ATLANTIC ZONE PROGRAMME

Report Nr. 4
Field Report 69

SOIL HYDRAULIC CONDUCTIVITY ON TWO TROPICAL SOIL TYPES UNDER FOREST AND A 25 YEAR OLD PASTURE

- Field measurements and data application -

G.J. Weerts

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AGRICULTURAL UNIVERSITY
WAGENINGEN - AUW

MINISTERIO DE AGRICULTURA
Y GANADERIA - MAG

The Atlantic Zone Programme (CATIE-AUW-MAG) is the result of an agreement for technical cooperation between the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), the Agricultural University Wageningen (AUW), The Netherlands and the Ministerio de Agricultura y Ganaderia (MAG) of Costa Rica. The Programme, that was started in April 1986, has as a long-term objective multidisciplinary research aimed at rational use of the natural resources in the Atlantic Zone of Costa with emphasis on the small landowner.

Location of the study area.

Preface

12 October 1990 till 5 april 1991, that is the period in which I took part in the activities of the co-operation program between CATIE, MAG and AUW.

This period of 6 months could not have been successful without the help of many people. First I want to thank prof. dr. J. Bouma who made this trip possible. In the second place I want to thank Ed and Antje for the fantastic co-operation and help. Further I want to thank all friends who made my stay in Costa Rica as pleasant as it was. I enjoyed working, I enjoyed Costa Rica.

Gert Jan Weerts

Summary

Soil hydraulic measurements were executed with the modified crust method on a Eutric Hapludand (Suelo Los Diamantes) under forest and under a 25 year old pasture and on a Andic Humitropept (Suelo Neguev) under forest and under a 25 year old pasture. For the same sites bulk density samples were taken.

The Eutric Hapludand appears to be more sensitive than the Andic Humitropept for changing the land use from forest to pasture, resulting in lower hydraulic conductivities.

In both soil types occur compaction after changing forest into pasture. The increase in bulk density in the soil layer from 0-5 cm is 26.5% for the Eutric Hapludand and 18.0% for the Andic Humitropept. And in the layer from 15-20 cm 16.4% and 18.7% for the Eutric Hapludand and the Andic Humitropept respectively.

Because of the lack of hydraulic conductivity data in the dryer range was fitting with the soil water model SWATRER impossible.

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Chapter 1 Introduction

In many countries in Central America deforestation is a matter of concern. Also Costa Rica faces this problem with high deforestation rates over the last decades. Of the total extent of forest area the remaining primary forest in 1940, 1950, 1961, 1977, and 1983 was respectively 67, 56, 45, 32 and 17 percent (Sader and Joyce, 1988). This deforestation results in major changes in soil physical properties like hydraulic conductivity, bulk density en soil temperature.

In the scope of this issue research was done to examine the change of soil physical properties after conversion of tropical lowland forest into pasture. Changes in the hydraulic conductivity and bulk density in relation to the land use change were investigated. First the obtained hydraulic conductivity data and bulk density data served in a qualitative way for the evaluation of the impact of land use on different soil types. Second the data served in a quantitative way as input for a soil water model to calculate soil water availability, which depends on soil physical properties.

For the hydraulic conductivity measurements, the modified crust method was used. This method is described by Booltink et al. (1991). For a quantitative simulation the model SWATRER (Dierickx et al. 1986) was used.

The research was being carried out in Costa Rica from 12 october 1990 till 5 april 1991, in the scope of a cooperation program between CATIE (Centro Agronómico Tropical de Investigación y Enseñanza), MAG (Ministerio de Agricultura y de Ganaderia) and AUW (Agricultural University of Wageningen). The field station is situated in the small town Guápiles, Province Limon in the Atlantic zone.

Various authors have studied the effect of forest clearing on soil physical properties. Seubert et al. (1977) measured on a Typic Paleudult in Peru an increase of the bulk density and a decrease in the infiltration rate in the topsoil due to forest clearing by bulldozer. They measured the infiltration rates by the double ring method. Lal and Cummings (1979) observed an increase of bulk density and a decrease in infiltration on an Alfisol in Nigeria due to forest clearing by bulldozer and by manual clearing. They measured infiltration rates by the double ring method. They measured with a constant head permeameter a decrease in saturated hydraulic conductivity. Spaans et al. (1989A, 1989B) observed a decrease in hydraulic conductivity due to forest clearing and land use practise, but did not find any increase in the bulk density. They measured with the traditional crust method in Costa Rica on a Humoxic Tropohumult under forest and on a Humoxic Tropohumult used as pasture. Ghuman et al. (1991) observed on an Ultisol in Nigeria an increase in the bulk density of the 0-10 cm layer of 22% and 14% respectively due to bulldozer and manual forest clearing. Between 10-20 cm there was in increase in the bulk density of 29% and 11% respectively. Only the bulldozer clearing had an impact between 20-30 cm by increasing the bulk density with 5%. They also measured the changes in bulk densities after two and four years on the bulldozered cleared forest sites to examine the time effect of land use practise. Under pasture the bulk density between 0-10 cm increased after two and four years by 25% and 13% respectively. Between 10-20 cm this land use practise resulted after two and four years in an increase of the bulk density of 21% and 11% respectively. Also a sharply decreased infiltration rate was observed. They measured these infiltration rates by the double ring method three months after clearing but before planting.

In the second chapter various field methods for obtaining hydraulic conductivity data in the field are evaluated for their application and there theories. Theory, the traditional application and the modifications of the crust method are described in the third chapter. In the fourth chapter the application of the modified crust method in the field is described. The two applications of the obtained data and their discussion is described in the fifth chapter.

Chapter 2 Field methods for obtaining unsaturated hydraulic conductivity data

Bouma (1983) indicates 11 methods to obtain unsaturated hydraulic conductivity data, including only two field methods: the crust method (traditional) and the instantaneous profile method. Klute (1986) indicates 5 field methods to obtain K(unsat) data: the unsteady drainage-flux method, the simplified unsteady drainage-flux method, the crust imposed steady flux method, the instantaneous profile method and the sprinkler imposed steady flux method.

The three steady state methods are mostly applied. During the instantaneous profile method the soil is flooded until the total profile is saturated. While the profile is draining the pressure head values and the water content are monitored with profile depth. Afterwards the unsaturated hydraulic conductivity is calculated by the change in gradient of the pressure head and water content.

During the sprinkler method a steady state situation is created by sprinkling the soil surface with a steady intensity, meanwhile the soil water suction is observed. When the sprinkling intensity is known, and the matrix potentials at certain depths are constant over a period of time, the unsaturated hydraulic conductivity can be calculated out of the sprinkler intensities and the matrix potentials.

The problem with the sprinkler method is that the water movement may go along macropores in an unsaturated soil matrix, the so-called by pass flow. This renders meaningless data (Bouma, 1983). The crust method (Chapter 3) does not have this problems.

The instantaneous profile method is based on a gradual decrease of cumulative evaporation as a function of time. However, drying of clay soils results in opening of planar voids, thereby increasing the evaporative surface and evaporation rate (Bouma, 1983).

Only the sprinkler method and the crust method can be used in stony soils.

Only the crust method can be used in heterogeneous soils. These soils require in situ sampling or selective installation of equipment, which is to be based on detailed soil observations. At random placement of tensiometers and neutron access tubes (e.g. the instantaneous profile method) is bound to yield erratic results (Bouma,1983).

Operational aspects of the three methods are given in figure 1. This figure includes qualitative assessments of preparation time needed for making the measurements and calculations, the costs involved both in terms of personnel and material, the complexity and the accuracy. In this figure the sprinkler method is called the infiltration column method.

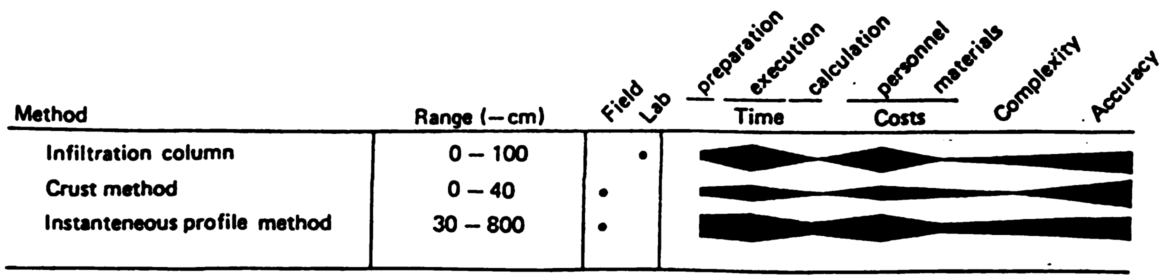


Fig. 1 Operational aspects of three methods measuring K(unsat) (Bouma, 1983)

Chapter 3 The crust method: theory, application and some modifications

3.1 Theory of a one dimensional flow

Before the unsaturated hydraulic conductivity is being calculated the assumption has to be made that there is only a one dimensional vertical flow. The general equation describing this one dimensional flow is the equation:

$$\frac{\partial\theta}{\partial t}=\frac{\partial}{\partial z}\left(K_{(\theta)}\frac{\partial H}{\partial z}\right) \quad (1)$$

where :

θ : the volumetric water content [cm^3/cm^3];

t : the time [day];

z : the vertical depth coordinate here taken as positive downward [cm];

$K_{(\theta)}$: the hydraulic conductivity as a function of the soil moisture content [cm/day];

H : the hydraulic head [cm].

Equation (1) expresses the change of the soil moisture content in time initiated by a soil moisture flow through a soil compartment of 1 cm^2 cross-section and 1 cm high. Taking the total soil moisture flow into account, from the soil surface till the end of the profile, equation (1) has to be integrated. This yields:

$$\int_0^z\left(\frac{\partial\theta}{\partial t}\right)dz = \left(K_{(\theta)}\frac{\partial H}{\partial z}\right)_z \quad (2)$$

The basis of the soil profile is at a depth of z cm below the soil surface. If the soil surface is covered to prevent evaporation and only internal drainage is allowed, the soil moisture flux can be obtained by integrating between successive soil moisture profiles down to depth z.

$$q = \int_0^z\left(\frac{\partial\theta}{\partial t}\right)dz=\left(K_{(\theta)}\frac{dH}{dz}\right)_z \quad (3)$$

And finally:

$$K_{(\theta)} = \frac{q}{\left(\frac{dH}{dz}\right)} \quad (4)$$

When the soil water flux through an isolated pedestal of soil is maintained at a value below the saturated conductivity under steady flow with unit hydraulic gradient, the hydraulic conductivity is equal to the imposed flux. Or, in a different way, if $dH/dz = 1$ then $K(\theta)=q$.

