Assessment of soil hydraulic functions for modeling the soil water dynamics of a soybean field

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Erstellung von bodenhydraulischen Funktionen für die Modellierung des Wasserhaushaltes am Beispiel eines Sojabohnenfeldes

1. Introduction and definition of the aims

The soil structural status, including soil and plant parameters, has, among others, a high influence on soil hydraulic properties and the water balance of a specific site. The aims of this study were to improve the methodological measurement of soil hydraulic properties, to test their applicability for modeling the soil water balance and to show how sensitive computer models react on soil structural changes.

2. Material and methods

2.1 Soil characteristics

The investigated soil is situated on the experimental farm of the University of Agricultural Sciences, Vienna, in Groß-Enzersdorf, about 5 km eastern from Vienna in the "Marchfeld" region, Lower Austria. The soil is a Chernozem, tilled to a depth of 25 cm, with a particle size distribution as shown in tab.1.

Zusammenfassung

Das Modell „SOIL" sowie unterschiedliche Labor- und Feldmethoden wurden angewendet, um den Wasserhaushalt eines Sojabohnen-Feldes in Groß-Enzersdorf, Niederösterreich, während einer Vegetationsperiode zu simulieren. Die Ergebnisse zeigten, daß hydraulische Wasserleitfähigkeitsfunktionen, geschätzt aus der pF-Kurve, eine enge Korrelation aufwiesen mit jenen mit der Augenblicksprofil-Methode im Labor gemessen. Der Durchlässigkeitsbeiwert wurde dabei mittels GUELPH-Permeameter und Stechzylinder bestimmt. Aus Messungen der Lagerungsdichte, der Tensionsinfiltration, des Durchlässigkeitsbeiwertes und aus Simulationsversuchen konnte gezeigt werden, daß es nicht möglich ist, die hydraulische Leitfähigkeitsfunktion des bearbeiteten Oberbodens während einer Vegetationsperiode mit nur einer hydraulischen Leitfähigkeitsfunktion darzustellen. Die Simulation der Wasserinfiltration in den Boden nach einem schweren Niederschlag, welcher auf eine vierwöchige Trockenperiode folgte, war lediglich nach Verwendung eines empirischen „bypass"-Fluß Algorithmus des SOIL-Modells erfolgreich.

Schlagworte: Bodenwasserhaushalt, hydraulische Leitfähigkeit, pF-Kurve, Infiltration.

Summary

The soil water dynamics of a soybean field in Groß-Enzersdorf, Lower Austria was simulated during one vegetation period with the computer "SOIL"-model, using different laboratory and field methods for the determination of the soil hydraulic input data. Hydraulic conductivity functions, as estimated from soil water retention curves, were highly correlated with those measured with an Evaporation Controlled Instantaneous Profile-method in the laboratory, where the GUELPH-permeameter-method for establishing the saturated soil hydraulic conductivity (K_{sat}) was used. The data obtained, i.e. bulk density, tension infiltration, saturated conductivity, and simulation results showed clearly that it is almost impossible to establish one unique soil hydraulic conductivity function of a tilled top soil during a vegetation period. Water infiltration after a heavy thunderstorm following a 4 week dry period could only successfully be simulated using an empirical bybass flow algorithm of the computer model.

Keywords: Soil water balance, hydraulic conductivity, water retention, infiltration.

Tablel.: Particle size distribution in weight % of the investigated soil in Groß-Enzersdorf, Lower Austria

Tabellel: Korngrößenverteilung in Gew. % des untersuchten Bodens in Groß-Enzersdorf, Niederösterreich

Horizon depth (cm)	%-SAND (2–0,063mm)	%-SILT (0,063-0,002mm)	%-CLAY (<0,002mm)
A_p (0–25)	30	48	22
A_h (25–40/45)	30	48	22
AC (40/45–55/120)	37	45	18
C(55/120+)	11–34	54–72	10–26

The depth of the C-horizon varies from 55 cm to more than 120 cm. The particle size distribution of the C-horizon varies in a wide range (e.g. clay content from 10 % up to 26 %), showing the inhomogeneity of the parent material. Despite the relatively low clay content of the topsoil, cracks deeper than 60 cm appeared during dry summer periods.

2.2 Experimental field

On a 100 x 50 m field, a soyabean crop (variety "Ceresia") was planted. After ploughing the field in autumn, the seedbed preparation to a depth of 6 – 8 cm and sowing were carried out in May 1995. Before seedbed preparation, the homogeneity of the depth of the C-horizon was preinvestigated augering the whole field on a regular grid of 7 x 7 m. Based on these indications, 8 subplots (size: 10 x 10 m) were selected with equal depth of C-horizon (70 cm) for taking soil and plant samples (fig. 1).

2.3 Methods

Soil hydraulic properties were obtained using different methods. The Soil Water Retention Characteristic (SWRC) were determined according to the DRAFT INTERNATIONAL STANDARD 11274 (1992) using soil cores (200 cm^3) and pressure plate extractors. The number of replications used was 8 soil cores (one from each subplot), taken from the A_p-and A_h-horizons respectively and 4 soil cores (only from subplot 1, 3, 5, 7) taken from the AC-horizon at 60 cm depth.

The saturated hydraulic conductivity (K_{sat}) was determined in the laboratory by the falling head method. From each subplot (1 through 8) 2 soil cores taken from the A_p horizon and 2 soil cores taken from the A_h horizon were used. From the AC horizon 2 soil cores were taken from subplots 1, 3, 5, 7.

