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Simulation to Support Interpretation of Field Measurements to Evaluate Cover Crop Effects

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A Master of Science Thesis

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ABSTRACT

To support the interpretation of soil water status measurements, simulations were performed with Hydrus_1D (version 3.0). Water content measurements were available at the experimental site where the effects of cover crops on the water balance were studied from Oct. 2002 to July 2005. The measured water contents are compared with the simulated results. The main objectives are the program handling for this specific case study, determining the data requirements and detecting shortcomings. Additionally, measurement gaps during the measurement failure of the FDR-devices could be filled and the moisture variation during different cropping seasons could be observed.

With the calibrated model water flow calculations, like top and bottom fluxes, could be performed. For a better interpretation all results are presented in graphical form. The simulation result of the bare soil period was found to be almost exactly equal to the measured ones. Since the root water uptake can be influenced by different factors, a good knowledge of parameters for a given crop is very important for the exact determination of the seasonal water content variation. Main emphasis was paid to the careful determination, of initial and boundary conditions, which is essential to achieve reliable simulation results. The period of mulch application on the soil surface needs substantial modification of input parameters.

By simulating the different cropping periods water flow could be estimated and the information obtained by monitoring could be substantially extended.

1. INTRODUCTION

Soil moisture in the unsaturated zone (vadose zone) is a key variable in the determination of water and energy balance which plays a crucial role in irrigation management, precision farming, and ground water recharge. It is becoming increasingly obvious that there is a pressing need for unsaturated water flow modeling, monitoring and characterization at the regional scale, such as agricultural field and watershed (Hopmanns JW and Shoups GH, 2003).

The unsaturated zone provides the best opportunities to limit or prevent subsurface environmental pollution. Soil and groundwater pollution is an alarmingly increasing problem of the world. Agriculture contributes many pollutants to the environment such as Phosphates, Herbicides, Pesticides, Nitrates and Bacteria. Nitrates and Pesticides are common contaminants of groundwater derived from agriculture. For the estimation of solute transport a prerequisite is the knowledge of soil water movement. In a soil profile infiltrated water can be stored and retained for water consumption by plant roots, for evaporation and cooling of the land surface, contributes to seepage to groundwater, and renewal of water resources.

Numerical modeling is becoming an increasingly important tool for analyzing complex problems involving water flow and contaminant transport in the unsaturated zone. Solute transport experiments under realistic conditions at the field scale are not easily implemented because of the often overwhelming problems of soil surface heterogeneity and variability in subsurface hydraulic and solute transport properties. (Schaap, M.G. and Wosten, H, 2003).

Various factors like soil properties, vegetation, solar radiation, atmospheric condition, prevailing topography, and general geo-environmental conditions affect evolution and variability of soil moisture. Soil moisture dynamic simulation in the unsaturated zone promotes to produce most effective output data and can lead to optimized design of experiments. Simulation supports data interpretation and may help to fulfill gaps when there are measurement failures. It promotes insight in to the underlying theory and can be applied to test and further develop new models, and may reduces the number of experiments.

1.1 Field experiment

The source of field measurements for this work is the project "Nitrogen Uptake and Biomass Yield of Catch Crops and Effects on Yield and Quality of subsequent Crops and Nitrate Contents in Soil Solution under Conditions of Organic Farming in the Pannonian Region" (Zwieschenfrucht). The project aims to improve management strategies (cutting regime versus green manure; pure legume crops versus legume grass mixtures) of forage legume stands during conversion to organic farming. The investigations were conducted to optimize the use of legume N by the following crops, while minimizing the risk of nitrate leaching and environmental impact (groundwater protection). The site of the project is at Raasdorf (Lower Austria) in Marchfeld about 5km east of Vienna located at about 154m above see level. For data recording a data logging equipment supplied by a solar panel was set up (Figure 1).

Figure 1: Fieldmeasuring site Project “Zwischenfrucht (Intermediate cropping)”

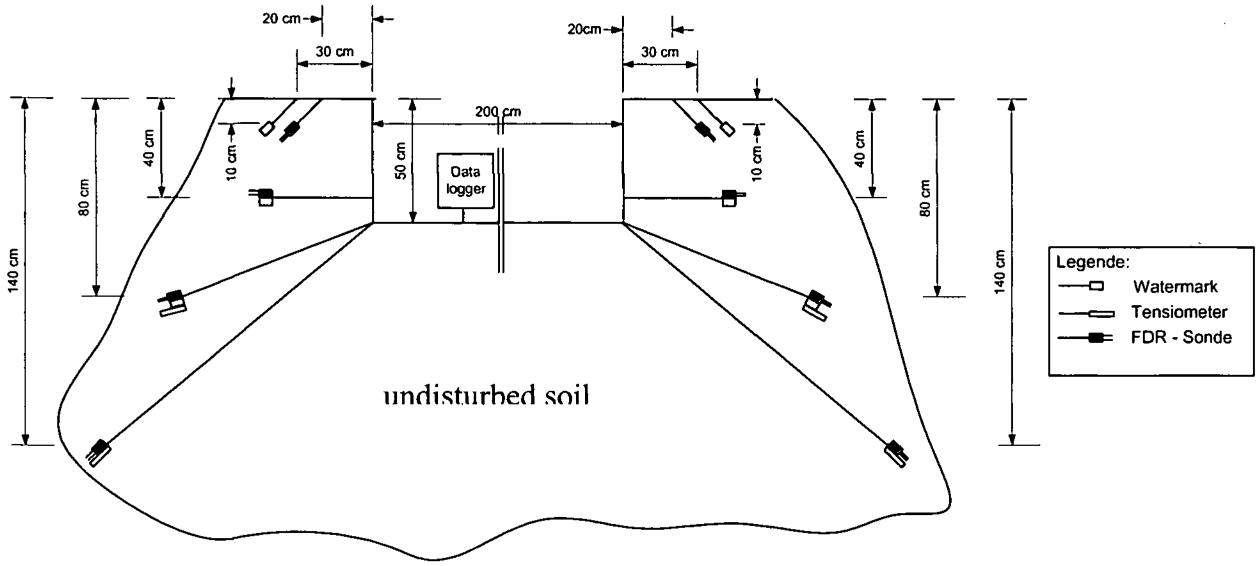
The data was collected from autumn 2002 to summer 2005. The consecutive cropping seasons of different crops in the project are Legumes (2002), potato (2003), winter rye (2003/04), Legumes (2004) and summer barely (2005).

1.2 Field plots

The soil type of the project site is humus and silty loam at the depth of 40-90 cm with lower to medium bulk density and with a pore volume of about 50%. The soil is well aerated, has a high available water capacity (estimated aFK ~ 200 mm) and shows good water permeability. Gravel is found approximately in a depth of 2 m.

The change of soil water content was measured in plot 6 and 9 by using FDR-sensors in a randomized block design (Figure 2b). Each measurement was done at the measurement depths of 10, 40, 80, and 140 cm. The water movement should be gripped by means of water tension (Tensiometer, Gypsumblock) in the soil. For each measurement profile, the FDR-sensor, Tensiometer and Gypsumblock were installed from on pit into the undisturbed soil (Figure 2a).

Cross-section



Plot design

16 Parzellen a 54 m² = 864 m²

Trial	plants (Report, Intermediate crop project)
1	Leg./NL-Gemenge: Platterbse, Saatwicke, Futtererbse, Phacelia, Ölrettich, Stoppelrübe
2	Leg.-Gemenge: Platterbse, Saatwicke, Futtererbse
3	Nichtleguminosen-Gemenge: Phacelia, Ölrettich, Stoppelrübe
4	Nullparzelle ohne Zwischenfrucht

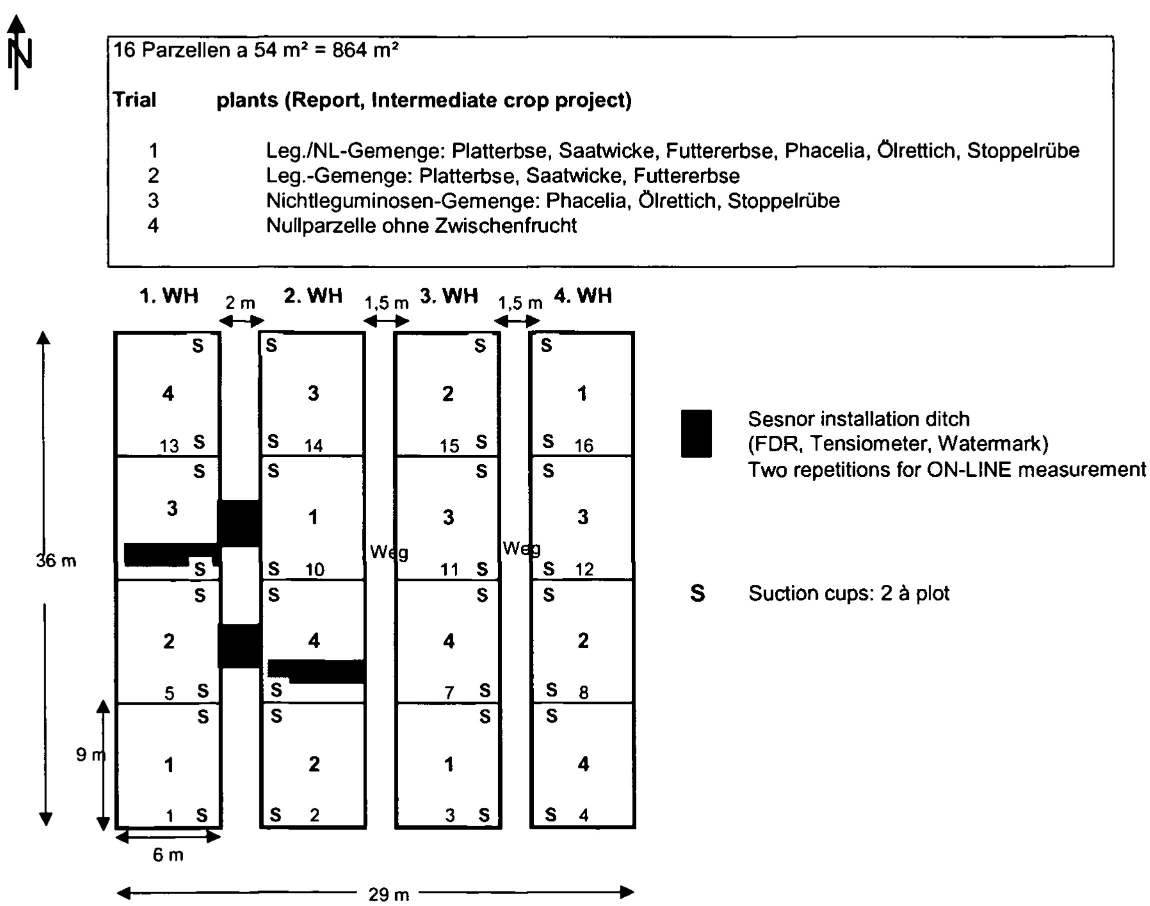


Figure 2: Soil water status sensor installation (cross-section), overview of experimental design (plot design)

Capacitive soil water content sensors were installed at all measurement levels, tensiometer were installed at depth levels and the top layers were equiped with block sensors. For temprature compensation a temprature sensor was placed in the top layer (Table 1). The termometer has an own temprature sensor incorporated.

Depth (cm)	FDR-sensor	Tensiometer	Gypsumblock	Temperature Sensor
10	X		X	X
40	X		X	
80	X	X	X	
140	X	X		

Table 1: Number of sensors in a profile and installation depth.

2. OBJECTIVE

The main objective of the presented study is to use simulation tools to support interpretation of field measurements and to represent soil water dynamics.

To address this, the following specific objectives are treated:

- General test of application of HYDRUS_1D for Project "Zwieschenfrucht".
- Detection of data requirement
  The available data are analysed and missing data are obtained from literature and other experimental sources
- Program handling of HYDRUS_1D
  A support for program users is provided to ensure good quality simulations

- Detection of Short comings

  What and what is not possible to be simulated in this context is addressed
- Evaluation of water dynamics

  By calculating water dynamic measurement failures may be compensated and closed time series are established. Further boundary flux values are provided.

3. METHODOLOGY

HYDRUS_1D was selected for the simulation and reasons for this are:

1, a vertical flow of water is assumed

2, root growth the 1_D model has

3, the movements are also given a presentation of vertical flow only

In this chapter a summary of the software features with respect to the simulation task is provided (HYDRUS_1D manual, 2005).

3.1 General introduction to HYDRUS_1D

HYDRUS_1D is a finite element model for simulating the movement of water, heat, and multiple solutes in variably saturated media. The program may be used to analyze water and solute movement in unsaturated, partially saturated, or fully saturated porous media. The program implements a Marquardt-Levenberg type parameter estimation technique for inverse estimation of selected soil hydraulic and/or solute transport and reaction parameters from measured transient or steady state flow and/or transport data. The procedure permits several unknown parameters to be estimated from observed water contents, pressure heads, concentrations and/or instantaneous or cumulative boundary fluxes (e.g. Infiltration or outflow data). Additional retention or hydraulic conductivity data, as well as a penalty function for constraining the optimized parameters to remain in some feasible region (Bayesian estimation) can be optionally included in the parameter estimation procedure (HYDRUS_1D manual, 2005).

The governing flow and transport equations are solved numerically using Galerkin type linear finite element schemes. Integration in time is achieved using an implicit (backwards) finite difference scheme for both saturated and unsaturated conditions. Additional measures are taken to improve solution efficiency for transient problems, including automatic time step adjustment and adherence to preset ranges of the Courant and Peclet numbers. The water content term is evaluated using the mass-conservative method proposed by Celia et al. [1990] as sited in HYDRUS_1D manual, 2005. Possible options for minimizing numerical oscillations in the transport solutions include upstream weighing, artificial dispersion, and/or performance indexing The model is supported by an interactive graphics-based interface for data-preprocessing, discretization of the soil profile, and graphic presentation of the results (HYDRUS_1D manual, 2005).

3.2 Water flow

The program numerically solves Richards`s equation for variably saturated water flow. The flow equation includes a sink term to account for water uptake by plant roots. Boundary conditions can be constant/time-varying hydraulic head or flux or boundaries controlled by atmospheric conditions. The code can also handle seepage face boundaries and free drainage boundary conditions.

The one dimensional uniform (equilibrium) water movement in a partially saturated rigid porous medium is described by a modified form of Richard`s equation using the assumptions that the air phase plays an insignificant role in the liquid flow process and that water flow due to thermal gradients can be neglected (HYDRUS_1D manual,2005).

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}\left[K\left(\frac{\partial h}{\partial x} + \cos\alpha\right)\right] - S \qquad (1)$$

Where h is the water pressure head $[L]$, θ is the volumetric water content L^3L^{-3}, t is time $[T]$, x is the spatial coordinate $[L]$ (Positive upward), S is the sink term $L^3L^{-3}T^{-1}$, α is the angle between the flow direction and the vertical axis (i.e., α = 0 for vertical flow, 90^0 for horizontal flow, and $0^0 < \alpha < 90^0$ for inclined flow) and K is the unsaturated hydraulic conductivity function $\lfloor LT^{-1} \rfloor$ given by:

$$K(h,x) = K_s(x)K_r(h,x) \qquad (2)$$

Where K_r is the relative hydraulic conductivity [–] and K_s the saturated hydraulic conductivity $\lfloor LT^{-1} \rfloor$.

The flow region itself may be composed of non-uniform soils. Flow and transport can occur in the vertical, horizontal, or a generally inclined direction. The water flow part of the model can deal with (constant or time-varying) prescribed head and flux boundaries, boundaries controlled by atmospheric conditions, as well as free drainage boundary conditions. Soil surface boundary conditions may change during the simulation from prescribed flux to prescribed head type conditions (and vice-versa).

The unsaturated soil hydraulic properties are described using van Genuchten [1980], Brooks and Correy [1964] and modified van Genuchten type analytical functions. Modifications were made to improve the description of hydraulic properties near saturation. The HYDRUS code incorporates hysteresis by using the empirical model introduced by Scott et al. [1983] and Kool and Parker [1987]. This model assumes that drying scanning curves are scaled from the main drying curve, and wetting scanning curves from the main wetting curve.

Root growth is simulated by means of a logistic growth function. Water and salinity stress response functions can be defined according to functions proposed by Feddes et al. [1978] or van Genuchten [1987] as cited in HYDRUS_1D manual, 2005.

According to Feddes et.al (1978), the sink term S is defined as the volume of water removed from a unit volume of soil per unit time due to plant water uptake:

$$S(h) = \alpha(h) S_p \quad (3)$$

Where the root water-uptake water response stress function α(h) is a prescribed dimensionless function of the soil water pressure head $(0 \le \alpha \le 1)$ and S_p is the potential water uptake rate $\lfloor T^{-1} \rfloor$

HYDRUS_1D allows the calculation of root growth using Verhulst-Pearl logistic growth function, in contrary to the constant root depth in HYDRUS_2D.

For this study the version 3.0 of HYDRUS_1D (Released in April 2005), which includes the one dimensional finite element model HYDRUS (version7) for simulating the movement of water heat and multiple solutes in variably saturated media.

3.3 Water flow parameters

The program allows users to select three types of models to describe the soil hydraulic properties: van Genuchten [1980], Brooks and Corey [1964] and modified van Genuchten type equations [Vogel and Cislerova, 1988].

In this simulation process Van Genuchten-Mualem Hydraulic Single Porosity model was used.

Van Genuchten [1980]:

$$\theta = \begin{cases} \theta_r + \dfrac{\theta_s - \theta_r}{\left(1 + [\alpha h]^n\right)^m} & h < h_s \\ \theta = \theta_s & h \geq h_s \end{cases} \qquad K(h) = K_s S_e^{0.5}\left[1 - \left(1 - S_e^{1/m}\right)^m\right]^2 \quad \text{.......(4)}$$

h_s - air-entry value [L]

θ_s - Saturated water content [-]

θ_r - Residual water content [-]

a, m, n - empirical parameters [1/L], [-], [-]

S_e - Effective water content [-] $S_e = \dfrac{\theta_s - \theta}{\theta_s - \theta_R}$

K_s - Saturated hydraulic conductivity [L/T]

K_r - Relative hydraulic conductivity [-]

K_k (h_k) - Unsaturated hydraulic conductivity at pressure head h_k [L/T]

Parameters for this function are determined by curve fitting to laboratory measured retention data pairs or by using texture information.

When the Van Genuchten model is used, either a non-hysteretic description, a hysteretic description in the retention curve only, or hysteretic descriptions in both the retention curve and the hydraulic conductivity curve can be used.

When hysteretic description of the soil hydraulic properties is selected, then the user must specify whether the initial condition is associated with the main wetting or main drying retention curve.

In the modified van Genuchten equation, the original Van Genuchten equations were modified to add extra flexibility in the description of the hydraulic properties near saturation Vogel and Cislerova, 1988 as sited in HYDRUS_1D manual, 2005.

In the soil hydraulic model as it is explained in the introduction part new features in Hydrus_1D version 3.0 (Released in April 2005) contains additional analytical models for the soil hydraulic properties suggested by Kosugi [1996] (log normal model) and Durner [1994] (dual porosity model) and water flow in the dual-porosity system. The dual porosity assume that the water flow is restricted to the fractures (inter-aggregate pores and macro pores), and that water in the matrix, consisting of immobile water pockets, can exchange, retain and store water, but does not permit convective flow. This conceptualization leads to two region, dual porosity type flow and transport models (Phillip, 1968 and Van Genuchten und Vierenga, 1976) that partition the liquid phase in to mobile (flowing inter aggregate) θ_m , and immobile (intra-aggregate) θ_{im} regions: $\theta = \theta_m + \theta_{im}$ since the soil profile analysis shows the texture to be dominated by loam and the presence of the fracture was not notified, the dual porosity model was not taken in the simulation rather Single hydraulic model, van Genuchten, with no hyteresis was taken.

3.4 Soil hydraulic properties

3.4.1 Soil water potential

The two forms of energy influencing water flow in the soil are: potential energy and kinetic energy. The potential energy is the primary source of energy in determining the movement of water in the soil. Since soil water velocities are slow, the kinetic energy is generally considered to be negligible.

The total energy state of the soil is defined by its equivalent potential energy, which is determined by the various forces acting on the water per unit quantity (Jury et. al 1991).

The driving force for the flow of water in the vadose zone is the change in potential energy with the distance, i.e. soil-water potential gradient. This driving force in the soil determines: the direction and magnitude of water flow, plant water extraction, drainage volumes, capillary rise, soil temperature changes and solute (contaminant) transport rates.

The total soil water potential is:

$$\psi_T = \psi_z + \psi_o + \psi_a + \psi_m \text{ (m)} \qquad (5)$$

where ψ_z , ψ_o , ψ_a and ψ_m (m) are , gravitational, osmotic(solute), air pressure and matric potential respectively (Jury et. al 1991).