3.2 The traditional crust method

In the traditional crust method the hydraulic conductivity is associated with soil water pressure less than zero. The pressure is measured by a single small tensiometer inserted into the soil pedestal, giving one point on a $K_{(h)}$-curve. Successive measurement with different crusts, each with a different hydraulic conductivity, provide the $K_{(h)}$-relationship over the range of pressures achieved. Figure 2 gives a schematic diagram of the procedure.

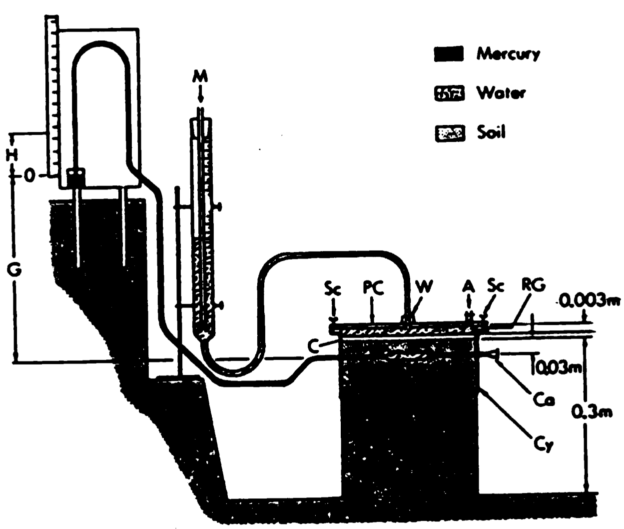


Fig. 2. Schematic diagram of a field installation of the measurement apparatus for the crust-imposed steady flux method (after Baker, 1977). M = constant-head device; Sc = wing nut; PC = plastic cover; W = water inlet; A = air outlet; RG = rubber gasket; C = gypsum-sand crust, Ca = tensiometer cap; Cy = metal cylinder with sharpened edge; H = height of mercury column above mercury pool; and G = height of mercury pool above tensiometer porous cup, P.

The installation of a column is described by Bouma 1977, Bouma 1983 and Spaans et al. 1989A, and is as follows: a cylindrical undisturbed soil column with a height of at least 25 cm and a diameter of 30 cm, is carved out by removing the surrounding soil. A ring-infiltrometer of 10 cm high, with a 2.5 cm wide brim at the top, is pressed down over the sample. The level of the soil surface inside the infiltrometer should be 1.5 - 2.0 cm below its brim. The wall of the soil column will be enclosed with mortar. This cement cover prevents as well the lateral flow of water as evaporation losses at the side of the column. In the temperate regions gypsum can be used also as cover material. Then the mixture for the crust can be placed at the soil surface inside the infiltrometer. Compressing it ensures good contact between crust and soil surface. Several crusts of different mixtures have been used in the past, e.g. crusts made of sand and clay or of gypsum and quick setting cement. A crust thickness of 1 cm is required. After the crust is hardened the tensiometers can be installed at a depth of 3 cm and 7 cm below the soil surface into the column. These tensiometers, connected to a mercury manometer or a pressure transducer, measure the pressure head in the soil column. After the crust is hardened a plastic cover is placed on the top of the infiltrometer. A rubber ring is placed between the plastic cover and the metal ring to prevent air entry. A water intake port and air vent are provided in the cover. Then water can be introduced into the infiltrometer chamber from a constant head device. During the filling the air vent is open. The plastic cover is cone-shaped towards the air vent to facilitate air removal during filling. The air vent has to be closed when all the air is removed and water is coming out of the air vent. When the bottom of the air inlet tube in the constant head device is placed at the same level as the crust the recording of the inflow volume and tensiometer reading versus time can start. Several runs with different crusts with different hydraulic conductivities are necessary to obtain the $K_{(h)}$-relation. At the end of the measurement the saturated K can be measured after removing the crust.

3.3 The modified crust method

Perfect contact between the crust and soil is the premier for a successful application of the crust method. One operational problem of the traditional method was the necessity to replace the crusts. Replacement is laborious and often involve disturbances of the pedestal soil surface. The modification of the method overcomes this problem. The range of unsaturated $K_{(h)}$-values will be obtained by using one single crust and by manipulating the height of the pressure head at the bottom of the crust. Therefore a movable feeder burette with a Mariotte device is connected to the plastic cover of the infiltrometer. The burette is installed on a vertical stand. Figure 3 shows a vertical stand with a moveable feeder and a Mariotte device. Movement is possible by a simple system of drilled holes in which a nail can be placed on which the burette feeder is resting. In the first measurement position (h = 0 cm) the nail is in the upper hole. Then the air inlet tube of the Mariotte device has to be positioned at the level of the bottom of the crust. By moving the nail to the hole 1 cm below the upper hole the air inlet tube is at the level of - 1 cm below the crust, the h = -1 cm position. Thus, different rates of steady infiltration of water will be obtained with corresponding negative sub-crust pressure heads.

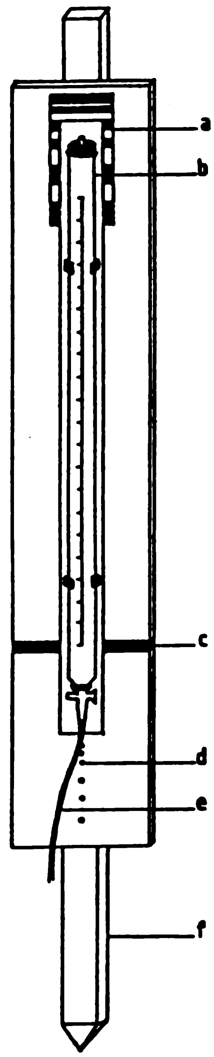


Figure 3 The vertical stand. a= scale for pressure head, b= burette with Mariotte device, c= line where h=0, d= nail hole, e= tube to water intake port and f= post.

Chapter 4 The field research

4.1 The field sites

Four sites on two different soil types were chosen with two different land use types:

* a poor Andic Humitropept (Suelo Neguev) under forest;
* a poor Andic Humitropept under 25 year old pasture;
* a rich Eutric Hapludand (Suelo Los Diamantes) under forest;
* a rich Eutric Hapludand under 25 year old pasture;

Soil profile descriptions and their locations are found in appendix nr 1.

4.2 The field measurements

4.2.1 The saturated and unsaturated hydraulic conductivity

At each site the hydraulic conductivity was measured at two different depths: 0-30 cm and 30-60 cm. A schematic diagram of a field installation of the modified crust method is drawn in figure 4. Three columns were installed at each depth. The K(sat), K(unsat) and K(sat) of both layers were measured three times. The following adaptions were made to the installation procedure. Three ring infiltrometers were pushed and beaten horizontally and carefully into the soil. (For the 0-30 cm layer a flat surface was used (as far as possible). For the 30-60 cm layer the surface on which the infiltrometers were pushed and beaten into the soil could be made horizontal with a level and a trowel or knife.)

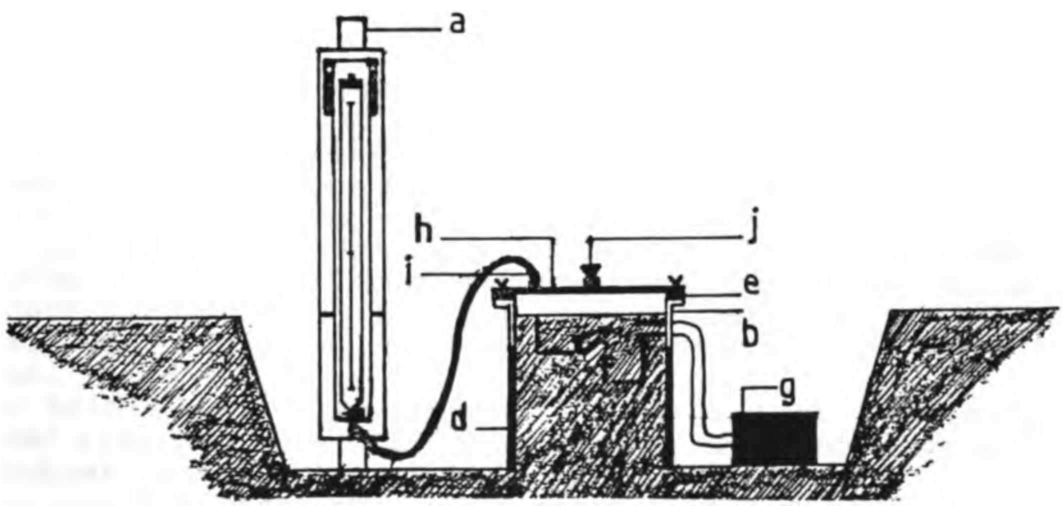


Figure 4. Schematic diagram of a field installation of the measurement apparatus for the modified crust method. a= vertical stand, b= ring infiltrometer, c= crust, d= soil column wall of Pegamix, e= rubber ring, f= tensiometer cups, g= tensiometer and pressure head transducer, h= plastic cover, i= water intake port and j= air outlet.

Pegamix, a local available product that consist of a mixture of cement and coarse sand, was enriched with extra cement and then used for the enclosure of the soil column wall. For a good sticky result a moist mixture of the pegamix was needed. Too wet pegamix did not stick to the soil column wall and fell of.
The crust was a mixture of sand (See table 1 for the size distribution.) smaller than 0.5 mm and 10 % (by weight) cement (not quick setting). The amount of water added was more or less 10 % (by weight). For a crust thickness of 1 cm a volume of ±700 cm^3 of sand was needed, weighing about 1200 g. The air entry value was -20 cm water column. The crust was flattened with a trowel and after that left overnight to ensure good hardening of the cement.

Table 1. The size distribution of the sand used for the crust

size (μm)	percent
420 - 600	1.05
300 - 420	9.31
210 - 300	24.07
149 - 210	35.66
105 - 149	22.81
50 - 105	6.75
> 50	0.3

At the day of the measurement micro tensiometers with a width of 6 mm were installed at about 3 and 7 cm below the crust. Therefore a hole with a width of 6 mm was drilled with a electrical wireless drilling machine. The tensiometer holes in the infiltrometer ring are wider than 6 mm and to prevent water to come out from the remaining space, the ring was glued with silicone paste. The tensiometers were connected to a TFDL pressure transducer (type 89.4, serial number 09, order number 20154) that indicates soil water suction in units cm water column.

The brim of the infiltrometer always had to be cleaned and greased with vaseline or silicone grease. This was done also with the rubber contact ring of the plastic cover.

The vertical stand was installed into the soil such that the air inlet tube was positioned at the level of the crust. During measurements, the burette with the Mariotte device can be lowered until air enters through the crust out of the soil column. Then the plastic cover has to be taken off and the leak has to be glued with silicone paste for further measuring. When the infiltration rate is sufficient enough so that the air bubbles come out of the air inlet tube quickly and in relatively large amounts, gluing is justified. When it takes several minutes, for air bubbles to leave the inlet tube in a reduced amount, the decision has to be made: stop the measurement.

