soil will cause only minor differences in soil water ba1ance as well as in yields of the irrigated maize crop on this rather sandy soil. This outcome of the simulation at first sight seems to be not rea1istic, because there are relative small reductions of the crop yield in both years. In Table 4, simulated evapotranspiration, drainage, and crop yields for each of the "non-compacted" and the "compacted" case are listed together, showing that, because of the high irrigation, input water demand of the maize could be met in the "compacted" case regardless of the distinct reduction of the rooting depth (Fig. 7).

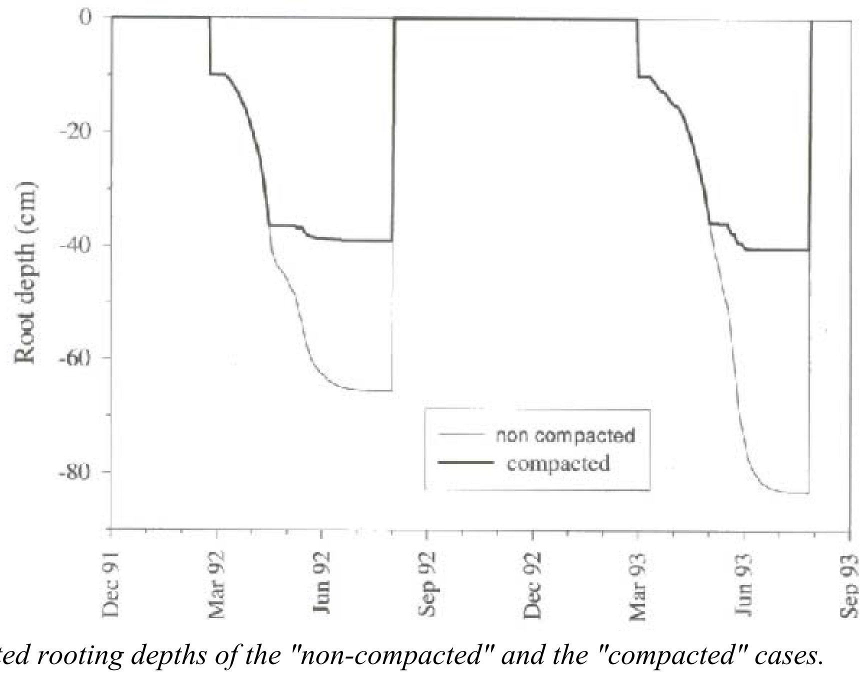

Fig. 7. Simulated rooting depths of the "non-compacted" and the "compacted" cases.

Because of the high porosity of the sandy soil, the volume of air filled pores within the root zone during the growing season of maize was mostly between 20 and 30 vol. % and never fell short of 10 vol. % (Fig. 8) indicating sufficient aeration.

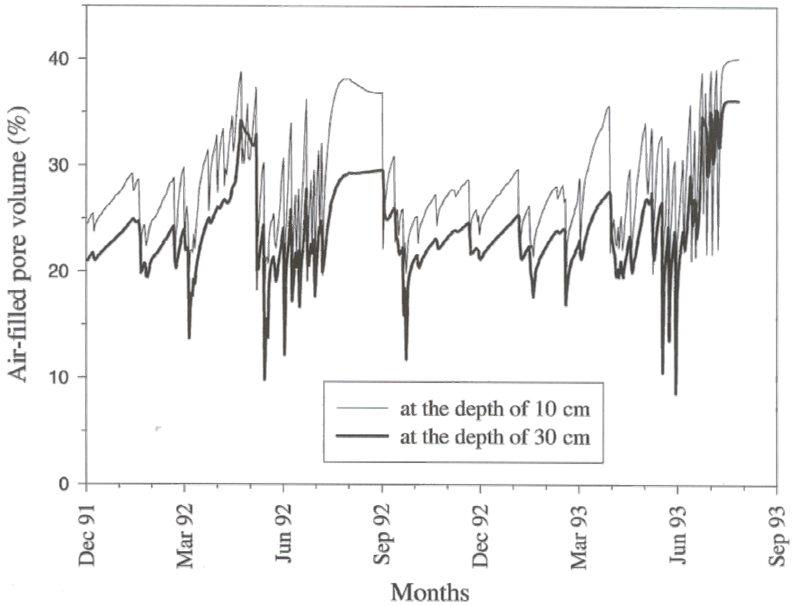

Fig. 8. Simulated air filled pore volume within the rooting zone of the "compacted" case.

We found no studies on subsoil compaction of irrigated sandy soils in Mediterranean climate from which the simulated findings could be judged in a comparative way. In Northern Ita1y BONARI et al. (1995) comparing the effects of conventional and minimum tillage on the root growth of winter oilseed rape *(Brassica napus* L.) in a very sandy soil *(Typic Xeropsamment)* found no significant differences in rape yield, although a reduction of root system mass and tap root length was caused by the minimum tillage. On the other hand COELHO et a1. (2000) working with irrigated cotton *(Gossypium hirsutum* L.) on a loam soil *(Eutric Fluvisol)* in Southern Spain reports a yield reduction of 28 % due to a compacted soil-layer in 20-40 cm depth. On this heavy soil irrigation may have caused aeration problems, which may be the main cause of growth reductions in cases with abundant water on soils with restricted drainage.
The simulated "worst case" therefore may be rea1istic at all and no severe yield reductions due to subsoil compaction on the irrigated sandy soil may be expected in a Mediterranean climate.

4.4 Conclusions

The model seems to be a useful tool for the assessment of the influence of subsoil compaction on soil water balance and crop yield in irrigated maize under Southern Spain conditions.
Simulation of the effect of subsoil compaction in this sandy soil indicates limited influence in soil water ba1ance and yields of the irrigated maize crop. Therefore, the simulated "worst case" may be realistic at all and no severe yield reductions due to subsoil compaction on the irrigated sandy soil may be expected in a Mediterranean climate.

Despite the reduction in rooting depth, in the case of compacted subsoil, the amount of water applied by irrigation is enough to met the needs of the maize crop under such conditions.
Taking into account the existing uncertainties in the present case study, we conclude, that SIMWASER may be a valuable tool in estimating the effects of soil compaction upon soil water balance and crop growth after having been further tested with data from relevant compaction experiments.

4.5 Acknowledgements

Thanks are due to O. Blazquez and J. Rodriguez for help with field measurements. Research was carried out in the framework of the contracts STEP-CT90-0032 and FAIR5-CT97-3589 of the EU and the Junta de Andalucia (Research Group AGR-O151).

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5 Simulation of the Impact of Afforestation of Agricultural Lands upon the Water Balance in a Dry Area

by
Elmar Stenitzer
(printed in Proceedings of Third International Conference on Water Recources and Environment Research (ICWRER) Volume I)

Abstract:

Simulation of the soil water balance for the period 1978 – 2001 in the semi-humid Marchfeld area in Austria shows that the groundwater recharge of arable lands amounts to about 110 mm/a on low yielding shallow soils and decreases to about 75 mm/a on the higher valued medium deep soils. Afforestation with pine plantations will halve the water yields on the shallow soils, while on the medium deep soils deep seepage will be cut down to one third.

5.1 Introduction

The groundwater in the "Marchfeld" basin east of Vienna (Fig. 1) has been overused for the last decades by agricultural irrigation and by industrial and private water consumption as well (VOLLHOFER 1995). In this semi-humid area (with precipitation of 520 mm/a and the climatic water balance during growing season being -380 mm/a) ground water recharge mainly takes place on the rather shallow soils at the "Hochterrasse" region where already some forests exist for protection against soil erosion by wind. Because of economical reasons another 8000 hectares of these low yielding shallow soils are planned to be afforested. Thus the groundwater recharge is supposed to be further diminished, the amount of which is estimated by simulation in the present paper. The study was partly financed by the INTERREG II C – Project Nr. 97005/A.

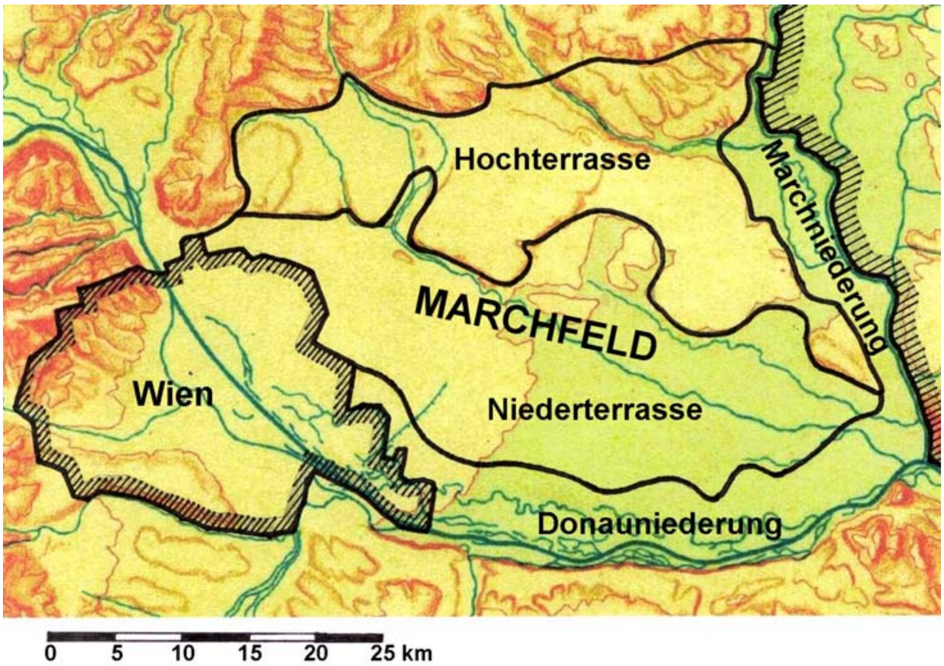

Fig. 1: Map of the Marchfeld area showing the relevant landscape units

5.2 Material and Methods

The effect of converting arable fields into forest plantation on ground water recharge is realised by comparison of their respective mean water balances, which are calculated by simulation models for the period 1978-2001. For validation of the models, the results of extensive field measurements on weather, soil moisture regime and ground water level at two sites in the central Marchfeld area were used, the one of which was situated in an agricultural experimental field while the other was established within a pine plantation.

5.2.1 Simulation models

For calculation of the water balance of field crops the model SIMWASER (STENITZER 1988) was used, while groundwater recharge below forest was assessed by the model SIMWASER_WALD (STENITZER 2001). Both models are deterministic and mechanistic using basic soil and plant properties as well as daily weather data as input. SIMWASER simulates the water balance and the crop yield of any number of crop rotations and years, provided that daily weather records (air temperature, humidity of air, global radiation, wind and precipitation) are available. The soil profile to be simulated is divided into a number of layers, usually 5-10 cm thick, down to a depth, where seasonal change of the water content is low and is believed to have minor impact upon the soil water regime. In case of capillary rise from groundwater the "model soil profile" is extended to the deepest ground water level, that is measured within the simulated period, and the daily course of groundwater level has to be included into the input data. Potential evapotranspiration, potential evaporation and potential transpiration are calculated according to the "Penman-Monteith-formula". The actual transpiration is equivalent to the root water uptake, which is the result of balanced forces at the root surface. The water balance on daily base is made at the soil surface with precipitation and irrigation as input and evaporation and transpiration as output. Interception is also taken into account. The water movement in the soil is calculated by Darcy's Law and the "continuity equation". Taking into account the soil physical parameters of each soil layer either capillary rise or seepage will be the result at the lower boundary of the soil profile. SIMWASER_WALD is based on the same principles and runs with the same input data as SIMWASER but with different “plant” parameters describing the stand architecture (height, leaf area index, light extinction), physiological (stomatal resistance) as well as aerodynamic characteristics.

5.2.2 Field measurements

Both models were validated using the soil water balances of an arable field and a pine plantation, which were measured according to the scheme illustrated in Fig. 2: Soil water content was measured by TDR-Sensors (“Trase System”, Soil Moisture Equipment Corp., Santa Barbara, California) while soil water tension was deduced from resistance readings of “Watermark” soil matric sensors and “Beckman CEL-WFD” gypsum blocks: measured block resistances at the also measured soil temperature at each measuring depth were corrected by an empirical function (STENITZER 1993) to the reference temperature at which the blocks had been calibrated in a pressure plate apparatus in the laboratory. All sensors at one site were connected to a battery powered data logger, which each hour automatically stored the measurements.

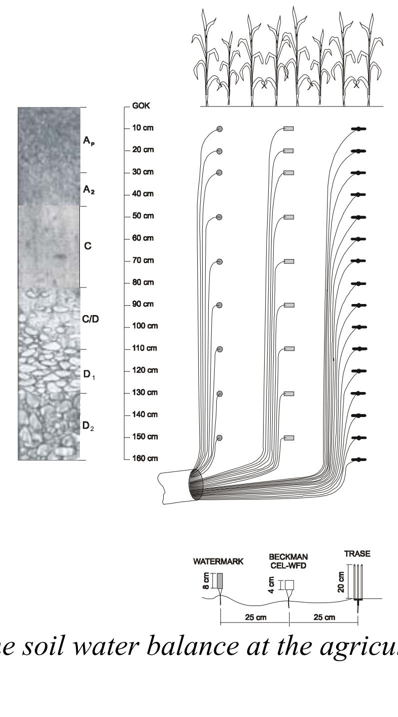

Fig. 2: Measuring scheme for the soil water balance at the agricultural field

Daily weather data were gathered automatically by a weather station near each measuring site and furthermore through fall was measured by a tipping bucket rainfall station at the soil moisture station in the pine plantation. Ground water level was continuously observed below the agricultural site as well as in the pine plantation.

Daily actual evapotranspiration was calculated by subtracting change in water storage and deep percolation from rainfall. Deep percolation was derived as the (positive) product of the hydraulic gradient across the deepest measuring depth and it's hydraulic conductivity as function of the matric potential. This function was derived from the soil moisture characteristic according to the method of Millington & Quirk (BOWER and JACKSON 1974) with the soil moisture characteristic deduced from concurrent field measurements of soil moisture and soil water tension. The fitting point for the conductivity curve was estimated from hourly measurements either of a evaporation or drainage situation with known water fluxes. Both soil moisture characteristic and hydraulic conductivity function were calibrated by running the models during periods of dormant vegetation and comparing the simulated and measured water contents.