In the description of water flow in the soil, the osmotic and the air pressure potential can be neglected.

The soil water potential was obtained by utilizing tensiometer and water-mark block type sensors.

3.4.2 Soil moisture characteristics

The soil water potential is obtained by utilizing Tensiometers and Water mark block type sensors. This information also provides the initial conditions for the simulation. The fundamental relationship between soil's moisture content θ and soil matric potential ψ_m is called soil moisture characteristics.

The moisture characteristic curve is the negative exponential relationship between pressure head and water content. When the soil is saturated (the water content = porosity) there is a tension head of zero. The tension head decreases to air-entry tension, where significant volumes of air appear in the soil pores, *i.e.*, at the top of the capillary fringe or tension-saturated zone (Tammo S. et al. 1995).

As mentioned by Lal R. and Shukla M.k 2004, the knowledge of this relationship is indispensable for simulation. It may be either established indirectly e.g. from texture or through laboratory investigation. This was the case for this experiment. This unique relationship depends on soil structure as determined by total porosity and the pore size distribution. Thus, change in structure and pore size distribution leads to changes in soil moisture characteristics.

A common way as used in HYDRUS_1D to express soil moisture characteristic is the soil water retention curve that describes the relation between volumetric water content Θ (L3L3), and soil water pressure head h (L), plus the relation between volumetric water content and hydraulic conductivity, k (L/T).

3.4.3 Soil moisture content

Water in the soil is held by the forces of cohesion and adhesion in which surface tension, capillarity and osmotic pressure play a significant role. There are two types of forces acting on soil water. Positive forces are those that enhance soil's affinitive for water (e.g. Forces of cohesion and adhesion). In contrast some negative forces that take water away from soil including gravity, activity of growing plant roots and evaporative demand of the atmosphere. At any given point in time, soil's moisture content is the net result of these positive and negative forces (Lal R. and Shukla M. 2004). The gradient causing flow in unsaturated soils is the negative pressure potential, i.e. matric potential.

The two important aspects of liquid water held within the pores are field moisture capacity and permanent wilting point. Field moisture capacity is moisture content when all macro-pores or transmission pores have been drained and water in the macro-pores has been replaced by air (Soil science glossary, 2007).

Permanent wilting point is the lower limit of moisture content of soil at which forces of cohesion and adhesion holding moisture in the soil exceeds the pull that plant roots can exert to extract moisture from the soil. The corresponding pressure head for permanent wilting point is less than -15,000cm.

These two limits determine the plant available water capacity (AWC) which reads as:

$$AWC = FC - PWP \qquad (6)$$

Where FC is water content at field capacity

PWP water content at permanent wilting point.

3.4.4 Hydraulic conductivity

Hydraulic conductivity of a soil is the rate at which water moves through a porous media under a unit potential-energy gradient.

Hydraulic conductivity is the function of particle size for saturated soil condition and particle size and degree of saturation for unsaturated condition.

Unsaturated hydraulic conductivity $K(\theta)$ is a non linear function of both moisture content θ and matric potential ψ_m

3.5 Upper and lower boundary conditions

Different configuration of the boundaries of the domain within which the phenomena under consideration takes place results in different solutions. Hence, stating them in a way that reflects the actual conditions of the problem is important.

Description of the interaction of the system under consideration with its environment i.e. conditions on the boundaries, even for a qualitative description, questioned to be answered include those of background conditions and what happens along the soil surface, lower root zone, water table and so on. For the time-dependent problems, the boundaries are with respect to the time domain as well as spatial boundaries; for steady-state problems, boundaries are only spatial.

Water flow boundary conditions: as it was indicated in the profile analysis the top 0 -10 cm depth of the profile is more of organic matter content and the texture of the profile was as indicated above. Therefore, the upper boundary condition in this simulation was taken to be atmospheric boundary condition with surface layer. This condition permits the water to build up on the soil surface. The height of the surface water layer increases due to precipitation, and reduce because of infiltration and evaporation. The pressure head determination through measurements indicated that the bottom of the soil profile has constant pressure head therefore; the lower boundary condition was taken to be constant pressure head.

The initial condition was specified in terms of pressure head. For the consecutive simulation step for each growing season of different crop the result of the first each season pressure head was taken as initial condition for the next growing season of the next crop. The measured pressure head value was used as an initial condition whenever the data for the given growing season was available. Another possibility was to take the pressure head from the PF curve of the measured moisture content.

The time variable boundary conditions, like precipitation and evaporation and potential evapotranspiration for the considered season were taken from the given data.

3.6 Water balance calculation

The water balance method is one of the indirect methods to determine the flux, where all of the water balance components are measured except for the lower boundary flux, i.e., the seepage.
From the amount of precipitation, evaporation, transpiration and the change of water content in the soil, it is possible to calculate the amount of seepages.

$$S = P - (E + T) - \Delta Mc \qquad (7)$$

P Precipitation

E Evaporation

T Transpiration

ΔM_c Change in water content in the soil

3.7 New features in HYDRUS_1D version 3.0

1. Root water uptake with compensation of water stress
2. Additional analytical models for the soil hydraulic properties suggested by Kosugi [1996] (log normal model) and Durner [1994] (dual porosity model)
3. Water flow in the dual-porosity system
4. Solute transport with attachment/detachment coefficients, permitting simulations of colloid, virus, and bacteria transport
5. Two kinetic sorption sites (one can be used for example for the air-water interface)
6. Filtration theory based evaluation of attachment coefficients
7. Carbon dioxide production and transport module
8. Geochemical carbonate chemistry module that considers transport, precipitation/dissolution, cation exchange, and complicated reactions for major ions.
9. The new model is (may be) about 3 times faster than the old model.

4. INPUT PARAMETERS FOR SIMULATION

Input parameters are the foundations upon which mathematical model rest and they are vulnerable because problems associate with scale and parameter heterogeneities make representative measurement elusive (Kramer and Cullen, 1995).

4.1 Soil profile information

Results of the soil texture analysis for the investigated plots were taken to determine the main geometry information to be implemented in HYDRUS_1D (Figure 3). The depth of soil profile is 140 cm. The soil profile depth is the basis for the module PROFILE for discretization the domain and the property distribution.

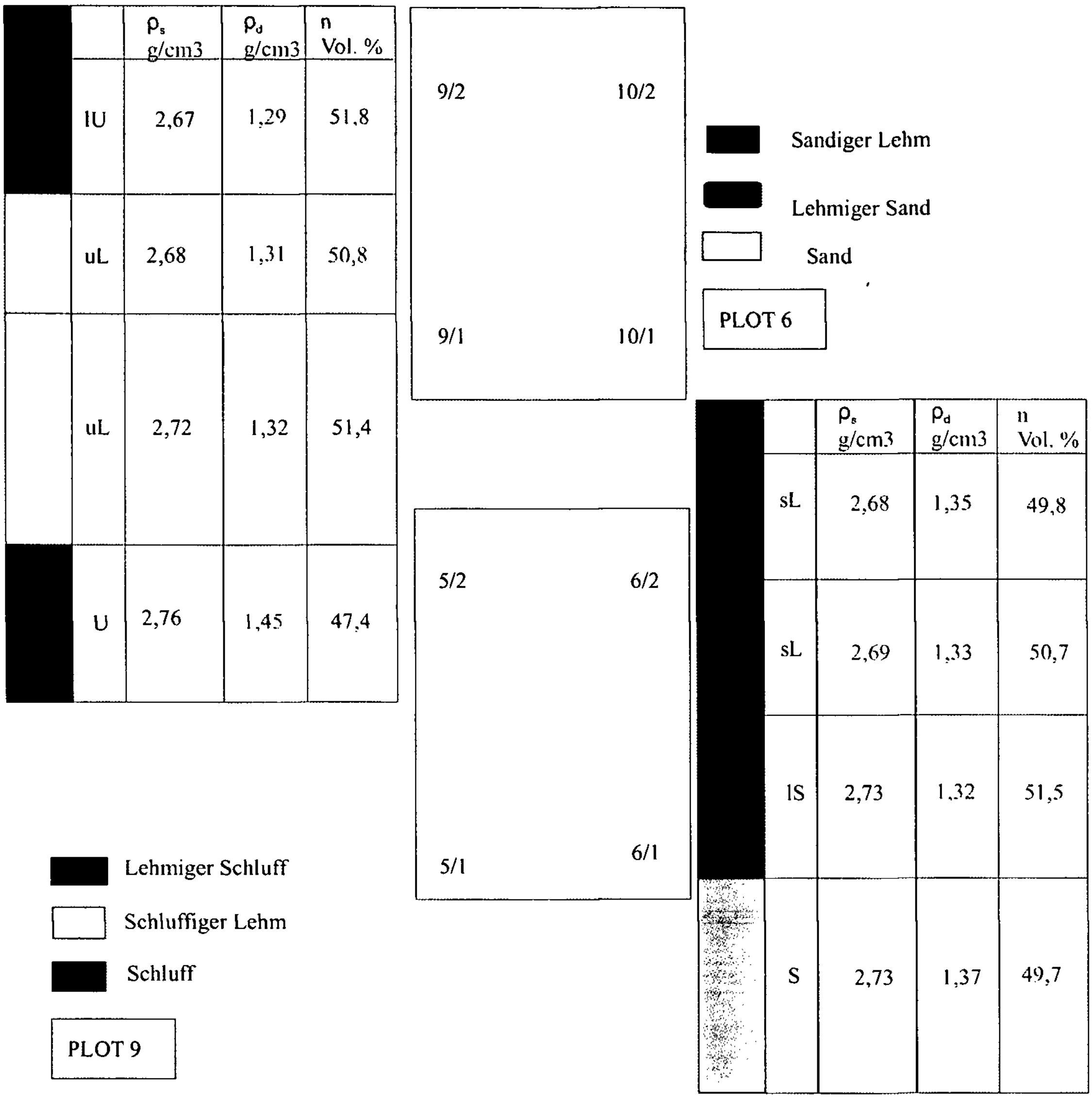


Figure 3: Texture and soil parameter distribution of plot6 and plot9

Samples for the particle size distribution analysis were taken for the depth in

Plot 6

0-33 cm, 33-60 cm, 60-90 cm, 90+ cm and for

Plot 9

0-35 cm, 35-64 cm, 64-103 cm, 103+cm respectively.

The texture of plot 6 is sandy loam, loamy sand and sand and that of plot 9 is loamy silt, silt loam and silt.

Four different soil materials were identified for the soil profile (Figure 4). Materials were then assigned to material numbers which are specified in the module PROFILE (Figure 5). The soil hydraulic and solute transport properties for each material are specified in a different simulation preparation steps.

The numbers of sub regions for which separate water and solute balances are being computed are equal to the profile geometry and hence also four. Sub regions are identified by sub region numbers which are specified in the PROFILE module. Since the soil column was vertical the inclination was taken to be zero. The observation points are placed at the depth of 10, 40, 80 and 140 cm (Figure 6) in accordance with the sensor depth in the field.

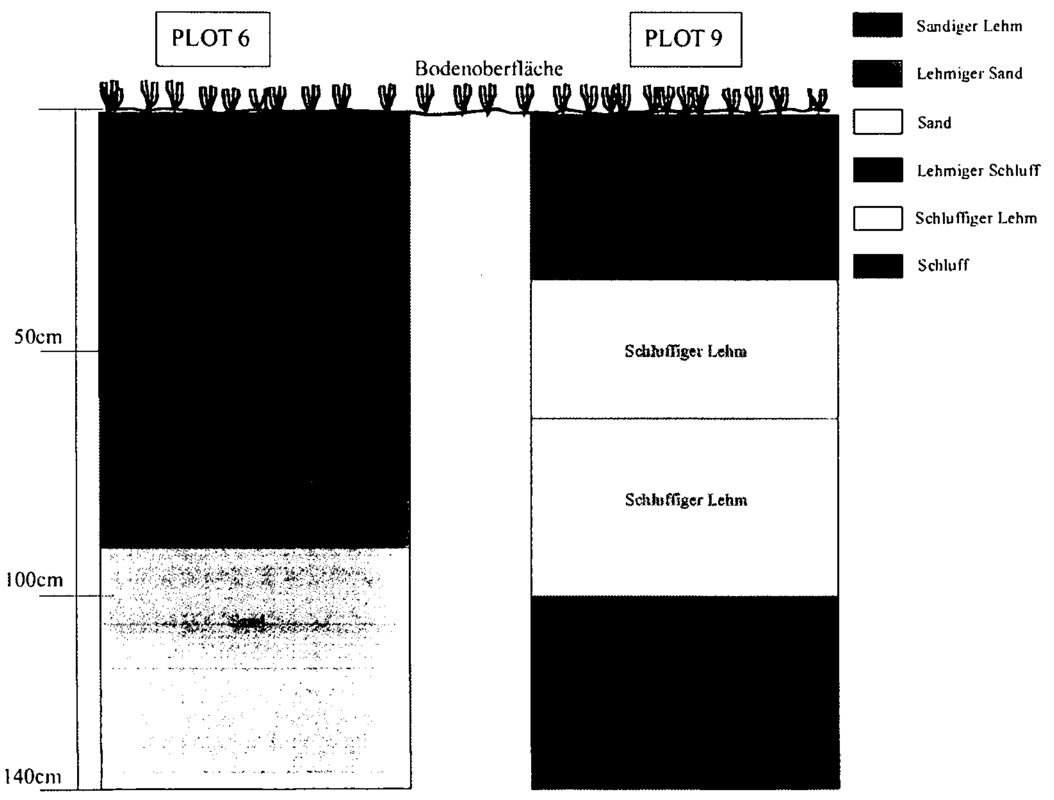


Figure 4: Identified soil profile of plot 6 and plot 9

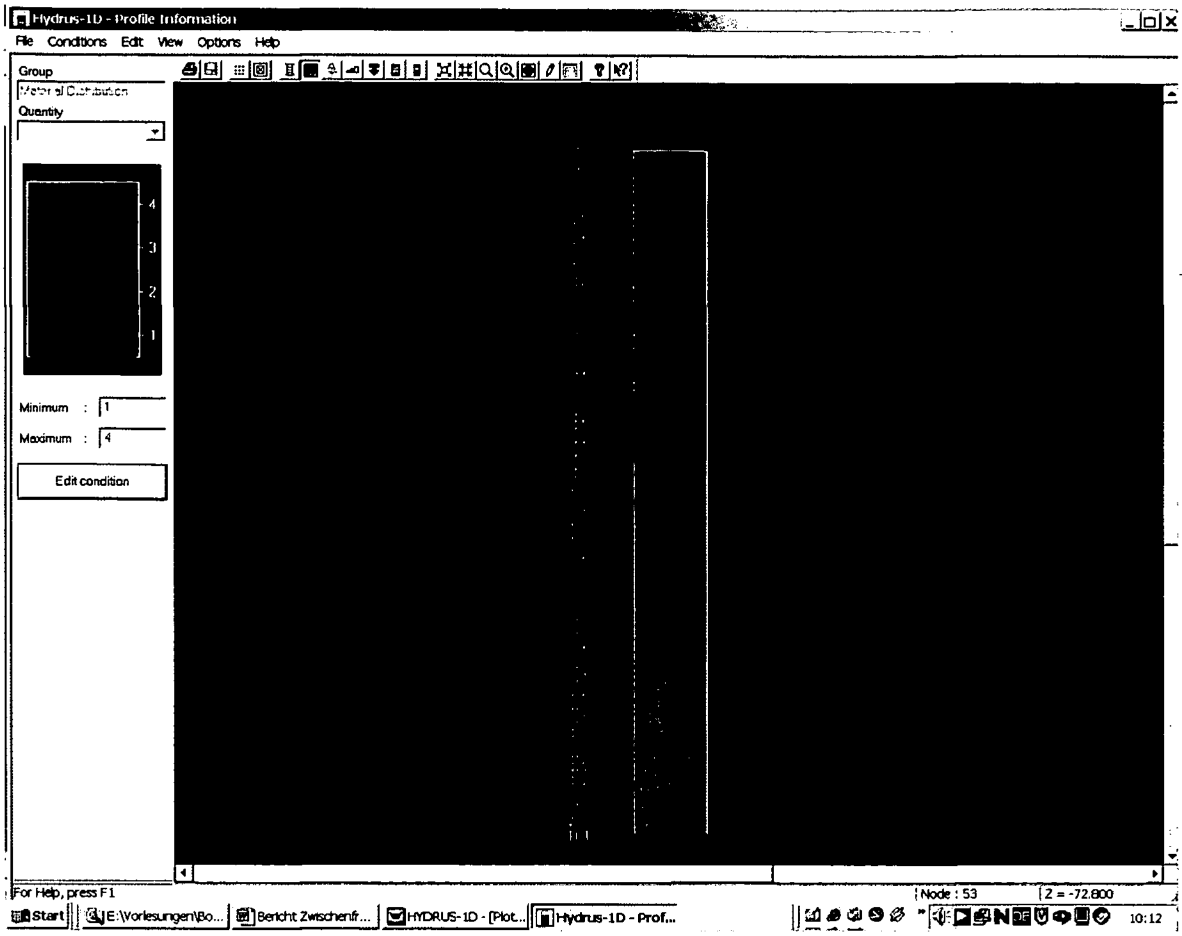


Figure 5: Material and sub region distribution of the soil profile

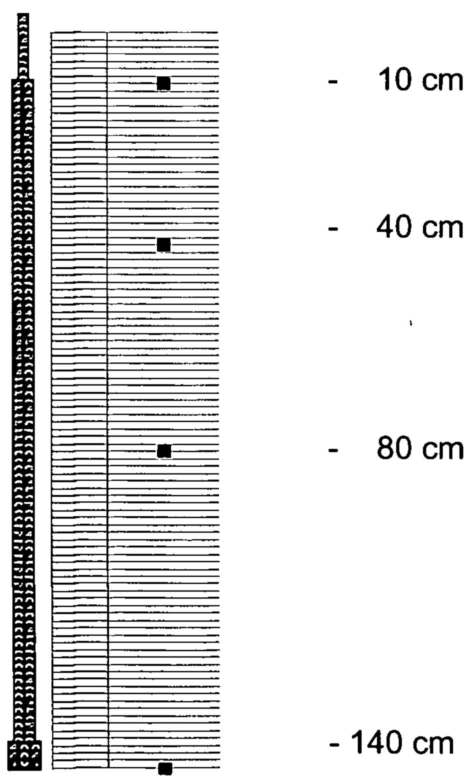


Figure 6: Placement of observation points

4.2 Growing pattern

The growing pattern determines the respective simulation period. Time units for the simulation are days, with the time variable boundary conditions being 0 for initial time and the last date of the growing season of the given crop. The default time step was taken for the time descretization.

The growing period of each crop are summarized in Table 2.

From	To	Days	Cropping pattern	Max. Root depth
01.08.2002	31.10.2002	92	Legumes 2002	50cm
01.11.2002	15.04.2003	166	Bare soil 2002/03	
16.04.2003	04.08.2003	111	Potato 2003	40 cm
05.08.2003	10.10.2003	67	Bare soil 2003	
11.10.2003	02.08.2004	297	Winter rye 2003	120 cm
03.08.2004	12.08.2004	10	Stubble field 2004	
13.08.2004	17.11.2004	97	Legumes 2004	50 cm
18.11.2004	31.03.2005	134	Mulch 2004/05	
01.04.2005	18.07.2005	109	Barely 2005	120 cm
19.07.2005	30.07.2005	13	Stubble field 2005	

Table 2: Growing seasons of crops in the field experiment

4.3 Water flow parameters

The laboratory determined, water flow Van Genuchten parameters such as residual soil water content θ_r, saturated soil water content θ_s and soil water retention function parameters like α, n and measured saturated hydraulic conductivity K_s were taken as water flow parameters. The pore connectivity parameter l in the hydraulic conductivity function was estimated to be about 0.5 as an average for many soils (Table 3 and 4).