The measurement of the saturated hydraulic conductivity was done after removing the crust carefully.

The time between two readings during the measurement of the unsaturated hydraulic conductivity was 15 seconds. During the measurement of the saturated K, readings where taken every 10 seconds.

4.2.2 The bulk density

The bulk density samples were taken with 100 cm^3 cores. Below a depth of 10 cm a core was driven into the ground by hand (!) to prevent compaction inside the core. This was necessary because of the stickiness of the soils. The depth of the samples was in relation to the soil column made by the hydraulic conductivity measurements:

* 0-5 cm (top layer of the 0-30 cm column
* 15-20 cm (bottom layer of the 0-30 cm column
* 30-45 cm (top layer of the 30-60 cm column
* 45-50 cm (bottom layer of the 30-60 cm column

Each layer was sampled at least three times with a maximum of 10 times.

Chapter 5 The application of K-data in the scope of the land evaluation

5.1 Discussion of the hydraulic conductivity data

The results of the measurements are in figure 5a till 12. The absolute data of the hydraulic conductivity are given in appendix nr 2.

The saturated flow in the soil matrix were obtained without a crust: Ksat and with a crust at h = 0 cm: K(sat). The unsaturated K values were obtained by using a crust and corresponding sub-crust pressure heads. Because of the crust used during the K(sat) measurements pores will be filled with water only if their capillary force is strong enough to 'pull' the water through the crust. The larger the pores, the smaller the capillary force that can be exercised (Bouma,1977). Therefore the less water will flow through the soil column. Table 2 shows the Ksat and K(sat) results.

Table 2. Ksat, K(sat) and Ksat-K(sat) results in cm/day

Eutric Hapludand						
	pasture			forest		
depth	Ksat	K(sat)	diff	Ksat	K(sat)	diff
0-30 cm	---	80.3	---	402.5	326.6	75.9
	185.7	120.2	65.5	431.3	256.4	174.9
	---	207.3	---	708.9	271.2	437.7
30-60 cm	298.2	227.3	70.9	526.8	355.3	171.5
	300.1	215.1	85.0	531.7	340.8	190.9
	525.6	206.4	319.2			
Andic Humitropept						
	pasture			forest		
depth	Ksat	K(sat)	diff	Ksat	K(sat)	diff
0-30 cm	385.9	193.8	192.1	321.4	257.8	63.6
	647.8	252.6	395.2	513.4	284.0	229.4
	613.2	188.2	425.0			
30-60 cm	352.0	224.3	127.7	484.2	280.5	203.7
	443.4	267.4	176.0	579.4	298.1	281.3
	369.6	180.8	188.8			

Every measurement done on the two different soils and under the two land use types shows this phenomenon (For the absolute values see appendix nr 2). The Ksat results and K(sat) results do not differentiate to soil type and to land use.

Figures 5a till 12 have a x-axis expressing the pressure head in -cm and a y-axis with K in cm per day. The different lines in a figure represent the replications. The a-figures represent results of the measurements on the 0-30 cm column and the b-figures represent those on the 30-60 cm column. The regression coefficient of the K-curves are listed in table 3.

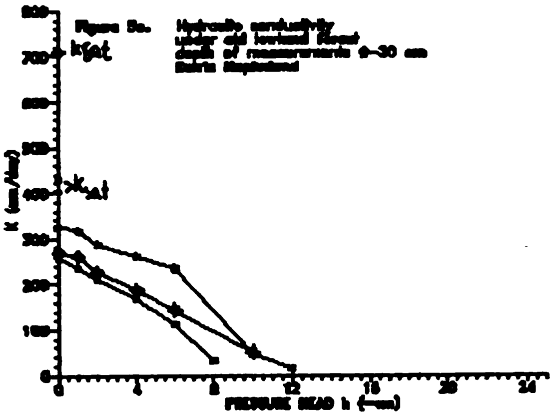
Table 3. Regression coefficient of the K-curves

	Eutric Hapludand		Andic Humitropept	
	pasture	forest	pasture	forest
0-30 cm	-0.7	-11.6	-7.9	-8.2
	-2.9	-10.7	-8.5	-7.3
	-5.0	-9.8	-6.0	
avg	-2.9	-10.7	-7.5	-7.8
30-60 cm	-3.8	-4.8	-2.7	-5.5
	-3.4	-5.0	-4.4	-4.6
	-4.1		-4.0	
avg	-3.8	-4.9	-3.7	-5.1

For the evaluation of the unsaturated hydraulic conductivities the figures 5a till 12 are being interpreted. The lines in figure 5a of the Eutric Hapludand under forest show a wide diversity of conductivity, while the lines in figure 5b are almost the same. The lines in figure 5a have an average regression coefficient (ARC) which is twice as small (more negative) as the ARC of the lines in figure 5b. This is due to the difference in structure of the two layers (given in the profile description) and thus due to a different system of pores: the topsoil has a strong medium crumb structure and the subsoil has a very weak coarse subangular blocky structure. The measurements in the topsoil were stopped at h=-8, -10 and -12 cm, while the measurements in the subsoil lasted till h=-16 cm.

The lines in figure 6a of the Eutric Hapludand under pasture show a wide diversity in the regression coefficients while the regression coefficients of the lines of the replicates are almost the same of in figure 6b. The influence of the structure is not evident. For one of the lines (with the lowest regression coefficient, most negative) it is possible to assume structure influence. However, the soil profile description gives only a slight structure difference between the topsoil and subsoil. The measurements of the topsoil stopped at h=-12 cm, h=-14 cm and h=-16 cm. In the subsoil readings where possible till h=-16 cm and h=-20 cm.

Figure 7a of the Andic Humitropept under forest show that the upper line is almost at the same level as the lines of figure 7b. At h=-10 cm the line drops to the level of the lower line of the topsoil. The measurements in the topsoil were stopped at h=-12 cm while the subsoil measurements could be continued till h=-16 cm and h=-20 cm. The ARC of the topsoil is 1.5 times smaller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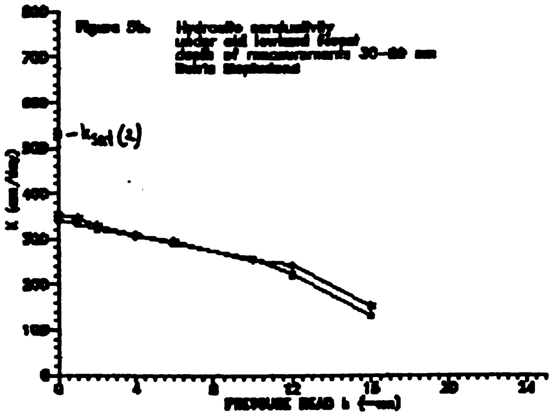
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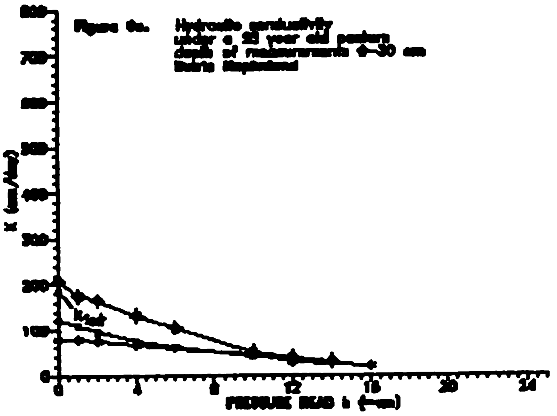
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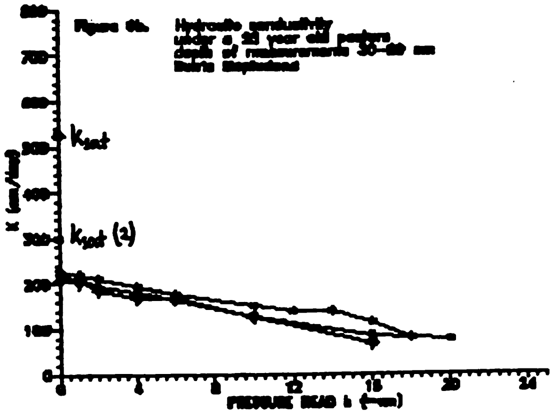
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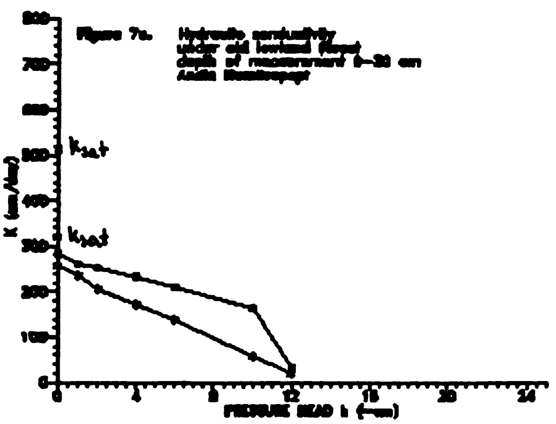
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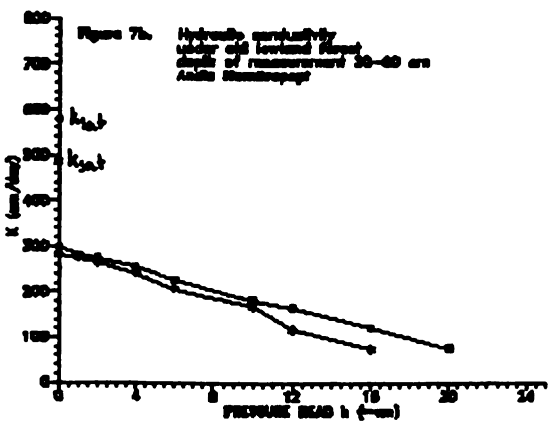
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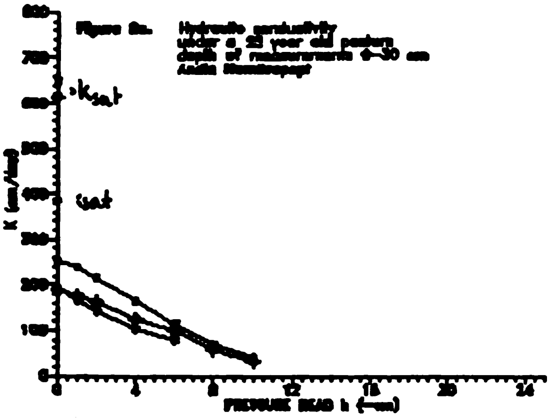
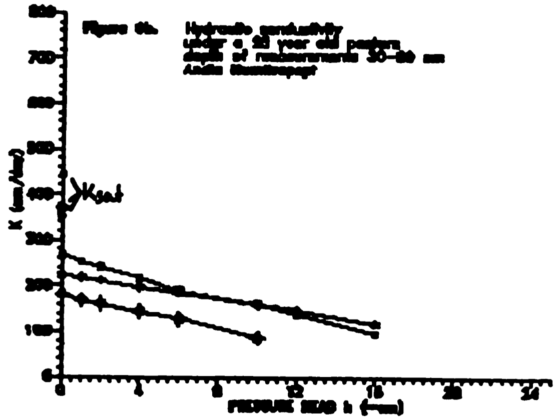
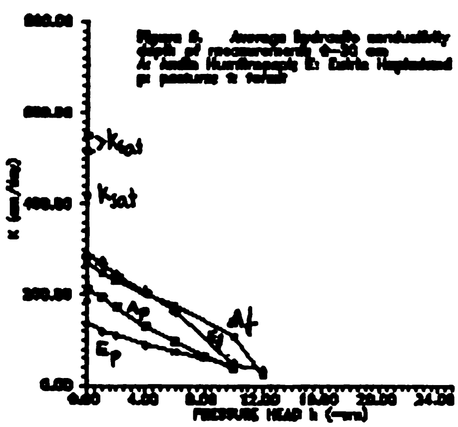
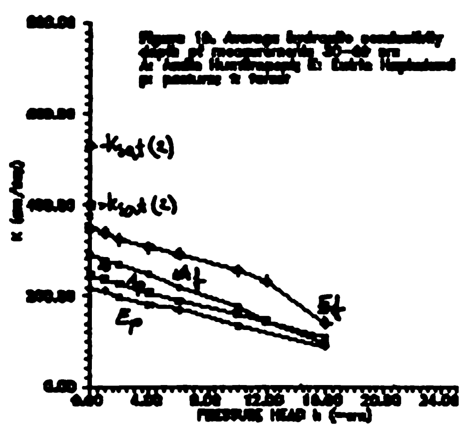
(more negative) than the ARC of the subsoil. The structure difference is not evident.