5.3 Results

Model validation

Validation of SIMWASER at the agricultural site (Fig. 3, Fig. 4) and of SIMWASER_WALD in the pine plantation (Fig. 5, Fig. 6) is shown below: simulated soil water storage, evapotranspiration and drainage closely followed the respective measurements and we may suppose, that both models will yield realistic results for the case study.

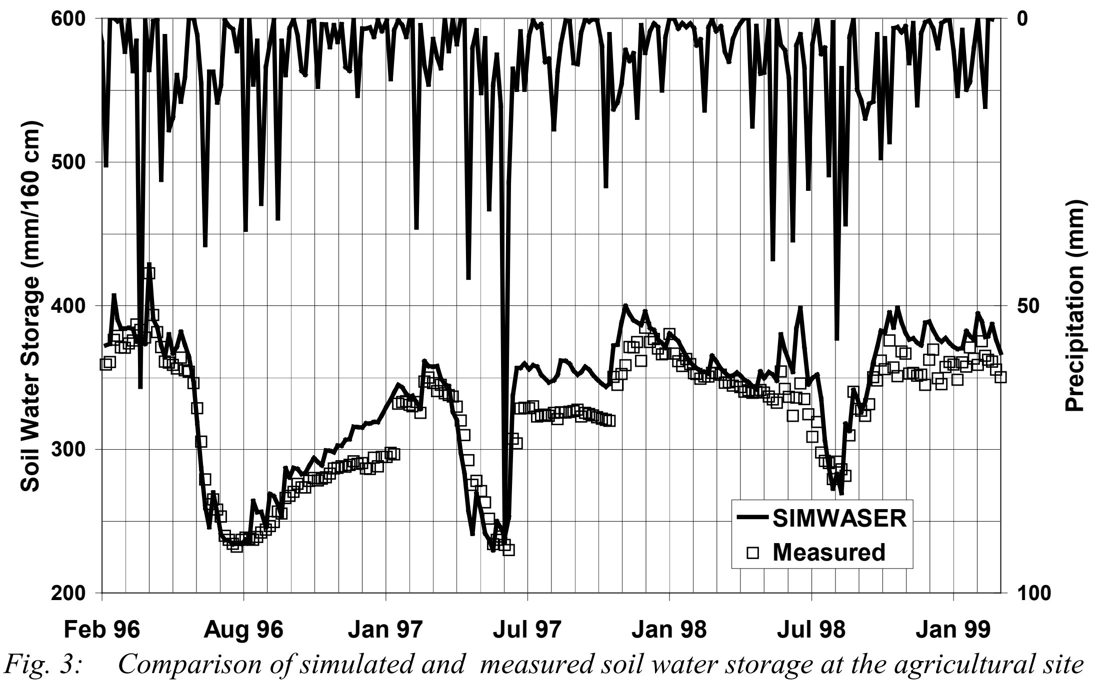

Fig. 3: Comparison of simulated and measured soil water storage at the agricultural site

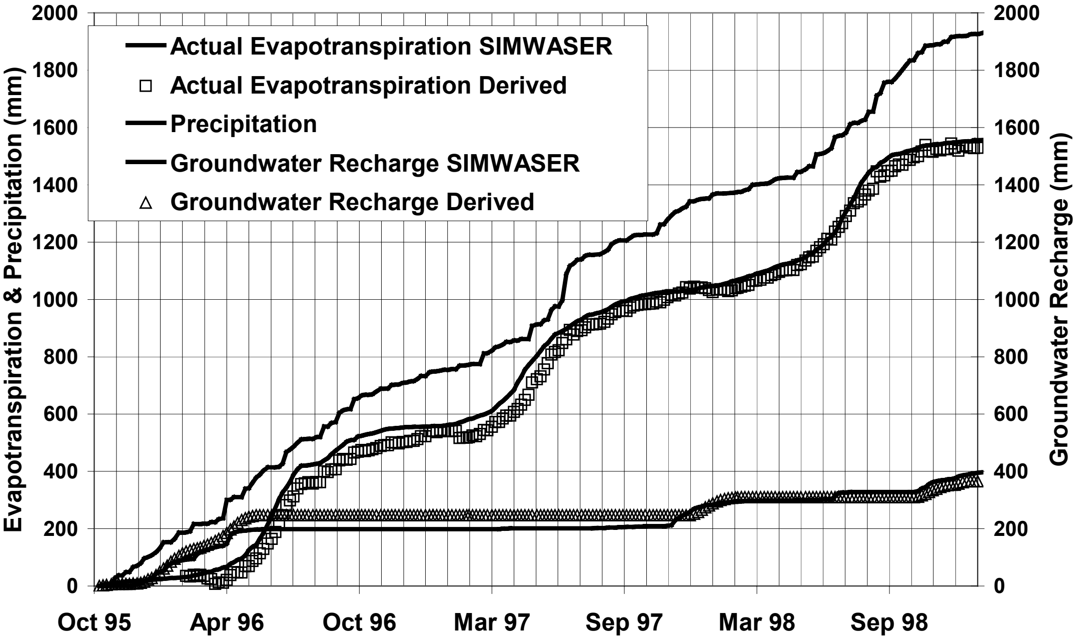

Fig. 4: Comparison of simulated and measured evapotranspiration and drainage at the agricultural site

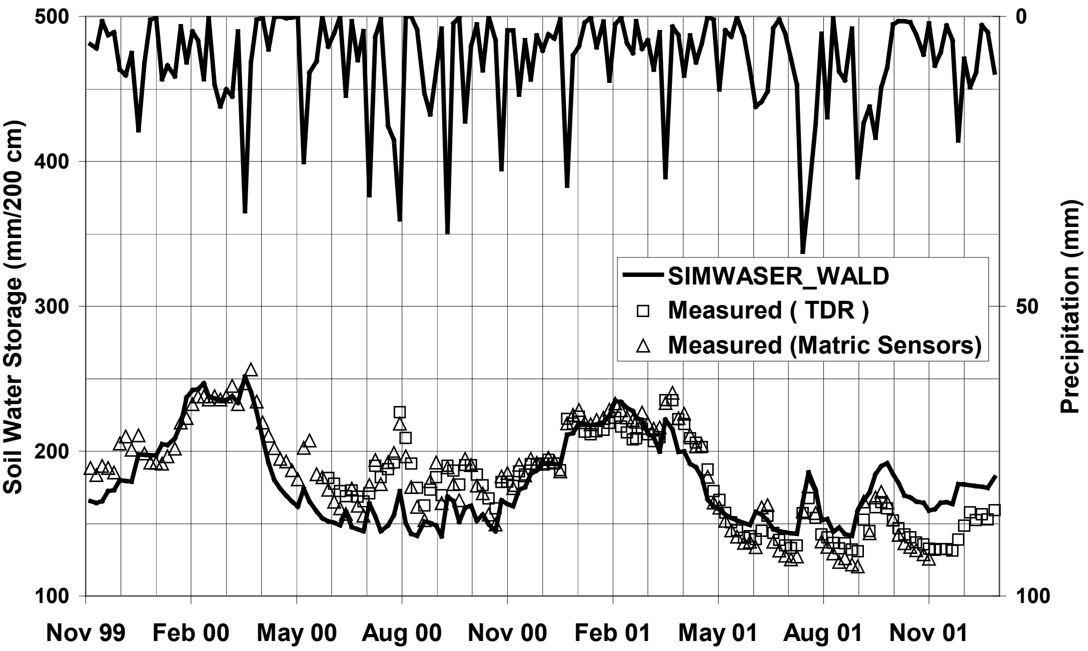

Fig. 5: Comparison of simulated and measured soil water storage at the pine plantation

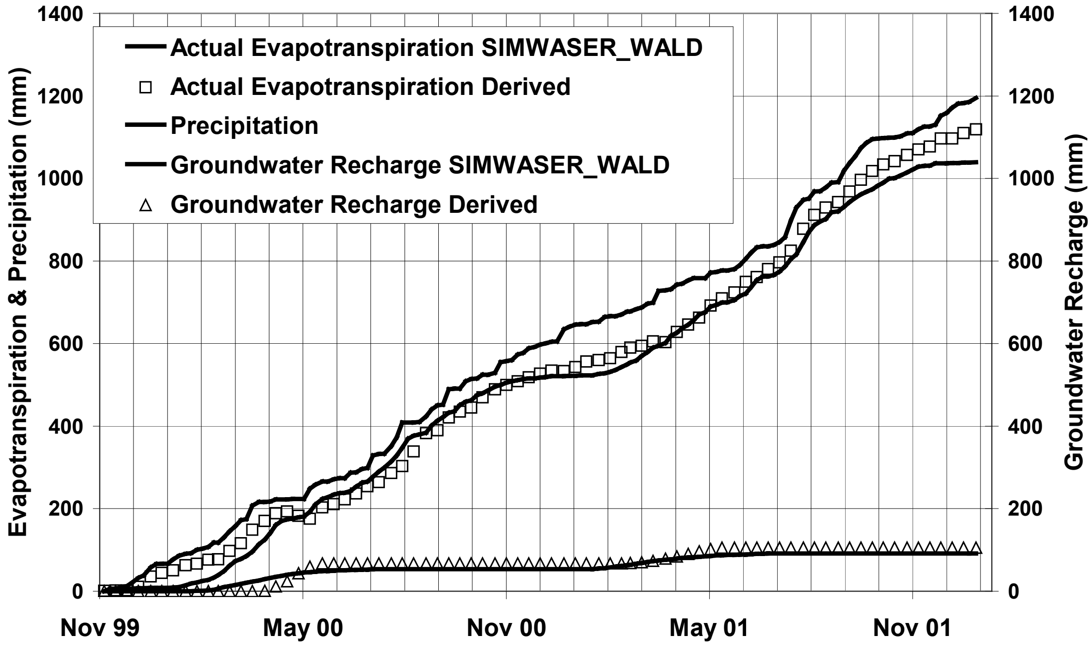

Fig. 6: Comparison of simulated and measured evapotranspiration and drainage at the pine plantation

5.4 Case study

A case study on the long term effect of afforestation of two typical soil types on their ground water recharge was made for a period of 24 years using the weather data 1978 - 2001 of the agricultural site. The first soil is a "Tschernosem" of medium depth down to 80-90 cm as shown in Fig. 2, while this second soil is a very shallow "Paratschernosem" with only 30-40 cm fine earth overlying stony and gravely deposits. Simulation results are summarised in the table below, showing that due to afforestation groundwater recharge will be reduced by more than 90 % on medium valued deep soils and be halved on the low yielding shallow soils.

Table 1

WATER BALANCE 1978-2001 (mm/a)				
	Precipitation	Evaporation	Change of soil moisture	Ground water recharge
Deep Agricultural	520	440	5	75
Deep Pine Plantation	520	510	5	5
Shallow Agricultural	520	410	0	110
Shallow Pine Plantation	520	460	5	55

5.5 References

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6 PROGRAM SOURCE:

program simwaser

```
include 'simwaser_inc.for'
      pfad='C:\SIMWASER_2002\SIMWASER\MODELLSTANDORTE\'
      CALL MODELLDATENSATZ
      CALL INPUT_OUTPUT_ORGANISATION
      CALL PROFIL

      READ(1,'(X,a15,x,i4,X,i4,i2,i2,X,i4,i2,i2)',END=900) CROP,
     1    ICROP,IDATB,IDATE
      monat=idatb(2)
      ntag=idatb(3)

      write(6,'(a80,x,a30)') place,icrop
      CALL INITIALIZE
      CALL BEGIN
      CALL LINKTO

      goto 150



 100  READ(1,'(X,a15,x,i4,X,i4,i2,i2,X,i4,i2,i2)',end=900) CROP,
     1     ICROP,IDATB,IDATE
      write(6,'(i4,xx,i4,2i2)') icrop,idatb
      DRAING=0.0
      GWRISE=0.0
      monat=idatb(2)
      ntag=idatb(3)

      call BEGIN

 150  read (2,rec=irec2) (lval(j),j=1,nvr)    ! Wetterdaten lesen
      if (peg(1:1).ne.' ') then
         read (3,rec=irec3) (mval(j),j=1,mvr)
         fla=mval(4)*.1
      end if
      irec2=irec2+1           ! incr. Rec-Nr.
      irec3=irec3+1
      rrsoil=rsoil+p(1)*0.01

 160  CALL WETTER

 190  IF(ICROP.EQ.0) goto 350
      if(ifrost.eq.1) goto 320
      if(daylgt.lt.cdayl) then
        ssptu=riping*0.041
        sumptu=riping*0.041
        drymat=50.
        grnlai=0.2
        sumlai=0.2
        goto 320
      end if
      if(temp.lt.ttemp(41,itclss)) then
      WRITE(9,1080)IYEAR,MONTH,IDAY,SUMWAT,SUMTRS,SUMETA,sumei,
     1   GWRISE,sumrain,DRAING,rain,snow,STRSSF,DRYMAT,sumrdm
 1080 FORMAT(I4,2I2.2,12f7.0)
      DRAING=0.0
      GWRISE=0.0
      call frost
```

```
      if(icrop.eq.0) goto 350
      end if
320  IF(PTU.GT.0.0) goto 330
      PTU=0.0
330  SUMPTU=SUMPTU+PTU
      ssptu=ssptu+ptu
      ptusum=ptusum+ptu
      DEVSTG=(SUMPTU/RIPING)*10.
      if(devstg.gt.11.0) devstg=11.0
      idvstg=int(devstg*10.+.5)
      rdevstg=(ptusum/rriping)*10.
      if(rdevstg.gt.10.0) rdevstg=10.0
      irdvstg=int(rdevstg*10.+0.5)

      IF(DEVSTG.LT.0.4) goto 350

      CALL POTRANS
      CALL ROOTEX
      IF(DEVSTG.GT.10.) goto 360
      CALL GROWTH
      PTU=PTU+DELTAT
      SUMPTU=SUMPTU+DELTAT
      goto 360

350  CALL EVAPOR

360  eta=asevap+atrans+ei+sublim
      sumeta=sumeta+eta
      sumtrs=sumtrs+atrans

      CALL OUTPUT_RESULT

      aday=aday+1.
      mday=mday+1
      call INCDT(idatl(1),idatl(2),idatl(3))
      IF(idatl(1)-idate(1)) 455,451,460
451  IF(idatl(2)-IDATE(2)) 455,452,460
452  IF(idatl(3)-IDATE(3)) 455,455,460
455  GOTO 150

460  CALL OUTPUT_WLAYER

      GOTO 100
900  STOP
      END
```