Water Flow Parameters

	Qr	Qs	Alpha	n	Ks	l
1	0	0,48	0,07	1,17	25	0,5
2	0	0,47	0,06238	1,16028	25	0,5
3	0,0598	0,49231	0,02638	1,77344	85,14	0,5
4	0,02821	0,47212	0,01439	2,75996	350,68	0,5

Soil Catalog | Neural Network Prediction | Temperature Dependence

OK | Cancel | Previous ... | Next ... | Help

Table 3: Van Genuchten Parameter for plot 6

Water Flow Parameters

	Qr	Qs	Alpha	n	Ks	l
1	0	0,49279	0,30927	1,13457	22	0,5
2	0	0,50294	0,75199	1,12328	17,5	0,5
3	0	0,5	0,10802	1,1418	16,5	0,5
4	0	0,49588	0,00696	1,43242	27,4	0,5

Soil Catalog | Neural Network Prediction | Temperature Dependence

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Table 4: Van Genuchten parameter for plot 9

The function for the given Van Genuchten parameter are graphically presented in Figure 7 and 8 for plot 6 and in Figure 9 and 10 for plot 9

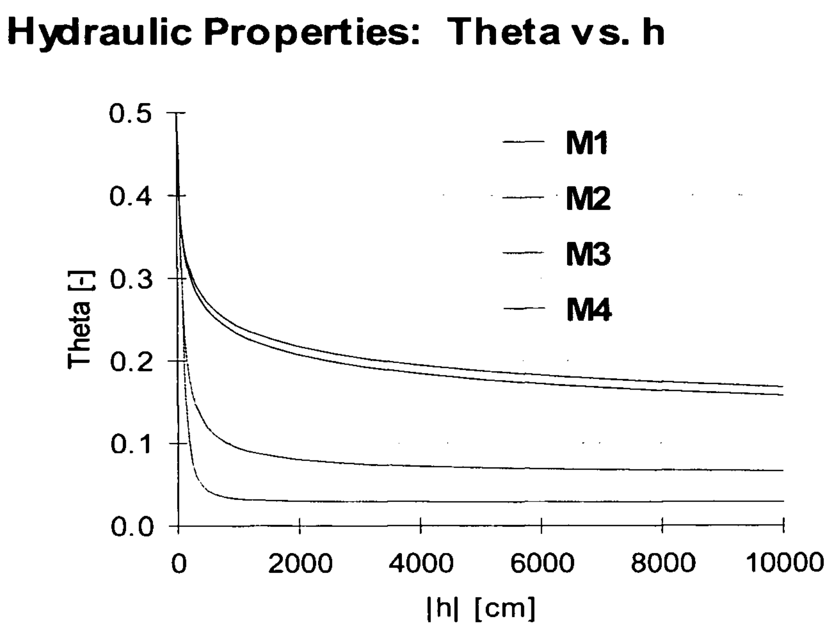

Figure 7: Van Genuchten functions of plot 6

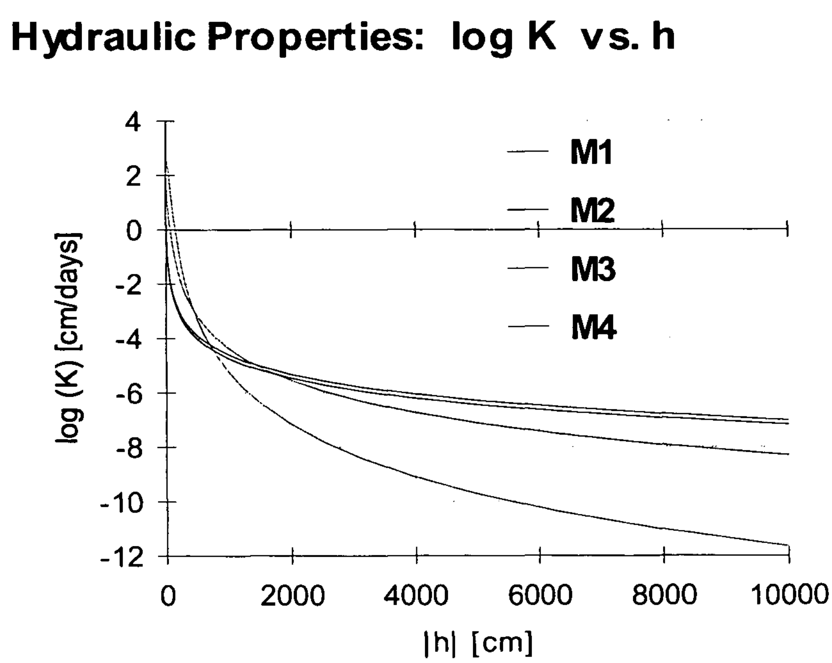

Figure 8: Capillary Hydraulic Conductivity functions of plot 6

M1 to M4 are the four different materials in the soil profile.

Hydraulic Properties: Theta vs. h

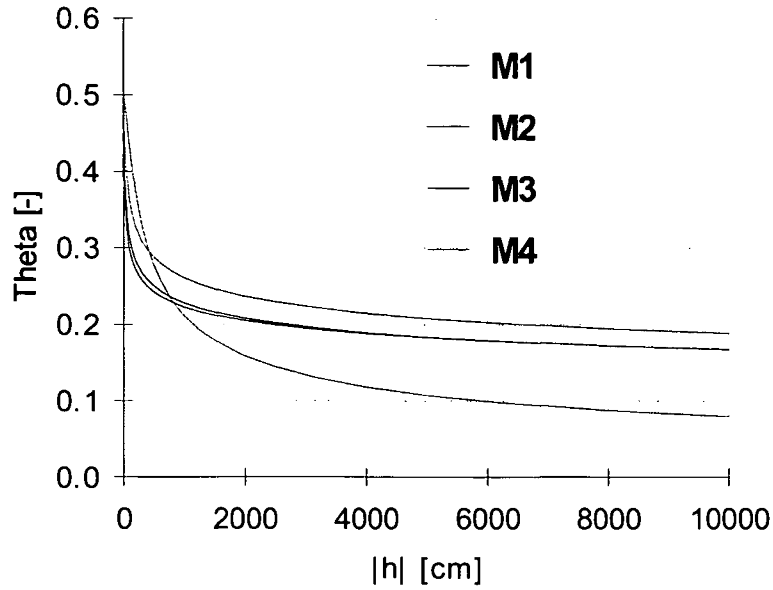

Figure 9: Van Genuchten functions of plot 9

Hydraulic Properties: log K vs. h

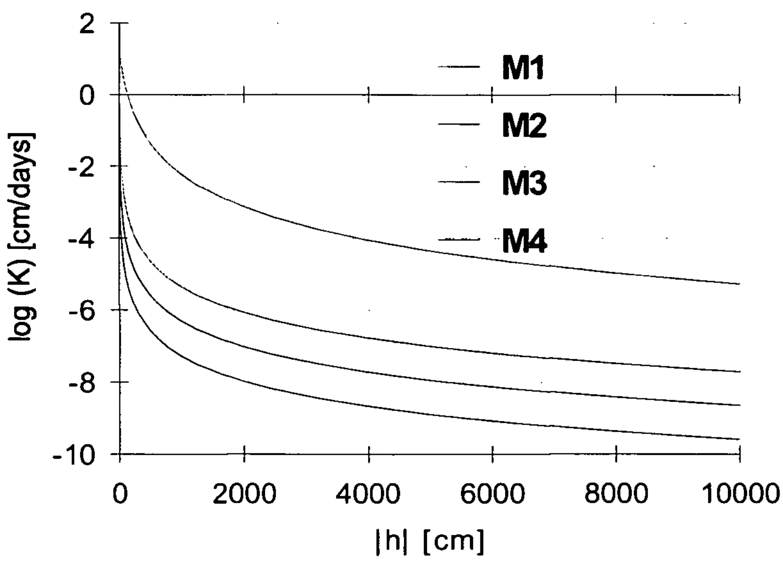

Figure 10: Capillary Hydraulic Conductivity function of plot 9

The root water up take and root growth were considered for growing season simulation of all crops, being excluded for the mulch application time and the bare soil water movement simulation.

The Feddes model, for the root water uptake with no solute stress was taken. Feddes parameters for different crops is given in the program therefore the parameters for the given specific crop was selected and since the root data was not sufficient, in the root growth factor was considered with the assumption of 50% of the rooting depth is reached at the midpoint of the growing season. The roots are assumed to be exponentially distributed. The maximum rooting depth of each crop was taken from literature review.

5. SIMULATION RESULTS

The simulation was done stepwise for different crops in different growing seasons and for bare soil between the cropping seasons. The simulation results were compared to the FDR measured water content and are presented using Sigma plot graphic options. By using sigma plot, it was possible to compare different plots and replication results on the same graph. Water dynamics calculations are a means for closing measurement gaps. With the calibrated user model it was possible to estimate boundary fluxes.

5.1 Model calibration and verification

The model calibration was performed by optimizing soil parameter function and boundary conditions with respect to measured data. Starting phase was bare soil in September 2003. Due to the fact that root water uptake is not present the soil parameter would be optimized independent to cover crop effects. For further simulation plant parameters had to be estimated for each crop.

Realistic initial conditions are supplied by a gravimetric calibration of the FDR-sensor. With these values a steady state simulation was performed to establish the initial pressure head calibration for the entire soil profile.

With the calibrated model the first transient simulation for bare soil were performed and the user model could be verified (Figure 11 and 12).

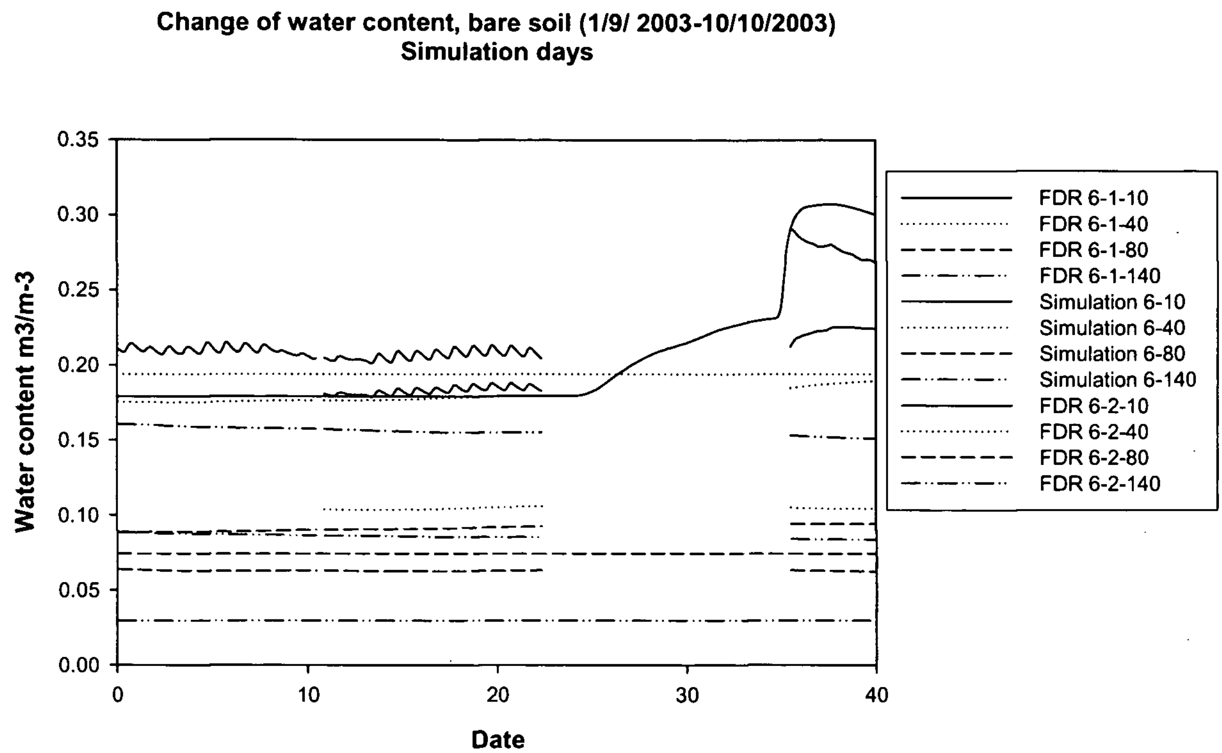

Figure 11: Comparison of the simulated and measured water content of bare soil 2003 plot 6

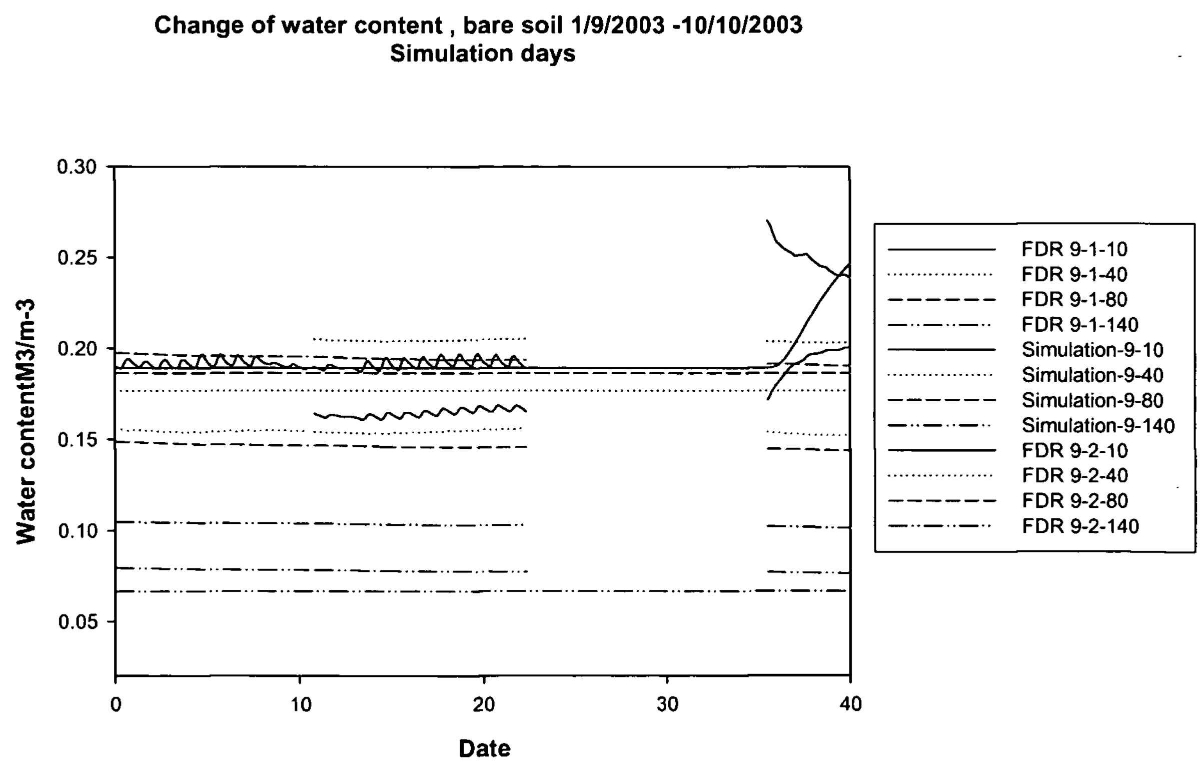

Figure 12: Comparison of the simulated and measured water content of bare soil 2003 plot 9

The constant water content values at the beginning of the simulation period could be represented quite well and the higher values at the end of the bare soil period are reached. The simulation results are mostly with in the range of the two measured time series.

5.2 Simulation for bare soil 2002/2003

After model verification through the simulation of bare soil period in 2003 for both plots, the next step was to simulate bare soil in 2002/03; the data was available only on two measuring days of 23-2-2002 and 31-3-2003. This simulation provides the water flow dynamics according to the precipitation (Figure 13). In Figure 13 also can be seen that measured water contents are in good agreement at the end of the simulation period.

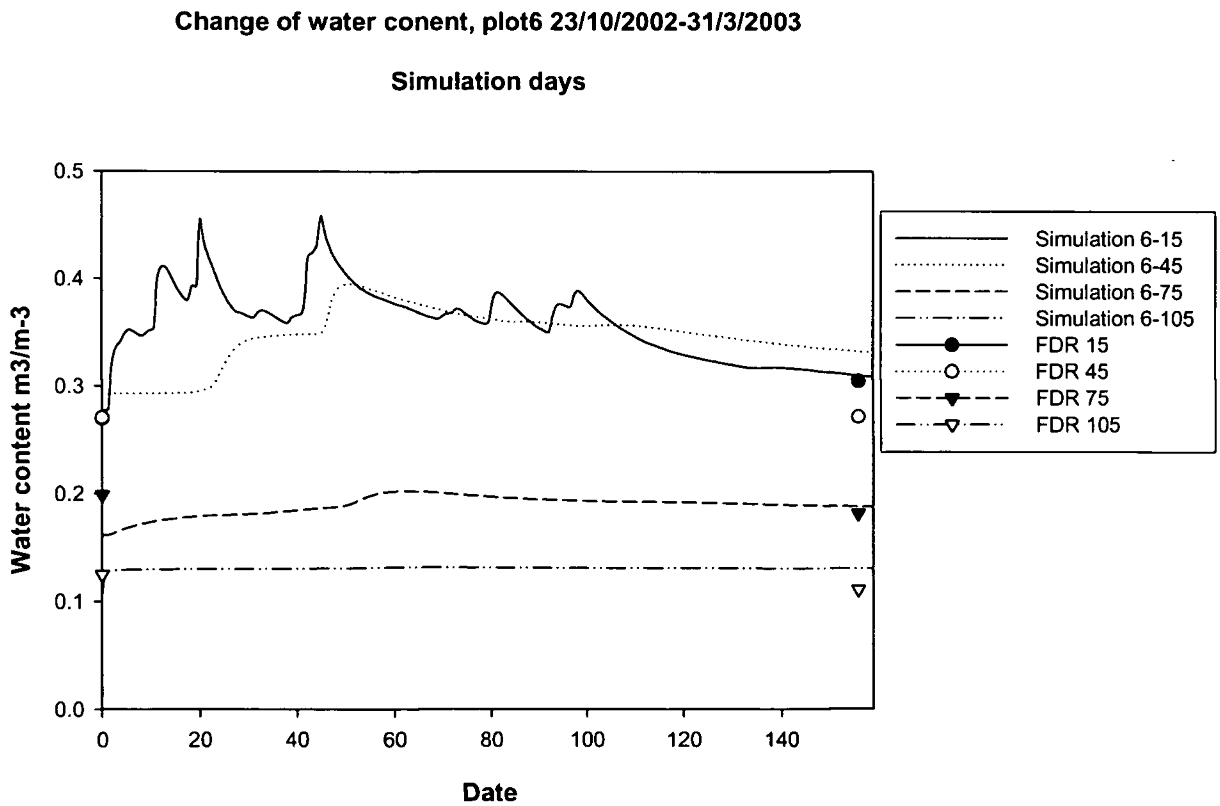

Figure 13: Comparison of the simulated and measured water content of bare soil 2002/3, plot6

5.3 Simulation for the growing period of winter rye, 2003

The next simulation was done for the season of winter rye. As indicated in Figure 14 and 15, the comparison of the simulation and measured result for both plots of 6 and 9, shows similar water content dynamics. The fluctuations of the water content are highest near the surface and decrease with the depth. It is observed that at the end of the simulation period the water content in the upper part of the soil profile is higher than the measured ones. This could be due to inconsistencies in precipitation data or an underestimation of root water uptake.

Most satisfactory results could be observed in the middle of the season, i.e. between mid of February and end of June, for plot9 and from mid February to the end of March for plot 6.

The maximum root depth was taken from the literature. The root depth can be different due to the difference in crop variety of the given crop, the soil condition and other environmental factors. Therefore the maximum root depth and the corresponding parameters might have not exactly corresponded to the real maximum growth condition of the crop in the field. In addition to this, according to Lal and Shukla 2004 the plant root uptake is highly variable because differences in their growth caused by variable amount of nutrients and water availability in the soil and possible effects of pests and pathogens.

Another possible cause to observe higher moisture content at the depth of 10 cm could be the influence of temperature. In the whole simulation process the temperature was taken to be constant. But according to White I. and Zegelin S.J 1995 in materials with large dipole moments, dielectric constant depends on temperature. For liquid water, as the temperature is increased, thermal motion of water molecules increased and oppose their tendency to orient in an electromagnetic field. This lowers the dielectric constant. The temperature dependence of the dielectric constant of the other soil constitutes is much less than that of water. Nevertheless, for near surface determination of dielectric constant, accurate measurement requires information on the surface soil temperature.

Also related to soil temperature are the higher fluctuation of measured data, which are explained by the freezing of the top soil, with the result that ice acts as insulator and the water content reading goes to zero.