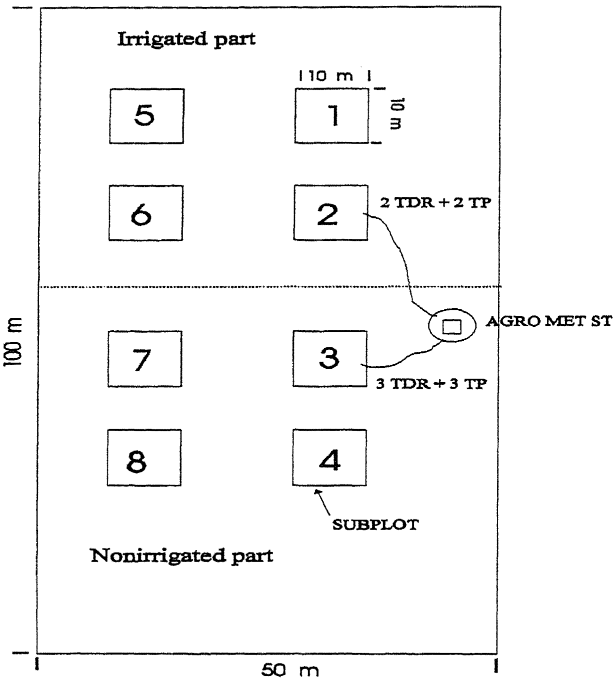

Figure 1: Design of the experimental field with 8 subplots, an agrometeorological station and location of the installed TDR- and temperature (TP)-probes

Abbildung 1: Lageplan des Feldversuches mit 8 Parzellen, einer agrometeorologischen Meßstation und der Lage der installierten TDR- und Temperatur (TP)-Sensoren

For the determination of the unsaturated hydraulic conductivity (k_u) in the laboratory, an Evaporation Controlled Instantaneous Profile-method was used (PLAGGE et al., 1989). Saturated soil cores of 10 cm height and 5.5 cm diameter were equipped with 5 TDR-miniprobes and 5 or 4 minitensiometers helically at equal distances (1, 3, 5, 7, 9 cm from the bottom of the soil core – if 4 tensiometers were used, the tensiometer at 3 cm was omitted), see fig. 2. A description of the equipment is given by SOBCZUK et al. (1992).

The bottom of the soil core was sealed and the top opened to allow free evaporation to the atmosphere. During the experiment the water potential (in hPa) and the water content were measured untill the water potential of the top tensiometer was less than -850 hPa. We calculated water potential gradients (dH/dz) by fitting the exponential function $\psi = a*e^{(b*z)}+c$ (ψ = matrix potential; z = height; a, b, c are fitting parameters) to the data for each time step. Fluxes (q) were calculated by fitting the second order polynomial function $\theta = a*t^2+b*t+c$ (θ = water content; t = time; a, b, c are fitting parameters) to the measured water content as a function of time (ROTH et al., 1995). The hydraulic con-

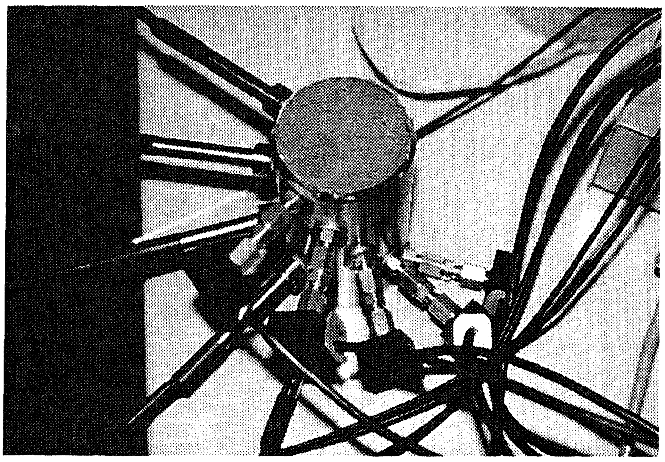

Figure 2: Evaporation-Controlled-Instantaneous-Profile-method (PLAGGE et al., 1989) for the measurement of the unsaturated hydraulic conductivity (K_u), showing the soil core with the installed microtensiometer and TDR-probes.

Abbildung 2: Stechzylinder mit den installierten Mikrotensiometern und TDR-Sonden zur Bestimmung der ungesättigten Wasserleitfähigkeit mit der Augenblicksprofil-Methode (PLAGGE et al., 1989).

ductivity was obtained for each depth increment from $q(t_i)$ and $dH(t_i)/dz$. A mean hydraulic conductivity function for the whole soil core was obtained by calculating the weighted geometric mean for certain water content or water potential classes.

The soil cores for measuring the soil water retention curve (SWRC), saturated and unsaturated hydraulic conductivity were taken in April 1995 before sowing. Additionally, 12 soil cores for measuring saturated hydraulic conductivity of the A_p-horizon were taken again in September 1995.

Before starting with the measurement of the SWRC and the unsaturated hydraulic conductivity, soil cores were capillary saturated applying a suction of -3 hPa at the bottom of the soil core, in order to minimize the influence of soil structure (swelling-shrinking phenomena).

The saturated hydraulic conductivity (K_{sat}) in the field was measured in boreholes in August 1995 using the GUELPH-permeameter at 3 soil depths for all 8 subplots. The calculation of K_{sat} from the steady state infiltration rate was performed by Laplace analysis (REYNOLDS and ELRICK, 1985).

Unsaturated hydraulic conductivity values near water saturation were obtained by tension infiltration measurements (ANKENY et al., 1991). A 20 cm diameter base plate connected to the tension infiltrometer was placed on a layer of fine silica sand (grain size: 0.1 mm – 0.3 mm) at the soil surface. Water was infiltrated at supplied suctions of -15, -6 and -3 hPa and infiltration rates were automatically recorded with two pressure transducers and a data logger untill steady state conditions were attained. With the help of the transducer installed at the base plate the applied suction was recorded. Since the measurement of tension infiltration could be influenced by temperature fluctuation (sensitivity of pressure transducers) an umbrella was used during sunny conditions. The tension infiltrometer measurements were made directly at the soil surface and at 10 cm depth for subplots 1 through 4 during August and September 1995. After infiltration measurements with an applied suction of -3 hPa the tension infiltrometer was removed and a metal ring with the same diameter as the base plate of the tension infiltrometer (20 cm) was carefully inserted to a depth of 1–2 cm into the soil at exactly the same place. Water was ponded to a depth of 3 cm and again infiltration rate was measured untill steady state conditions were achieved. The infiltration rate was obtained by linear regression of steady state infiltration data (usually reached within 30 minutes of infiltration).