Simwaser_inc.for

```
CHARACTER crop*19,csoil*20,filboden*150,filgw*150,
     1  fili*150,peg*150,pegel*150,pfad*150,pflanzenart*15,
     2  place*80,stn*31,stnn*80,wetterstation*150
      INTEGER*2 lval,mval
      COMMON/ARR01/COND(90,20),PLANTF(12,10),PSI(90,20),RGF(90,20),
     1 RRGF(100,3),TTEMP(42,5)
      COMMON/ARR02/C(50),depth(50),diff(90),efficiency(110),effsat(50),
     1 frhgtg(50),frrotg(100),fwlog(50),h(50),idatb(3),idate(3),
     2 idati(3),idatl(3),isoil(50),lval(20),mval(4),P(50),RD(50),
     3 rdm(50),RF(50),rextr(50),sicker(50),V0(50),W(50),WSAT(50),
     4 W0(50),Z(50)
      COMMON/VAR01/airmin,alpha,areawt,asevap,asymp,atrans
      COMMON/VAR02/bastmp,bew
      COMMON/VAR03/cdayl,crootl,crop,csoil
      COMMON/VAR04/d1,daylgt,ddryweight,depthirrig,deltat,devstg,dfla,
     1 draing,drymat
      COMMON/VAR05/ei,egreen,energy,eta,etamean,etpot,etotal,excoef,
     1 expar
      COMMON/VAR06/f,f_aeration,fbulk,filboden,fili,filgw,fla,flxgw,
     1 flxrd,flxtop,freeze,fresp,fwind
      COMMON/VAR07/gfla,globr,grnlai,gwneu,gwneumean,gwrise
      COMMON/VAR08/icrp,icrop,iday,idvstg,ifrost,ipv,irdvstg,irec2,
     1 irec3,irrigation,irtclss,is,itclss,iyear
      COMMON/VAR09/mday,mdayi,mmr,monat,month,mrd,mvr
      COMMON/VAR10/n,nbew,nbilanz,nirrigation,npeg,nroot,ntag,nvr
      COMMON/VAR11/peg,pegel,pfad,pflanzenart,pflux,photsr,place,plthgt,
     1 potevap,pothgt,profiltiefe,psevap,ptrans,ptu,ptusum
      COMMON/VAR12/R,rain,rair,rcrop,rdevstg,riping,rhgtg,rmleaf,
     1 rriping,rsoil,rootdmgain,rootdrymat,rootds,rootf,rootlg,rrotg,
     2 rrsoil
      COMMON/VAR13/satdef,slope,snow,ssptu,stn,stnn,sstrss,strssf,
     1 strssfwlg,sstrsd,sublim,sumbew,sumbot,sumei,sumeta,sumlai,sumptu,
     2 sumrain,sumrdm,sumrunoff,sumtrs,sumwat
      COMMON/VAR14/temp,text,totlai
      COMMON/VAR15/wetterstation,wind,widthleaf
```

subroutine BEGIN

```
      include 'simwaser_inc.for'
      character text*150
      rewind (unit=7)
c  Einlesen der Bestandeskennwerte
      do i=1,10
        read(7,'(a)') text
      end do
   5  read(7,100,iostat=iostat,end=1000)pflanzenart,icode,excoef,
     1  areawt,POTHGT,RMLEAF,PHOTSR,ITCLSS,ROOTLG,ROOTDS,
     1  IRTCLSS,widthleaf,RIPING,grnlai,airmin,cdayl
      if(pflanzenart(1:14).eq.crop(1:14)) goto 200
      goto 5
100  format(x,a15,x,i2,x,f4.2,x,f5.4,x,f3.1,x,f3.1,x,f4.1,x,i1,x,
     1      f3.0,x,f3.1,x,i1,x,f4.1,x,f5.0,x,f4.3,x,f4.1,x,f4.1)
200  write(20,300)idatb,pflanzenart,icode,excoef,
     1  areawt,POTHGT,RMLEAF,PHOTSR,ITCLSS,ROOTLG,ROOTDS,
     1  IRTCLSS,widthleaf,RIPING,grnlai,airmin,cdayl
 300  format(i4,i2,i2,x,a15,x,i4,x,f4.2,x,f5.4,x,f3.1,x,f3.1,x,f4.1,
     1    x,i1,x,f3.0,x,f3.1,x,i1,x,f4.1,x,f5.0,x,f4.3,x,f4.2,x,f4.1)
      ifrost=0
      ETOTAL=1.0
      SUMETA=0.0
      sumei=0.0
      SUMRAIN=0.0
      sumrunoff=0.0
      sumbew=0.0
rriping=riping
IF (ICROP.EQ.0) THEN
        icrp=0
        do i=1,n
          rextr(i)=0.0
          rd(i)=0.0
          rdm(i)=0.0
        end do
C   INITIAL VALUES FOR CROPPING ELEMENT FALLOW
         ATRANS=0.0
         SUMTRS=0.0
         PLTHGT=0.0
         rsoil=rmleaf
         sumlai=0.0
         GRNLAI=0.0
         totlai=0.0
         DRYMAT=0.0
         rootdrymat=0.0
         sumrdm=0.0
         crootl=0.0
         strssf=0.0
         NROOT=0
         RETURN
       END IF
C       CONSTANTS & INITIAL VALUES FOR CURRENT CROP
 10     IF(ICROP.LT.1000) THEN
         ICRP=ICROP
       ELSE
         ICRP=ICROP-1000
         if(icrp.gt.1000) icrp=icrp-1000
        END IF

        expar=excoef*1.5
        alpha=0.1+.005*photsr
        widthleaf=alog(widthleaf)


C      TEMPERATURE- & DEVELOPMENT-FUNCTION OF CURRENT CROP
```

```
      bastmp=ttemp(42,itclss)
      freeze=ttemp(41,itclss)

      RHGTG=1./(.45*RIPING)
      RROTG=1./(.30*RIPING)

C     SLOPE & ASYMPTOTE OF LIGHT RESPONSE CURVE OF CURRENT CROP
      SLOPE=-.005+.025/RMLEAF
      ASYMP=.05+1.05/RMLEAF

C     INITIAL VALUES OF CURRENT CROP

      PLTHGT=0.05*POTHGT
      POTHGT=0.95*POTHGT

     if(icrop.gt.1000) then
        ssptu=riping*0.041
        sumptu=riping*0.041
        grnlai=0.10
        sumlai=0.20
        rsoil=1.3
        drymat=100.
        goto 20
     end if
NROOT=1
      CROOTL=1.
      SUMPTU=0.0
      ptusum=0.0
      rootdmgain=50.
      rootdrymat=50.
      sumrdm=50.
      DRYMAT=50.
      do i=1,n
       if(crootl.le.depth(i)) then
         nroot=i
         goto 15
       end if
end do

 15     rtdm=rootdrymat/nroot
do i=1,nroot
        rdm(i)=rtdm
        rd(i)=rdm(i)*.010
       end do
 20     atrans=0.0
       sumlai=grnlai
       totlai=grnlai
       SUMTRS=0.0
       SUMETA=0.0
       sumei=0.0
       FBULK=0.0
       STRSSF=1.0
       SSTRSD=0.0
       SSTRSS=0.0

       ETOTAL=EXP(-EXCOEF*TOTLAI)
       EGREEN=EXP(-EXPAR*GRNLAI)
       DO I=1,N
         W0(I)=WSAT(I)-AIRMIN
       END DO
C
     RETURN
 1000 END
```

subroutine BEWAESSERUNG

```
      include 'simwaser_inc.for'
      integer*4 day_diff
C
      if(mday.eq.mdayi) then
        bew=depthirrig
        nbew=nbew+1
        if(nbew.gt.nirrigation) goto 100
        read(4,'(i4,x,i2,x,i2,x,f10.1)') jyear,jmonth,jday,depthirrig
        mdayi=day_diff(jyear,jmonth,jday)
      end if
C
  100 RETURN
      END
```

integer*4 **function DAY_DIFF**(iyear,month,iday)

```
integer*2 iyear, month, iday
integer*2 month_day(12)
data month_day/31,28,31,30,31,30,31,31,30,31,30,31/
if (iyear.lt.1900) then
day_diff=-1                    ! signals error
else
day_diff=0
do j=1900,iyear-1
if ((j.and.3).ne.0) then
m=365
else
m=366
end if
day_diff=day_diff+m
end do
if ((iyear.and.3).ne.0) then
month_day(2)=28
else
month_day(2)=29
end if
do j=1,month-1
day_diff=day_diff+month_day(j)
end do
day_diff=day_diff+iday
end if
return
end
```

subroutine EVAPOR

```
      include 'simwaser_inc.for'



      atrans=0.0
      RAIR=0.5*fwind
      PSEVAP=(F*ENERGY+.864*SATDEF/RAIR)/(F+1.+rrsoil/RAIR)
      if(psevap.lt.0) then
        asevap=0.0
        goto 50
      end if

      WS=W(1)
      IF (WS.GT.WSAT(1)) WS=WSAT(1)

      SEVAP=.41*DIFF(int(WS))**.56

      IF(PSEVAP.GT.SEVAP) THEN
        ASEVAP=SEVAP
      ELSE
        ASEVAP=PSEVAP
      END IF

      wms=w(1)*h(1)
      if(asevap.gt.wms) asevap=wms*.1


 50   if(peg(1:1).eq.' ') then
        call fargw_brache
      else
        call neargw_brache
      end if

      RETURN
      END
```

subroutine FARGW_BRACHE

```
      include 'simwaser_inc.for'

      SUMTIM=0.0
      FLXGW=0.0
      FLXBD=0.0
      SUMWAT=0.0
      runoff=0.0

      if(snow.gt.0.0) then
        asevap=0.0
        if(snow.lt.sublim) then
          sublim=snow
          snow=0.0
          goto 200
        end if
        snow=snow-sublim
 200      flxtop=rain+bew
        goto 210
      end if


     FLXTOP=RAIN+BEW-ASEVAP

C      TIMESTEP

 210  nstau=0
     TIMSTP=0.1
     X=FLXTOP
     do i=1,n
       Y=ABS(X-V0(I))
       if(y.eq.0.0) goto 215
       IF(Y.GE.H(I)*.1/TIMSTP) THEN
         TIMSTP=H(I)*.1/Y
       END IF
 215    X=V0(I)
     END DO

     SUMTIM=SUMTIM+TIMSTP
     IF(SUMTIM.GT.1.0) THEN
        TIMSTP=1.0-(SUMTIM-TIMSTP)
        SUMTIM=1.0
     END IF

C      WATER MOVEMENT WITHIN THE SOIL PROFILE

     FLUXT=FLXTOP*TIMSTP
     j=isoil(1)
     fluxb=v0(1)*timstp
     w(1)=w(1)+(fluxt-fluxb)/h(1)
     if(w(1).lt.1.0) then
       p(1)=psi(1,j)
       c(1)=cond(1,j)
       goto 320
     end if

     if(w(1).lt.effsat(1)) then
       x=w(1)-int(w(1))
       y=1.0-x
       p(1)=psi(int(w(1)+1.),j)*x+psi(int(w(1)),j)*y
       c(1)=cond(int(w(1)+1.),j)*x+cond(int(w(1)),j)*y
     else
       nstau=1
       iw=int(effsat(1))
       is=isoil(1)
```

```
      p(1)=psi(iw,is)
      c(1)=cond(iw,is)
     end if

 320  v0(1)=(c(1)+c(2))*.5*((p(2)-p(1))/z(1)+1.0)
     fluxt=fluxb

     DO I=2,(n-1)
      J=ISOIL(I)
      FLUXB=V0(I)*TIMSTP
      W(I)=W(I)+(FLUXT-FLUXB)/H(I)
      if(w(i).lt.1.0) then
        p(i)=psi(1,j)
        c(i)=cond(1,j)
        goto 330
      end if

        IF(W(I).LT.effsat(I)) THEN
          X=W(I)-INT(W(I))
          Y=1.0-X
          P(I)=PSI(int(W(I)+1.),J)*X+PSI(int(W(I)),J)*Y
          C(I)=COND(int(W(I)+1.),J)*X+COND(int(W(I)),J)*Y
        ELSE
          nstau=1
          iw=int(effsat(i))
          is=isoil(i)
          p(i)=psi(iw,is)
          c(i)=cond(iw,is)
        END IF

 330      V0(I)=(C(I)+C(I+1))*.5*((P(I+1)-P(I))/Z(I)+1.0)
        FLUXT=FLUXB
        if(i.eq.mrd) flxgw=flxgw+fluxb
      END DO

C     FLUX AT BOTTOM OF unsaturated SOIL PROFILE

      j=isoil(n)
      fluxb=v0(n)*timstp
      w(n)=w(n)+(fluxt-fluxb)/h(n)

      if(w(n).lt.1.0) then
        p(n)=psi(1,j)
        c(n)=cond(1,j)
        goto 340
      end if

      if(w(n).lt.effsat(n)) then
        X=W(n)-INT(W(n))
        Y=1.0-X
        P(n)=PSI(int(W(n)+1.),J)*X+PSI(int(W(n)),J)*Y
        C(n)=COND(int(W(n)+1.),J)*X+COND(int(W(n)),J)*Y
      else
        nstau=1
        p(n)=psi(int(effsat(n)),isoil(n))
        c(n)=cond(int(effsat(n)),isoil(n))
      end if

 340    v0(n)=c(n)

     if(n.eq.mrd) flxgw=flxgw+fluxb
c---------------------------------------------

      if (nstau.eq.1) then
        do i=n,2,-1
```

```
          if(w(i).ge.effsat(i)) then
            delta=w(i)-effsat(i)
            j=isoil(i)
            w(i)=effsat(i)
            i1=i-1
            w(i1)=w(i1)+delta*h(i)/h(i1)
          end if
        end do

        if(w(1).ge.effsat(1)) then
          runoff=runoff+(w(1)-effsat(1))*h(1)
          w(1)=effsat(1)
          iw=int(effsat(1))
          is=isoil(1)
          p(1)=psi(iw,is)
          c(1)=cond(iw,is)
        end if

        do i=2,n
          if(w(i).gt.effsat(i)) then
            iw=int(effsat(i))
            is=isoil(i)
            p(i)=psi(iw,is)
            c(i)=cond(iw,is)
            goto 345
          end if

        j=isoil(i)
        x=w(i)-int(w(i))
        y=1.0-x
        p(i)=psi(int(w(i)+1.),j)*x+psi(int(w(i)),j)*y
        c(i)=cond(int(w(i)+1.),j)*x+cond(int(w(i)),j)*y
 345    continue
        end do

        do i=1,n-1
          v0(i)=(c(i)+c(i+1))*.5*((p(i+1)-p(i))/z(i)+1.0)
        end do
        v0(n)=c(n)
       end if
c-----------------------------------------------------------
      IF(SUMTIM.NE.1.0) GO TO 210
      sumrunoff=sumrunoff+runoff
      DO I=1,MRD
        SUMWAT=SUMWAT+W(I)*H(I)
      END DO

     if(flxgw.lt.0.0) then
       flxbd=flxgw
       flxgw=0.0
       gwrise=gwrise+flxbd
       goto 350
     end if
      DRAING=DRAING+FLXGW

 350  RETURN
      END
```