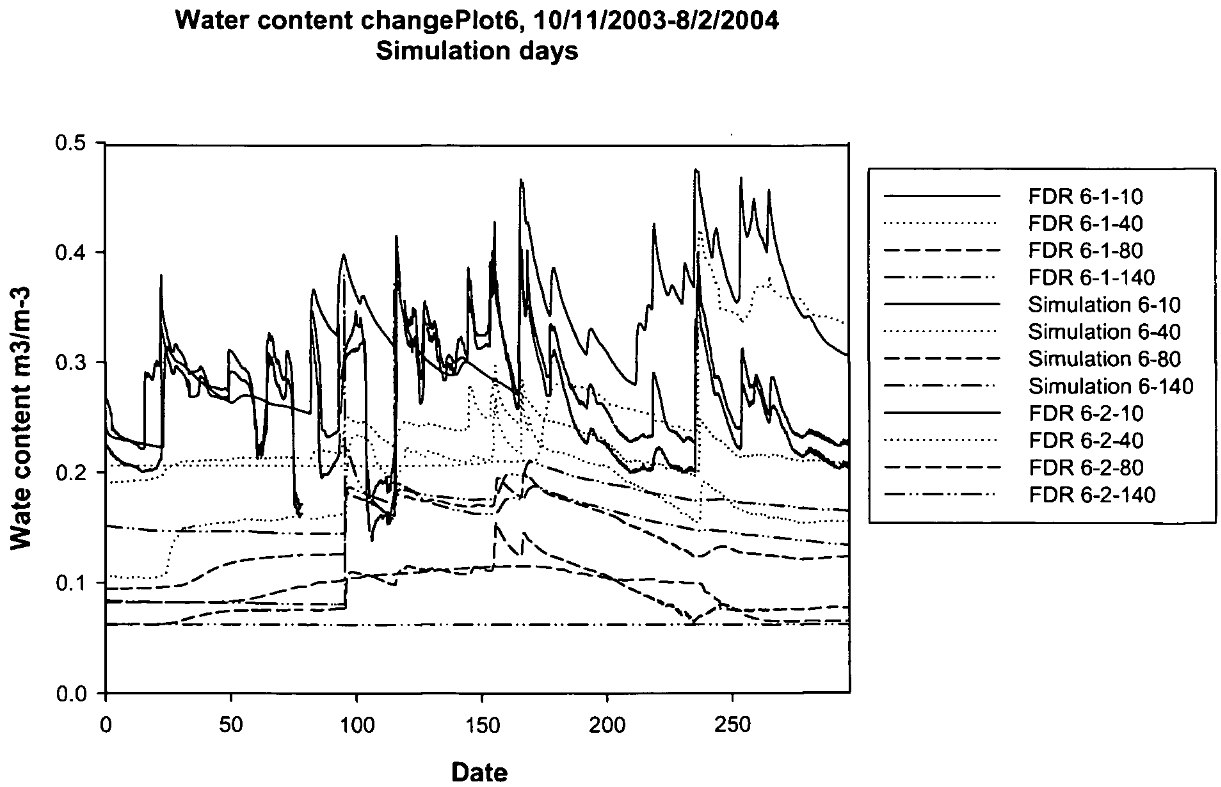

Figure 14: Comparison of Simulated and measured water content change during the growing season of winter rye, 2003 plot6

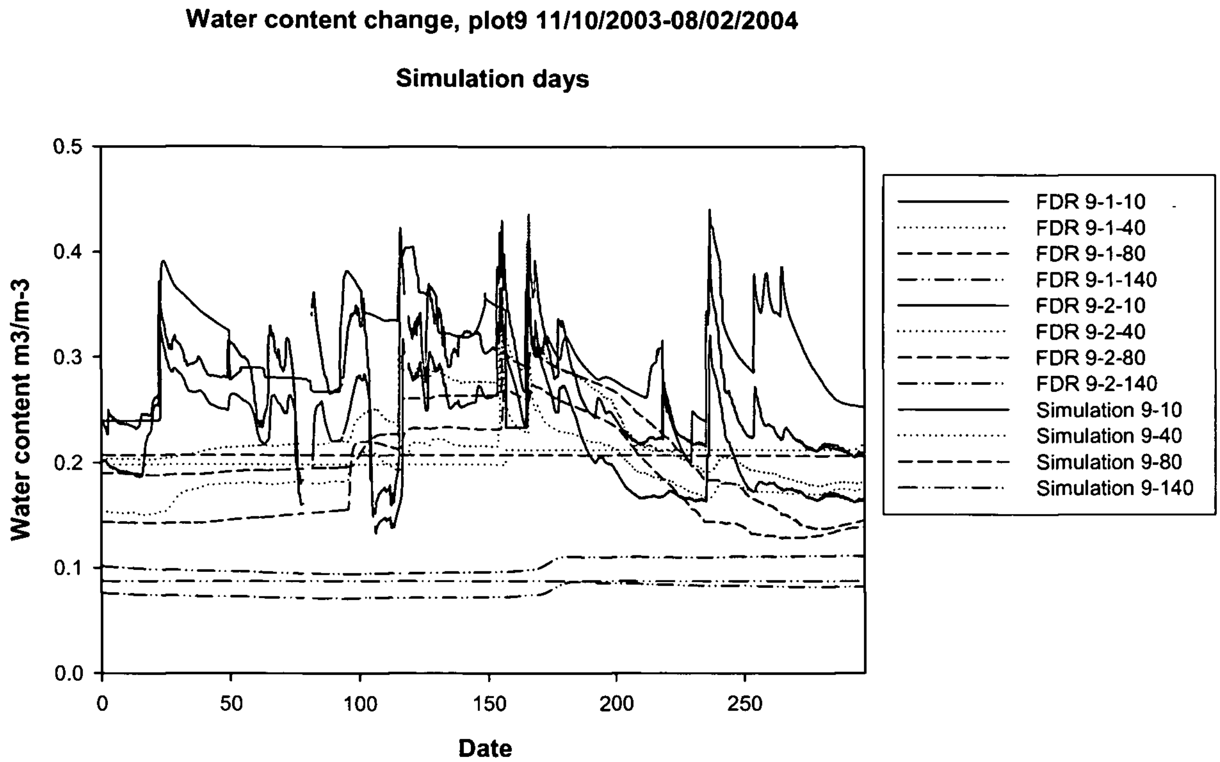

Figure 15: Comparison of Simulated and measured water content change during the growing season of winter rye, 2003 plo9

The actual surface flux, actual root water uptake, all cumulative fluxes and cumulative infiltration are given in Figure 31 - 34 respectively and all cumulative fluxes for plot 9 is given in Appendix 15. The boundary fluxes are needed for the water balance analysis and hence enable the assessment of nitrate leaching potential.

In the water balance analysis of the initial growing season of the winter rye, the calculated deep percolation was -6.33cm while the measured one was -2.32cm Table 5.

5.4 Simulation for the growing period of potato

The water content dynamic simulation of the potato growing period in 2003 can be seen in Figure 16 and 18. The non-measured gaps could be filled with the help of simulation. For this growing season there was no pressure head measurement for the use as an initial condition. Therefore, the initial condition for the simulation was taken from the plot specific PF-curve taking the measured moisture content into consideration. At the beginning it could be observed that the simulated water content was very much similar to the measured one and the increase in moisture content follows the precipitation (Figure 17) increase. Here, it can be concluded that that the simulation gave more reliable moisture content variation during the growing period than it was measured. The measurements were object to system failures and the time series was not complete. The simulation helps to overcome such problems during field measurements.

In this simulation process, in order to determine the source sink term S which was used to account for water uptake by plant roots, the Feddes et al. 1978 model was used. This model is empirical which contains parameters that depend on specific crop, soil and environmental conditions. The actual root water uptake is shown in Appendix 8.

The result of higher water content in the soil from the simulation may be like before due to underestimation of the root water uptake by the plant root. According to Van Genuchten and Sudicky 1999, much research remains needed in the development of realistic process-based models of root growth and root water uptake as a function of growth and root water uptake as a function of various stresses such as water, salinity, temperature, nutrients and others in the root zone and to couple this with suitable crop growth models.

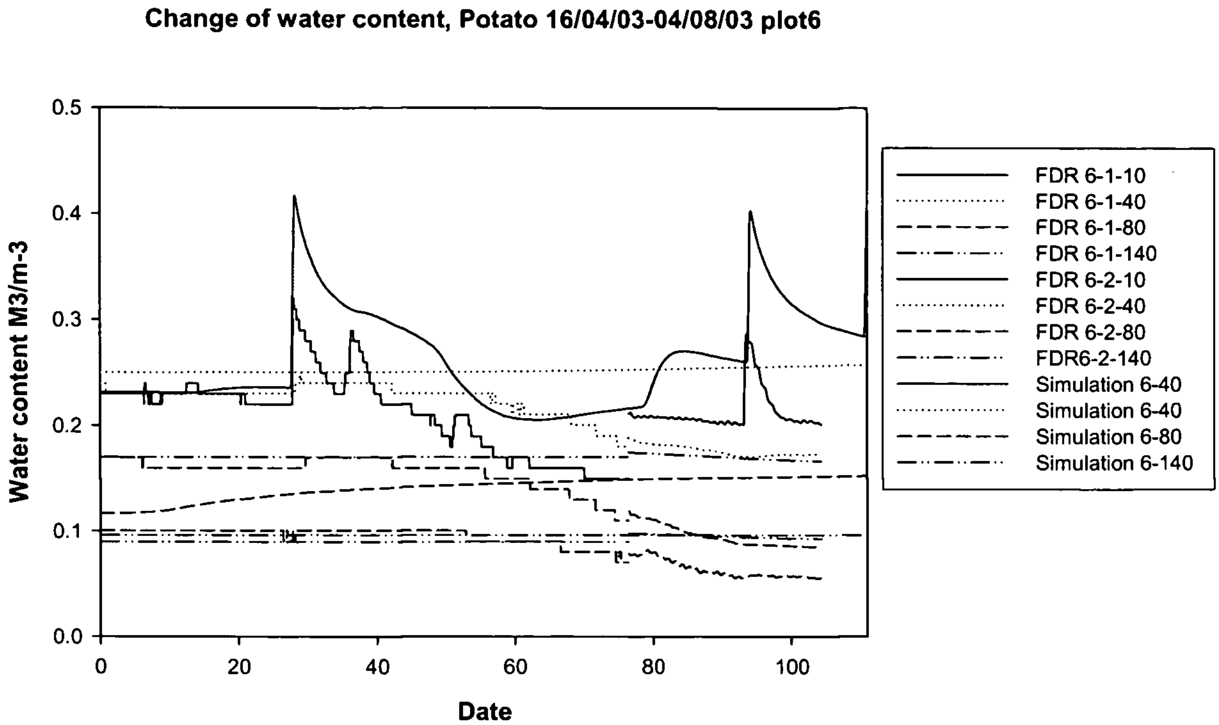

Figure 16: Comparison of Simulated and measured water content for the growing season of potato 2003, plot 6.

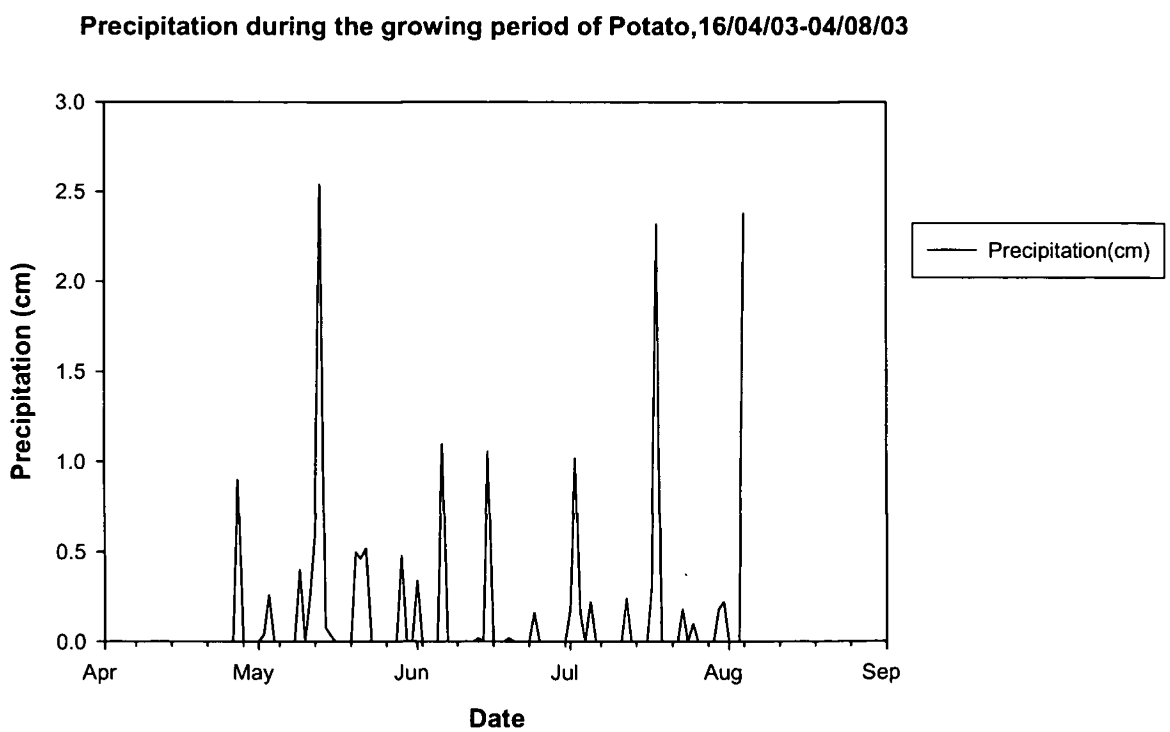

Figure 17: Precipitation in the growing season of potato

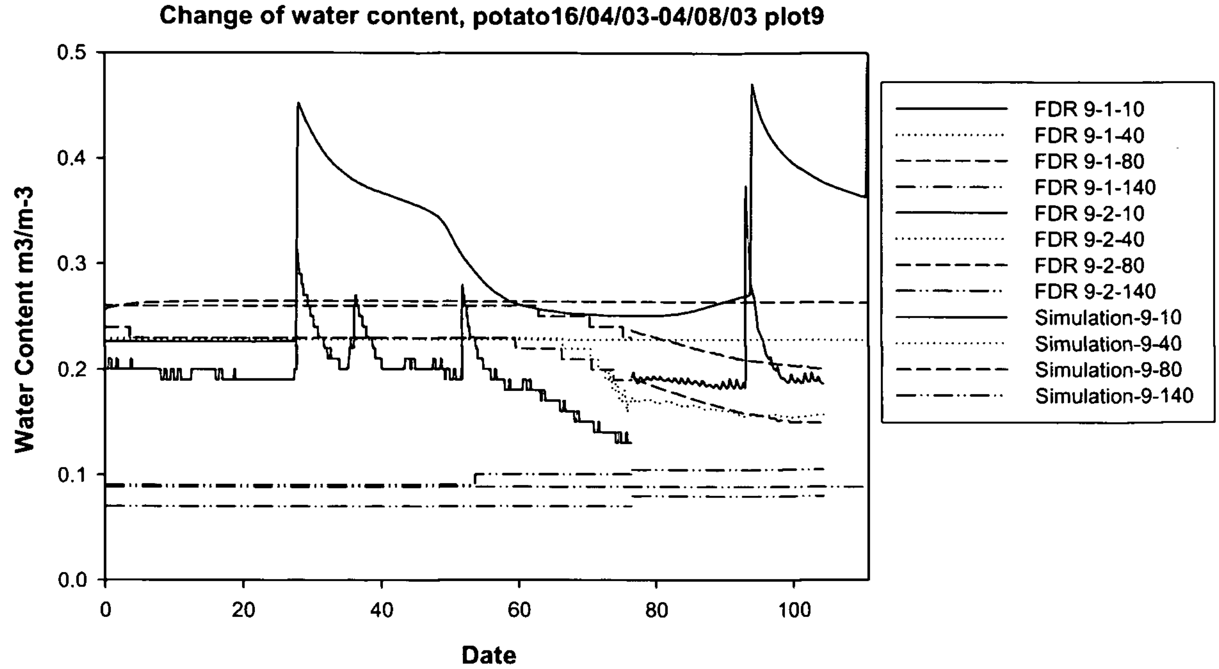

Figure 18: Comparison of simulated and measured water content for the growing season of potato 2003, plot 9

5.5 Simulation for stubble field

In the case of stubble field, as it can be seen in Figure 19 and 20, the results were found to be reliable. The simulation result lies between the two replications of the measured ones. Since there had not been rainfall during this period there was no fluctuation of water content. As it can be seen without the other parameters like root depth the simulation fitted almost exactly to the measurement results for both plots.

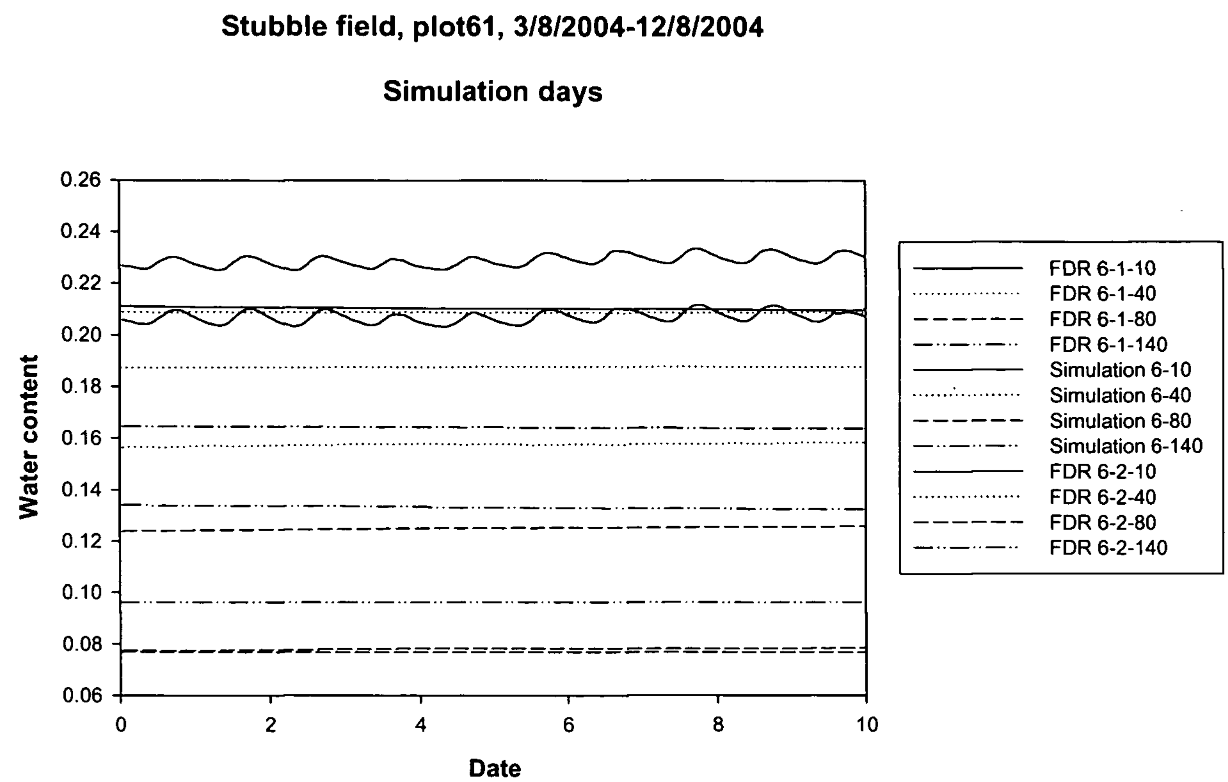

Figure 19: Comparison of the simulated and measured water content change during the period of stubble field, plot 6, 2004

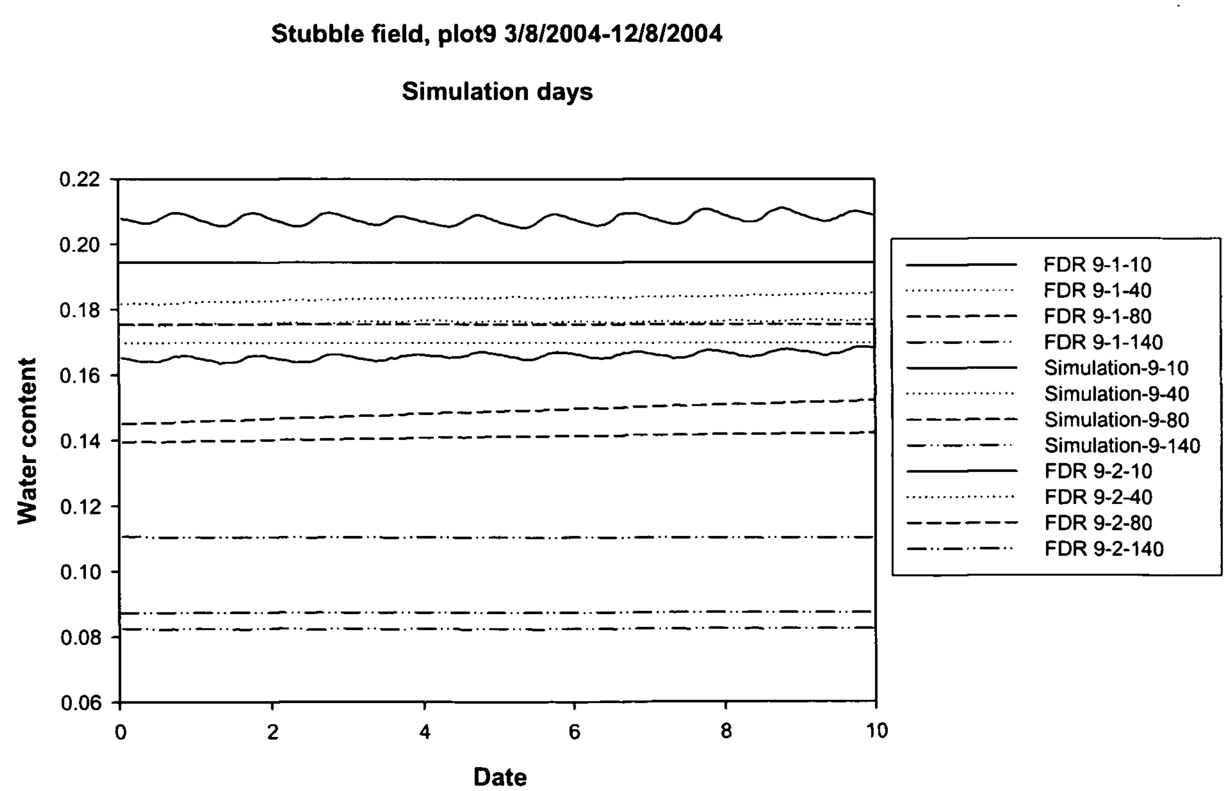

Figure 20: Comparison of the simulated and measured water content change during the period of stubble field, plot 9 2004

5.6 Simulation for the growing period of legumes

In the growing season of Legumes 2004, the initial pressure head of the soil profile at all observation points, was taken from the measured data of August. It can be observed in the comparison of measured and simulated results, the graphs at the depth of 40, 80 and 140 cm are very much compiled with the measured ones (Figure 21 and 23). But at the depth of 10 cm beginning after 40 days more water is accumulated to the simulation. This deviation can be again in relation with the root water up take.