The unsaturated hydraulic conductivity was calculated using Wooding's approximation (WOODING, 1968)

$$Q = \pi r^2 K\left[1 + \frac{4}{\pi r \alpha}\right] \tag{1}$$

where Q is the volume of water entering the soil per unit time, K is the hydraulic conductivity, r is the radius of the base plate and α is a parameter.

The unsaturated hydraulic conductivity is described as proposed by GARDNER (1958):

$$K(h) = K_{sat} \exp(\alpha h) \tag{2}$$

where h is the matric potential at the source and K_{sat} is the saturated hydraulic conductivity. For this case K_{sat} must not be seen as the true "Saturated Hydraulic Conductivity" but rather as a scaling parameter for the unsaturated conductivity curve.

The saturated hydraulic conductivity was also calculated using the tension infiltration measurements at supplied suction of -3 hPa and ponded infiltration measurements.

The rooting system of plants was determined using the "Profil Wall Method" (BÖHM, 1979). The root growth during the vegetation period was estimated assuming that the maximal rooting depth is reached at the flowering time. Maximal rooting depth and root distribution within the soil profile was recorded at the end of the vegetation period.

The volumetric soil water content was continuosly recorded with TDR-probes installed at subplot 3 at depths of 15 cm, 35 cm and 60 cm. An agrometeorological station for measuring precipitation, air temperature, relative humidity, wind speed and global radiation was installed near subplot 3, see fig. 1.

The measurements of the meteorological parameters were carried out by the institute of Meteorology and Physics, University of Agricultural Sciences, Vienna. The measurements of plant related properties were carried out in cooperation with the institute of Plant Production and Plant Breeding, University of Agricultural Sciences, Vienna.

Simulation Model "SOIL"

The "SOIL"-model (JANSSON, 1991, 1993) simulates one-dimensional water and heat dynamics in a cropped, layered soil profile. The central part of the model are two coupled differential equations for the water (Darcy's Law, Richard's equation) and heat (Fourier's law) flow. The potential transpiration is calculated from the Penman-Monteith's combination equation. The reduction of potential to an actual transpiration depends on actual water tension and soil temperature conditions. The evaporation from the soil surface can be calculated from a Penman-type equation or from an iterative solution of the energy balance method. As driving variables for the model, meteorological data (precipitation, mean daily temperature, wind speed, relative humidity, global radiation) and plant related properties (leaf area index, surface resistance, roughness length, displacement height, root depth and root distribution) are used. The input of soil hydraulic properties (SWRC, hydraulic conductivity) is obtained by fitting an extended version of the Brooks&Corey-model (BROOKS and COREY, 1964) to experimental SWRC data. The hydraulic conductivity function is calculated using measured K_{sat} data and the Mualem-model (MUALEM, 1976). In order to consider the influence of macropores, an additional equation of the hydraulic conductivity is considered when water content exceeds a value $f = \Theta_s - 0.04$, i.e. between the saturated water content and the water content 4 vol- % less saturation). An optional switch to account for bypass flow has been included in the model to consider rapid flow in macropores during conditions when smaller pores are only partially filled with water. Bypass flow starts when the infiltration flow rate or the vertical flow at any soil depth exceeds the ordinary Darcy flow rate, q_{mat}. q_{mat} is limited by an empirically calculated value S_{mat} which is defined as:

$$S_{mat} = a_{scale} a_r k_{mat} pF$$

where k_{mat} is the maximum conductivity of smaller pores (i.e. matrix pores), a_r is the ratio between compartiment thickness and the unit horizontal area represented by the model, pF is $^{10}\log\Psi$ (suction), a_{scale} is an empirical scaling coefficient accounting for the geometry of aggregates.

3. Results and discussion

Almost all of the SWRCs of the soil Groß-Enzersdorf are showing a very distinct air entry pressure at -30 hPa , see figures 3, 4, 5. This might be due to an uncomplete saturation of the soil cores at a suction of -3hPa. The range of water content for a given pressure step is about 5 vol % for the A_p- and the A_h-horizons whereas for the AC-horizon (60 cm) it was much higher (about 10 vol %), due to the higher variability of the particle size distribution at the depth of 60 cm.

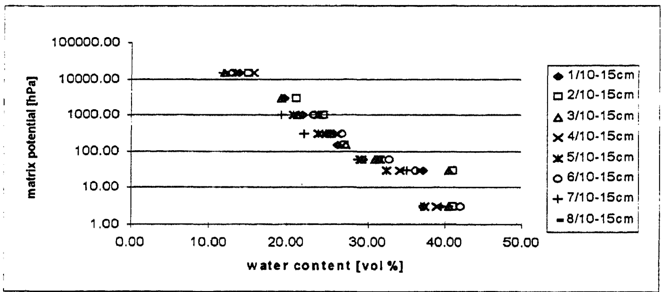

Figure 3: SWRCs of the A_p-horizon in all 8 subplots
Abbildung 3: pF-Kurven des A_p-Horizontes in allen 8 Parzellen

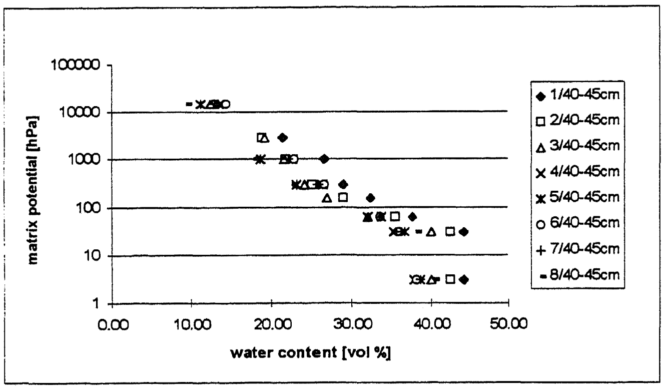

Figure 4: SWRCs of the A_h-horizon in all 8 subplots
Abbildung 4: pF-Kurven des A_h-Horizontes in allen 8 Parzellen