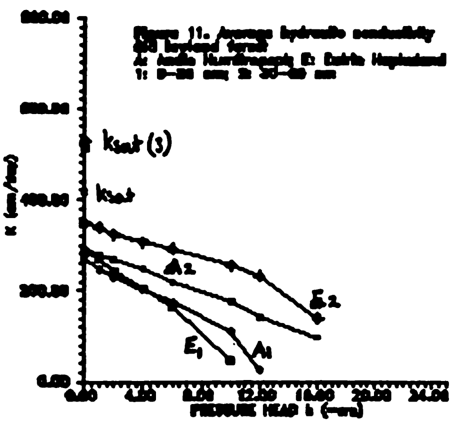
Figures 8a and 8b of the Andic Humitropept under pasture show some remarkable results. The lines of figure 8a have an ARC that is twice as small (negative) as the ARC of the lines in figure 8b. The structure difference is evident: the topsoil has an angular/subangular blocky structure and the subsoil has a weak fine granular structure. The replicate, that resulted in the lowest line in figure 8b was stopped at h=-10 cm like all the measurements in the topsoil, unlike the other two subsoil replicates that ended at h=-16 cm. This indicates that the compaction in that soil column goes beyond the first 30 cm. Because of the same soil structure this line is parallel with the other lines in figure 8b.





To evaluate the influences of the land use types and the different soil types on the hydraulic conductivity averages were calculated for all sites and all depths. Figure 9 with the average of the measurements for the layer of 0-30 cm clearly indicate the effects of the different land use. The forest sites for both soil types show a higher hydraulic conductivity than the pasture sites. Also the average Ksat and K(sat) for the forest sites are higher. The gap between the forest line and pasture line is bigger for the Eutric Hapludand. This means that this soil type is more sensitive for the land use change from forest to pasture.

Figure 10 with the average of the measurements for the layer of 30-60 cm shows that the effects of the land use change goes beyond the topsoil. Also this figure confirm the conclusions of figure 9.



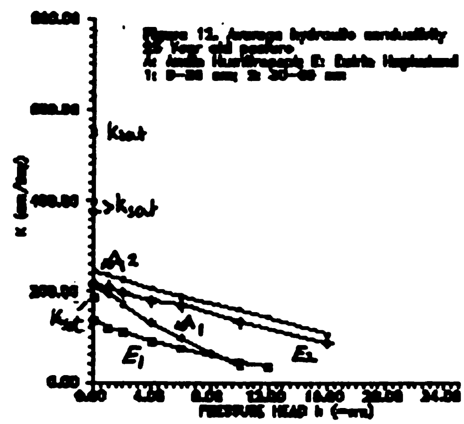


Figure 11 together with figure 12 show clearly the effect of the land use change. All topsoil lines in figure 12 are below the topsoil lines in figure 11 and this the same with the subsoil lines. The difference in the average Ksat and K(sat) between the two figures is not that evident.

5.2 Discussion of the bulk density data

All bulk density data are found in appendix nr 3. The average bulk densities are given in Table 2 and set out graphically in figure 13. The averages make clear that in both soil profiles compaction occurs after changing forest into pasture. Especially the layer 12-17 cm in the Eutric Hapludand and the layers 0-5 cm and 15-20 cm in the Andic Humitropept are compacted. Because of an increase in the bulk densities in all pasture profiles, in relation to the forest profiles, the conclusion can be made that compaction as a factor of the land use goes beyond the topsoil for both soil types.

The increase of the bulk densities of the different layers of the different soil types confirm the results of the hydraulic conductivity measurements. The Eutric Hapludand is most vulnerable for this type of land use. Table 3 shows also that the increase in bulk density goes beyond 30 cm and confirms that the hydraulic conductivity is mostly decreased in the topsoil.

Table 4. Average bulk densities in g/cm³ of an Eutric Hapludand under forest and pasture and an Andic Humitropept under forest and pasture.

Eutric Hapludand			
forest		25 year old pasture	
soil layer	bulk density	soil layer	bulk density
0- 5 cm	0.68(0.04)**	0- 5 cm	0.86(0.02)
14-19 cm	0.73(0.01)	12-17 cm	0.85(0.03)
30-35 cm	0.77(0.03)	28-33 cm	0.82(0.02)
45-50 cm	0.84(0.02)	43-48 cm	0.87(0.03)
65-70 cm	0.95(0.05)	58-63 cm	1.16(0.05)
82-87 cm	1.04(0.01)		
92-97 cm	1.13(0.04)		

Andic Humitropept			
forest		25 year old pasture	
soil layer	bulk density	soil layer	bulk density
1- 6 cm	0.61(0.03)	1- 6 cm	0.72(0.05)
16-21 cm	0.75(0.01)	15-20 cm	0.89(0.03)
30-35 cm	0.75(0.03)	30-35 cm	0.79(0.04)
45-50 cm	0.77(0.03)	45-50 cm	0.79(0.03)
75-80 cm	0.83(0.02)	65-70 cm	0.81(0.02)

** standard deviation is given in parenthesis

Table 5. Increase in bulk densities in % of an Eutric Hapludand and an Andic Humitropept as a result of 25 year old use as pasture.

Eutric Hapludand		Andic Humitropept	
soil layer	increase	soil layer	increase
0- 5 cm	26.5%	1- 6 cm	18.0%
14-19 cm	16.4%	16-21 cm	18.7%
30-35 cm	6.5%	30-35 cm	5.3%
		45-50 cm	2.6%

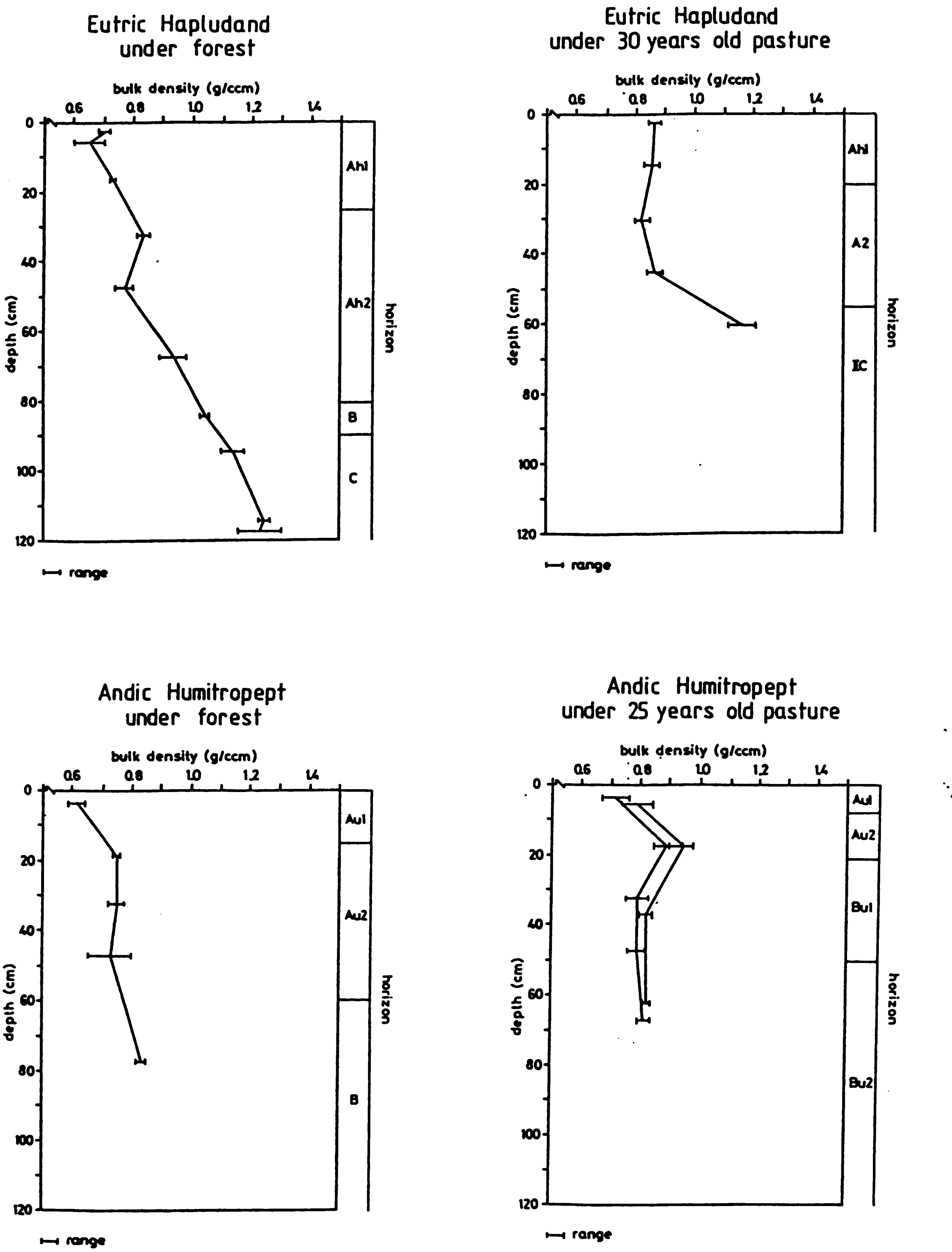


Figure 13. Average bulk densities results (graphically)

Chapter 6 Hydraulic conductivity data used as input for the soil water simulation model SWATRER

To simulate the soil water regimes in this research the soil water model SWATRER was used. This model was developed in Belgium at the University of Leuven, but was revised several times. The version of 1986 described by Dierickx (1986), was used in this research.