subroutine FARGW_CROP

```
       include 'simwaser_inc.for'

       SUMTIM=0.0
       FLXGW=0.0
       FLXBD=0.0
       SUMWAT=0.0
       runoff=0.0
       atrans=0.0

       if(snow.gt.0.0) then
         asevap=0.0
         if(snow.lt.sublim) then
           sublim=snow
           snow=0.0
           goto 200
         end if
         snow=snow-sublim
         asevap=sublim
 200       flxtop=rain+bew
         goto 210
       end if


      FLXTOP=RAIN+BEW-ASEVAP

C      TIMESTEP

 210  nstau=0
      TIMSTP=0.1
      X=FLXTOP
      do i=1,n
        Y=ABS(X-V0(I))
        if(y.eq.0.0) goto 215
        IF(Y.GE.H(I)*.1/TIMSTP) THEN
          TIMSTP=H(I)*.1/Y
        END IF
 215  X=V0(I)
      END DO

      SUMTIM=SUMTIM+TIMSTP
      IF(SUMTIM.GT.1.0) THEN
         TIMSTP=1.0-(SUMTIM-TIMSTP)
         SUMTIM=1.0
      END IF

C      WATER MOVEMENT WITHIN THE SOIL PROFILE
C ------------------------------------------------------
C      ROOT EXTRACTION

      trans=0.0
      do i=1,n
        rextr(i)=0.0
      end do

      if(snow.gt.1.or.ptrans.le.0.0) then
         r=1.0
         goto 310
      end if

      sprex=0.0
      DO I=1,NROOT
        P1=1500.-P(I)
        IF(P1.GT.0.0) GO TO 260
        P1=0.0
```

```
 260    rres=1.0E2/efficiency(idvstg)
       REXTR(I)=((FWLOG(i)*P1*RD(I)/(rres+1.0/C(I))))*timstp
 265    if(rextr(i).lt.0.0) rextr(i)=0.0
       SPREX=SPREX+REXTR(I)
      end do
      r=sprex/(ptrans*timstp)
      if(r.lt.1.0) goto 300
      do i=1,nroot
       rextr(i)=rextr(i)/r
      end do
      r=1.0

 300  do i=1,nroot
       trans=trans+rextr(i)
      end do
c ------------------------------------------------------------------
 310    FLUXT=FLXTOP*TIMSTP
       j=isoil(1)
       fluxb=v0(1)*timstp
       w(1)=w(1)+(fluxt-fluxb-rextr(1))/h(1)
       if(w(1).lt.1.0) then
        p(1)=psi(1,j)
        c(1)=cond(1,j)
        goto 320
       end if

       if(w(1).le.effsat(1)) then
        x=w(1)-int(w(1))
        y=1.0-x
        p(1)=psi(int(w(1)+1.),j)*x+psi(int(w(1)),j)*y
        c(1)=cond(int(w(1)+1.),j)*x+cond(int(w(1)),j)*y
       else
        nstau=1
        iw=int(effsat(1))
        is=isoil(1)
        p(1)=psi(iw,is)
        c(1)=cond(iw,is)
       end if

 320    v0(1)=(c(1)+c(2))*.5*((p(2)-p(1))/z(1)+1.0)
       fluxt=fluxb

       DO I=2,(n-1)
        J=ISOIL(I)
        FLUXB=V0(I)*TIMSTP
        W(I)=W(I)+(FLUXT-FLUXB-rextr(i))/H(I)
       if(w(i).lt.1.0) then
        p(i)=psi(1,j)
        c(i)=cond(1,j)
        goto 330
       end if

        IF(W(I).LE.effsat(I)) THEN
         X=W(I)-INT(W(I))
         Y=1.0-X
         P(I)=PSI(int(W(I)+1.),J)*X+PSI(int(W(I)),J)*Y
         C(I)=COND(int(W(I)+1.),J)*X+COND(int(W(I)),J)*Y
        ELSE
         nstau=1
         P(I)=PSI(int(effsat(I)),isoil(i))
         C(I)=COND(int(effsat(I)),isoil(i))
        END IF

 330     V0(I)=(C(I)+C(I+1))*.5*((P(I+1)-P(I))/Z(I)+1.0)
        FLUXT=FLUXB
```

```
          if(i.eq.mrd) flxgw=flxgw+fluxb
        END DO

C       FLUX AT BOTTOM OF unsaturated SOIL PROFILE

        j=isoil(n)
        fluxb=v0(n)*timstp
        w(n)=w(n)+(fluxt-fluxb-rextr(n))/h(n)

        if(w(n).lt.1.0) then
          p(n)=psi(1,j)
          c(n)=cond(1,j)
          goto 340
        end if

        if(w(n).le.effsat(n)) then
          X=W(n)-INT(W(n))
          Y=1.0-X
          P(n)=PSI(int(W(n)+1.),J)*X+PSI(int(W(n)),J)*Y
          C(n)=COND(int(W(n)+1.),J)*X+COND(int(W(n)),J)*Y
        else
          nstau=1
          p(n)=psi(int(effsat(n)),isoil(n))
          c(n)=cond(int(effsat(n)),isoil(n))
        end if

 340    v0(n)=c(n)

       if(n.eq.mrd) flxgw=flxgw+fluxb
c---------------------------------------------
        if (nstau.eq.1) then
          do i=n,2,-1
            if(w(i).ge.effsat(i)) then
              delta=w(i)-effsat(i)
              j=isoil(i)
              w(i)=effsat(i)
              i1=i-1
              w(i1)=w(i1)+delta*h(i)/h(i1)
            end if
          end do

          if(w(1).ge.effsat(1)) then
            runoff=runoff+(w(1)-effsat(1))*h(1)
            w(1)=effsat(1)
            iw=int(effsat(1))
            is=isoil(1)
            p(1)=psi(iw,is)
            c(1)=cond(iw,is)
          end if

          do i=2,n
            if(w(i).gt.effsat(i)) then
              iw=int(effsat(i))
              is=isoil(i)
              p(i)=psi(iw,is)
              c(i)=cond(iw,is)
              goto 345
            end if

          j=isoil(i)
          x=w(i)-int(w(i))
          y=1.0-x
          p(i)=psi(int(w(i)+1.),j)*x+psi(int(w(i)),j)*y
          c(i)=cond(int(w(i)+1.),j)*x+cond(int(w(i)),j)*y
 345      continue
```

```
          end do

          do i=1,n-1
            v0(i)=(c(i)+c(i+1))*.5*((p(i+1)-p(i))/z(i)+1.0)
          end do

          v0(n)=c(n)
                end if
c-----------------------------------------------------------
      atrans=atrans+trans
        IF(SUMTIM.NE.1.0) GO TO 210
        sumrunoff=sumrunoff+runoff
        DO I=1,MRD
          SUMWAT=SUMWAT+W(I)*H(I)
        END DO

      if(flxgw.lt.0.0) then
         flxbd=flxgw
         gwrise=gwrise+flxbd
         flxgw=0.0
         goto 350
      end if
        DRAING=DRAING+FLXGW

 350    RETURN
        END
```

subroutine FROST

```
      include 'simwaser_inc.for'
      ifrost=1
      SUMTRS=0.0
      SUMETA=0.0
      sumei=0.0
      SUMRAIN=0.0
      sumrunoff=0.0
      sumbew=0.0
      do i=1,n
         rextr(i)=0.0
      end do

      FBULK=Fbulk*.1
      STRSSF=1.0
      SSTRSD=0.0
      SSTRSS=0.0
      DRYMAT=Drymat*.1

C       CONSTANTS & INITIAL VALUES FOR FROZEN CROP

      if(icrp.eq.15) goto 10
      if(icrp.eq.21) goto 10
      if(icrp.eq.30) goto 10

      rootdrymat=0.0
      DO I=1,N
        RD(I)=0.0
        rdm(i)=0.0
      END DO
      NROOT=1
      CROOTL=1.

      atrans=0.0
      ETOTAL=1.0
      EGREEN=1.0
      icrop=0
      return

 10     grnlai=0.2
      sumlai=grnlai
      totlai=2.0
      SUMPTU=0.0
      ETOTAL=EXP(-EXCOEF*TOTLAI)
      EGREEN=EXP(-EXPAR*GRNLAI)

      RETURN
      END
```

subroutine GROWTH

```
      include 'simwaser_inc.for'

      f_aeration=1.0
      f1=0.0
      do i=1,nroot
       f1=f1+fwlog(i)*h(i)
      end do
      f_aeration=f1/crootl
      if(f_aeration.gt.1.0) f_aeration=1.0

      IF(DEVSTG.GT.5.5) GO TO 2490
      IF(DEVSTG.LT.4.5) GO TO 2490
      SSTRSD=SSTRSD+1.
      SSTRSS=SSTRSS+R
      STRSSF=SSTRSS/SSTRSD


 2490 if(temp.lt.1.0) then
        tfass=0.0
        go to 4650
      end if
      itemp=int(temp)
      tfass=ttemp(itemp,itclss)
      effphot=photsr*efficiency(idvstg)*r

 2600 pflux=0.0
      dlai=grnlai*0.10
      par=globr*0.5
      do i=1,10
        efflai=dlai*i
        effglob=exp(-expar*efflai)*par*(expar/0.9)*r
        a=effphot+alpha*effglob
        b=a*a-4.*alpha*effglob*effphot
        if(b.lt.0.0) b=0.0
        dflux=(a-sqrt(b))*0.5*dlai
        pflux=pflux+dflux
      end do
 2800 ASSIM=.75*PFLUX*DAYLGT*TFASS*R*0.8*f_aeration

C     PLANT GROWTH

      frdmat=exp(0.26-0.52*rdevstg)
      froot=2.0*frdmat
      fdeadl=exp(-4.51+.451*devstg)
      ftotlai=exp(-5.5+.5*devstg)
      FRESP=10.**(0.0642*temp-3.9263)*efficiency(idvstg)

      IF(DEVSTG.LT.5.0) GO TO 4200
      FBULK=1.0
      GO TO 4500
 4200 FBULK=exp(-3.22+2.00*log(devstg))
 4400 PLTHGT=PLTHGT+RHGTG*PTU*frhgtg(idvstg)*R*POTHGT
 4500 if (icrop.gt.2000) irdvstg=99
      rrlg=frrotg(irdvstg)*rrotg

      CROOTL=CROOTL+rrlg*PTU*froot*ROOTLG*RF(nroot)
      if(crootl.gt.profiltiefe) crootl=profiltiefe
 4600 maintenance=drymat*fresp
      ddryweight=assim-maintenance
      rootgain=ddryweight*frdmat
      rootloss=rootdrymat*fresp
      if(rdevstg.gt.10.0) rootloss=0.0
      rootdmgain=rootgain-rootloss
      rootdrymat=rootdrymat+rootdmgain
```

```
      DMGAIN=ddryweight-rootgain
      GBULK=DMGAIN*FBULK
      dleafmass=dmgain-gbulk

      DRYMAT=DRYMAT+DMGAIN-maintenance
      claigain=dleafmass*areawt

      sumlai=sumlai+claigain
      totlai=sumlai-sumlai*ftotlai
      if(totlai.lt.0.1) totlai=0.1
      grnlai=sumlai-sumlai*fdeadl
      if(grnlai.lt.0.0) grnlai=0.0
      EGREEN=EXP(-EXPAR*GRNLAI)
      extot=excoef-0.2*fdeadl
      etotal=exp(-extot*totlai)


4650  RETURN
      END
```