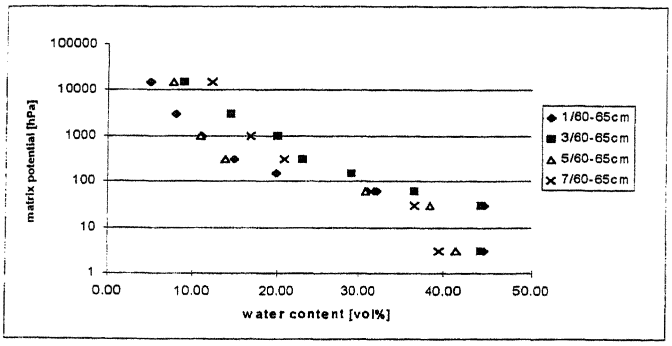

Figure 5: SWRCs of the AC horizon in the subplots 1, 3, 5, 7
Abbildung 5: pF-Kurven des AC-Horizontes in den Parzellen 1, 3, 5, 7

The results of the saturated hydraulic conductivity (K_{sat}) for the different horizons are shown in table 2. No statistics were stated for the saturated hydraulic conductivity calculated from tension infiltration measurements at 10 cm depth and at the tilled surface because of the small sample population.

The highest values of saturated hydraulic conductivity were obtained by the falling head method in the laboratory, using soil cores of 6 cm length, reflecting the high content of macropores in the ploughed horizon, due to tillage operations and the high density of rainworm furrows as compared to the GUELPH-permeameter-method. It was experimentally proved that a GUELPH-permeameter measurement directly on a crack will lead to a high infiltration rate at the beginning of the infiltration but after filling of the crack it will result in a similar steady state infiltration rate (which is used for calculating K_{sat}) compared with measurements conducted at a place without cracks.

Comparing Guelph permeameter and soil core method the measurements at 60 cm depth resulted in most similar values of K_{sat} because the "primary" texture-depending pore system of the soil is of higher importance than in the upper horizons but differences are still substantial between the two methods. The specific modeling approach of the "SOIL"-model considers K_{sat}-values measured by soil cores as input for the macropore velocity of a defined soil layer, whereas the results of the GUELPH-permeameter measurements reflect more the saturated hydraulic conductivity of the soil matrix.

Because of the high silt content and the low aggregate stability, the structure of the investigated soil of Groß-Enzersdorf is very susceptible for compaction due to rainfall impact and setting after soil tillage. This resulted in an increase of the bulk density (d_B) and a strong reduction of the K_{sat} of the A_p-horizon during the vegetation period, see table 2. This fact was considered in modeling the water balance by splitting the vegetation period in a first (from 4th of May to 15th of August) and a second half (from 15th of August to 4th of October), using the corresponding K_{sat} value as input of macropore velocity for the two periods.

The calculated K_{sat} values from tension infiltration measurements in September on the soil surface and at 10 cm depth resulted in nearly the same saturated hydraulic conductivity values compared to the measurement of soil cores taken in September, see tab. 2.

Figure 6 shows the unsaturated hydraulic conductivity (K_u) in the range of -60 hPa to -850 hPa of the A_p-, A_h- and AC-horizons for the subplot 3, measured with the Instantaneous Profile Method in the laboratory. For the entire measurement range the highest values for K_u were measured in the AC-horizon, the lowest in the A_p-horizon.

Table 2: Saturated hydraulic conductivity in cm/day of the soil Groß-Enzersdorf measured by different methods (SC = soil-core-laboratory-method; Guelph = GUELPH-permeameter-method; TI = tension-infiltrometer-method; TI-til = measurement on surface of freshly tilled soil; per = percentile; n = number of samples)
Tabelle 2: Durchlässigkeitsbeiwerte in cm/Tag des Bodens Groß-Enzersdorf gemessen mittels verschiedener Methoden (SC = Stechzylinder-Methode, Guelph = GUELPH-Permeameter-Methode, TI = Tensionsinfiltrometer-Methode, TI-til = gemessen im frisch bearbeiteten Oberboden, per = Perzentile, n = Probenanzahl)

	SC 10cm april	SC10cm septemb.	SC 40cm	SC 60cm	Guelph 8-25cm	Guelph 28-45cm	Guelph 50-67cm	TI surf.	TI 10cm	TI-til surf.
geo. mean	3286	79	887	753	26	56	219	108	70	720
arit. mean	5953	310	2431	827	32	66	231	126	77	
St. dev.	5883	708	6209	446	27	39	83	64.8	-	
25 per.	768	24	362	555	15	41	166	71	-	
75 per.	8880	221	1353	868	34	101	287	165	-	
Maximum	21640	2513	25598	1788	96	137	382	240	-	
Minimum	274	14	279	455	10	41	123	32	-	
n	15	12	16	7	8	8	8	8	3	3

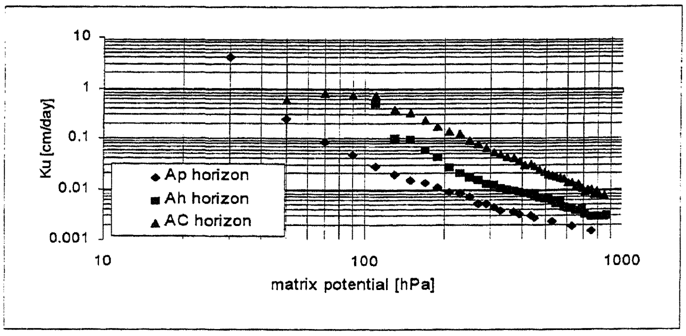

Figure 6: Unsaturated hydraulic conductivity of the A_p-, A_h- and AC-horizons (subplot 3)
Abbildung 6: Ungesättigte Wasserleitfähigkeit der A_p-, A_h- und AC-Horizonte (Parzelle 3)