Basic data necessary for simulation of soil water regimes are: soil water retention data (h-Θ) of surface and subsurface soil horizons; hydraulic conductivity data (K-h) for surface and subsurface soil horizons; root depth and a function which defines water uptake from the root zone (the so-called sink term). In addition, environmental data are needed in terms of precipitation, potential evaporation and potential transpiration.

Due to time restrictions SWATRER is only being used to process the soil type Andic Humitropept under the land use type pasture. The grass type was 100% Axonopus compressus.

To check and evaluate the output of SWATRER tensiometers were installed at several depths (10 cm, 15 cm, 30 cm, 45 cm and 60 cm) in the soil profile under the Axonopus.

6.1 Input data and parameters

For the soil water retention data core samples of 100 cm^3 were taken at four depths (12-17 cm, 28-33 cm, 43-48 cm and 58-63 cm). The soil water retention data of these cores were obtained by the MAG-lab in San Jose. Therefore the total profile was divided into four soil layers. To check these data some field pF-values were determined by calculating volumetric water content using gravimetrical samples at the four depths (see appendix 4).

The hydraulic conductivity data were as described in Chapters 4 and 5.

The root depth was estimated at 30 cm. The parameters for the sink term and upper boundary conditions were taken from Dierickx et al. (1986).

The climate data were obtained from CORBANA, which has a meteorological station 200 meter north of the site (see appendix 5). The initial values to start the calculations were measured pressure head values measured at 5 November 1990. The simulation was done for the period from 5 November 1990 till 28 February 1991.

6.2 Data processing

For the relations (h-Θ) and (K-h) the measured K-data were processed with a fitting program called RETC, see manual for details. This program can be used to fit several analytical functions to observed retention data and unsaturated hydraulic conductivity or diffusivity data. The functions are described by the parameters of the van Genuchten model (van Genuchten, 1980):

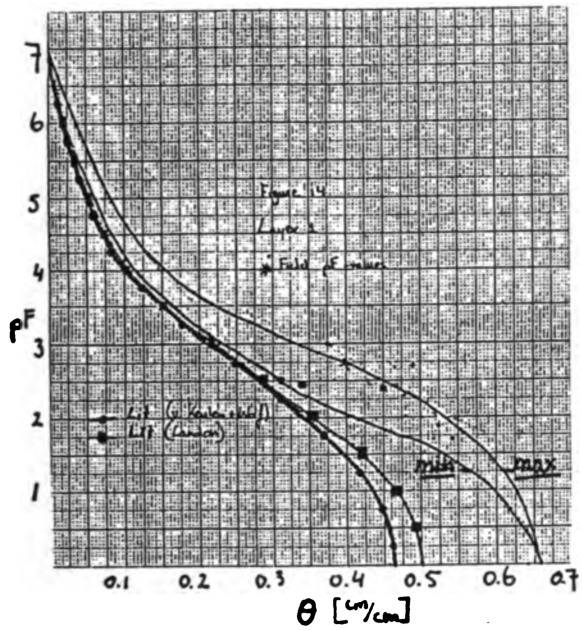


Figure 14. pF-curves Layer 1
* : field pF-values

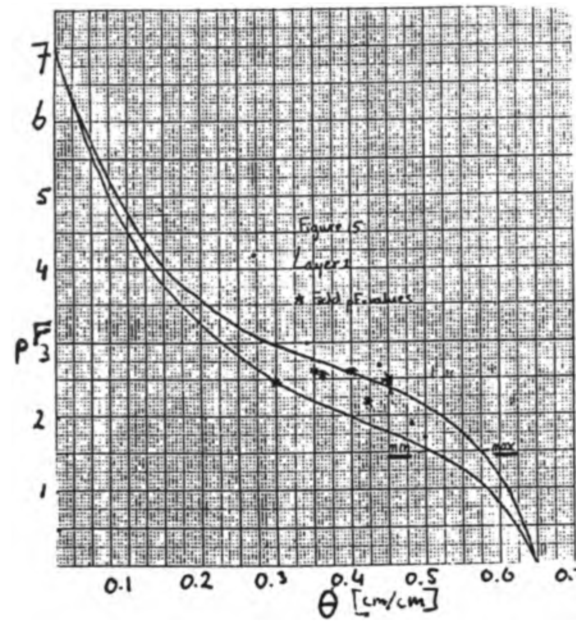


Figure 15. pF-curves Layer 2
* : field pF-values

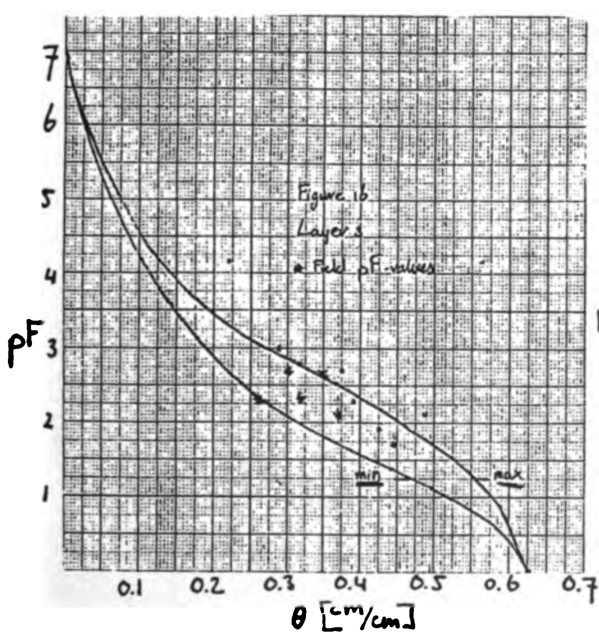


Figure 16. pF-curves Layer 3
* : field pF-values

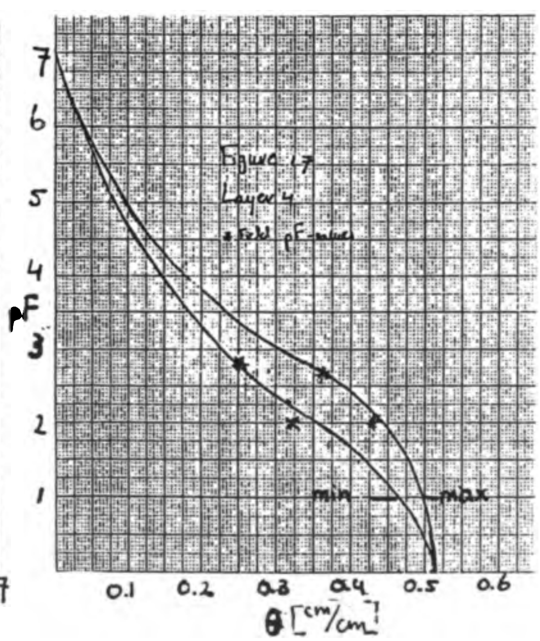


Figure 17. pF-curves Layer 4
* : field pF-values

α, n, Θsat, Θdry. These parameters were used as input for a fortran program HKGENU (see appendix 6) to calculate the input data table of physical soil parameters needed in SWATRER.

The measured tensiometer pressure heads were transformed into average Θ-values for the whole profile using the van Genuchten model with the same input parameters as given by the RETC program.

Because of the doubts on the lab quality, the decision was made to estimate a pF-curve by hand from the lab pF values and the field pF-values together with a standard loam pF-curve. This procedure resulted in three new pF-curves: a maximum, a minimum and a average one. Figure 14 till 17 show the different pF curves and measured field pF values.

6.3 Different runs of SWATRER

In total six runs were made with different parameters or different boundary conditions. The parameters derived by the different fits as used in SWATRER are listed in appendix 7. The input files and the outputs of the different runs are listed in appendix 8. Figures 18 till 24 compare simulated Θ-values and measured Θ-values over the simulated period.

Run 1

This run was made with a (h-Θ)-relation calculated by the data coming from the MAG and a (K-h)-relation given by field measurements. PF and K functions were simultaneously fitted in RETC. The pF value of 4.2 was left out of the fit. The bottom boundary condition (how water interacts at the end of the simulated profile) was taken as draining freely in the under ground.

Because of a large gap between the SWATRER results (see appendix 8 and figure 18) and calculated average Θ-values for the whole profile changes were made.

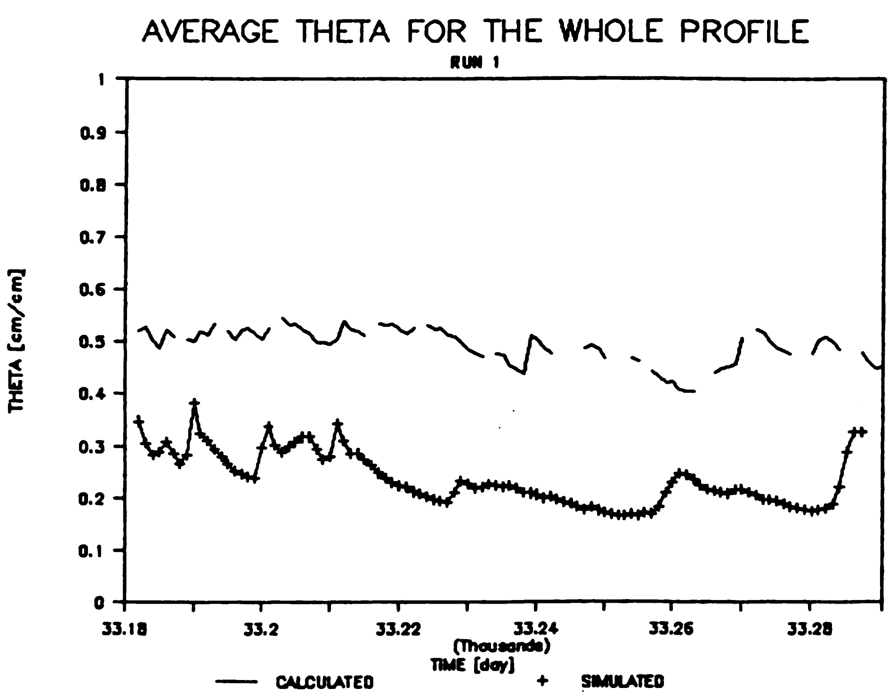


Figure 18.