subroutine HYDRAP

```
      include 'simwaser_inc.for'
      dimension iws(10),p1(20),val(3,5),wg(20),ak(20),ap(20),
     1apsi(80),b(20)
      character csoils*25,text*150

      do i=1,10
        iws(i)=0
      end do

      m=index(csoil,' ')

      csoils=csoil(1:m-1)//'.bkw'
      m=index(pfad,' ')
      text=' '
      m1=index(pfad,' ')
      m2=index(place,' ')
      m3=index(csoils,' ')

      text(1:m1)=pfad
      text(m1:(m1+m2))=place
      m=index(text,' ')
      text(m:m)='\'
      text((m+1):(m+1+m3))=csoils

      open (unit=13,file=text,status='old')
      READ(13,'(a)') TEXT
      READ(13,'(30x,i2)') NCURVE
      DO I=1,NCURVE
        READ(13,'(30x,i2)') IWS(I)
      end do
      DO I=1,3
        READ(13,'(a)') TEXT
      end do

      DO I=1,NCURVE
        IF(IWS(I).GT.IPV) GO TO 220
      end do
  220 I1=I-1
      I2=I
      if(i1.eq.0) then
         i1=1
         x=1
         goto 230
      end if

      X1=(IPV-IWS(I1))
      X2=(IWS(I2)-IWS(I1))
      X=X1/X2

  230 DO I=1,20
        READ(13,1030) P1(I),VAL
        AP(I)=LOG10(P1(I))
        WG(I)=VAL(1,I1)+(VAL(1,I2)-VAL(1,I1))*X
        A=VAL(2,I1)+(VAL(2,I2)-VAL(2,I1))*X
        B(I)=VAL(3,I1)+(VAL(3,I2)-VAL(3,I1))*X
        AK(I)=LOG10(A)
      end do
 1030 FORMAT(E6.1,5(X,F4.1,X,E7.1,X,F4.1))

      NW=WG(1)
      I=1
      DO J=NW,1,-1
```

```
      WJ=J
310   IF(WJ.GE.WG(I+1)) GO TO 320
      I=I+1
      GO TO 310
320   X=AP(I+1)-AP(I)
      Y=WG(I)-WG(I+1)
      APSI(J)=AP(I)+(X/Y)*(WG(I)-WJ)
      PSI(J,IS)=10.0**APSI(J)
    end do

    NP=20
    DO J=1,NW
400   DO I=NP,1,-1
        IF(P1(I).LE.PSI(J,IS)) GO TO 450
      end do
450   X=AP(I+1)-AP(I)
      Y=AK(I)-AK(I+1)
      Y1=B(I)-B(I+1)
      Z1=AP(I+1)-APSI(J)
      A=AK(I+1)+(Y/X)*Z1
      COND(J,IS)=10.0**A
      RGF(J,IS)=B(I+1)+(Y1/X)*Z1+1.
      if(rgf(j,is).gt.100.) rgf(j,is)=100.0
      NP=I+1
    end do

    CLOSE(13)
    RETURN
    END
```

subroutine INCDT (iyear, month, iday)

```
c   Datum weiterschreiben
c   beruecksichtigt Schaltjahre
c
c  call:
c     call incdt (iyear, month, iday)
c  parameter:   input und output
c     iyear...Jahr,  word
c     month...Monat, byte
c     iday....Tag,   byte
c
c  1988-01-07: 3 getrennte Parameter (statt einem einzigen)
c
c -----------------------------------------------------------------
        integer*2 iyear,
     1  days(12)/31,28,31,30,31,30,31,31,30,31,30,31/
        integer*2 month, iday

        if (mod(iyear,4).eq.0) then
          days(2)=29            ! Schaltjahr
        else
          days(2)=28
        end if

        iday=iday+1
        if (iday.gt.days(month)) then
          iday=1
          month=month+1
          if (month.gt.12) then
            month=1
            iyear=iyear+1
          end if
        end if
        return
end
```

subroutine INITIALIZE

```
include 'simwaser_inc.for'
DRAING=0.0
GWRISE=0.0

write(6,'(i4,xx,i4,2i2)') icrop,idate
fili=' '
m1=index(pfad,' ')
m2=index(place,' ')
fili(1:m1)=pfad
fili(m1:m1+m2)=place
m=index(fili,' ')
fili(m:m+22)='\pflanzenkennwerte.bkw'
open(unit=7,file=fili,status='old')

return
end
```

subroutine INPUT_OUTPUT_ORGANISATION

```
      include 'simwaser_inc.for'
      character filn*150,scr*150,fruchtfolge*100,text*150,txt*150,
     1   filbew*150
      character*7 header(50)
      integer*4 day_diff

      data header/
     1 'N= 01','N= 02','N= 03','N= 04','N= 05',
     2 'N= 06','N= 07','N= 08','N= 09','N= 10',
     3 'N= 11','N= 12','N= 13','N= 14','N= 15',
     4 'N= 16','N= 17','N= 18','N= 19','N= 20',
     5 'N= 21','N= 22','N= 23','N= 24','N= 25',
     6 'N= 26','N= 27','N= 28','N= 29','N= 30',
     7 'N= 31','N= 32','N= 33','N= 34','N= 35',
     8 'N= 36','N= 37','N= 38','N= 39','N= 40',
     9 'N= 41','N= 42','N= 43','N= 44','N= 45',
     1 'N= 46','N= 47','N= 48','N= 49','N= 50'/


      text=' '
      text(1:7)='Datum'
      text(12:16)='SUMWG'
      text(20:24)='SRAIN'
      text(29:32)='SETA'
      text(37:40)='SGWN'
      text(46:48)='STRS'
      text(52:58)='SGWRISE'
      text(61:65)='SROFF'
      text(69:73)='ETA'
      text(77:80)='RAIN'
      text(85:88)='SNOW'
      text(93:97)='FLXGW'
      text(101:104)='GRNLAI'
      text(109:114)='CROOTL'
      text(118:123)='DRYMAT'

      txt=' '
      txt(2:6)='Datum'
      txt(11:15)='SWG'
      txt(18:22)='STRS'
      txt(26:29)='SETA'
      txt(33:36)='SEI'
      txt(41:43)='GWR'
      txt(46:50)='RAIN'
      txt(53:57)='SGWN'
      txt(61:64)='IRR'
      txt(68:71)='ROFF'
      txt(75:77)='FSS'
      txt(82:84)='SGTM'
      txt(89:91)='RDM'

      open (unit=1, file='ACTUAL.SIM',status='old')

      read(1,'(a)') scr
      m=index(scr,':')+1
      place=scr(m:)
      do while (place(1:1).eq.' ' .and. place.ne.' ')
        place=place(2:)
      end do
      scr=' '
      read(1,'(a)') scr
      m=index(scr,':')+1
      fruchtfolge=scr(m:)
```

```
READ(1,'(a)')
READ(1,'(a)')

fili=' '
filn=' '
filbew=' '
filboden=' '
m1=index(pfad,' ')
m2=index(place,' ')
m3=index(fruchtfolge,' ')
filn(1:m1)=pfad
filbew(1:m1)=pfad
filboden(1:m1)=pfad
filn(m1:(m1+m2))=place
filbew(m1:(m1+m2))=place
filboden(m1:(m1+m2))=place
m=index(filn,' ')
filn(m:m)='\'
filbew(m:m)='\'
filboden(m:m)='\'
m=index(filn,' ')
filn((m):(m+m3))=fruchtfolge
filbew((m):(m+m3))=fruchtfolge
filboden((m):(m+m3))=fruchtfolge
m4=index(filn,' ')
filn(m4:(m4+12))='\ergebnisse'
filbew(m4:(m4+19))='\Bewaesserungen.txt'
filboden(m4:(m4+16))='\bodenprofil.bkw'
m5=index(filn,' ')
filn(1:m5-1)=filn
filn(m5:m5+12)='\result.neu'
open (unit=8, file=filn, status='unknown')
write(8,'(100a)') filn
filn(m5:m5+12)='\wlayer.neu'
open (unit=9, file=filn, status='unknown')
write(9,'(100a)') filn
fili(1:m1)=pfad
fili(m1:(m1+m2))=place
m=index(fili,' ')

filn(m5:m5+12)='\saugsp.neu'
open (unit=10, file=filn, status='unknown')
write(10,'(100a)') filn
write(10,'(a9,50a7)') 'Datum  ',(header(j),j=1,50)
filn(m5:m5+12)='\wasser.neu'
open (unit=11, file=filn, status='unknown')
write(11,'(100a)') filn
write(11,'(a9,50a6)') 'Datum  ',(header(j),j=1,50)

filn(m5:m5+12)='\monatsw.neu'
open (unit=21, file=filn, status='unknown')
write(21,'(100a)') filn


filn(m5:m5+12)='\input.daten'
open (unit=20, file=filn, status='unknown')
write(20,'(100a)') filn

open (unit=4,file=filbew,status='old',err=10)
irrigation=1
nbew=1
read(4,'(a)')
read(4,'(20x,i3)') nirrigation
read(4,'(i4,x,i2,x,i2,x,f10.1)') jyear,jmonth,jday,depthirrig
mdayi=day_diff(jyear,jmonth,jday)
```

```
10  write(8,'(120a)') text
    WRITE(9,'(a)') txt

    return
    end
```

subroutine LINKTO

```
      integer*2 start_date_w(3), start_date_g(3)
      character filn*150
      integer*4 day_diff
      include 'simwaser_inc.for'

      do j=1,3
        idatl(j)=idatb(j)
      end do

      jyear=idatb(1)
      mday=day_diff(jyear,idatb(2),idatb(3))
      m=index(wetterstation,' ')
      wetterstation=wetterstation(1:m-1)
      filn='c:\WETTERDATEI\'//wetterstation
      open (unit=2,file=filn,status='OLD',access='DIRECT',
     1recl=nvr*2,iostat=iostat)
      if(iostat.ne.0) then
        write(6,*) 'Wetterdatei kann nicht geoeffnet werden'
        stop
      end if
      write(6,'(a50)') wetterstation
      fili=' '
      inquire (unit=2, name=fili)
      read (2,rec=1) (start_date_w(j),j=1,3)
      mday0w=day_diff(start_date_w(1),start_date_w(2),start_date_w(3))
      irec2=mday-mday0w+1     ! Rec# vom ersten Satz in Wetterdatei

      if (peg(1:1).ne.' ') then
        pegel=' '
        m=index(peg,' ')
        pegel='c:\GRUNDWASSERDATEI\'//peg
        open (unit=3,file=pegel,status='OLD',access='DIRECT',
     1  recl=mvr*2,iostat=iostat)

        filgw=' '
        write(6,'(a50)') pegel

        inquire (unit=3, name=filgw)
        read (3,rec=1) (start_date_g(j),j=1,3)
        mday0g=day_diff(start_date_g(1),start_date_g(2),start_date_g(3))
        irec3=mday-mday0g+1     ! Rec# vom ersten Satz in Grundwasserdatei
        inquire (unit=3, recl=l_record)
      end if

      return
      end
```

subroutine MODELLDATENSATZ

```
      include 'simwaser_inc.for'

       DATA TTEMP/
     1   .00,.03,.09,.15,.30,.45,.60,.75,.90,.95,
     2   .99,1.0,1.0,1.0,.99,.98,.98,.97,.97,.96,
     3   .95,.94,.92,.90,.87,.84,.80,.76,.72,.68,
     4   .65,.61,.57,.53,.49,.45,.41,.36,.31,.25,
     5   -25.0,0.0,
     1   .00,.00,.00,.00,.18,.29,.44,.61,.76,.85,
     2   .90,.94,.97,.98,.99,1.0,1.0,1.0,1.0,1.0,
     3   1.0,1.0,.99,.99,.98,.97,.96,.95,.94,.92,
     4   .89,.85,.81,.76,.72,.67,.61,.55,.49,.43,
     5   -1.0,4.0,
     1   .00,.00,.00,.00,.00,.00,.06,.13,.21,.30,
     2   .37,.44,.51,.58,.65,.71,.76,.82,.87,.92,
     3   .96,.98,.99,1.0,1.0,1.0,1.0,1.0,1.0,1.0,
     4   1.0,.99,.98,.95,.91,.87,.84,.77,.68,.60,
     5    00.0,8.0,
     1   .00,.00,.00,.00,.00,.00,.02,.03,.06,.08,
     2   .12,.16,.20,.26,.35,.43,.52,.61,.72,.82,
     3   .94,.97,.99,1.0,1.0,1.0,1.0,1.0,1.0,1.0,
     4   1.0,.99,.98,.95,.91,.87,.84,.77,.68,.60,
     5    00.0,8.0,
     1   .00,.00,.00,.20,.30,.40,.50,.60,.70,.80,
     2   .90,.99,1.0,1.0,1.0,1.0,.95,.85,.75,.65,
     3   .54,.42,.30,.16,.07,.03,.01,.01,.01,.00,
     4   .00,.00,.00,.00,.00,.00,.00,.00,.00,.00,
     5   -03.0,3.0/

       DATA RRGF/
     1   1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,
     2   1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,0.990,
     3   0.982,0.956,0.930,0.905,0.880,0.856,0.831,0.808,0.784,0.761,
     4   0.738,0.716,0.694,0.672,0.651,0.630,0.610,0.589,0.570,0.550,
     5   0.531,0.512,0.494,0.476,0.458,0.441,0.424,0.407,0.391,0.375,
     6   0.360,0.344,0.330,0.315,0.301,0.287,0.274,0.261,0.248,0.236,
     7   0.224,0.213,0.201,0.191,0.180,0.170,0.160,0.151,0.142,0.133,
     8   0.125,0.117,0.109,0.102,0.095,0.089,0.082,0.077,0.071,0.066,
     9   0.061,0.057,0.053,0.049,0.044,0.041,0.037,0.033,0.029,0.025,
     1   0.022,0.018,0.014,0.010,0.007,0.004,0.001,0.001,0.001,0.001,
     1   1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,
     2   1.000,0.990,0.980,0.961,0.940,0.913,0.877,0.846,0.815,0.785,
     3   0.756,0.727,0.699,0.672,0.645,0.618,0.593,0.567,0.543,0.519,
     4   0.495,0.472,0.450,0.428,0.407,0.386,0.366,0.347,0.328,0.310,
     5   0.292,0.275,0.258,0.243,0.227,0.212,0.198,0.178,0.162,0.150,
     6   0.136,0.123,0.111,0.102,0.092,0.083,0.074,0.066,0.057,0.050,
     7   0.044,0.038,0.032,0.027,0.022,0.015,0.012,0.009,0.005,0.002,
     8   0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,
     9   0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,
     1   0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,
     1   1.000,1.000,1.000,1.000,1.000,1.000,0.992,0.973,0.939,0.917,
     2   0.872,0.827,0.784,0.742,0.701,0.662,0.623,0.586,0.550,0.515,
     3   0.481,0.449,0.417,0.387,0.358,0.330,0.304,0.278,0.254,0.231,
     4   0.209,0.188,0.169,0.150,0.133,0.117,0.102,0.089,0.076,0.065,
     5   0.055,0.046,0.038,0.031,0.025,0.020,0.014,0.009,0.004,0.001,
     6   0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,
     7   0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,
     8   0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,
     9   0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,
     1   0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001,0.001/
```

```
      DATA frrotg/
     1 0.05,0.05,0.06,0.06,0.07,0.07,0.08,0.09,0.10,0.11,
     2 0.13,0.15,0.18,0.20,0.23,0.26,0.29,0.34,0.40,0.46,
     3 0.56,0.67,0.78,0.89,1.00,1.12,1.28,1.40,1.55,1.70,
     4 1.85,2.00,2.12,2.24,2.32,2.40,2.45,2.48,2.49,2.50,
     5 2.49,2.40,2.30,2.10,1.80,1.65,1.40,1.30,1.20,1.10,
     6 1.05,1.00,0.95,0.90,0.85,0.81,0.77,0.74,0.71,0.70,
     7 0.68,0.65,0.62,0.59,0.56,0.53,0.50,0.48,0.46,0.44,
     8 0.42,0.40,0.38,0.36,0.34,0.32,0.30,0.28,0.27,0.26,
     9 0.25,0.24,0.23,0.22,0.21,0.20,0.19,0.18,0.17,0.16,
     1 0.15,0.14,0.13,0.13,0.12,0.12,0.11,0.10,0.10,0.10/

      DATA efficiency/
     1 1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
     2 .998,.996,.994,.991,.988,.985,.982,.979,.976,.973,
     3 .970,.967,.964,.960,.956,.952,.948,.943,.938,.933,
     4 .927,.920,.910,.902,.892,.881,.870,.858,.846,.832,
     5 .818,.804,.790,.775,.760,.745,.730,.715,.699,.683,
     6 .667,.650,.632,.614,.596,.578,.559,.540,.520,.500,
     7 .476,.455,.435,.417,.400,.385,.370,.357,.345,.333,
     8 .300,.285,.255,.225,.200,.180,.160,.140,.120,.100,
     9 .080,.065,.050,.035,.025,.015,.010,.008,.006,.005,
     1 .005,.005,.005,.005,.005,.004,.004,.004,.004,.003,
     1 .003,.003,.002,.002,.002,.001,.001,.001,.001,.001/

      DATA frhgtg/
     1 0.10,0.10,0.11,0.11,0.12,0.13,0.14,0.16,0.18,0.20,
     2 0.23,0.25,0.28,0.31,0.34,0.38,0.43,0.48,0.54,0.60,
     3 0.68,0.76,0.84,0.92,1.00,1.08,1.16,1.24,1.32,1.40,
     4 1.46,1.52,1.57,1.62,1.66,1.69,1.72,1.75,1.78,1.80,
     5 1.82,1.84,1.86,1.87,1.88,1.89,1.90,1.90,1.90,1.90/

      data nvr/20/   ! Anzahl Werte im Wetterdatensatz
      data mvr/4/    ! Anzahl Werte im Grundwasserdatensatz

      ADAY=1.
      ssptu=0.0
      snow=0.0
      ptusum=0.0
      sumdrain=0.0
      etamean=0.0
      gwneumean=0.0
      filgw=' '
      return
      END
```