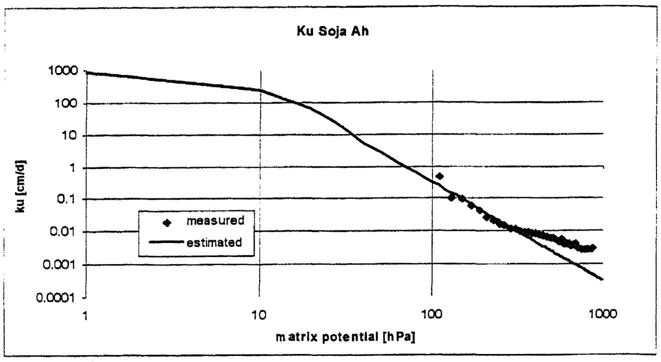

Figure 8: Measured unsaturated hydraulic conductivity values and estimates according to BROOKS and COREY (1964) of the A_h-horizon
Abbildung 8: Gemessene und nach BROOKS und COREY (1964) geschätzte ungesättigte Wasserleitfähigkeit des A_h-Horizontes

The unsaturated hydraulic conductivity functions which were used as input for the "SOIL"-model, were estimated from fitting the Brooks&Corey-model to the SWRC and calculating the K_u function after MUALEM (1976). For the A_p-horizon two different K_u functions were estimated for the first and the second half of the vegetation period using the corresponding K_{sat} values shown in fig. 7. The higher saturated hydraulic conductivity values (macropores and soil matrix) are producing a parallel shift of the K_u function. The estimated K_u for the second half of the vegetation period was in high agreement with the measured values.

The estimated values of K_u for the A_h-horizon fitted reasonably well to the data (fig. 8).

Using the first estimation of the K_u function for the AC-horizon, the simulated water content for this horizon was generally too high during the vegetation period. In this case the model was calibrated by decreasing the water content of each pressure step of the SWCR for 2 % vol and estimating the unsaturated conductivity using this new SWRC. This calibrated K_u function was in better agreement with the measured unsaturated conductivity and produced a better fit of the simulated water content to the measured water content data for the AC-horizon, see fig. 9.

For modeling the soil water balance, climatic and plant data are needed as driving variables (daily input) or as function over time. During the month of June rainfall was high. The period between the beginning of July and July 28th was a dry and hot. On 28th of July there was a heavy thunderstorm with 30 mm of rain within 1 hour. The precipitation was higher in September with a maximum of 60 mm on September 15th.

Independently measured data are needed in order to compare model results with observations and for calibration pur-

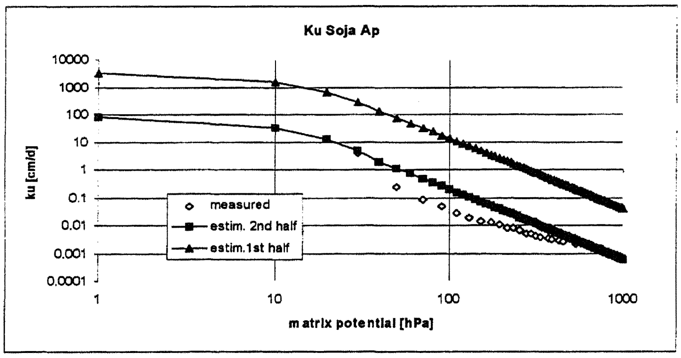

Figure 7: Measured unsaturated hydraulic conductivity values and estimates according to BROOKS and COREY (1964) of the A_p-horizon with K_{sat} of the soil matrix during the first and second half of the vegetation period
Abbildung 7: Gemessene und nach BROOKS und COREY (1964), geschätzte ungesättigte Wasserleitfähigkeit des A_p-Horizontes mit K_{sat} der Bodenmatrix in der ersten und zweiten Hälfte der Vegetationsperiode

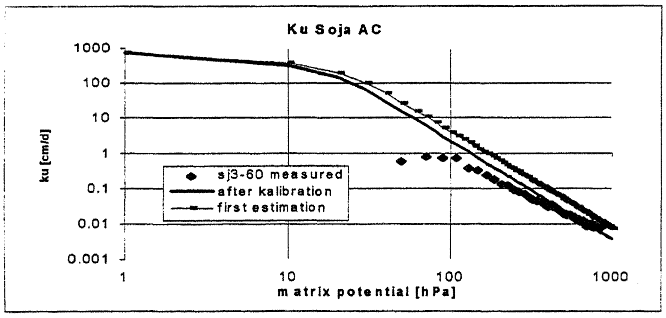

Figure 9: Measured unsaturated hydraulic conductivity values and estimates according to BROOKS and COREY (1964) of the AC-horizon
Abbildung 9: Gemessene, nach BROOKS und COREY (1964) geschätzte und kalibrierte ungesättigte Wasserleitfähigkeit des AC-Horizontes

poses. In this case the water content was recorded with TDR-probes during the vegetation period. To prove the accuracy of the TDR-system, the volumetric soil water content of the experimental site was occasionally measured with soil cores (weighting and oven drying in the laboratory). The results showed a high comparability between the two methods. The deviation was for all cases smaller than 5 vol % and can be interpreted as normal variability of the water content data.

The TDR-data of the A_p-horizon showed a steady increase of the highest water content peaks after extensive precipitation events from 30 vol % at the beginning of the vegetation period to 35 vol % at the end of the vegetation period and also an increase of the so called "field capacity level". This could be explained by the fact that the pore size distribution changes during the vegetation period and that the changing of bulk density during the vegetation period influences the measurement of volumetric water by the TDR-system (PLAGGE et al., 1995).