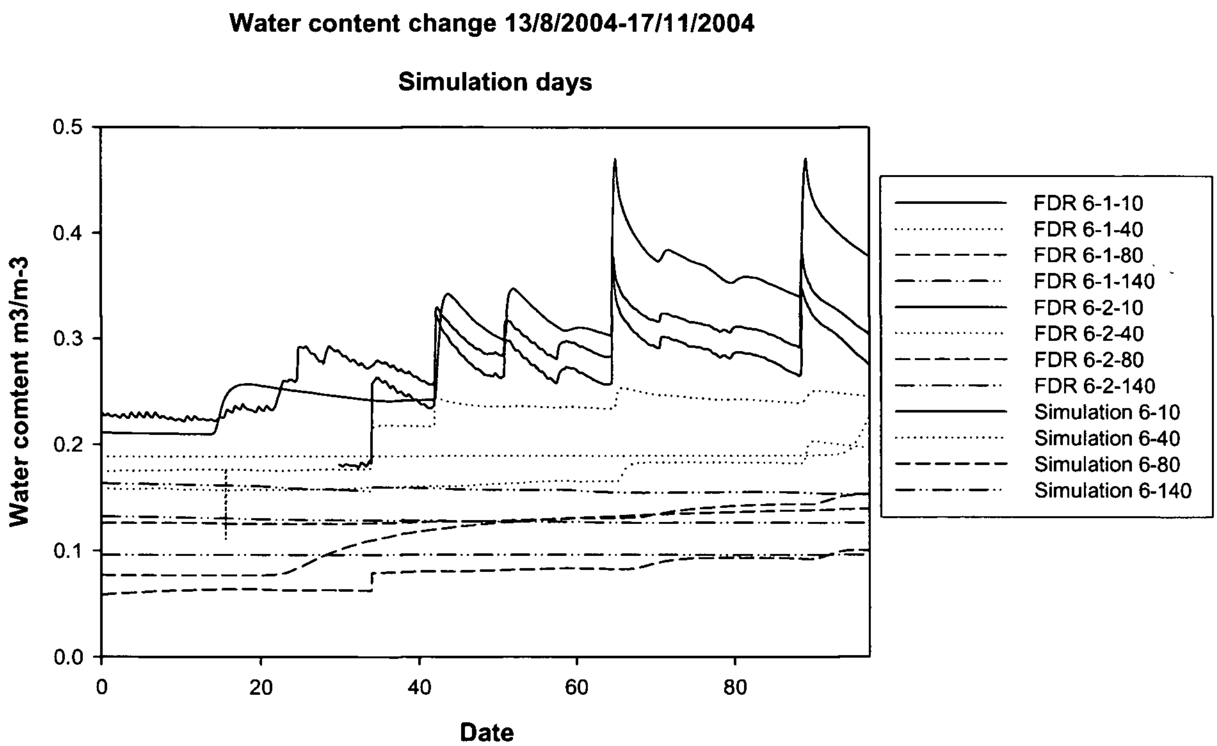

Figure 21: Comparison of the simulated and measured water content change during the period of Legumes, plot 6 2004

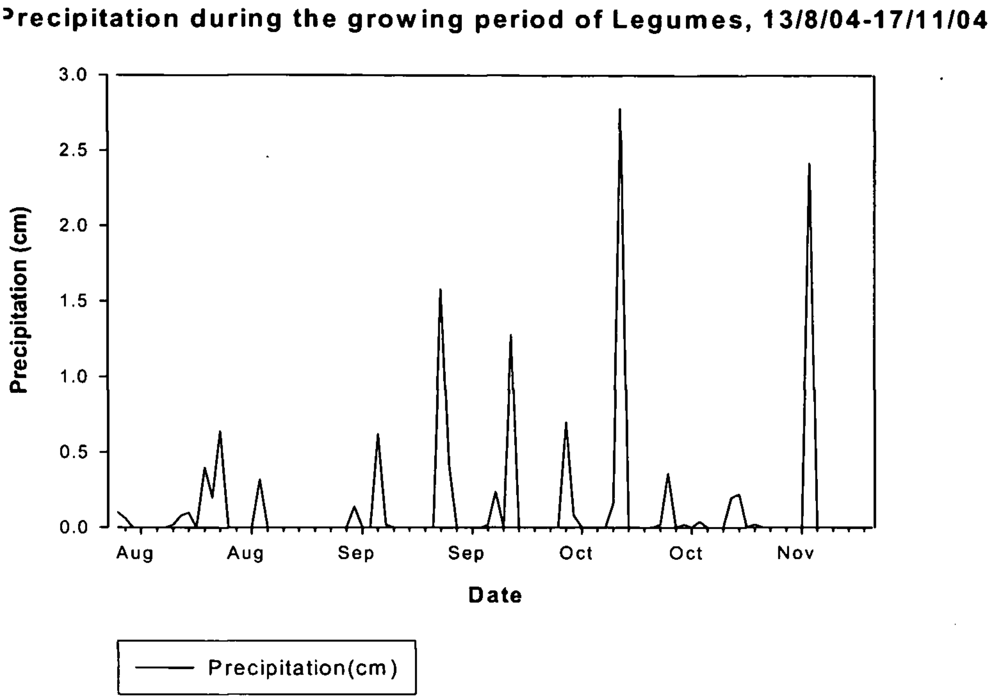

Figure 22: Graph of precipitation in the growing season legumes 2004.

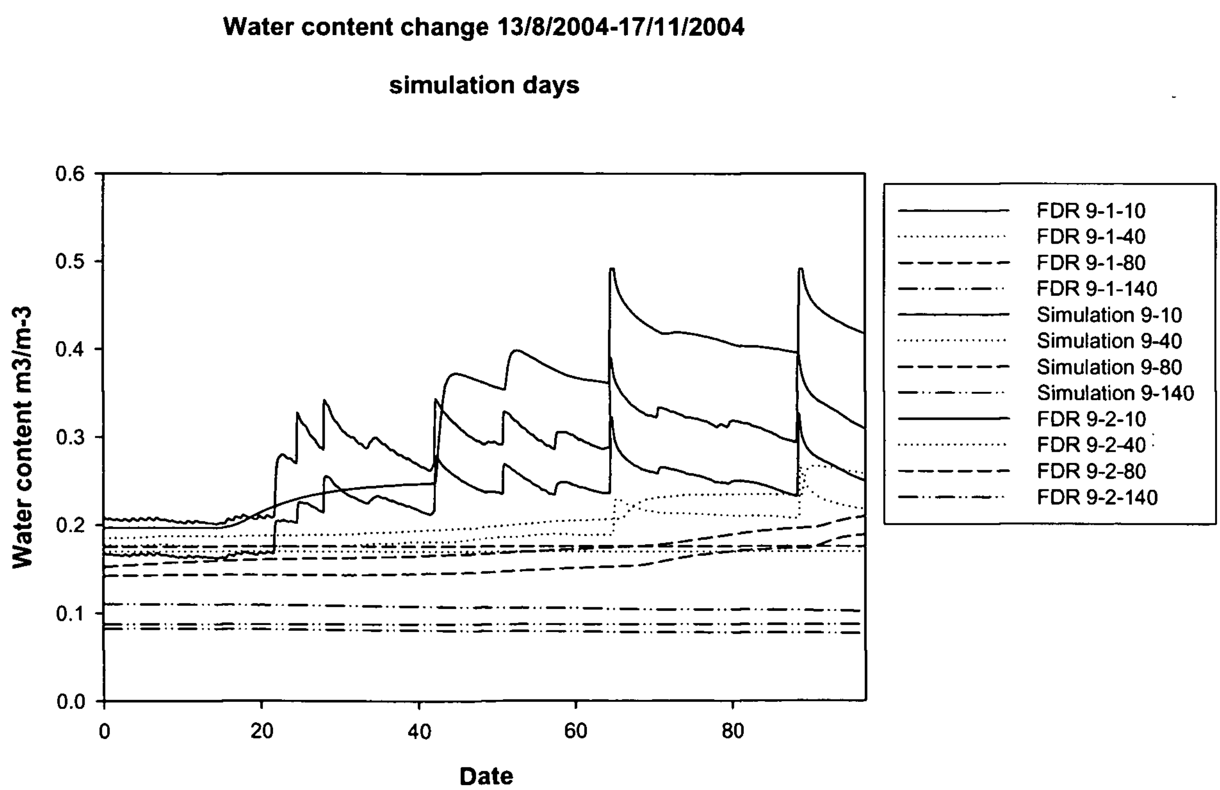

Figure 23: Comparison of the simulated and measured water content change during the period of Legumes, plot 9 2004

5.7 Simulation during the period of mulching

The simulation results for the season with mulch application in winter season of 2004/2005 are presented in Figure 24 and 25. It can be observed that measured moisture content fluctuation is more pronounced than the simulated one. This indicates that mulching parameter is not included in the simulation process because the upper boundary condition was taken the same like the other growing seasons. To include mulch cover the soil profile for simulation needed to be extended by an additional layer. The specific hydraulic characteristic could be then assigned to this layer. The boundary condition alone is not sufficient reproduce mulching effects.

Mulching the surface with vapor barriers or with reflective materials can reduce the intensity with which external factors, such as radiation and wind, act up on the surface. Thus such surface treatments can retard evaporation during the initial stage of drying (Hillel 1991).

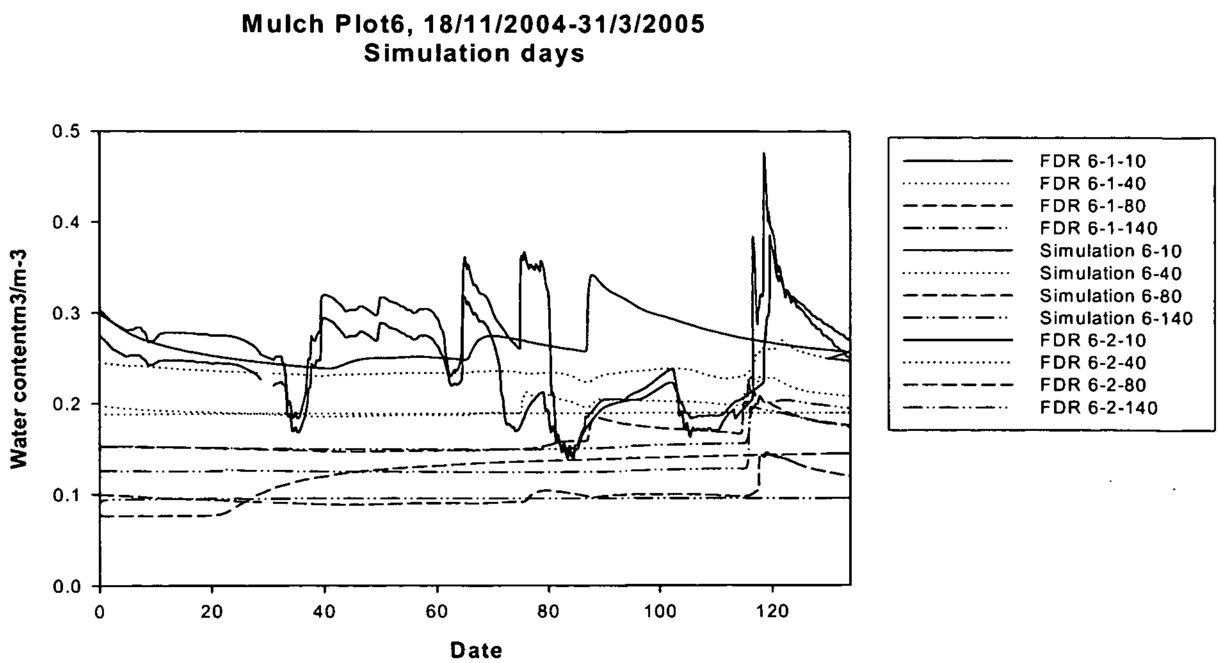

Figure 24: Comparison of the simulated and measured water content change during the period of mulch cover, plot 6 2004

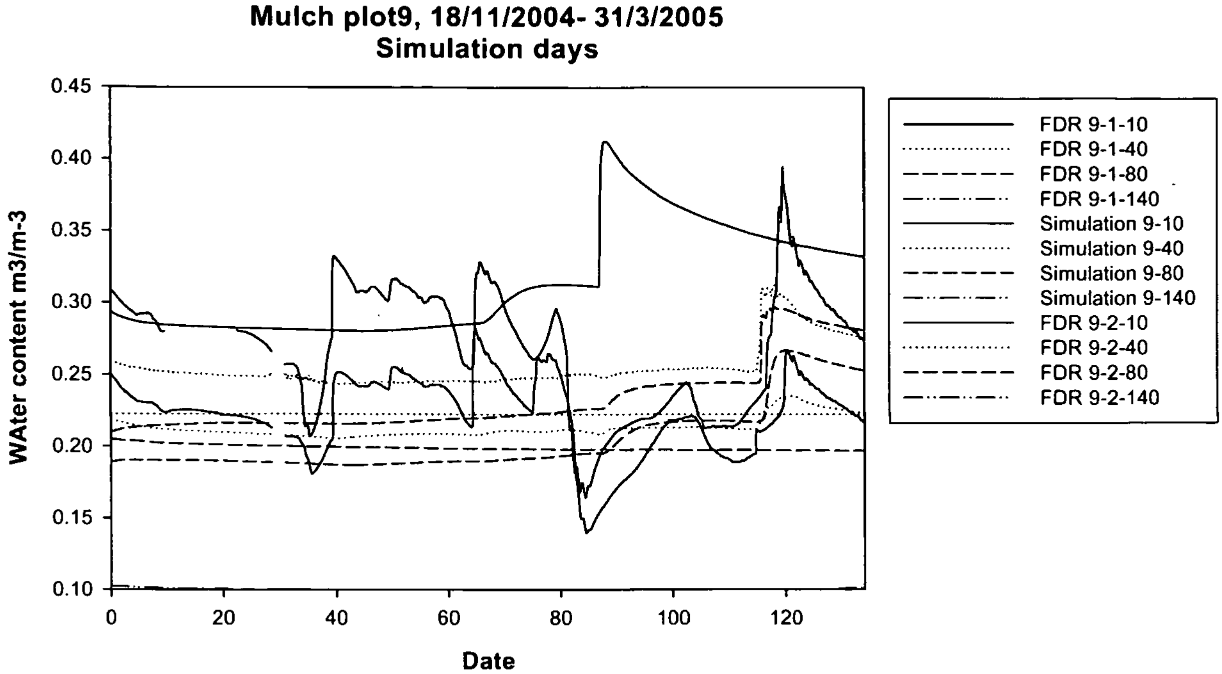

Figure 25: Comparison of the simulated and measured water content change during the period of mulch cover, plot9 2004

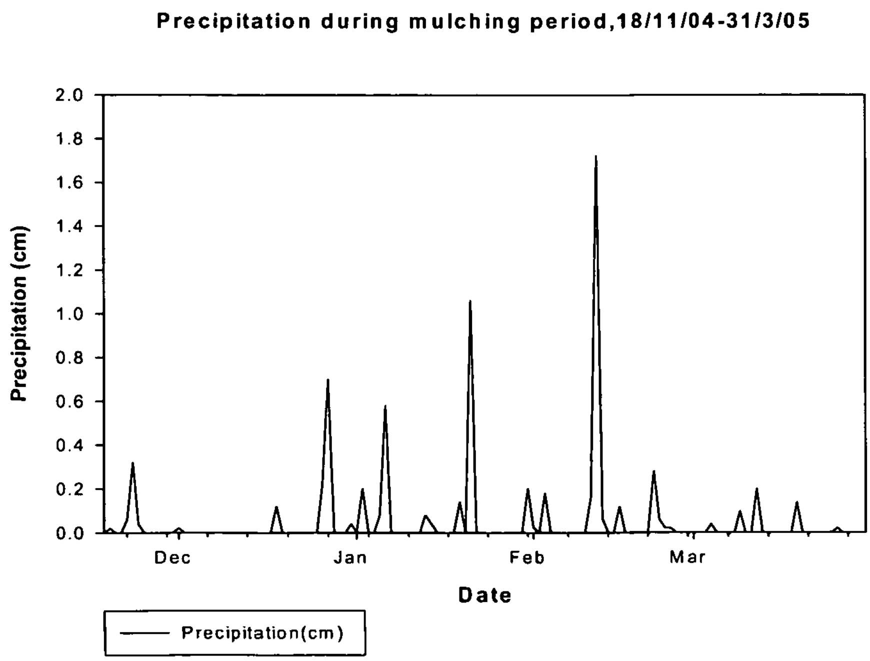

Figure 26: Precipitation during mulching period

The lay discrepancy between simulation and measurements in February can be again explained by freezing of the soil. In February the soil temperature at 10 cm depth was between -2 (°C) and -6 (°C) (Figure 27).

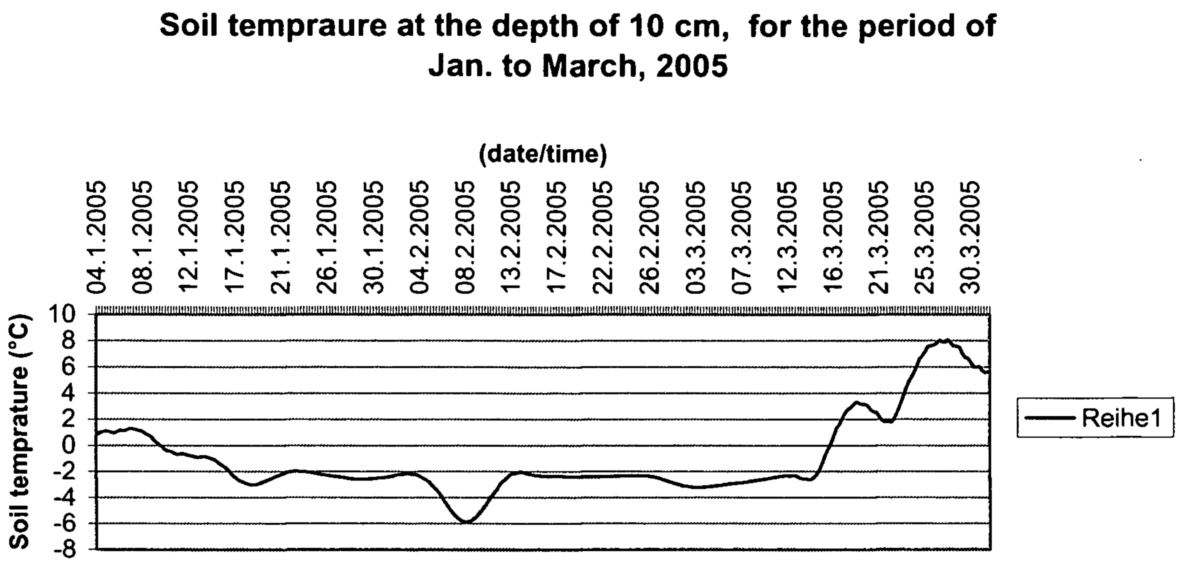

Figure 27: Soil temperature at the depth of 10 cm for the period 04/1/2005-31/3/2005

5.8 Simulation for the growing period of barely

At about the beginning of the growing season of barely the simulation result shows constant water content even a small precipitation was recorded (Figure 28 and 29). This is due to considerable amount of evaporation. From day 60 to day 90 of the simulation period date of the season the actual water uptake was low, and the precipitation was high (Figure 30) which made the water content obviously high. The actual root water uptake, cumulative fluxes, cumulative infiltration is presented in Appendix 22-26.