Run 2

This run was made with a (h-θ)- and (K-h)-relation calculated from the estimated maximum pF-data. The pF and K functions were simultaneously fitted in RETC. No other changes were made.

No improvement was obtained (See figure 19) in comparison to run 1 regarding the simulated results in relation to the observations.

Run 3

This run was made with a (h-θ)- and (K-h)-relation calculated the estimated minimum pF-data. The pF and K functions were simultaneously fitted in RETC. No other changes were made.

Also this run resulted in a similar relation between calculated and simulated θ-values as run 1 and run 2 (See figure 20).

Run 4

This run was made with a (h-θ)- and (K-h)-relation calculated from the estimated average pF-data. The pF and K functions were simultaneously fitted in RETC. No other changes were made. Similar results were obtained as in run 1-3 (See figure 21).

From the results of run 1-4, the conclusion was evident that the pF-curves did not have great influence on the behaviour of the simulated soil water content. Also the dynamics of the measured changes in soil water content were not simulated well. Changes in tendencies of simulated functions seem to appear later than those of the field measurements.

Run 5

This run was made with a (h-θ)- and (K-h)-relation calculated from the estimated average pF-data. The pF and K function were simultaneously fitted in RETC. The bottom boundary condition was changed. Now the measured pressure head values at the lowest investigated depth in the field profile were taken as input.

This run resulted in a almost flat line, at about the same level as of the measured θ-values (See figure 22).

Finally the sensitivity of SWATRER for the input parameter K was checked. The simulated low average θ-values would be a result of the assumed profile drainage properties, which allow very quick drainage of the profile. The RETC method used to fit the functions (K and the h-theta) used a type of least square procedure, showing high correlations. However, the measured K-values were only obtained in the wet range, just below saturation, the fitted curve was therefore not related to measurements in the dryer range. The curve fitting program was able to generate about any possible function without a decrease in the overall fit. The used K-functions in run 1 till run 5 gave too high conductivity values for the different soil horizons. Therefore an estimated K-function was used in run 6.

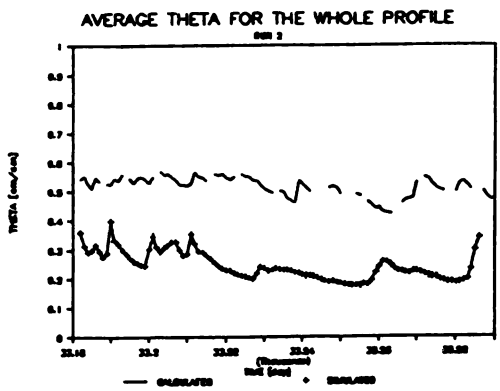


Figure 19.

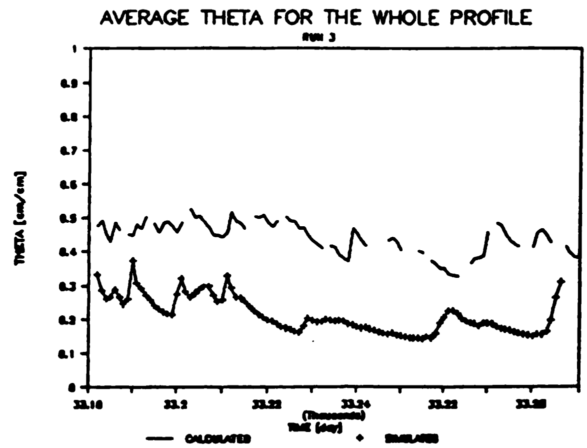


Figure 20.

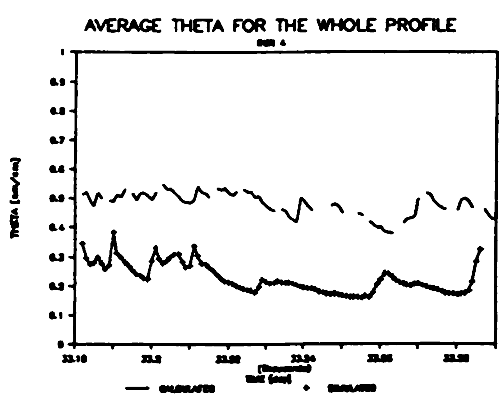


Figure 21.

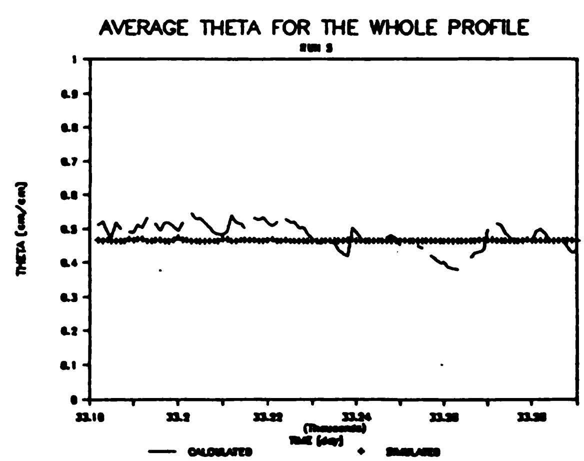


Figure 22.

Run 6

This run was made with a (θ-h)-relation calculated from the estimated average pF-data. The fit in RETC was done with pF-values only. The (K-h)-relation was estimated in the lower h-range (the measured values) by a linear regression. And in the dryer suction range with a double exponential decrease of K (See for the functions appendix 9). The bottom boundary is the same as in run 5.

These assumptions resulted in a smaller gap between calculated and simulated average θ-values in the beginning of the season (See figure 23). But because of the double exponential decrease of K, once the soil starts drying out (about half December), the hydraulic conductivity becomes too low for the soil to absorb water.

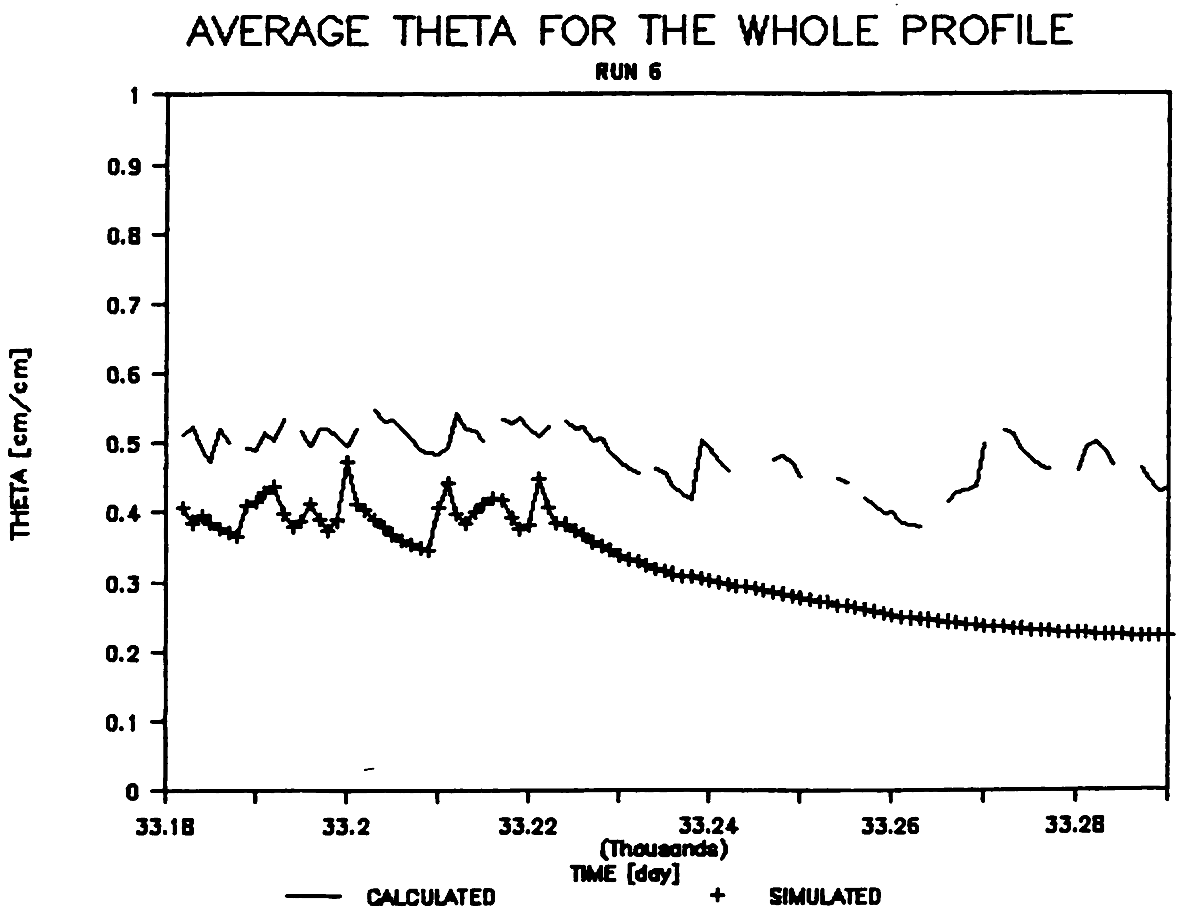


Figure 23.

Chapter 7 Conclusions

Conclusion towards the crust method:
* The modification save a lot of time and disturbances of the soil pedestal surface will be minimized.
* Is the method applied on a site that is difficult to reach than lots of water (kilo's) has to be carried.

Conclusions towards the hydraulic conductivity results:
* The Eutric Hapludand is most sensitive for the land use change from forest to pasture resulting in lower hydraulic conductivity rates than the Andic Humitropept.
* Both soils show a decrease in hydraulic conductivity in the subsoil.

Conclusions towards the bulk density results:
* In both soils occur compaction in the topsoil.

Conclusions towards the soil water model SWATRER:
* The hydraulic conductivity data have a great impact on the total result of the output.
* The K-data measured with the modified crust method only, as obtained in this research, do not serve as input data for the SWATRER simulation model, because there is no information over the hydraulic conductivity behaviour in relatively dry soil conditions. Therefore the hydraulic conductivity data at lower negative pressure heads need to be measured with e.g. the one step outflow method. With this method the outflow of soil moisture can be measured till pressure heads of -800 cm. Together the methods will give a sufficient range for the hydraulic conductivity of the soil profile what finally can be used in the SWATRER soil water model.