From the beginning of May to the 11th of September the bulk density of the A_p-horizon increased from 1.33 g/cm^3 to 1.56 g/cm^3. Using a matrix sensitiv calibration function for calculating water content from TDR-measurements (PLAGGE et al., 1995) it could be obtained that the error caused by using a calibration function without considering the change of bulk density during the vegetation period is less than 3 vol % in the water content range from 30 to 35 vol %. From this, it can be concluded that at least partially the increase of the field capacity level and highest peaks of water content is caused by the changing pore size distribution. Of course if the bulk density of the A_p-horizon is changing, the hydraulic properties of the soil must change as well. This fact was taken into account for modeling the water balance by using different saturated and unsaturated hydraulic conductivity values for the first and second half of the vegetation period (K_{sat} of macropores was reduced from 3288 to 79 cm/day and K_{sat} of soil matrix from 720 to 26 cm/day).

Using all the described hydraulic conductivity functions, SWRCs, climatic and plant related driving variables, the modeling of water balance for subplot 3 resulted in calculated water content data which were in high agreement with the measured data (fig. 10, 11, 12).

The application of different hydraulic conductivity functions during the vegetation period for the A_p-horizon results in a better fit of the simulated water content to the measured data than using only one data set for the whole time. In this case the compaction and increase of the bulk density of tilled soil layers during the vegetation period should be taken into account for modeling the water balance.

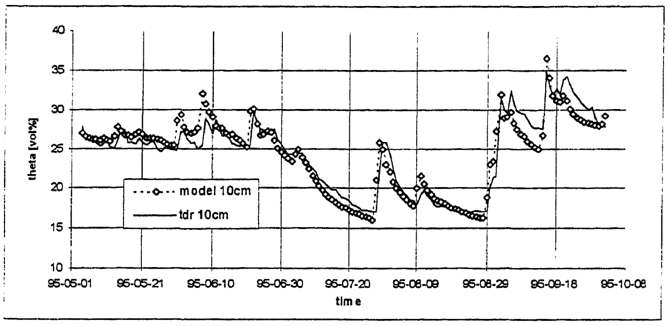

Figure 10: Measured and simulated water content of the A_p-horizon of subplot 3 using different hydraulic conductivity functions for the first and second half of the vegetation period

Abbildung 10: Gemessener und simulierter Wassergehalt des A_p-Horizontes in Parzelle 3 mittels unterschiedlicher Wasserleitfähigkeitsfunktionen für die erste und die zweite Hälfte der Vegetationsperiode

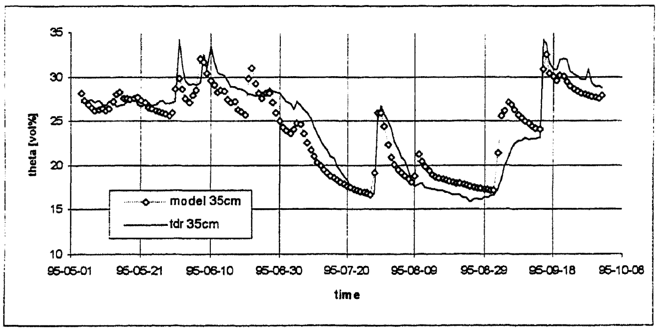

Figure 11: Measured and simulated water content of the A_h-horizon of subplot 3 using different hydraulic conductivity functions for the first and second half of the vegetation period

Abbildung 11: Gemessener und simulierter Wassergehalt des A_h-Horizontes in Parzelle 3 mittels unterschiedlicher Wasserleitfähigkeitsfunktionen für die erste und die zweite Hälfte der Vegetationsperiode

The "SOIL"-model is using the saturated hydraulic conductivity of the top layer and daily precipitation data for the calculation of the infiltration rates. Therefore if there are precipitation events with high rainfall intensity, the model cannot detect a restriction of infiltration and ponding of water on the soil surface. Summing up the water content change of the whole soil profil on the 28th of July, it can be shown that at least 50 mm of water is necessary to cause this increase of water content down to a depth of 60 cm and probably deeper. The measured precipitation on 28th of July was only 34,2 mm. This explains why the model could not fit the TDR-measured water content peak during the end of July. The excess water had to flow to the place where the TDR-probes were installed because of ponding and a not absolutely flat soil surface.

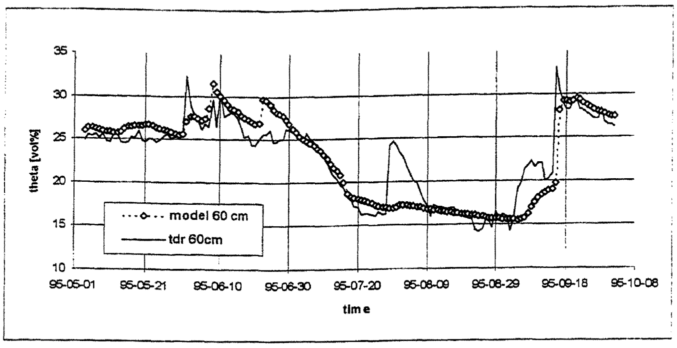

Figure 12: Measured and simulated water content of the AC-horizon of subplot 3 using different hydraulic conductivity functions for the first and second half of the vegetation period

Abbildung 12: Gemessener und simulierter Wassergehalt des AC-Horizontes in Parzelle 3 mittels unterschiedlicher Wasserleitfähigkeitsfunktionen für die erste und die zweite Hälfte der Vegetationsperiode

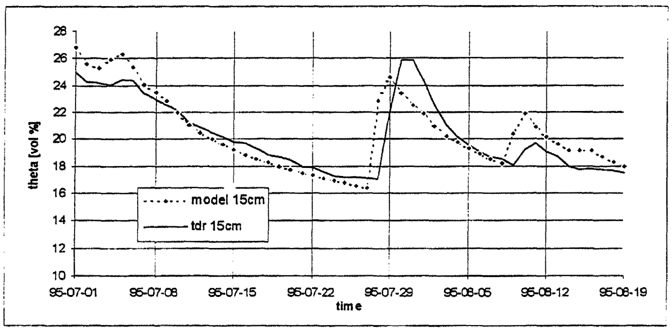

Figure 13: Measured and simulated water content of the A_p-horizon in subplot 3 using bypass flow in the period from 30th of June to 19th of August