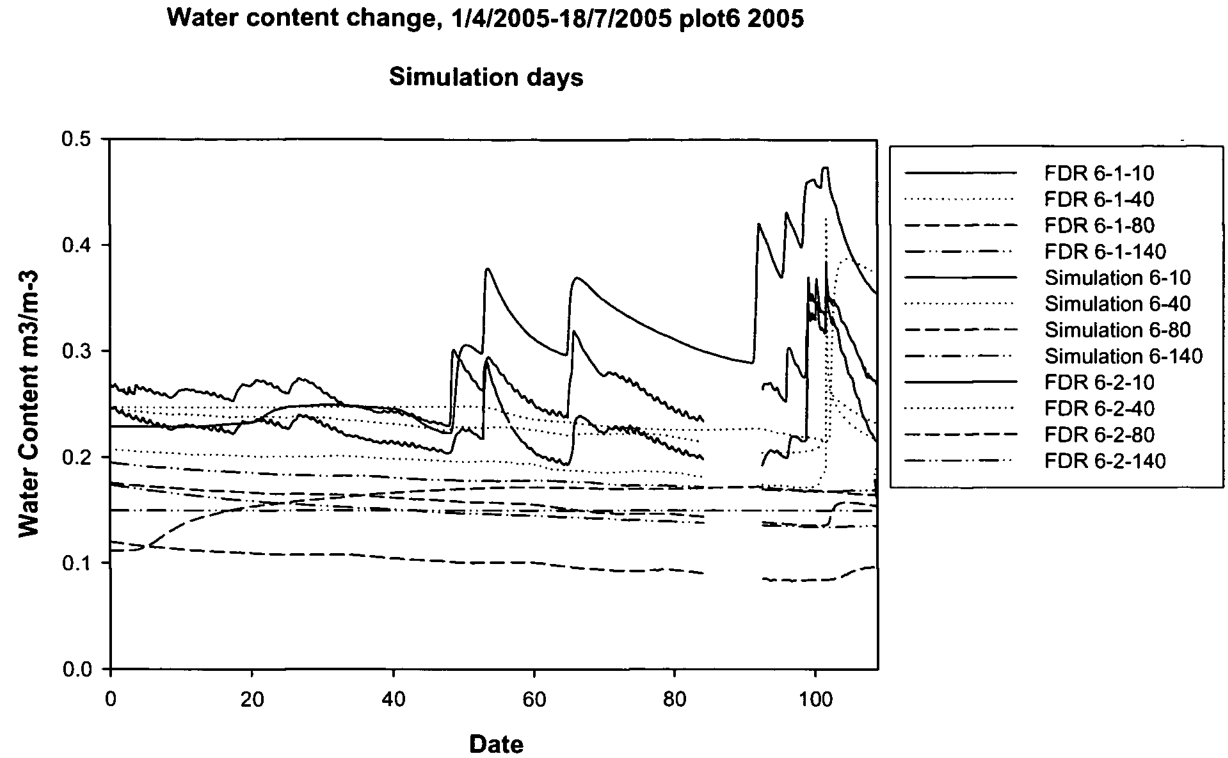

Figure 28: Comparison of the simulated and measured water content change during the growing season of barely, plot 6, 2005

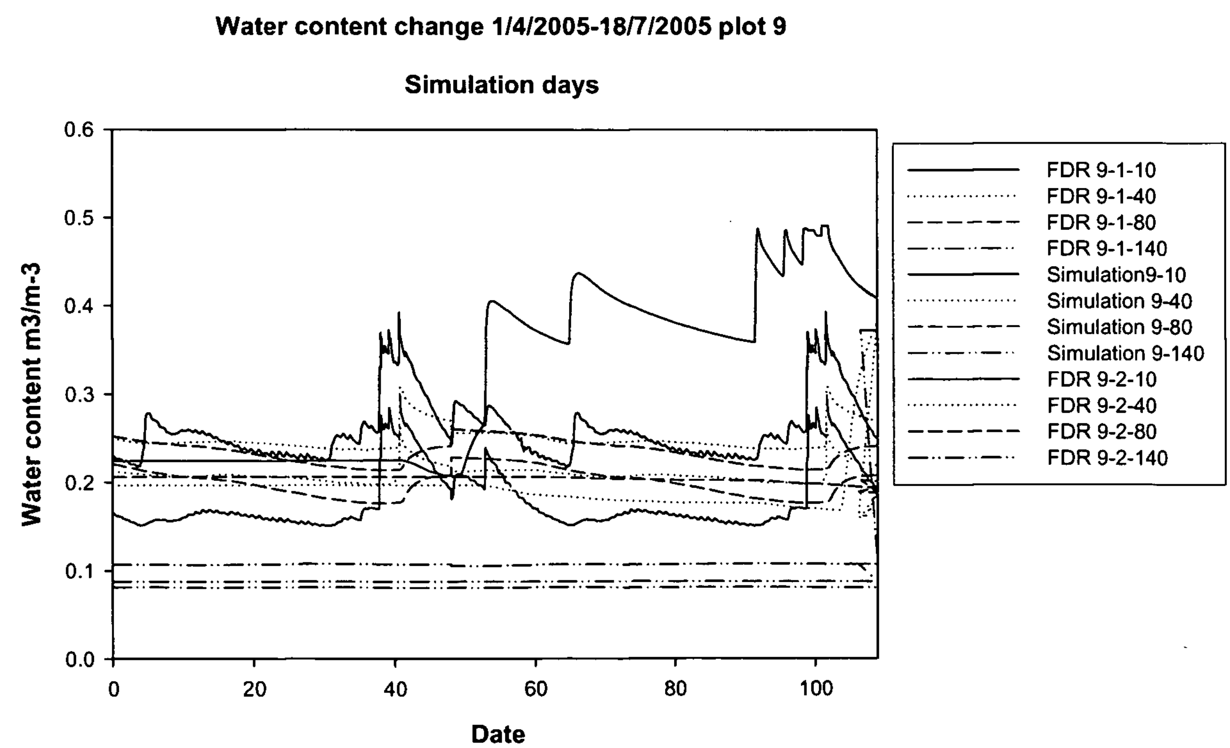

Figure 29: Comparison of the simulated and measured water content change during the growing season of barely, plot9 2005

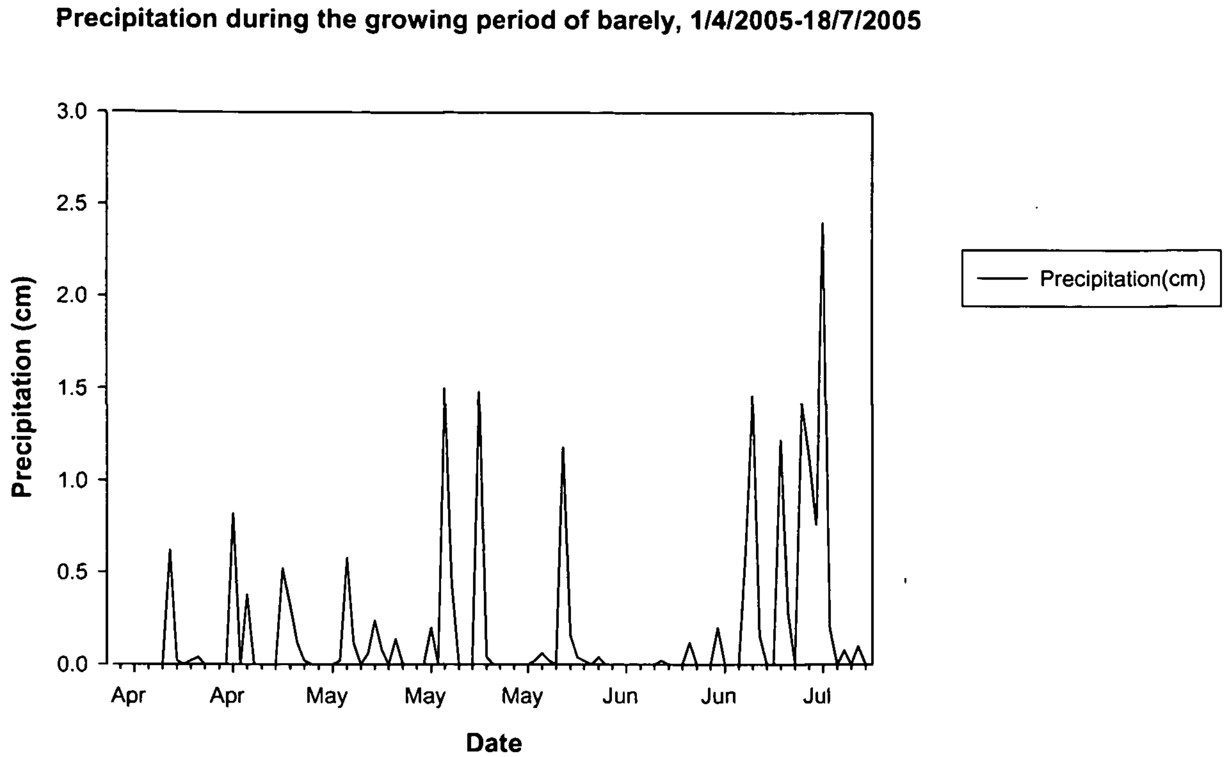

Figure 30: Precipitation graph during the growing season of barely

5.9 Boundary fluxes

From the stepwise simulation for different crops in different growing periods; it was possible to estimate boundary fluxes. There was groundwater recharge during the winter period, 23/10/2002- 31/3/2003 and the opposite was true for the winter period of the year 2003/2004. There was ground water recharge in the period of 5/8/2004 – 4/11/2004 too and the opposite in the period of 4/11/2004 - 16/12/2004 (Table 5, Figure 31-36, Appendix 4-26).

Date	Percolation (cm) (Calculated)	Percolation (cm) (Simulated)	Crop/season
23/10/2002-31/3/2003	1.93E+00	1.89E+00	Bare soil 02
9/10/2003-9/4/2004	-6.33E+00	-2.32E+00	Winter rye 03
5/8/2004- 4/11/2004	2.52E+00	4.48E+00	Legumes 04
4/11/2004-16/12/2004	-3.36E+00	-2.24E+00	Mulch 04/05

Table 5 Summary of water balance analysis, plot 6

Actual Surface Flux

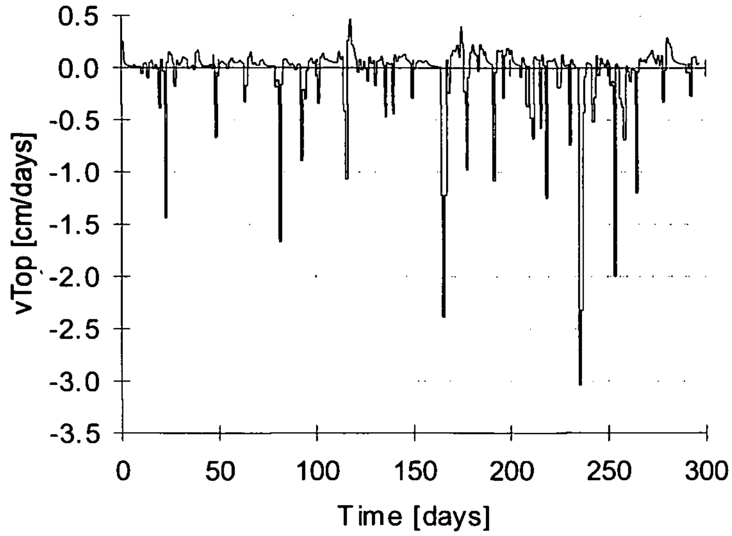

Figure 31: Actual surface flux in the growing season of winter rye 2003

Actual Root Water Uptake

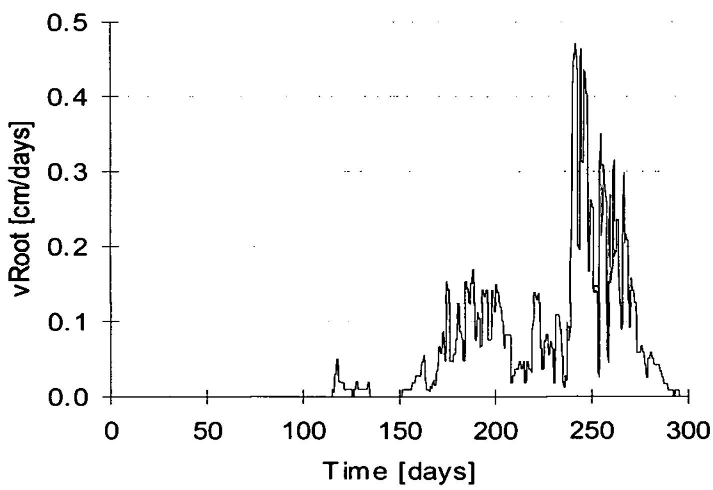

Figure 32: Actual root water uptake in the growing season of winter rye 2003

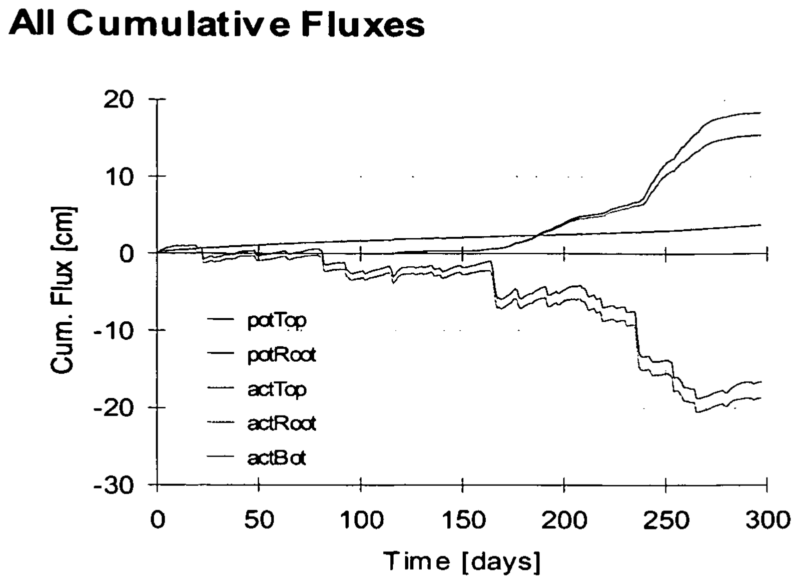

Figure 33: Al I cumulative fluxes in the growing season of winter rye 2003 plot 6

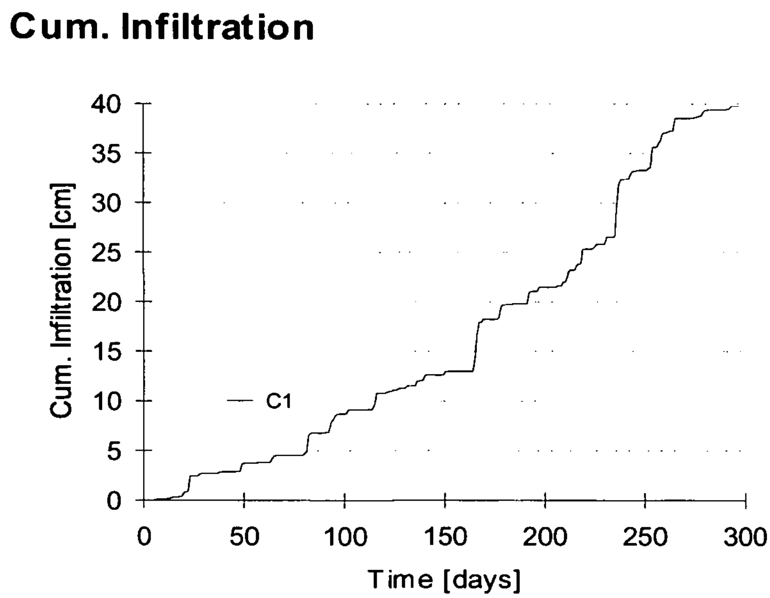

Figure 34: Cumulative infiltration in the growing season of winter rye 2003 plot 6

In the water balance analysis for legumes growing period, the calculated deep percolation was lower than the simulated cumulated bottom flux. From the water balance analysis (Table 5) and the higher moisture content result of the simulation, it can be concluded that the root parameters are underestimated or the maximum root depth is too small. Even when a maximum root depth of 50 cm was taken as an input for water uptake-water stress analysis, simulation results did not change (Appendix 21 and 23).

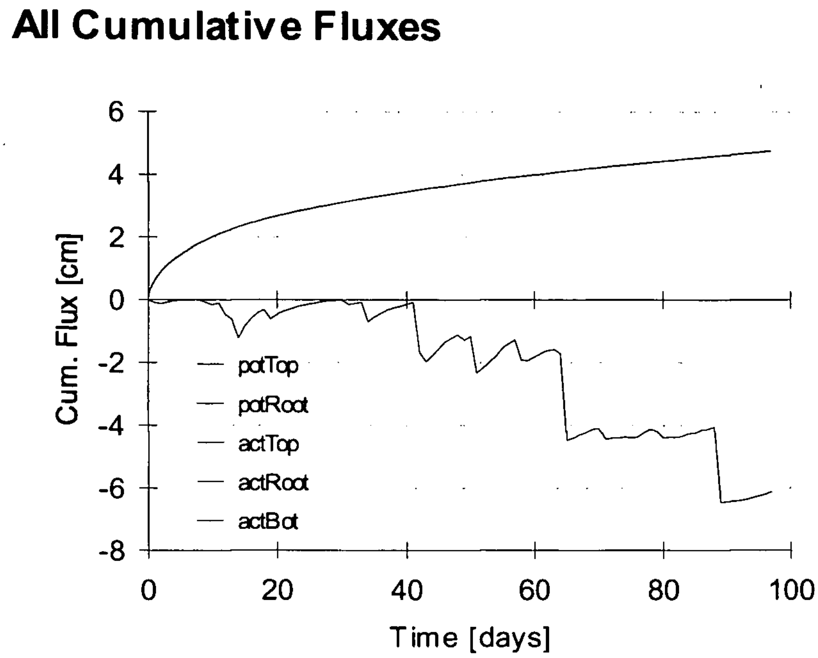

Figure 35: Cumulative flux in the growing season of legumes 2004 plot 6

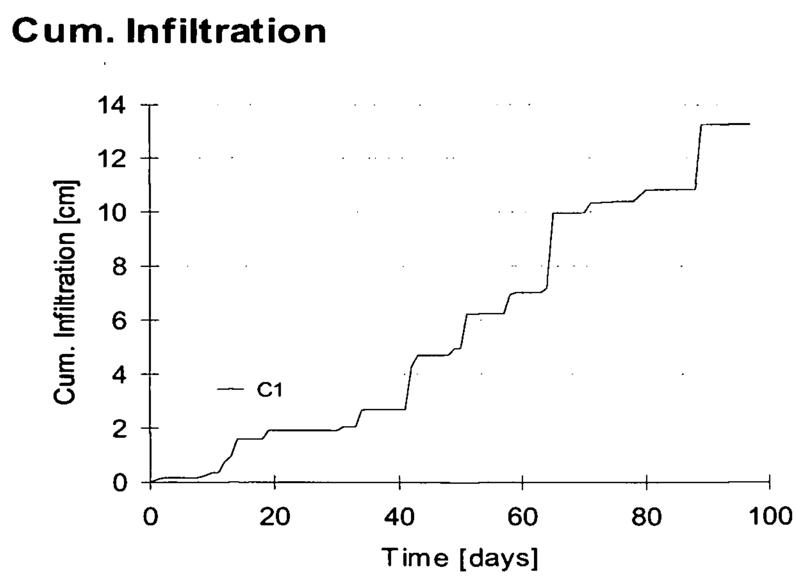

Figure 36: Cumulative infiltration in the growing season of legumes 2004 plot 6

6. SUMMARY

The determination of appropriate initial condition is one of the most influencing factors to get appropriate simulation result. Therefore having measured data for the given season or appropriate determination of the initial pressure head from the PF- curve to use it as an initial condition is the most important step in the simulation process.

Since the root growth depends on different environmental conditions and the variety of a given crop, it is not possible to rely on the general data only from the literature review and get the actual water content. Therefore, it is important to take the actual root data rather than considering the root growth factor with the assumption of 50% of the rooting depth is reached at the midpoint of the growing season. Here the root growth was assumed to be exponentially distributed.