subroutine MONATSMITTELWERTE

```
      include 'simwaser_inc.for'
      dimension numda(12)
      data numda/31,28,31,30,31,30,31,31,30,31,30,31/

      if (mod(iyear,4).eq.0) then
         numda(2)=29          ! Schaltjahr
        else
         numda(2)=28
      end if
c  Berechnungen
      itag=iday
      etamean=etamean+eta
      gwneumean=gwneumean+flxgw
      if(monat.eq.month.and.itag.eq.numda(monat)) then
       write(21,'(i4,2i2.2,2f10.1)')iyear,monat,iday,etamean,gwneumean
       monat=monat+1
       if(monat.gt.12) monat=1
       etamean=0.0
       gwneumean=0.0
      end if
      return
      end
```

subroutine NEARGW_BRACHE

```
      include 'simwaser_inc.for'

      SUMTIM=0.0
      FLXGW=0.0
      FLXBD=0.0
      SUMWAT=0.0
      runoff=0.0

C     BOUNDARY CONDITION AT GROUNDWATER LEVEL

      GFLA=FLA-DFLA
      if(gfla.le.0.0) then
         DO I=1,MRD
           SUMWAT=SUMWAT+W(I)*H(I)
         END DO
         return
      end if

      IGFLA=INT(GFLA*100.)
      DO I=1,N
        IDEPTH=INT(DEPTH(I)*100.)
        IF(IDEPTH.GE.IGFLA) GO TO 10
      END DO
 10   NNS=I
      M=I-1
      if(m.eq.0) then
         DO I=1,MRD
           SUMWAT=SUMWAT+W(I)*H(I)
         END DO
         return
      end if

      if((m-1).lt.mrd) nbilanz=(m-1)
      J=ISOIL(NNS)
      I0=WSAT(NNS)
      H0=Int(GFLA*10.-DEPTH(NNS)*10.+H(NNS)*10.)*.1
      P0=H0*.5
      Z0=(H(M)+H0)*.5
      if(h0.le.0.0) then
        v0(m)=(c(m)+cond(i0,j))*.5*((P0-P(M))/Z0+1.)
        goto 25
      end if

      DO I=I0,1,-1
        IF(PSI(I,J).GT.P0) GO TO 20
      END DO
 20   WG=I
      P1=PSI(I,J)
      P2=PSI(I+1,J)
      WG=WG+(P1-P0)/(P1-P2)

      iw=int(wg)
      jw=int(wsat(m))
      if(iw.ge.jw-1) then
         v0(m)=cond(jw,j)
         goto 25
      end if
      X=WG-iw
      Y=1.0-X
      C0=COND(iw+1,J)*X+COND(iw,J)*Y
      V0(M)=(C(M)+C0)*.5*((P0-P(M))/Z0+1.)

 25   if(snow.gt.0.0) then
        asevap=0.0
```

```
      if(snow.lt.sublim) then
        sublim=snow
        snow=0.0
        goto 30
      end if
      snow=snow-sublim
      asevap=sublim
 30     flxtop=rain+bew
      goto 35
    end if


   FLXTOP=RAIN+BEW-ASEVAP

C      TIMESTEP

 35    nstau=0
    TIMSTP=0.1
    X=FLXTOP
    DO I=1,M
      Y=ABS(X-V0(I))
      if(y.eq.0.0) goto 215
      IF (Y.GE.H(I)*.1/TIMSTP) then
        TIMSTP=H(I)*.1/Y
      end if
 215    x=v0(i)
    END DO

    SUMTIM=SUMTIM+TIMSTP
    IF (SUMTIM.GT.1.0) THEN
      TIMSTP=1.0-(SUMTIM-TIMSTP)
      SUMTIM=1.0
    END IF

C      WATER MOVEMENT WITHIN THE SOIL PROFILE

    FLUXT=FLXTOP*TIMSTP
    j=isoil(1)
    fluxb=v0(1)*timstp
    w(1)=w(1)+(fluxt-fluxb)/h(1)
    if(w(1).lt.1.0) then
    p(1)=psi(1,j)
    c(1)=cond(1,j)
    goto 40
    end if

    iw=int(w(1))
    if(w(1).le.wsat(1)) then
      x=w(1)-iw
      y=1.0-x
      p(1)=psi(iw+1,j)*x+psi(iw,j)*y
      c(1)=cond(iw+1,j)*x+cond(iw,j)*y
    else
    nstau=1
    iw=int(wsat(1))
    is=isoil(1)
      p(1)=psi(iw,is)
      c(1)=cond(iw,is)
    end if

  40   v0(1)=(c(1)+c(2))*.5*((p(2)-p(1))/z(1)+1.0)
    fluxt=fluxb

    DO I=2,(M-1)
      J=ISOIL(I)
```

```
        FLUXB=V0(I)*TIMSTP
        W(I)=W(I)+(FLUXT-FLUXB)/H(I)
      if(w(i).lt.1.0) then
        p(i)=psi(1,j)
        c(i)=cond(1,j)
        goto 50
      end if
        iw=int(w(i))
        IF(W(I).LE.wsat(I)) THEN
          X=W(I)-iw
          Y=1.0-X
          P(I)=PSI(iw+1,J)*X+PSI(iw,J)*Y
          C(I)=COND(iw+1,J)*X+COND(iw,J)*Y
        ELSE
          nstau=1
          iw=int(wsat(i))
          is=isoil(i)
          P(I)=PSI(iw,is)
          C(I)=COND(iw,is)
        END IF

 50     V0(I)=(C(I)+C(I+1))*.5*((P(I+1)-P(I))/Z(I)+1.0)
      FLUXT=FLUXB
      IF(I.EQ.mrd) flxgw=flxgw+fluxb
      END DO

C     FLUX AT GROUNDWATER SURFACE

      FLUXB=V0(M)*TIMSTP
      W(M)=W(M)+(FLUXT-FLUXB)/H(M)
      if (w(m).gt.wsat(m)) w(m)=wsat(m)

      iw=int(w(m))
      J=ISOIL(M)
      X=W(M)-iw
      Y=1.0-X
      P(M)=PSI(iw+1,J)*X+PSI(iw,J)*Y
      C(M)=COND(iw+1,J)*X+COND(iw,J)*Y
      V0(M)=(C(M)+C0)*.5*((P0-P(M))/Z0+1.)
c---------------------------------------------
      if (nstau.eq.1) then
          do i=m,2,-1
          if(w(i).ge.wsat(i)) then
            delta=w(i)-wsat(i)
            j=isoil(i)
            w(i)=wsat(i)
            i1=i-1
            w(i1)=w(i1)+delta*h(i)/h(i1)
          end if
        end do

        if(w(1).ge.wsat(1)) then
          runoff=runoff+(w(1)-wsat(1))*h(1)
          w(1)=wsat(1)
          iw=int(wsat(1))
          is=isoil(1)
          p(1)=psi(iw,is)
          c(1)=cond(iw,is)
        end if

        do i=2,m
          j=isoil(i)
          iw=int(w(i))
          x=w(i)-iw
          y=1.0-x
```

```
        p(i)=psi(iw+1,j)*x+psi(iw,j)*y
        c(i)=cond(iw+1,j)*x+cond(iw,j)*y
       end do

       do i=1,n-1
        v0(i)=(c(i)+c(i+1))*.5*((p(i+1)-p(i))/z(i)+1.0)
       end do
      end if
c-------------------------------------------------
      IF(SUMTIM.NE.1.0) GO TO 35

      x=H0/H(NNS)
      y=1.-x
      w(nns)=wg*x+wsat(nns)*y
      if(w(nns).gt.wsat(nns)) w(nns)=wsat(nns)
      DO I=NNS+1,N
       W(I)=WSAT(I)
       p(i)=0.01
      END DO

      sumrunoff=sumrunoff+runoff
      DO I=1,MRD
       SUMWAT=SUMWAT+W(I)*H(I)
      END DO

      IF(FLXgw.LT.0.0) then
       flxbd=flxgw
       flxgw=0.0
       gwrise=gwrise+flxbd
       goto 60
      end if
      DRAING=DRAING+FLXGW

 60    RETURN
      END
```