Abbildung 13: Gemessener und simulierter Wassergehalt des A_p-Horizontes in Parzelle 3 mittels „bypass-flow" in der Zeit von 30. Juni bis 19. August

The next step to improve the model fit was to increase the precipitation amount on 28th of July up to 50 mm. This did not improve the modeling result because the higher precipitation only increased the water content on 28th of July at a soil depth of 15 cm and 35 cm but the water content increase in 60 cm depth was still meaningless. Therefore it was concluded that only bypass flow can describe this situation accurately. This is confirmed by the observation of a distinct crack system on the experimental site during the second half of July. Cracks are observed to develop down to a depth of 60 cm and deeper. Also WILSON et al. (1990) pointed out that preferential flow is occurring at extreme water conditions of the soil, that means under wet or very dry conditions which was the case for the soil Groß-Enzersdorf before the thunderstorm on 28th of July occurred.

The "SOIL"-model provides for this situation an empirical procedure by which bypass flow can be modelled. After some trials the water content during the period from 30th of June to the 19th of August could be simulated satisfactorily with the help of the optional crack procedure, see fig. 13, 14, 15.

The strong rise of water tension beginning in the first half of July was caused by root water extraction, see fig. 16. The tensiometer results and the simulated tension at subplot 3 at a depth of 60 cm were corresponding in a high degree. Therefore it could be concluded that the moment when the roots were reaching the depth 60 cm (at 7th of July) was properly estimated.

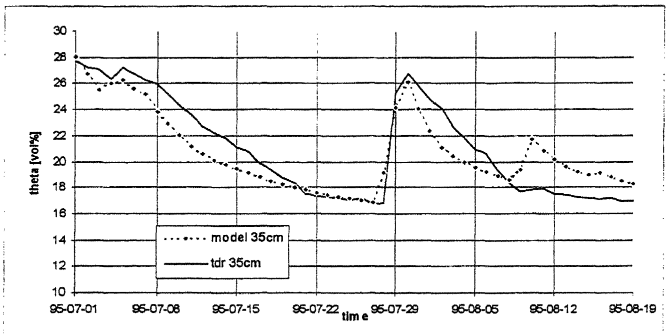

Figure 14: Measured and simulated water content of the A_h-horizon in subplot 3 using bypass flow in the period from 30th of June to 19th of August

Abbildung 14: Gemessener und simulierter Wassergehalt des A_h-Horizontes in Parzelle 3 mittels „bypass-flow" in der Zeit von 30. Juni bis 19. August

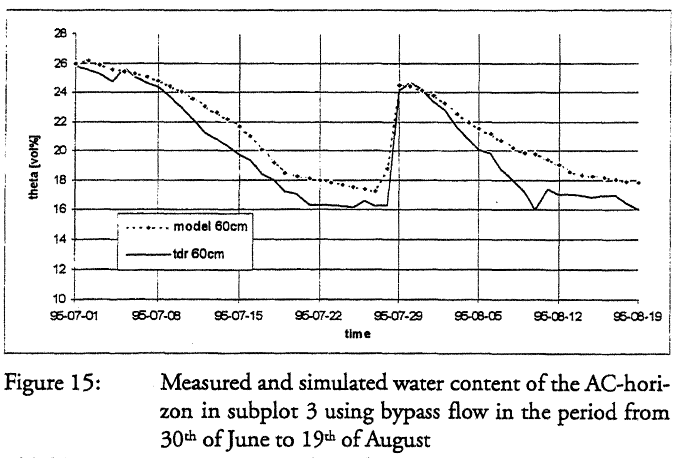

Figure 15: Measured and simulated water content of the AC-horizon in subplot 3 using bypass flow in the period from 30th of June to 19th of August

Abbildung 15: Gemessener und simulierter Wassergehalt des AC-Horizontes in Parzelle 3 mittels „bypass-flow" in der Zeit von 30. Juni bis 19. August

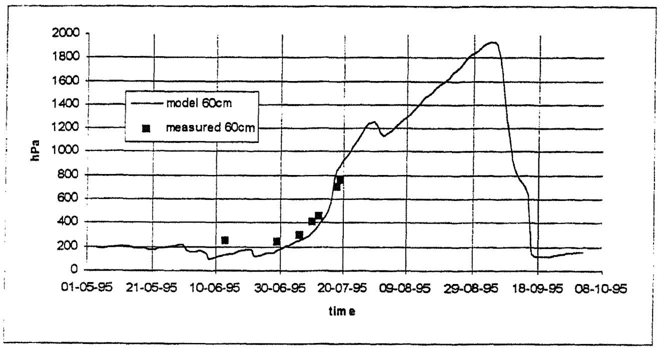

Figure 16: Measured and simulated tension at 60 cm soil depth in subplot 3

Abbildung 16: Gemessene und simulierte Saugspannung in 60 cm Bodentiefe in Parzelle 3

4. Conclusions

There exists a large number of methods for the assessment of the soil structural status concerning the hydraulic properties of a particular soil. In order to get a complete overview about the water transport phenomena, a combination of different field and laboratory methods should be used, especially considering the wide range of soil moisture from saturation to dry conditions and also considering time variability of soil hydraulic properties.

The GUELPH-permeameter is best suitable for obtaining the saturated conductivity of different soil layers as input for soil water balance simulations. Because of the big measurement volume dead ending macropores do not excessively effect the results and therefore the variability of results is quite low. This method is recommended for obtaining the saturated hydraulic conductivity of the soil matrix.