A more precise simulation result can be achieved when the data requirements like a direct measured value or PF-curve supported initial pressure head and actual root growth data are taken. Then water dynamic measurement failures resulted to measurement gaps could be filled and a closed time series could be established. Therefore the simulation helps to overcome the problems during incomplete measurements.

For the simulation during the period of mulch application the boundary condition alone is not sufficient to include the mulching effect. Therefore a mulch cover needs to be included by extending an additional soil layer.

The boundary fluxes of each growing season are helpful for the water balance analysis hence enables the assessment of nitrate leaching.

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http://uregina.ca/~sauchyn/geog327/soil.html

http://www.ars.usda.gov/research/publications/publications.htm?seq_no_115=148559

http://www.ars.usda.gov/research/publications/publications.htm?seq_no_115=168170

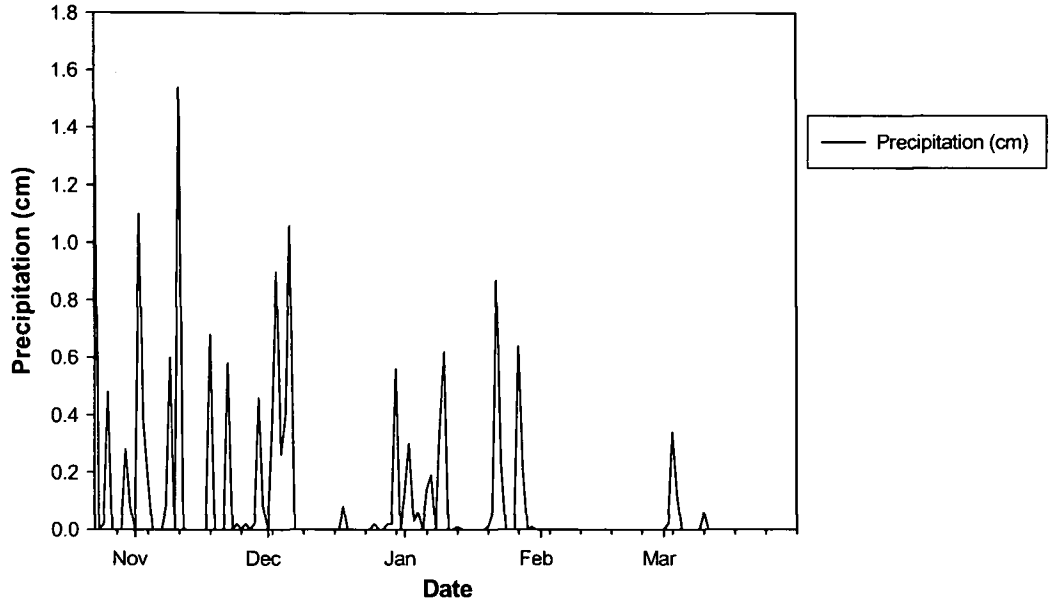
http://www.mssanz.org.au/modsim05/papers/abbaspour.pdf

8. LIST OF APPENDICES

APPENDIX PAGE

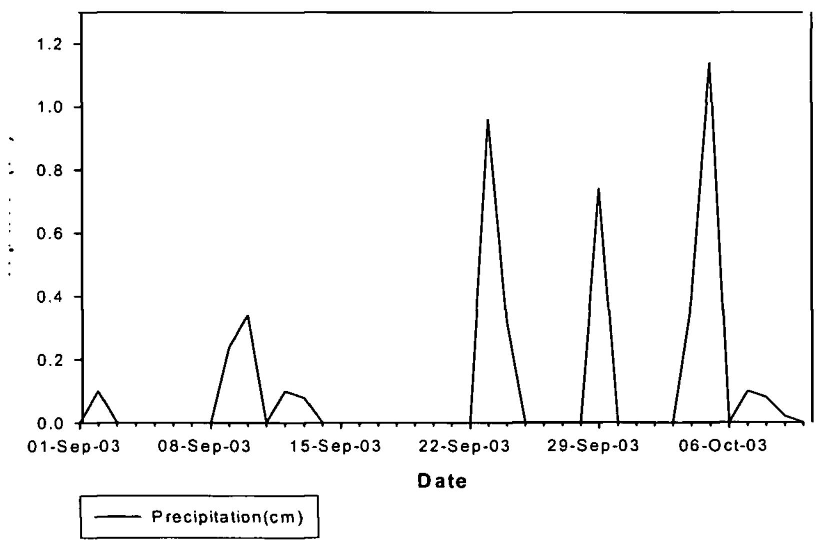
9. APPENDICES

Precipitation during the season of bare soil, 23/10/2002-31/3/2003



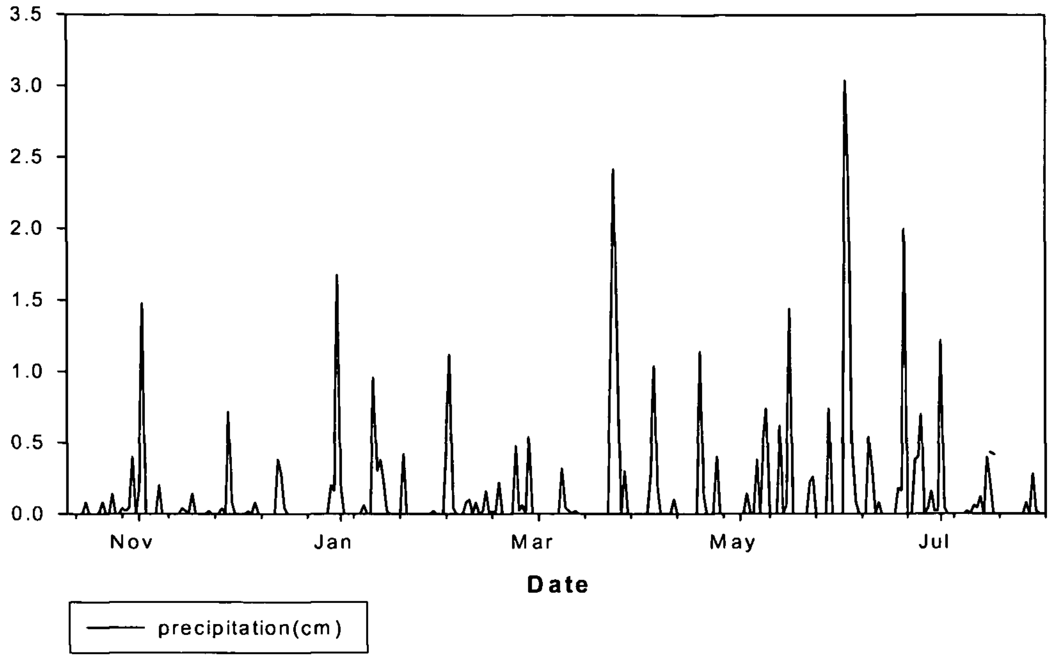
Appendix 1: Precipitation during the season of bare soil in 2002

Precipitation during the period of 05/08/03-10/10/03

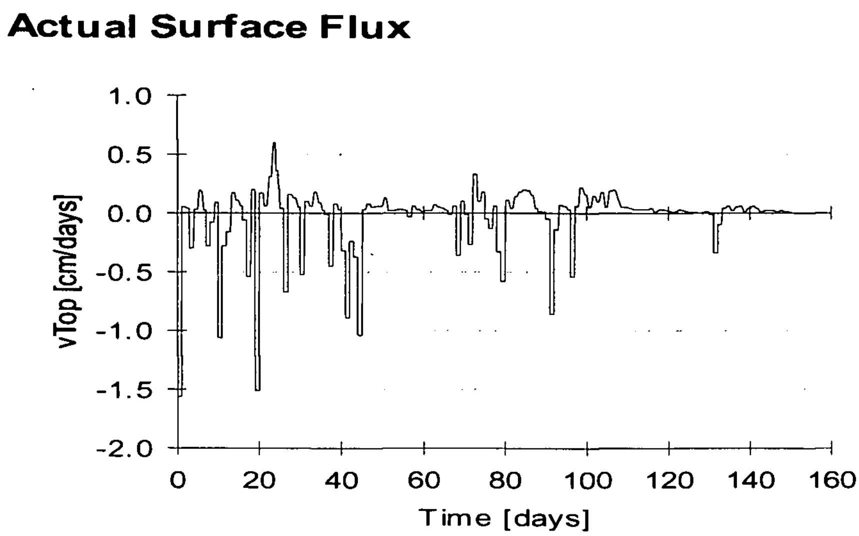


Appendix 2: Precipitation during the period of bare soil 2003

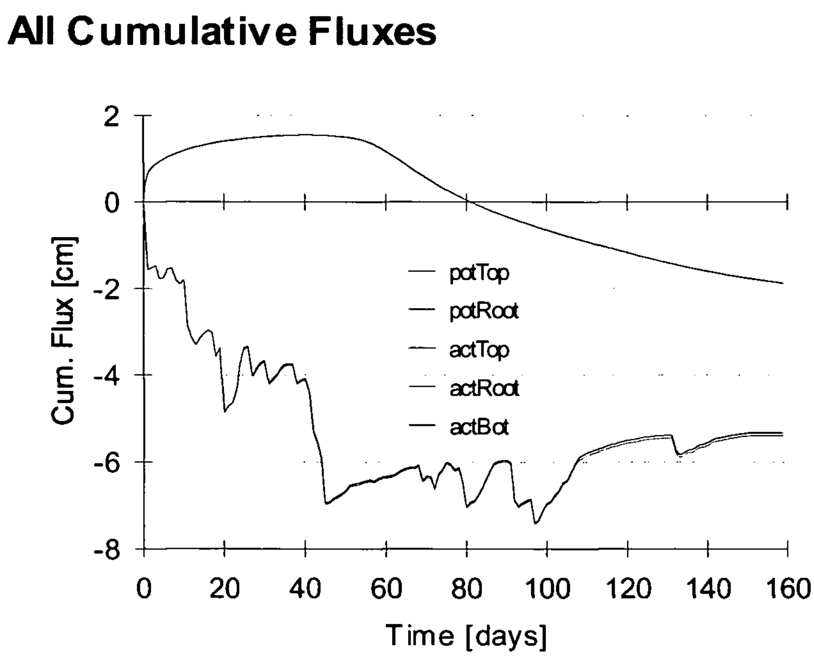
Precipitation in the period of 11/10/03-02/08/04



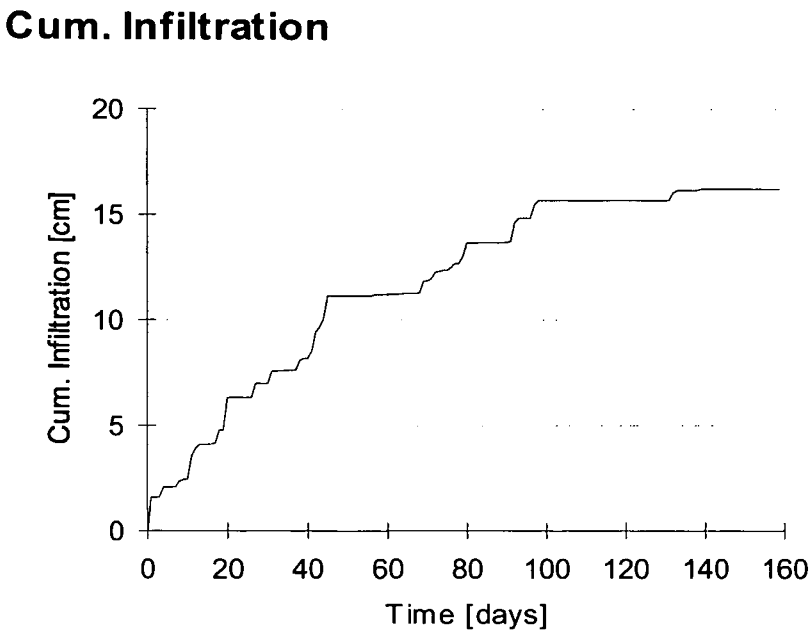
Appendix 3: Precipitation during the growing period of winter rye 2003/04



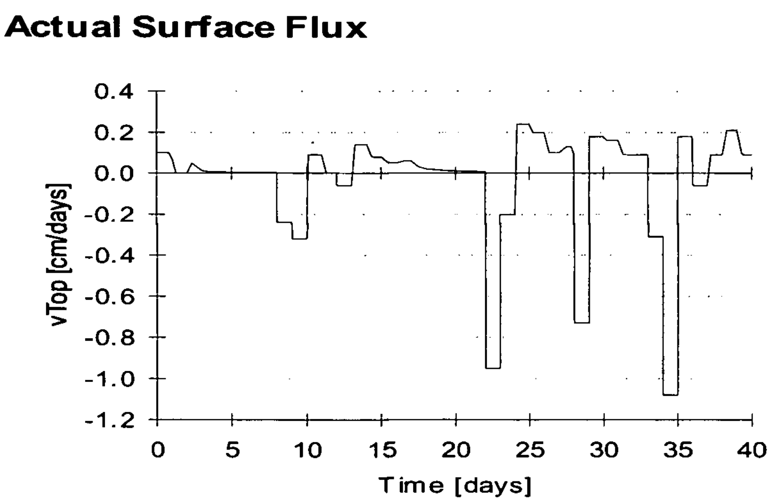
Appendix 4: Actual surface flux of bare soil 2002/03



Appendix 5: All cumulative fluxes in bare soil 2002/03, plot 6

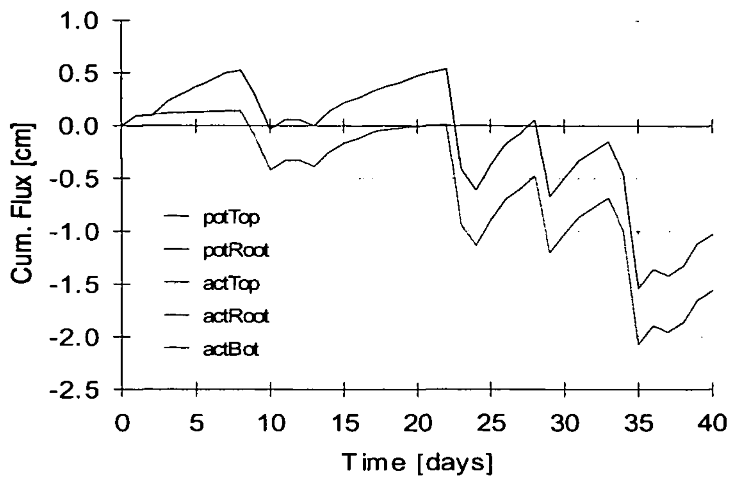


Appendix 6: Cumulative infiltration of bare soil 2002/03, plot 6



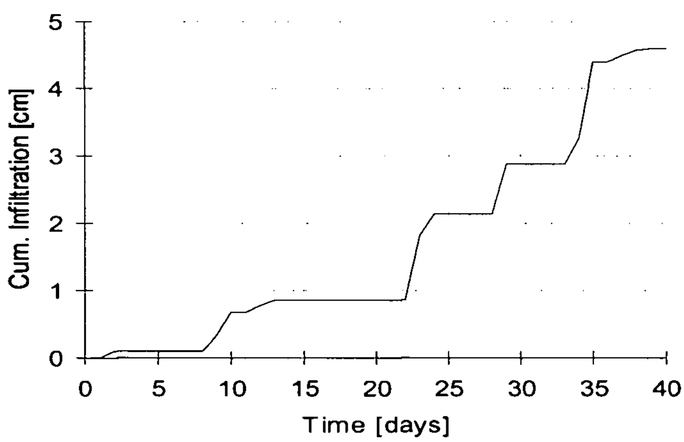
Appendix 7: Actual surface flux in bare soil 2003

All Cumulative Fluxes



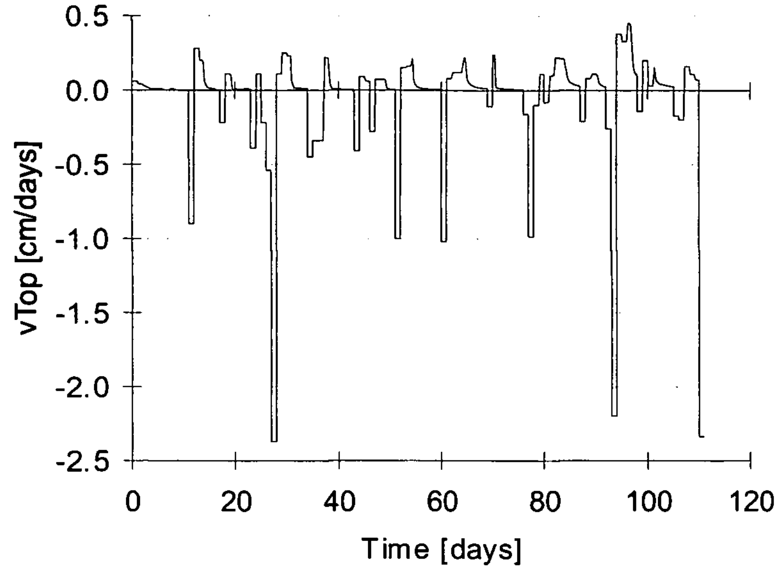
Appendix 8: All cumulative fluxes in bare soil 2003 plot 6

Cum. Infiltration



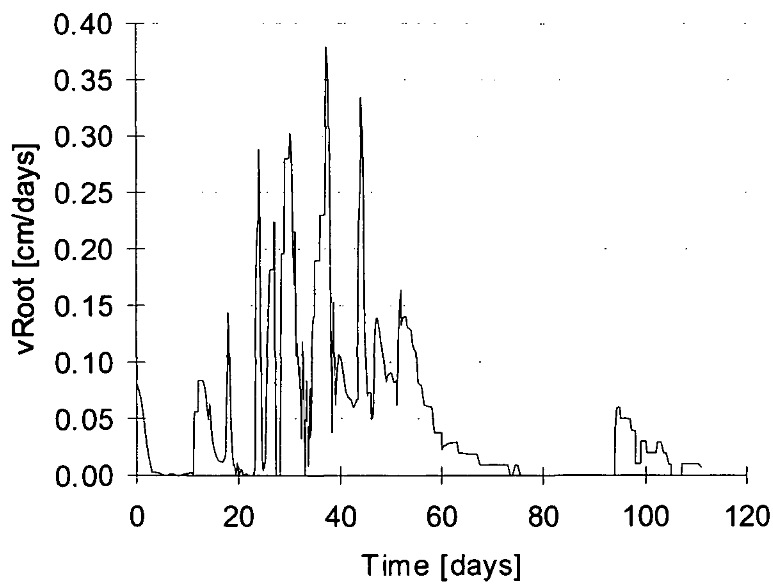
Appendix 9: Cumulative infiltration in bare soil 2003 plot 6

Actual Surface Flux



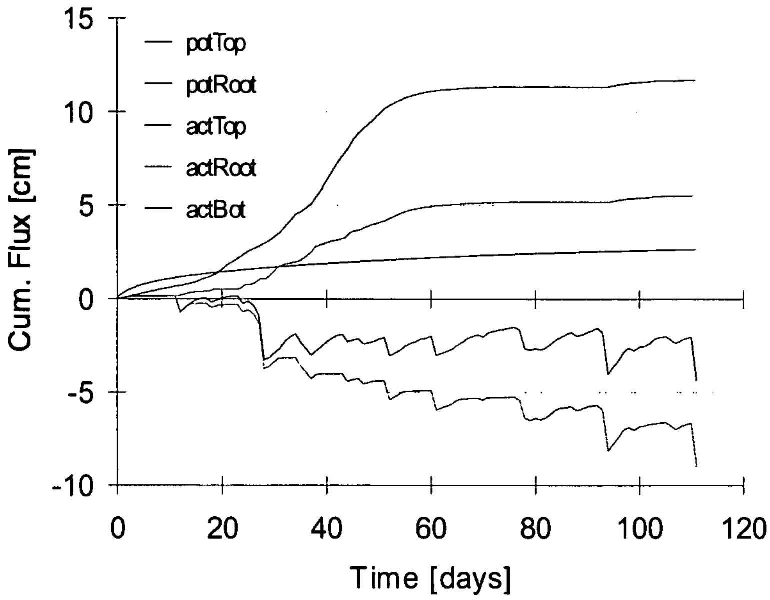
Appendix 10: Actual surface flux in the growing season of potato 2003