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NN:manual RETC

Appendix 1 THE SOIL PROFILE LOCATIONS AND DESCRIPTIONS

INFORMATION ON THE SITE:

Profile number: GJWEV1
Soil name: Suelo Los Diamantes
Higher category classification: USDA: Eutric Hapludand
Date of examination: 20 November 1990
Authors: Weerts, G.J.; Veldkamp, E.
Location: Costa Rica, Province Limon near the town Guápiles. At the experimental station named "Los Diamantes". Near the pig farm at the end of the station. Approximately 561.3E and 249N (map Guápiles; Hoja 34461 IV; edition 3-IGNCR 1989)
Elevation: 140 m
Land form: 1) physiographic position: on an alluvial fan
2) surrounding land form: undulating
3) microtopography: nil
Slope on which the profile is sited: gently sloping (2 - 6%); position on the slope: half way; length of the slope: 100 m.
Vegetation: grass (98%) and Madeiro Negro fences (2%)
Climate: (31 year) average annual rainfall about 4464 mm. Average monthly temperature is 24.4 degrees Celsius; average maxima monthly temperature is 29.1 degrees Celsius; average minima temperature is 19.9 degrees Celsius; average annual relative humidity is 87%
Actual use: pasture

GENERAL INFORMATION ABOUT THE SOIL:

Parent material: alluvial deposits of volcanic origin
Drainage: well drained
Moisture conditions in the profile: moist throughout
Depth of ground water: deeper than 75 cm.
Presence of surface stones and rock outcrops: nil
Evidence of erosion: nil
Presence of soil fauna: ants, earth worms, larves, spring tails, etc. Holes filled up with humic material and with sharp boundaries, because of the inside greyish reduction and the outside brownish red oxidation colours appear at any possible depth.
Human influence: very slight, sometimes cutting of grass

BRIEF DESCRIPTION OF THE PROFILE:

A well drained profile with a very dark greyish brown Ah1 (10YR3/2) horizon overlying a A2 horizon which is also dark brown (10YR3/3). Beneath the A-horizons a very stony/bouldery 2C brown (10YR4/3) horizon appears. The structure is very weak throughout. All horizons are thixotropic. The profile have a sponge structure. Roots appearing to be very frequent in the A horizons but few in the 2C horizon.

PROFILE DESCRIPTION:

Ah1 0 - 20 cm : Dark brown (10YR3/2) when moist; no mottling; weak medium to fine granular structure; loam; friable; slightly sticky; slightly plastic; no concretions and/or rock fragments; many coarse to very fine continuous tubular pores; very frequent coarse to very fine roots; thixotropic; a diffuse and smooth boundary.

A2 20 - 55 cm : Dark brown (10YR3/3) when moist; no mottling; weak fine granular structure; loam; very friable; slightly sticky; slightly plastic; no concretions and/or rock fragments; many coarse to very fine continuous tubular pores; very frequent coarse to very fine roots; thixotropic; an abrupt and irregular boundary.

2C 55 cm + : Dark yellowish brown (10YR3/4) when moist; no mottling; sandy loam; very stony (50 - 90%); very bouldery (50 -90%); very friable; slightly sticky; slightly plastic; very frequent stones; very frequent boulders; many medium to very fine continuous tubular pores; few fine to very fine rocts; thixotropic.

INFORMATION ON THE SITE:
Profile number: GJWEV2
Soil name: Suelo Los Diamantes
Higher category classification: USDA: Eutric Hapludand
Date of examination: 23 January 1991
Authors: Weerts, G.J.; Veldkamp, E.
Location: Costa Rica, Province Limon near the town Guápiles. Near the experimental station named "Los Diamantes". Near the river Santa Clara at the property of Poly Technic. The path to it starts at the property of the experimental station. Approximately 561E and 245,3N (map Guápiles; Hoja 3446 IV; edition 3-IGNCR 1989)
Elevation: 215
Land form: 1) physiographic position: on an alluvial fan
2) surrounding land form: undulating
3) microtopography: nil
Slope on which the profile is sited: gently sloping (2 - 6%); position on the slope: half way
Vegetation: Tropical rain forest
Climate: (31 year) average annual rainfall about 4464 mm. Average monthly temperature is 24.4 degrees Celsius; average maxima monthly temperature is 29.1 degrees Celsius; average minima temperature is 19.9 degrees Celsius; average annual relative humidity is 87%
Actual use: nil

GENERAL INFORMATION ABOUT THE SOIL:
Parent material: alluvial deposits of volcanic origin
Drainage: somewhat excessively drained
Moisture conditions in the profile: moist throughout
Depth of ground water: deeper than 120 cm.
Presence of surface stones and rock outcrops: nil
Evidence of erosion: nil
Presence of soil fauna: ants, earth worms, larves, spring tails, termites, mites, etc. Holes filled up with humic material and with sharp boundaries, because of the inside greyish reduction and the outside brownish red oxidation colours appear at any possible depth.
Human influence: very slight, only a cut path

BRIEF DESCRIPTION OF THE PROFILE:
A profile with very dark horizons: Ah1 (10YR2/2); Ah2 (10YR3/3); AC (10YR3/3) and C (10YR2/2). The structure in the Ah1 horizon is strongly developed but beneath this horizon very weakly developed. In the Ah2 and deeper very few stones and gravels appear. Roots appear to be frequent in the Ah-horizons and the AC.

PROFILE DESCRIPTION:

Ah1 0 - 25 cm : Very dark brown (10YR2/2) when moist; no mottling; strong medium crumb; sandy loam; very friable; slightly sticky; slightly plastic; no concretions and/or rock fragments; many coarse to very fine continuous tubular pores; frequent coarse to very fine roots; a diffuse and smooth boundary.

Ah2 25 - 80 cm : Dark brown (10YR3/3) when moist; no mottling; very weak coarse subangular blocky; sandy loam; very friable; slightly sticky; slightly plastic; very few gravels; very few stones; many fine to very fine continuous tubular pores; very frequent coarse to very fine roots; a gradual and smooth boundary;(between 40 - 50 cm tunnels of termites, some parts of it are filled up with rests of insects).

AC 80 - 90 cm : Dark brown (10YR3/3) when moist; no mottling; loamy sand; very weak coarse subangular blocky; friable; slightly sticky; slightly plastic; very few gravels; very few stones; many fine to very fine continuous tubular pores; few fine roots; an abrupt and smooth boundary.

C 90 -120 cm+: Very dark brown (10YR2/2) when moist; no mottling; sand; loose; very few gravels; very few stones; no pores; no roots.

INFORMATION ON THE SITE:
Profile number: GJWEV3
Soil name: Suelo Neguev
Higher category classification: USDA: Andic Humitropept
Date of examination: 5 February 1991
Authors: Weerts, G.J.; Veldkamp, E.
Location: Costa Rica, Province Limon, 5 km south of Santa Rosa. Approximately 558,6E and 257,7N (map Rio Sucio; Hoja 3447 III; edition 2-IGNCR 1985)
Elevation: 60 m
Land form: 1) physiographic position: flat top of hillock
2) surrounding land form: rolling
3) microtopography: nil
Slope on which the profile is sited: flat or almost flat (0 - 2%)
Vegetation: grass (95%) and herbs (5%)
Climate: (31 year) average annual rainfall about 4464 mm. Average monthly temperature is 24.4 degrees Celsius; average maxima monthly temperature is 29.1 degrees Celsius; average minima temperature is 19.9 degrees Celsius; average annual relative humidity is 87%
Actual use: pasture

GENERAL INFORMATION ABOUT THE SOIL:
Parent material: fluvio laharic deposits
Drainage: well drained
Moisture conditions in the profile: moist throughout
Depth of ground water: deeper than 200 cm.
Presence of surface stones and rock outcrops: nil
Evidence of erosion or compaction: first 23 cm very compact
Presence of soil fauna: ants, earth worms; Holes filled up with humic material and with sharp boundaries, because of the inside greyish reduction and the outside brownish red oxidation colours appear at any possible depth.
Human influence: very slight

BRIEF DESCRIPTION OF THE PROFILE:
A well drained profile with dark brown Au1 and Au2 horizons and dark yellowish brown Bu1 and Bu2 horizons. The Au1 has some mottling because of the compaction. A macro structure, moderate medium columnar, is present. The A horizons have a moderate micro structure, the B horizons have a weak micro structure. The texture is clay throughout. The Au1,Au2 and Bu1 horizons contain many medium to very fine roots.

PROFILE DESCRIPTION:

Au1 0 - 8 cm : Dark brown (10YR3/3) when moist; An common abundance of clear and distinct fine yellow and grey mottles; moderate medium columnar macro structure; fine moderate angular/subangular blocky (micro structure); locally fine crumb; clay; friable; sticky; plastic; no concretions and/or rock fragments; common medium to fine continuous tubular pores; frequent medium to very fine roots; a clear and smooth boundary.

Au2 8 - 21 cm : Dark brown to brown (10YR4/3) when moist; no mottling; moderate medium columnar macro structure; fine moderate angular/subangular blocky (micro structure); clay; firm; sticky; plastic; no concretions and/or rock fragments; few medium to fine continuous tubular pores; common medium to fine roots; a clear and smooth boundary.

Bu1 21 - 50 cm : Dark yellowish brown (10YR4/4) when moist; no mottling; weak fine crumb; clay; very friable; sticky; plastic; very few large soft irregular white gibbsite nodules; many medium to very fine continuous tubular pores; common medium to very fine roots; a gradual and smooth boundary.

Bu2 50 - 90 cm+: Dark yellowish brown (10YR4/4) when moist; no mottling; weak fine crumb; clay; very friable; sticky; plastic; very few large soft irregular white gibbsite nodules; many medium to very fine continuous tubular pores; few medium to very fine roots.