subroutine NEARGW_CROP

```
      include 'simwaser_inc.for'

      SUMTIM=0.0
      FLXGW=0.0
      FLXBD=0.0
      SUMWAT=0.0
      runoff=0.0
      atrans=0.0

C     BOUNDARY CONDITION AT GROUNDWATER LEVEL

      GFLA=FLA-DFLA
      if(gfla.le.0.0) then
        DO I=1,MRD
          SUMWAT=SUMWAT+W(I)*H(I)
        END DO
        atrans=ptrans
        r=1.0
        return
      end if

      IGFLA=INT(GFLA*100.)

      DO I=1,N
        IDEPTH=INT(DEPTH(I)*100.)
        IF(IDEPTH.GE.IGFLA) GO TO 10
      END DO
 10   NNS=I
      M=I-1
      do i=nns+1,n
        w(i)=wsat(i)
        p(i)=0.01
      end do

      if(m.eq.0) then
        DO I=1,MRD
         SUMWAT=SUMWAT+W(I)*H(I)
       END DO
       atrans=ptrans
       r=1.0
       return
     end if

      if((m-1).lt.mrd) nbilanz=(m-1)
      J=ISOIL(NNS)
      I0=WSAT(NNS)
      H0=Int(GFLA*10.-DEPTH(NNS)*10.+H(NNS)*10.)*.1
      P0=H0*.5
      Z0=(H(M)+H0)*.5
      if(h0.le.0.0) then
        v0(m)=(c(m)+cond(i0,j))*.5*((P0-P(M))/Z0+1.)
        goto 25
      end if

      DO I=I0,1,-1
        IF(PSI(I,J).GT.P0) GO TO 20
      END DO

 20   WG=I
      P1=PSI(I,J)
      P2=PSI(I+1,J)
      WG=WG+(P1-P0)/(P1-P2)

      iw=int(wg)
```

```
      jw=int(wsat(m))
      if(iw.ge.jw-1) then
        v0(m)=cond(jw,j)
        goto 25
      end if
      X=WG-iw
      Y=1.0-X
      C0=COND(iw+1,J)*X+COND(iw,J)*Y
      V0(M)=(C(M)+C0)*.5*((P0-P(M))/Z0+1.)

 25   if(snow.gt.0.0) then
       asevap=0.0
       if(snow.lt.sublim) then
         sublim=snow
         snow=0.0
         goto 30
       end if
       snow=snow-sublim
       asevap=sublim
30       flxtop=rain+bew
       goto 35
      end if


     FLXTOP=RAIN+BEW-ASEVAP

C      TIMESTEP

 35   nstau=0
      TIMSTP=0.1
      X=FLXTOP
      DO I=1,M
        Y=ABS(X-V0(I))
        if(y.eq.0.0) goto 215
        IF (Y.GE.H(I)*.1/TIMSTP) then
          TIMSTP=H(I)*.1/Y
        end if
215     x=v0(i)
      END DO

      SUMTIM=SUMTIM+TIMSTP
      IF (SUMTIM.GT.1.0) THEN
        TIMSTP=1.0-(SUMTIM-TIMSTP)
        SUMTIM=1.0
      END IF



     FLUXT=FLXTOP*TIMSTP
      j=isoil(1)
      fluxb=v0(1)*timstp
      w(1)=w(1)+(fluxt-fluxb)/h(1)
      if(w(1).lt.1.0) then
        p(1)=psi(1,j)
        c(1)=cond(1,j)
        goto 216
      end if

      iw=int(w(1))
      if(w(1).lt.wsat(1)) then
        x=w(1)-iw
        y=1.0-x
        p(1)=psi(iw+1,j)*x+psi(iw,j)*y
        c(1)=cond(iw+1,j)*x+cond(iw,j)*y
      else
```

```
          nstau=1
          iw=int(wsat(1))
          is=isoil(1)
          p(1)=psi(iw,is)
          c(1)=cond(iw,is)
        end if

216     v0(1)=(c(1)+c(2))*.5*((p(2)-p(1))/z(1)+1.0)
        fluxt=fluxb

        DO I=2,(M-1)
          J=ISOIL(I)
          FLUXB=V0(I)*TIMSTP
          W(I)=W(I)+(FLUXT-FLUXB)/H(I)
        if(w(i).lt.1.0) then
          p(i)=psi(1,j)
          c(i)=cond(1,j)
          goto 217
        end if
          iw=int(w(i))
          IF(W(I).LE.wsat(I)) THEN
            X=W(I)-iw
            Y=1.0-X
            P(I)=PSI(iw+1,J)*X+PSI(iw,J)*Y
            C(I)=COND(iw+1,J)*X+COND(iw,J)*Y
          ELSE
            nstau=1
            iw=int(wsat(i))
            is=isoil(i)
            P(I)=PSI(iw,is)
            C(I)=COND(iw,is)
          END IF

 217      V0(I)=(C(I)+C(I+1))*.5*((P(I+1)-P(I))/Z(I)+1.0)
        FLUXT=FLUXB
          IF(I.EQ.mrd) flxgw=flxgw+fluxb
        END DO

C       FLUX AT GROUNDWATER SURFACE

        FLUXB=V0(M)*TIMSTP
        W(M)=W(M)+(FLUXT-FLUXB)/H(M)
        if (w(m).gt.wsat(m)) w(m)=wsat(m)

        iw=int(w(m))
        J=ISOIL(M)
        X=W(M)-iw
        Y=1.0-X
        P(M)=PSI(iw+1,J)*X+PSI(iw,J)*Y
        C(M)=COND(iw+1,J)*X+COND(iw,J)*Y
        V0(M)=(C(M)+C0)*.5*((P0-P(M))/Z0+1.)
c---------------------------------------------
        if (nstau.eq.1) then
          do i=m,2,-1
            if(w(i).ge.wsat(i)) then
              delta=w(i)-wsat(i)
              j=isoil(i)
              w(i)=wsat(i)
              i1=i-1
              w(i1)=w(i1)+delta*h(i)/h(i1)
            end if
          end do

          if(w(1).ge.wsat(1)) then
            runoff=runoff+(w(1)-wsat(1))*h(1)
```

```
          w(1)=wsat(1)
          iw=int(wsat(1))
          is=isoil(1)
          p(1)=psi(iw,is)
          c(1)=cond(iw,is)
         end if

         do i=2,m
         j=isoil(i)
         iw=int(w(i))
         x=w(i)-iw
         y=1.0-x
         p(i)=psi(iw+1,j)*x+psi(iw,j)*y
         c(i)=cond(iw+1,j)*x+cond(iw,j)*y
         end do
         do i=1,n-1
           v0(i)=(c(i)+c(i+1))*.5*((p(i+1)-p(i))/z(i)+1.0)
         end do
        end if
c-----------------------------------------------------------
       IF(SUMTIM.NE.1.0) GO TO 35
C      WATER MOVEMENT WITHIN THE SOIL PROFILE

 255  trans=0.0
      do i=1,n
        rextr(i)=0.0
      end do

      if(snow.gt.10.or.ptrans.le.0.0) then
       r=1.0
       goto 280
      end if

      sprex=0.0
      nrext=nroot
      if(nrext.gt.m) nrext=m
      DO I=1,nrext
       P1=1500.-P(I)
       IF(P1.GT.0.0) GO TO 260
       P1=0.0
 260    rres=1.0E2/efficiency(idvstg)
       REXTR(I)=(FWLOG(i)*P1*RD(I)/(rres+1.0/C(I)))
 265    if(rextr(i).lt.0.0) rextr(i)=0.0
       SPREX=SPREX+REXTR(I)
      end do
      r=sprex/ptrans
      if(r.lt.1.0) goto 270
      do i=1,nrext
       rextr(i)=rextr(i)/r
      end do
      r=1.0

 270  do i=1,nrext
       trans=trans+rextr(i)
      end do
      atrans=atrans+trans
      do i=1,nrext
        w(i)=w(i)-rextr(i)/h(i)
      end do

 280   x=H0/H(NNS)
       y=1.-x
       w(nns)=wg*x+wsat(nns)*y
       if(w(nns).gt.wsat(nns)) w(nns)=wsat(nns)
       DO I=NNS+1,N
```

```
  W(I)=WSAT(I)
  p(i)=0.01
END DO

sumrunoff=sumrunoff+runoff
DO I=1,MRD
  SUMWAT=SUMWAT+W(I)*H(I)
END DO

IF(FLXgw.LT.0.0) then
  flxbd=flxgw
  flxgw=0.0
  gwrise=gwrise+flxbd
  goto 300
end if
DRAING=DRAING+FLXGW

300   RETURN
      END
```

subroutine OUTPUT_RESULT

```
      include 'simwaser_inc.for'

      WRITE(8,1070)IYEAR,MONTH,IDAY,sumwat,sumRAIN,SUMETA,
     1 draing,Sumtrs,GWRISE,SUMRUNOFF,eta,asevap,snow,flxgw,grnlai,
     1 crootl,DRYMAT,gfla
 1070 FORMAT(I4,2I2.2,15F8.1)
      write(10,1071)iyear,month,iday,(p(j)*10.,j=1,50)
 1071 format(i4,2i2.2,50f10.2)
      write(11,1072)iyear,month,iday,(w(j),j=1,50)
 1072 format(i4,2i2.2,50f10.2)

      CALL monatsmittelwerte
      return
      end
```

subroutine OUTPUT_WLAYER

```
      include 'simwaser_inc.for'
 460  WRITE(9,1080)IYEAR,MONTH,IDAY,SUMWAT,SUMTRS,SUMETA,sumei,
     1 GWRISE,sumrain,DRAING,sumbew,sumrunoff,
     1 STRSSF,DRYMAT,sumrdm
 1080 FORMAT(I4,2I2.2,12f7.0)

      return
      end
```

subroutine POTRANS

```
      include 'simwaser_inc.for'

C       AERODYNAMIC RESISTANCE OF THE STAND

      fleafdensity=alog(totlai/plthgt)
      fa=exp(.26*fleafdensity-.79)
      fb=exp(.18*fleafdensity-2.26)
      rair1=fa-fb*widthleaf

      rair=rair1*fwind

      IF(DEVSTG.LT.10.) GO TO 10
      GRNLAI=0.0
      fplant=0.0
      goto 30

C       BULK RESISTANCE OF THE STAND

 10     fplant=0.0
      fleaf=asymp*efficiency(idvstg)
      if(grnlai.gt.1.) goto 20
      efflai=0.5*grnlai
      effglob=exp(-expar*efflai)*globr
      fplant=((slope*effglob*fleaf)/(slope*effglob+fleaf))*grnlai
      goto 30

 20     ngrnlai=int(grnlai)
      do i=1,ngrnlai
        efflai=i-0.5
        effglob=exp(-expar*efflai)*globr
        dfplant=(slope*effglob*fleaf)/(slope*effglob+fleaf)
        fplant=fplant+dfplant
      end do
      dlai=grnlai-ngrnlai
      efflai=dlai*0.5+ngrnlai
      effglob=exp(-expar*efflai)*globr
      dfplant=((slope*effglob*fleaf)/(slope*effglob+fleaf))*dlai
      fplant=fplant+dfplant

 30     FSOIL=ETOTAL/RRSOIL
      RCROP=1.0/(FPLANT+FSOIL)

C       POTENTIAL EVAPOTRANSPIRATION

      a=F*ENERGY*(1.-etotal)+.864*SATDEF/RAIR
      b1=F+1.+RCROP/RAIR
      b2=f+1.
      etpot=a/b1
      potevap=a/b2
      ptrans=etpot*(1.-exp(-0.6*totlai))
      if(ptrans.lt.0.0)  ptrans=0.0

      rs=rrsoil/etotal
      a=F*ENERGY*etotal+.864*SATDEF/RAIR
      b1=F+1.+rs/RAIR
      psevap=a/b1

      IF(ETPOT.GT.0.0) GO TO 90
      etpot=0.0
      psevap=0.0
      atrans=0.0
      r=1.0
      return
```

```
c       INTERCEPTION OF RAIN BY CROP

 90     if (rain.eq.0.0) go to 100
       if (temp.lt.3.0) go to 100
       if (totlai.lt.0.1) go to 100

       eimax=(6.25*totlai)/(1.25*totlai+5.0)
       ei=0.33*rain
       if(ei.gt.eimax) ei=eimax
       if(ei.gt.potevap) ei=potevap
       if(ei.gt.rain) ei=rain
       rain=rain-ei
       sumei=sumei+ei
 100  if (ptrans.le.0.0) then
        ptrans=0.0
        atrans=0.0
        r=1.0
      end if
      return
      end
```

subroutine PROFIL

```
      include 'simwaser_inc.for'
      character text*150
      text=' '
      open (unit=12, file=filboden, status='old')
      READ(12,'(a)')TEXT
      write(20,'(a)')text
      READ(12,'(22x,f6.2)')HGEL
      READ(12,'(22x,a)')WETTERSTATION
      READ(12,'(22x,a)')PEG
      write(20,'(a)')peg
      IF(PEG(1:1).EQ.' ') THEN
        READ(12,'(a)') TEXT
        READ(12,'(a)') TEXT
      ELSE
        READ(12,'(22x,f6.2)')HPEG
        READ(12,'(22x,f6.2)')DGW
        DFLA=((HPEG-HGEL)+DGW)*10.
      END IF
      READ(12,'(21x,i3)')mrd
      write(20,'(a,i3)') 'Bilanzschicht:',mrd
      READ(12,'(21x,i3)')n
      write(20,'(a,i3)') 'Schichtanzahl:',n
      READ(12,'(a)') TEXT

      IS=0
      DO I=1,N
        csoil=' '
        READ(12,1050) D,DEPTH(I),CSOIL,IWSAT,ISOIL(I),W(I)
        write(20,1051)i,d,depth(i),csoil,iwsat,isoil(i),w(i)
        H(I)=DEPTH(I)-D
        WSAT(I)=IWSAT
        IF((IS+1).EQ.ISOIL(I)) THEN
          IS=IS+1
          IPV=IWSAT
          CALL HYDRAP
        END IF

      effsat(i)=wsat(i)-1.0
      END DO
 1050 FORMAT(10X,F4.1,X,F4.1,2X,a,I2,3X,I2,4X,F4.1)
 1051 FORMAT(i2,8X,F4.1,X,F4.1,2X,a,I2,3X,I2,4X,F4.1)
      CLOSE(12)

      DO I=2,N
        Z(I-1)=(H(I-1)+H(I))*.5
      END DO
      Z(N)=H(N)

      DO I=1,N
        J=ISOIL(I)
        X=W(I)-INT(W(I))
        Y=1.0-X
        P(I)=PSI(int(W(I)+1.),J)*X+PSI(int(W(I)),J)*Y
        C(I)=COND(int(W(I)+1.),J)*X+COND(int(W(I)),J)*Y
      END DO
      DO I=1,N-1
        V0(I)=(C(I)+C(I+1))*.5*((P(I+1)-P(I))/Z(I)+1.)
      END DO
      V0(N)=C(N)
      profiltiefe=depth(n)

      IW=WSAT(1)
      DO I=2,IW-1
        DIFF(I)=(PSI(I-1,1)-PSI(I+1,1))*COND(I,1)*50.
```

```
END DO
DIFF(1)=DIFF(2)
diff(iw)=diff(iw-1)

sumwat=0.0
do i=1,mrd
  sumwat=sumwat+w(i)*h(i)
end do

write(10,'(a9,50f7.2)') 'Datum  ',(depth(j),j=1,n)
write(11,'(a9,50f7.2)') 'Datum  ',(depth(j),j=1,n)
RETURN
END
```

subroutine ROOTEX

```
      include 'simwaser_inc.for'

 30    WS=W(1)
      IF (WS.GT.WSAT(1)) WS=WSAT(1)
      if (psi(int(w(1)),isoil(1)).gt.10000.) then
        asevap=0.0
        goto 100
      end if

      SEVAP=.41*DIFF(int(WS))**.56

      IF(PSEVAP.GT.SEVAP) THEN
        ASEVAP=SEVAP
      ELSE
        ASEVAP=PSEVAP
      END IF

 100    ptrans=ptrans-ei
      do i=1,n
      if(crootl.le.depth(i)) then
         nroot=i
         goto 110
      end if
      end do
      if(ptrans.le.0.0) goto 200

 110    do i=1,nroot
        if(airmin.eq.0.0) then
          fwlog(i)=1.0
          goto 115
       end if
       if(w(i).ge.wsat(i)) then
          fwlog(i)=0.0
          goto 115
       end if
       if(w(i).lt.w0(i)) then
          fwlog(i)=1.0
          goto 115
       end if
       fwlog(i)=(wsat(i)-w(i))/airmin
  115   continue

     end do

      SPREX=0.0
      sumrdm=0.0
      rrootl=crootl
      sumrf=0.0
      do i=1,nroot
        IRF=RGF(int(W(I)),ISOIL(I))*10.
        if(irf.gt.99) irf=99
        RF(i)=RRGF(IRF,IRTCLSS)
        sumrf=sumrf+rf(i)*h(i)
      end do

      rrdmgain=rootdmgain/sumrf*crootl

      if(nroot.eq.1) goto 190
      DO I=1,(nroot-1)
        deltaroot=rrdmgain*rf(i)*h(i)
        rdm(i)=rdm(i)+deltaroot
        rd(i)=(rdm(i)*.005)/h(i)
        sumrdm=sumrdm+rdm(i)
        rrootl=crootl-depth(i)
```

```
          rootdmgain=rootdmgain-deltaroot
          if(rootdmgain.lt.0.0) rootdmgain=0.0
          rrdmgain=rootdmgain/rrootl
         end do

 190    irf=rgf(int(w(nroot)),isoil(nroot))*10.
        if(irf.gt.99) irf=99
        rf(nroot)=rrgf(irf,irtclss)
 195    deltaroot=rrdmgain*rf(nroot)*h(nroot)
        rdm(nroot)=rdm(nroot)+deltaroot
        rd(nroot)=(rdm(nroot)*.005)/h(nroot)
        sumrdm=sumrdm+rdm(nroot)

 200    IF(PEG(1:1).EQ.' ') then
          call fargw_crop
        else
          call neargw_crop
        end if
        if(ptrans.le.0.0) then
          r=1.0
          return
        end if

        r=atrans/ptrans
        if(r.lt.1.0) then

C        INCREASE OF SENSIBLE HEAT

          fx=245./(daylgt*.29)
          deltat=((ptrans-atrans)*fx)/(12.0/rair+6.0)
          return
        end if

 500    RETURN
        END
```