Actual Root Water Uptake



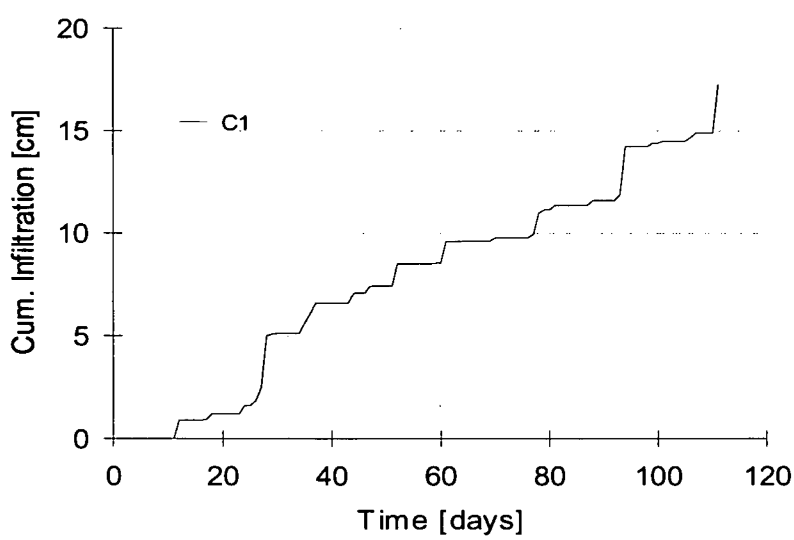
Appendix 11: Actual root water uptake in the growing season of potato 2003

All Cumulative Fluxes



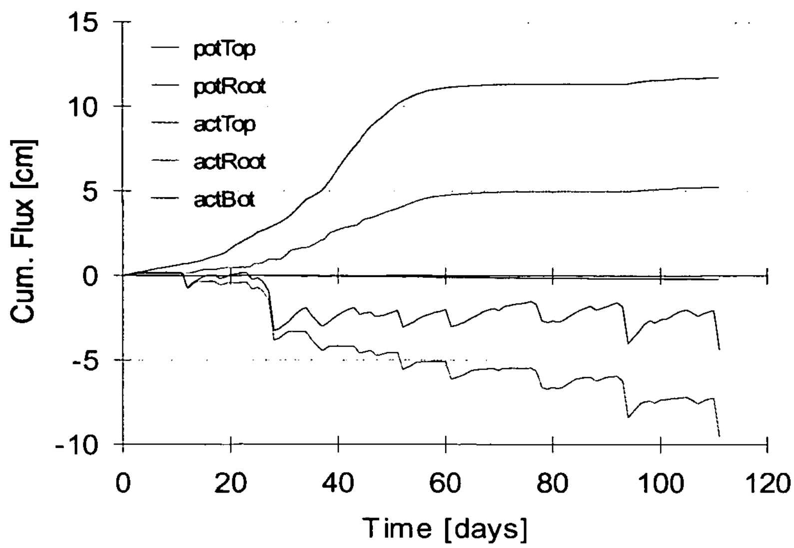
Appendix 12: All cumulative fluxes in the growing season of potato 2003 plot 6

Cum. Infiltration



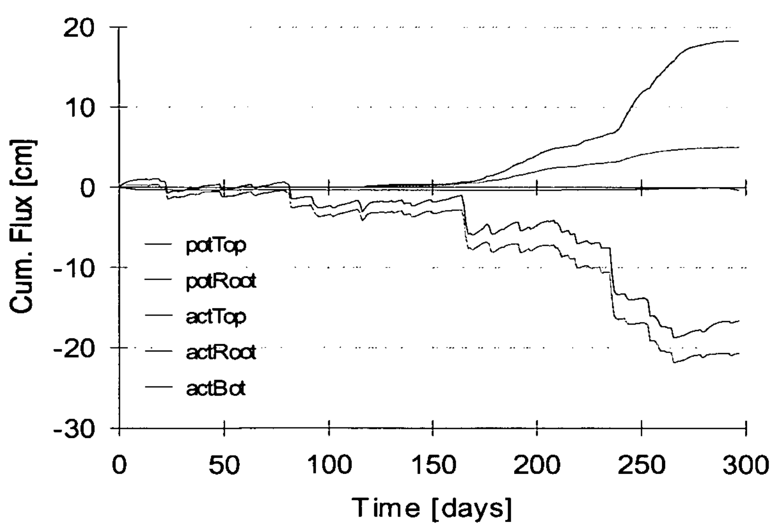
Appendix 13: Cumulative infiltration in the growing season of potato 2003 plot 6

All Cumulative Fluxes



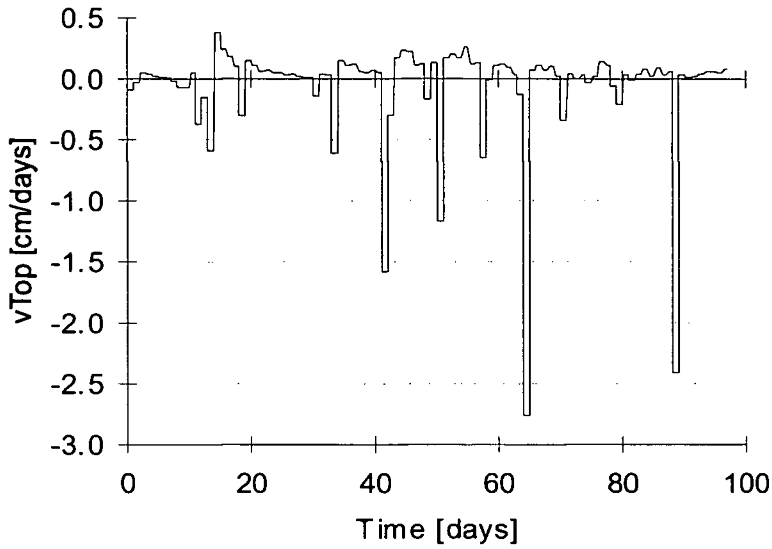
Appendix 14: All cumulative fluxes in the growing season of potato 2003 plot9

All Cumulative Fluxes



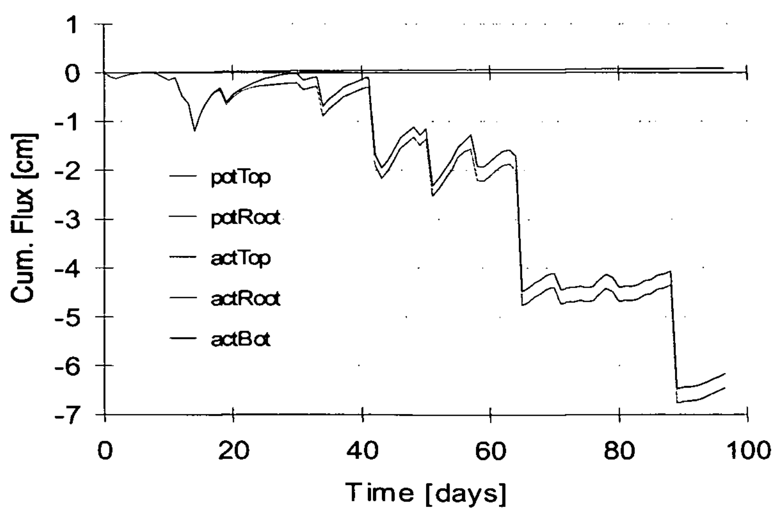
Appendix 15: Cumulative fluxes in the growing season of winter rye plot 9

Actual Surface Flux



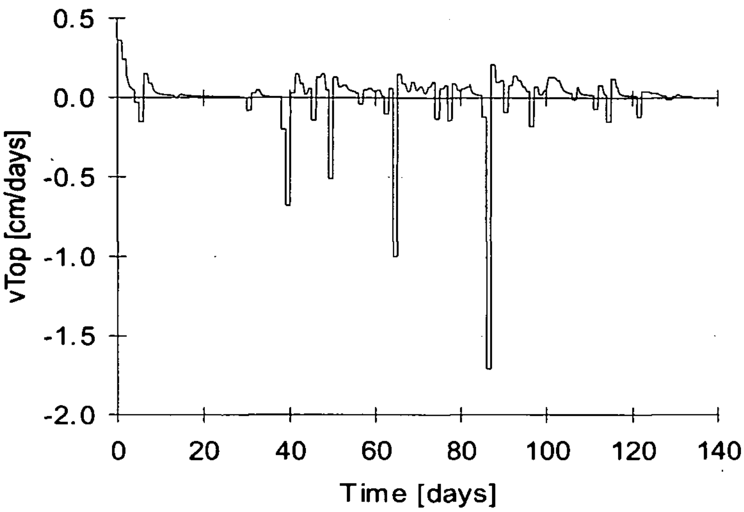
Appendix 16: Actual surface flux in the growing season of legumes 2004

All Cumulative Fluxes



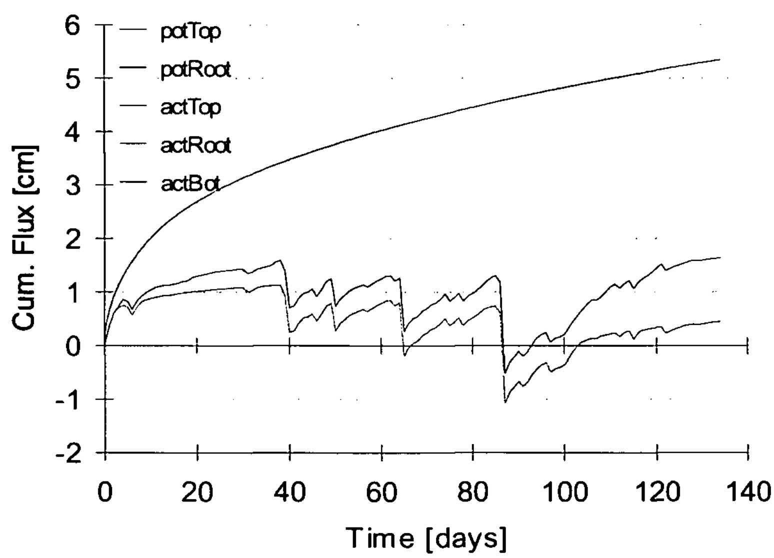
Appendix 17: All cumulative fluxes in the growing season of legumes 2004 plot 9

Actual Surface Flux



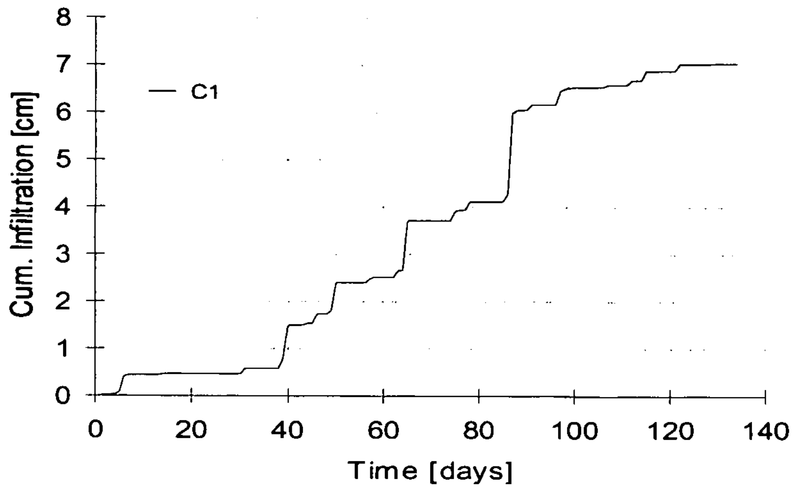
Appendix 18: Actual surface flux during mulching 2004/5 plot 6

All Cumulative Fluxes



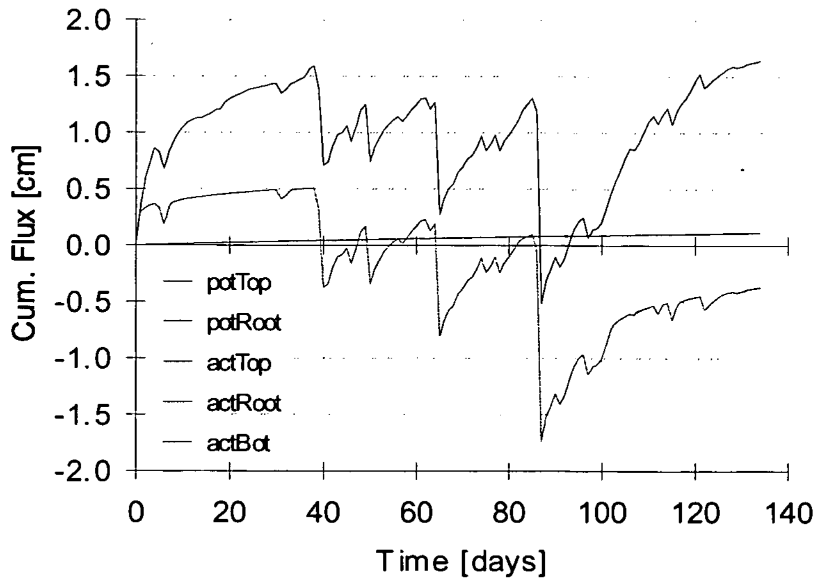
Appendix 19: All cumulative fluxes during mulching 2004/5 plot 6

Cum. Infiltration



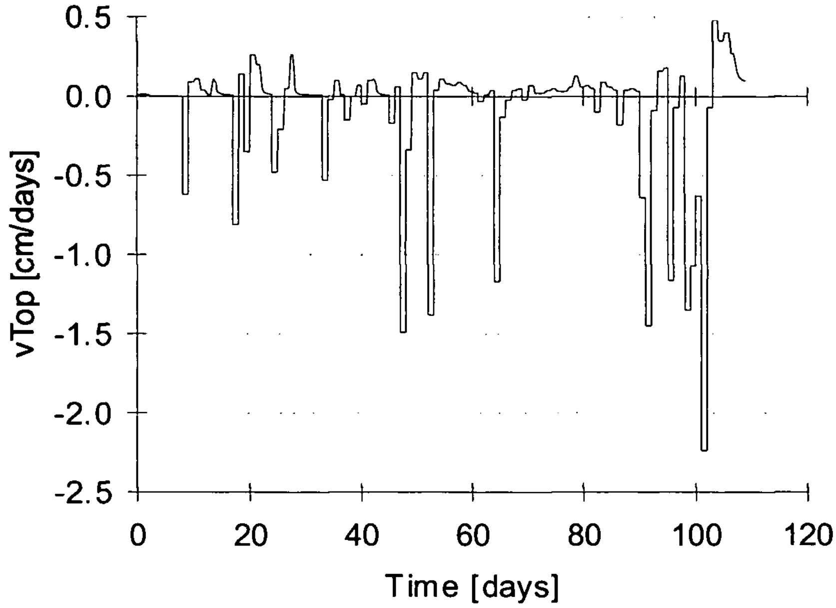
Appendix 20: Cumulative infiltration during mulching 2004/5 plot 6

All Cumulative Fluxes



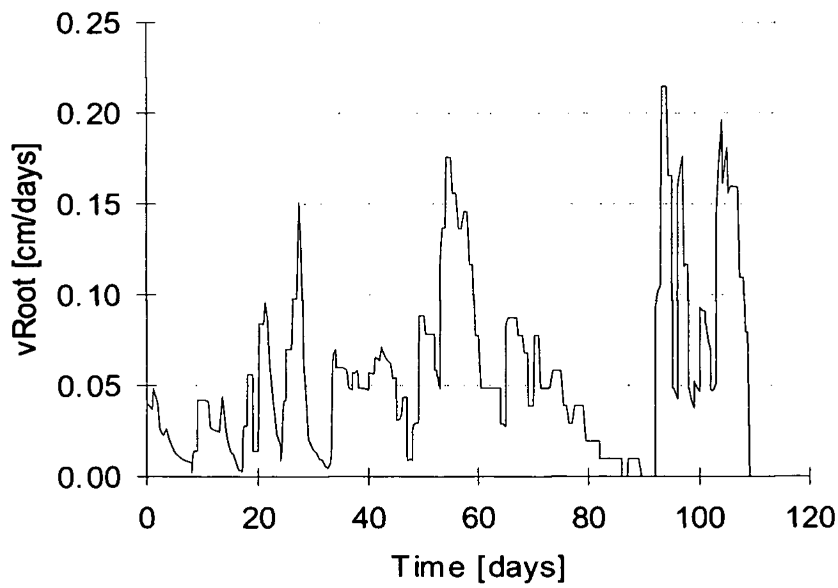
Appendix 21: All cumulative fluxes during mulching 2004/5 plot 9

Actual Surface Flux



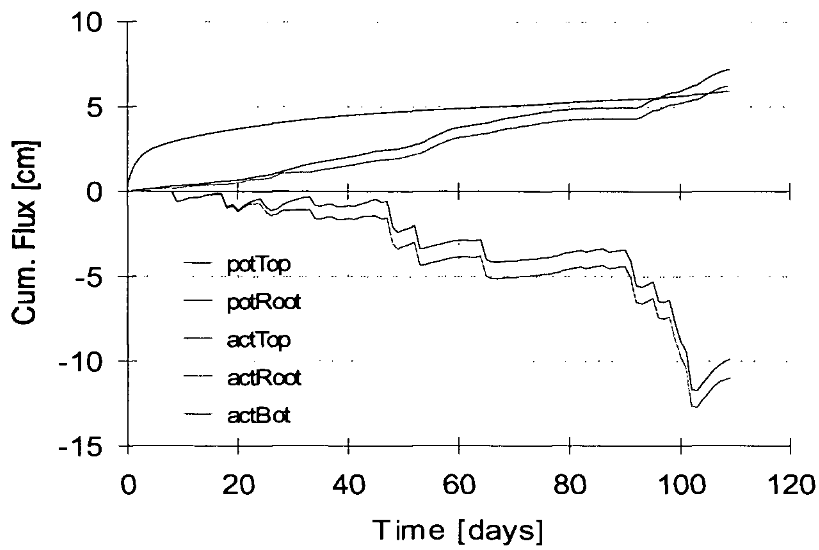
Appendix 22: Actual surface flux during the growing season of barely 2005

Actual Root W ater Uptake



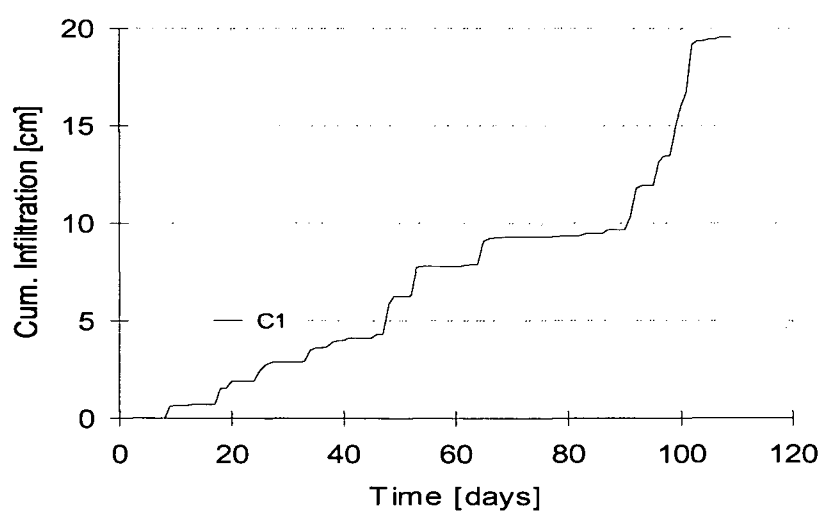
Appendix 23: Actual root water uptake during the growing season of barely 2005

All Cumulative Fluxes



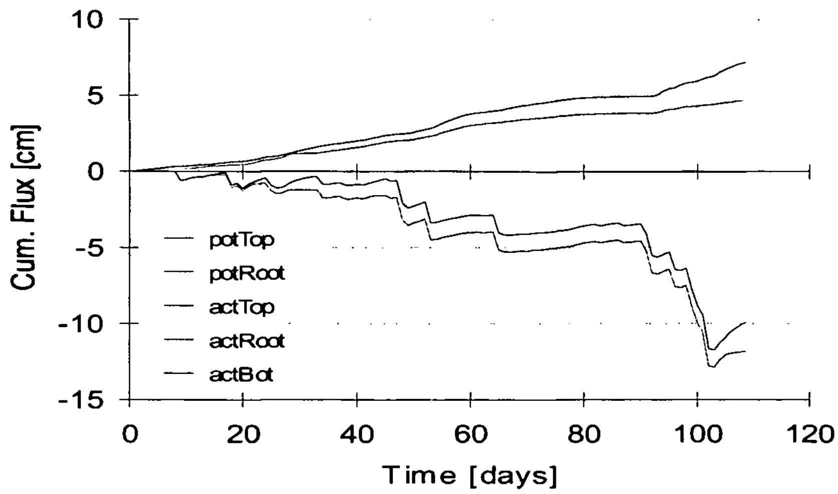
Appendix 24: All cumulative fluxes during the growing season of barely 2005 plot 6

Cum. Infiltration



Appendix 25: Cumulative infiltration during the growing season of barely 2005

All Cumulative Fluxes



Appendix 26: All cumulative fluxes during the growing season of barely 2005 plot 9

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