Macropores produced by rainworms or cracks can cause a high variability of saturated conductivity measurement with soil cores in the laboratory and therefore many replicates have to be taken. This method cannot reproduce the field situation in a realistic way if many of the continuous macropores penetrating through the whole length of the soil core are dead ending within the next few centimeters of the underlying soil layer. If the density of macropores is high, this method can give informations on the saturated conductivity including macropores of distinct soil layers for simulating soil water balance. For the case Groß-Enzersdorf, during the vegetation period 1995 the simulation of soil water balance was not sensitive on the saturated conductivity including macropores since the near saturation moisture range (saturation minus 4 %vol) was only rarely occuring . This might be the opposite for simulation models which are using input data of a shorter time scale but not mean daily input data as for the "SOIL"-model.

Using accurately measured soil hydraulic parameters for the input for the "SOIL"-model, which are highly sensitive to soil structure, the simulated water balance of the site Groß-Enzersdorf was in high agreement with measured water content data.

Exact unsaturated conductivity data as input for simulating the soil water balance are most important in the moisture range from saturation to about -200 to -300 hPa (so called field capacity) since water movement is significant only within this moisture range but can more or less be neglected for drier moisture conditions compared to root water extraction. The Instantaneous Profile Method is suitable for measuring the unsaturated hydraulic conductivity within this moisture range.

The estimation of the unsaturated hydraulic conductivity functions using different models (e.g. VAN GENUCHTEN, 1980; BROOKS and COREY, 1964), which are necessary as input for many soil water balance and solute transport simulation models, should always be compared and supported with measured results, especially if the effects of soil strucural differences caused by different tillage systems are to be studied. It is not recommended to rely on estimated unsaturated conductivity functions although many times the estimation proved to be satisfying compared to measured data.

The model results are not showing a negative influence of soil compaction on the soil water balance of the soil in Groß-Enzersdorf and therefore no reduction of plant growth can be expected. On the contrary, the model results showed a higher water retention if bulk density is increased and saturated conductivity is decreased.

The influence of soil structure on root growth could not be tested with the chosen computer model since root properties are needed as input parameters. But in many cases a reduction of root growth and rooting depth will significantly influence the biomass production. Answering this question will need future activities using different simulation models.

Since only mean daily input data are used as driving variables and the precipitation is uniformly distributed over the whole day, the infiltration of water into the soil cannot be simulated exactly. Therefore ponding of precipitation water and subsequent surface flow of water caused by compaction or crusting of the soil surface (which will also occure under so called flat conditions) could not be detected with the chosen simulation model for situations with high rainfall intensity.

References

ANKENY, M. D., M. AHMED, T. C. KASPAR and R. HORTON (1991): Simple Field Method for Determining Unsaturated Hydraulic Conductivity. Soil Sci. Soc. Am. J., 55, 467–470.

BROOKS, R. H. and A. T. COREY (1964): Hydraulic properties of porous media. Hydrology Paper No. 3, Colorado State University, Fort Collins, Colorado.

BÖHM, W. (1979): Methods of Studying Root Systems. Springer-Verlag Berlin, Heidelberg, New York, Tokyo.

DRAFT INTERNATIONAL STANDARD 11274, (1992): Soil quality – Determination of the water retention characteristic – Laboratory method.

GARDNER, W. R. (1958): Some Steady State Solutions of Unsaturated Moisture Flow Equations with Application to Evaporation from a Water Table. Soil Sci., 85, 228–232.

JANSSON, P. E. (1991): Simulation Model for Soil Water and Heat Conditions – Description of the SOIL model. Report 165 of the Swedish University of Agricultural Sciences, Uppsala.

JANSSON, P. E. (1993): PLOTPF User's Manual. Communications 93:6, Swedish University of Agricultural Sciences, Uppsala.

MUALEM, Y. (1976): A New Model for Predicting the hydraulic Conductivity of Unsaturated Porous Media. Water Resour. Res., 12, 513–522.

PLAGGE, R., M. RENGER and C. H.. ROTH (1989): A new laboratory method to quickly determine the unsaturated hydraulic conductivity of undisturbed soil cores within a wide range of textures. Z. Pflanzenern. Bodenkde, 153, 39–45.

PLAGGE, R., C. H. ROTH, M. A. MALICKI and M. RENGER (1995): Berücksichtigung der Lagerungsdichte bei der dielektrischen Bestimmung des Wassergehaltes von Böden mit Hilfe der Time Domain Reflectometry (TDR). Mitt. der DBG, 76, 133–136.

REYNOLDS, W. D. and D. E. ELRICK (1985): Measurement of Field-Saturated Hydraulic Conductivity, Sorptivity and the Conductivity-pressure Head Relationship Using the "Guelph permeameter". Proc. of National Water Well Assoc. Conf. Denver, USA, November 1985, 9–33.

ROTH, C. H., R. PLAGGE, H. BOHL and M. RENGER (1995): Improved Procedures for the Measurement and Calculation of Unsaturated Hydraulic Conductivity of Structured Soils. In: HARTGE, K. H. and B. A. STEWARD (Ed.): Soil Structure – its Development and Function. Advances in Soil Science, Lewis Publishers, Boca Raton, 299–323.

SOBCZUK, H. A., R. PLAGGE, R. T. WALCZAK and C. H. ROTH (1992): Laboratory Equipment and Calculation Procedure to Rapidly Determine Hysteresis of Some Soil Hydrophysical Properties under Nonsteady Flow Conditions. Z.Pflanzenernähr. Bodenk.,155, 157–163.

VAN GENUCHTEN, M. TH. (1980): A Closed-form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils. Soil Sci. Soc. Am. J., 44, 892–898.

WILSON, G. V., P. M. JARDINE , R. J. LUXMOORE and J. R. JONES (1990): Hydrology of a Forested Hillslope during Storm Events. Geoderma, 46, 119–138.

WOODING, R. A. (1968). Steady Infiltration from a Shallow Circular Pond. Water Resourc. Res., 4, 1259–1273.

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