subroutine WETTER

```
      include 'simwaser_inc.for'

      sublim=0.0
      fdayl=1.0
      bew=0.0
      IYEAR=LVAL(1)
      MONTH=LVAL(2)
      IDAY=LVAL(3)
      if(irrigation.eq.1) call bewaesserung
      DAYLGT=LVAL(4)*.1
      tmax=lval(5)*.1
      tmin=lval(6)*0.1
      TEMP=(tmax+tmin)*.5
      GLOBR=LVAL(20)/(DAYLGT*.29)
c--------------------------------------------
      if((devstg.lt.0.4).and.(p(1).gt.1000.)) then
        ptu=0.0
        goto 100
      end if
c---------------------------------------------
      t1=temp-bastmp
      if(t1.lt.0.0) t1=0.0
      dayl=(daylgt-cdayl)
      if(dayl.lt.0.0) fdayl=0.0
      ptu=t1*fdayl

 100    SATDEF=LVAL(17)*.01
      WIND=LVAL(18)*0.13
      fwind=1./(0.8+0.2*wind)
      RAIN=LVAL(19)*.10
      veq=lval(20)*.00408
      sumrain=sumrain+rain
      sumbew=sumbew+bew
      ei=0.0

      if(temp.le.-1.0) then
       snow=snow+rain
       rain=0.0
      end if
      if(snow.gt.0.0) sublim=0.02*veq
      if(snow.gt.0.0.and.temp.gt.0.0) then
       rclday=380.*daylgt-2690.
       fclday=(10.*(lval(20)/rclday))
       a=10.**(0.05*fclday)
       b=10.**(-1.0*log10(fclday))
       smelt=(lval(20)*b-a)*0.0298
       if(smelt.lt.0.) smelt=0.0

 190     if(smelt.gt.snow) smelt=snow
       rain=rain+smelt
       snow=snow-smelt
      end if

      RADNET=0.65*veq-1.0
      if(snow.gt.0.0) radnet=radnet*0.05
 200    ENERGY=RADNET*.96-.17
      F=EXP(-.296+.053*TEMP)

      RETURN
      END
```

7 GLOSSARY

aday	Counter of currently simulated day
airmin	Minimum air filled pore space needed for unrestricted plantgrowth ("plant factor") of the crop (% vol)
alog	Antilogarithmus
alpha	Function of the photosynthesis light response curve, needed for calculation of photosynthetic flux of a crop
areawt	Leaf area per weight of leaf dry matter ('plant factor') of the crop (ha/kg)
asevap	Actual soil-evaporation of a crop
asymp	Asymptotic value of the photosynthetic light response curve of the crop (kg CH2O/ha,h)
atrans	Actual transpiration of the crop (mm/d)
bastmp	Base temperature for calculation of degree days of the crop (°C)
bew	Variable name of irrigation rate (mm/d) within subroutine ‚WETTER‘
cdayl	Critical day length below of which no phasic development of the crop takes place (h)
claigain	daily gain of new leaf area (m2/m2)
crootl	Current root length of the crop (dm)
crop	Name of the crop
csoil	Code of soil within a certain soil layer
day_diff(i,j,k)	Function calculating number of days from 1900-01-01 to actual date i-j-k
dayl	"growth day" (h)
daylgt	Day length (h)
ddryweight	Daily increase of dry matter (kg CH2O/ha,day) of the crop
deltat	Increase of air temperature within the crop stand due to sub-potential transpiration (°C) of the crop
depth(i)	Depth of the bottom of the soil layer (i) below soil surface (dm)
depthirrig	Variable name of irrigation rate (mm/d) within subroutine ‚BEWAESSERUNG‘
devstg	Development stage of the crop
dfla	Difference between groundwater level depths at simulated site and site of ground water gauge (dm)
dlai	increment of green leaf area
dleafmass	Daily increase of leaf dry matter (kg CH2O/ha,d) of the crop
dmgain	Daily gain of above soil dry matter (kg CH2O/ha,d) of the crop

draing	Daily drainage rate (mm/d) at bottom of the soil profile of a crop
drymat	Accumulated dry matter (kg CH2O/ha) of the crop
effglob	Effective global radiation within the crop stand
efflai	Effective leaf area above a sub layer within a crop stand
effphot	Effective photosynthetic rate of a crop leaf
efficiency(i)	Tabulated function (Subroutine MODELLDATENSATZ) of efficiency of growth processes depending on current development stage of the crop
egreen	Light extinction due to leaf area of the crop
ei	Interception evaporation of the crop (mm/d)
energy	Net energy available for evapotranspiration within the crop (mm/d)
eta	Actual evapotranspiration of the crop (mm/d)
etamean	Monthly sum of actual evapotranspiration (mm)
etpot	Potential evapotranspiration (mm/d) of the crop (mm/d)
etotal	Extinction of global radiation by green and dead leaves of the crop
exp	Exponent
excoef	Extinction coefficient for global radiation of the crop ('plant factor')
expar	Extinction coefficient for light of the crop
extot	Extinction coefficient for total (green and dead) leaf area
f1	Factor
f	Weighing factor of the combination evapotranspiration formula
fbulk	Fraction of dry matter gain converted to plant tissue except roots and leaves of the crop
fclday	Factor in estimating snow melt
fdayl	Factor taking into account if length of day light hours is sufficiently for growth
fdeadl	Fraction of dead leaves
filboden	Directory containing pathway to data file containing soil profile data
fili	Directory containing pathway to data file containing input data
filgw	Directory containing pathway to data file containing groundwater data
filn	Directory containing pathway to data file containing weather data
fla	Daily groundwater depth at observation well
fluxg	Flux at groundwater surface (mm/time step)
fluxgw	Drainage rate at bottom of soil profile (mm/d) of a crop
flxtop	Flux at top of soil layer (mm/time step)
freeze	Air temperature below which a certain crop is killed by freezing
fresp	Fraction of daily dry matter gain of the crop used for respiration
frdmat	Fraction of daily assimilation used for root growth

frhgt	Growth function frhgtg(i), describing dependence of height growth relative to the mean height growth velocity at current development stage
froot	Factor used in estimating root length growth
ftotlai	Fraction of total leaf area of theoretical accumulated leaf area
fwind	Auxiliary factor for calculating aerodynamic resistance
fwlog(i)	Water logging factor describing aeration situation within a rooted soil layer: fwlog(i)=1 when aeration requirement is met; fwlog(i)=0 when the soil layer is completely waterlogged
f_aeration	Auxiliary factor for calculation root extraction of the crop depending on actual amount of air filled pores within the rooted soil layers
gbulk	Growth of the bulk (stem, storage organs etc. except of roots and leaves)
gfla	Ground water depth at simulated site (dm)
globr	Mean daily global radiation flux (W/m^2)
grnlai	Leaf area index of active green leaves (m^2/m^2) of the crop
gwneu	Daily deep percolation (mm/d)
gwneumean	Monthly mean of deep percolation (mm)
gwrise	Daily capillary rise at bottom of the soil profile below a crop (mm/d)
icrop	Code for simulated crop in 'plant factor' data set
icrp	Code for simulated crop in simulation program
idatb(i,j,k)	Calendar date of begin of current cropping element
idate(i,j,k)	Calendar date of the last day of current cropping element
idatl(i,j,k)	Calendar date of current day
iday	Number of day in Month in daily date in output file
idvstg	Index of the accumulated development stage of the crop
ifrost	Flag: ifrost =1 if crop is damaged by chilling, otherwise ifrost = 0
ipv	Index for pore volume of each soil type within the soil profile
irdvstg	Index of the accumulated root development stage of the crop
irec2	Record number of the first record in weather data corresponding to the first day of the current cropping element
irec3	Record number of the first record in ground water data corresponding to the first day of the current cropping element
irf	Index of actual penetrometer resistance
irrigation	Flag: irrigation =1 if crop is irrigated, otherwise irrigation = 0
irtclss	Index of root class ('plant factor') of the crop
is	Index of soil type in each soil layer of the soil profile
itclss	Index of the temperature class ('plant factor') of the crop
iyear	Number of Year in daily date (output)

jyear	Number of Year in daily date (output)
lval(20)	Array of weather data
m	counter
mday	number of days since 1900-01-01 for actual date
mdaye	number of days since 1900-01-01 for date of ending of current calculated cropping season
mdayi	number of days of irrigation date since 1900-01-01
mday0w	number of days since 1900-01-01 for date of first day in weather data
mday0g	number of days since 1900-01-01 for date of first day in groundwater data
monat	Index for Number of month in year in daily date in output file
month	Number of month in year in daily date in output file
mrd	Number of soil layer at depth of soil water balance
mvr	Constant (record length) for reading binary groundwater data
n	Counter
nbew	Number of irrigations during the simulated period
nirrigation	Number of irrigation within simulated period
npeg	Index for groundwater gauge
nroot	Number of soil layers, which are currently rooted by the crop
nvr	Constant (record length) for reading binary weather data
par	Photosynthetic active radiation
peg	Name of groundwater data set
pegel	Name of groundwater gauge
pfad	Directory
pflanzenart	Name of crop
pflux	Photosynthetical flux of the crop (kg CH20/ha,d)
pfluxgr	Photosynthetical flux of the -culture (kg CH20/ha,d)
photsr	Maximum photsynthetic rate (kg CH2O/ha,h) of a crop leaf (‘plant factor’)
place	Name of the simulated site
plthgt	Actual height of the crop (m)
potevap	Potential evapotranspiration (mm/d)
pothgt	Potential height (m) of crop (‘plant factor’)
profile	depth of soil profile
psevap	Potential soil evaporation of crop (mm/d)
ptrans	Potential transpiration of crop (mm/d)

ptu	Growing degree day of crop (°C)
ptusum	Accumulated sum of growing degree days of crop (°C)

r	Relative transpiration of the crop
radnet	Net radiation (expressed as evaporation equivalent: mm/d)
rain	Rain (mm/d)
rair	Aerodynamic resistance (s/cm) of crop
rclday	Factor in estimating snow melt
rcrop	Crop resistance (s/cm) of the crop
rd(i)	Root length density (cm/cm3) in soil layer (i)
rdevstg	Development stage of the roots of the crop
rdm(i)	Root dry matter (kg CH2O/ha) in soil layer (i)
rextr(i)	Root extraction in soil layer (i)
rf(i)	Actual root factor in soil layer i
rgf(i,j))	Index for root growth factor of soil type j at water content i (=Penetrometer resistance)
rhgtg	Relative height growth (dm/°C) of the crop
riping	Amount of growing degree days (°C) needed for riping of the crop ('plant factor')
rmleaf	Minimum resistance (s/cm) of a plant leaf against loss of water vapour ('plant factor')
rootds	Maximum root length density (cm/cm^3) of crop ('plant factor')
rootdmgain	Daily gain of root dry matter (kg CH2O/ha,d) of the crop
rootdrymat	Accumulated dry matter of the plant roots (kg CH2O/ha)
rootlg	Potential length (m) of roots ('plant factor')
rrdmgain	Relative gain of root dry matter per unit of root length of the crop
rrgf(i,j)	Root growth factor (function of penetration resistance index i and of root type class j)
rriping	Amount of growing degree days (°C) needed for full development of the roots of the crop
rrlg	Relative root length growth according to development stage of the crop
rrotg	Growth of root length of the crop per unit of riping
rsoil	Typical soil resistance against evaporation (s/cm) given as standard in table 'plant factors'
rrsoil	Actual soil resistance against loss of water vapour (s/cm) depending on matric potential in uppermost soil layer
rtdm	Mean root dry matter in each rooted soil layer
runoff	Daily runoff (mm/d) in crop

satdef	Saturation deficit (g $H2O/m^3$ air) of the air ('weather data')
slope	Slope of light response curve of a leaf
smelt	Amount of melted snow (mm)

snow	Actual daily amount of snow (mm water equivalent)
sstrsd	Sum of stress days
sstrss	Sum of stress due to lack of water
start_date_w(i)	Calendar date of the first day in the weather data
start_date_g(i)	Calendar date of the first day in the ground water data
strssf	Stress factor due to lack of water (1 = no stress; 0 =full stress)
sumbew	Accumulated amount of irrigation (mm)
sumei	Accumulated interception evaporation (mm)
sumeta	Accumulated actual evapotranspiration of a crop (mm)
sumlai	Accumulated leaf area of the crop (m^2/m^2)
sumrain	Accumulated amount of rain (mm)
sumrdm	Accumulated root dry matter within rooted soil layers of the crop (kg CH_2O/ha)
sumptu	Accumulated sum of growing degree days (°C) of the crop
sumrunoff	Accumulated runoff (mm) from a crop
sumtrs	Accumulated transpiration (mm)
sumwat	Actual soil water storage (mm) in the soil profile

t1	"growth temperature" (°C)
temp	Daily mean air temperature (°C)
tfass	factor describing assimilation efficiency dependence on temperature
text	Name of variable containing text
tmax	Maximum air temperature (°C)
tmin	Minimum air temperature (°C)
totlai	Total leaf area index – including green and dead leaves-of the crop (m^2/m^2)
ttemp(i,j)	Tabulated function (Subroutine MODELLDATENSATZ) of efficiency of photosynthesis of plant type code (j) at temperature (i)
txt	Name of variable containing text

veq	Evaporation equivalent of the incoming global radiation (mm/d)
w0(i)	Maximum of water content (vol%) in soil layer (i) with minimum allowable air content for the current crop type
wetterstation	Name of weather station
widthleaf	Characteristic length of aerodynamic structures of the crop (cm) ('plant factor')
wind	Daily mean of wind velocity at 2 m height (m/s)
wsat(i)	Saturated water content (vol%) of soil layer (i)

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