INFORMATION ON THE SITE:
Profile number: GJWEV4
Soil name: Suelo Neguev
Higher category classification: USDA: Andic Humitropept
Date of examination: 13 February 1991
Authors: Weerts, G.J.; Veldkamp, E.; Weitz, A.
Location: Costa Rica, Province Limon; Asentamiento de Neguev, parcel 252. Approximately 587.4E and 240,3N (map Guácimo; Hoja 3446 I; edition 2-IGNCR 1973)
Elevation: 30 m
Land form: 1) physiographic position: flat top of dissected area
2) surrounding land form: flat
3) microtopography: nil
Slope on which the profile is sited: flat or almost flat (0 - 2%);
Vegetation: Tropical lowland rainforest
Climate: (31 year) average annual rainfall about 4464 mm. Average monthly temperature is 24.4 degrees Celsius; average maxima monthly temperature is 29.1 degrees Celsius; average minima temperature is 19.9 degrees Celsius; average annual relative humidity is 87%
Actual use: nil

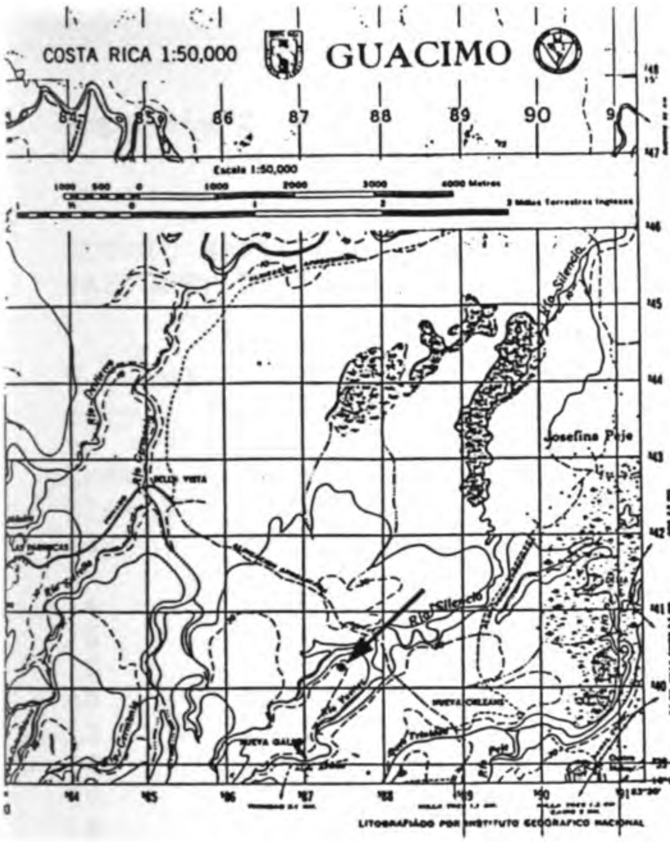
GENERAL INFORMATION ABOUT THE SOIL:
Parent material: fluvio laharic deposits
Drainage: somewhat excessively drained
Moisture conditions in the profile: moist throughout
Depth of ground water: deeper than 100 cm.
Presence of surface stones and rock outcrops: nil
Evidence of erosion: nil
Presence of soil fauna: ants, earth worms, larves, spring tails, etc.
Human influence: very slight, some special trees cut out

BRIEF DESCRIPTION OF THE PROFILE:
A dark brown (Au1 10YR3/3) to dark yellowish brown (Au2 and B 10YR 3/4) profile. Strong fine crumby structure throughout; the texture is silty clay throughout. A frequent abundance of coarse to very fine roots in the Au1. Few coarse to very fine roots appear in the Au2 and B.

PROFILE DESCRIPTION:
Au1 0 - 15 cm : Dark brown (10YR3/3) when moist; no mottling; strong fine medium to fine crumb; silty clay; very friable; sticky; plastic; no concretions and/or rock fragments; many coarse to very fine continuous tubular pores; very frequent coarse to very fine roots; a diffuse and smooth boundary.

Au2 15 - 60 cm : Dark yellowish brown (10YR3/4) when moist; no mottling; strong fine crumb; silty clay; very friable; sticky; plastic; no concretions and/or rock fragments; many coarse to very fine continuous tubular pores; few coarse to very fine roots; an clear and smooth boundary.

B 60 -100 cm+: Dark yellowish brown (10YR3/4) when moist; no mottling; strong fine crumb; silty clay; very friable; sticky; plastic; no concretions and/or rock fragments; many coarse to very fine continuous tubular pores; few coarse to very fine roots.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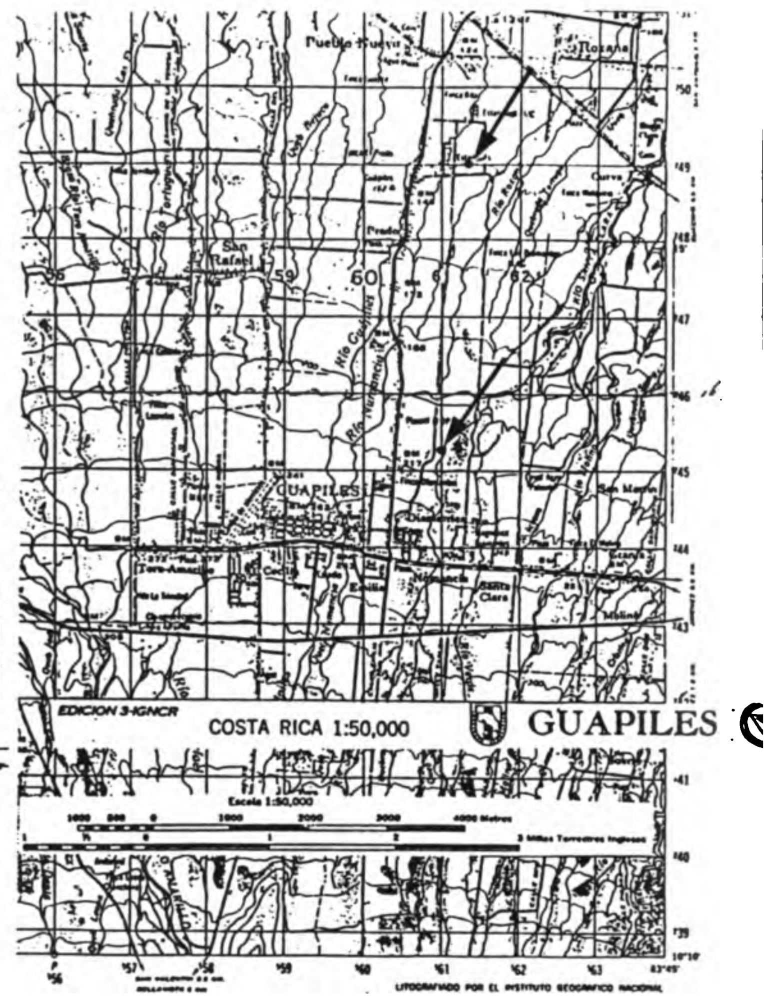
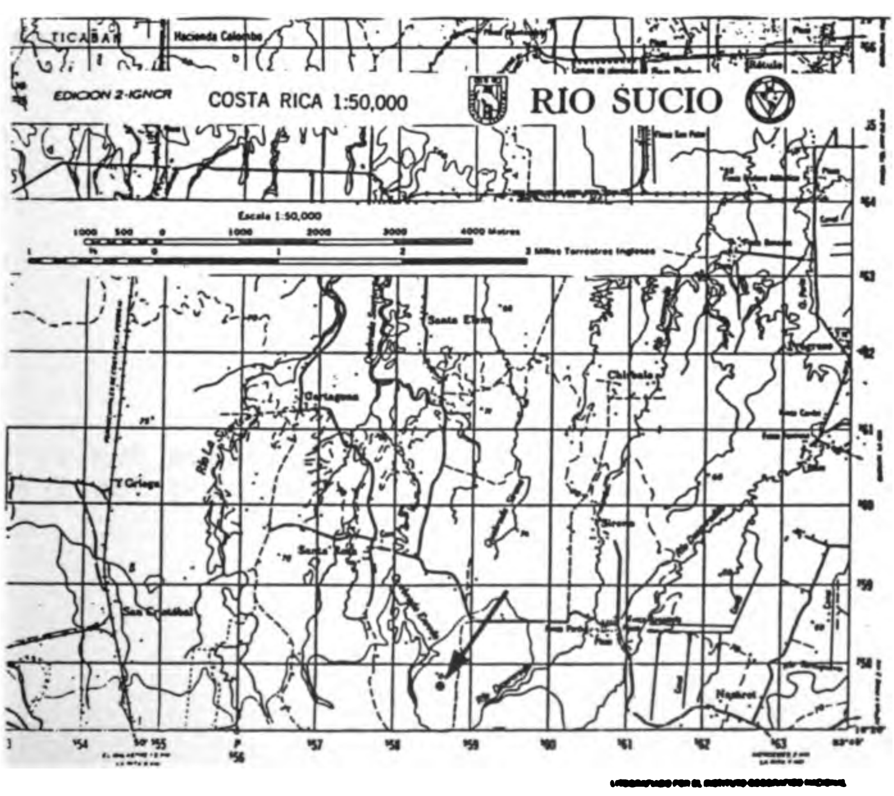
GUACIMO
Escala 1:50,000
Josefina Paje
Rio Silencio
LITOGRAFIADO POR INSTITUTO GEOGRAFICO NACIONAL


Pueblo Nuevo
Rozana
San Rafael
GUAPILES
Santa Clara
San Martin
EDICION 3-IGNCR
COSTA RICA 1:50,000
GUAPILES
Escala 1:50,000
LITOGRAFIADO POR EL INSTITUTO GEOGRAFICO NACIONAL


TICABAN
Hacienda Colombo
EDICION 2-IGNCR
COSTA RICA 1:50,000
RIO SUCIO
Escala 1:50,000
Santa Elena
Cartagena
Chirbola
Y Griega
Santa Rosa
San Cristóbal
Naranjo

Appendix 2 RESULTS OF THE K MEASUREMENTS

EUTRIC HAPLUDAND
PASTURE: DEPTH 0-30 CM

h (-cm)	K (cm/day)			log K		
ksat	-1	185.7	-1	* *	2.27	* *
k(sat)	80.3	120.2	207.3	1.90	2.09	2.32
1	77.8	108.0	174.1	1.89	2.03	2.24
2	75.4	93.7	163.7	1.88	1.97	2.21
4	64.9	73.3	131.0	1.81	1.86	2.12
6	59.4	60.4	103.2	1.77	1.78	2.01
8	-1	-1	-1	* *	* *	* *
10	42.9	40.4	50.0	1.63	1.61	1.70
12	27.2	37.8	37.6	1.43	1.58	1.57
14	-1	-1	29.0	* *	* *	1.46
16	18.0	-1	-1	1.26	* *	* *
18	-1	-1	-1	* *	* *	* *
20	-1	-1	-1	* *	* *	* *

h (-cm)	avg K (cm/day)	avg log K	σn
ksat	185.7	2.27	* *
k(sat)	135.9	2.10	53.0
1	120.0	2.05	40.2
2	110.9	2.02	38.1
4	89.7	1.93	29.4
6	74.3	1.85	20.4
8	* *	* *	* *
10	44.4	1.65	4.1
12	34.2	1.53	5.0
14	29.0	1.46	* *
16	18.0	1.26	* *
18	* *	* *	* *
20	* *	* *	* *

-1 : not measured
* * : not possible

EUTRIC HAPLUDAND
PASTURE: DEPTH 30-60 CM

h (-cm)	K (cm/day)			log K		
ksat	298.2	300.1	525.6	2.47	2.48	2.72
k(sat)	227.3	215.1	206.4	2.36	2.33	2.31
1	220.0	208.2	204.6	2.34	2.32	2.31
2	210.2	193.9	186.2	2.32	2.29	2.27
4	192.3	178.9	168.1	2.28	2.25	2.23
6	177.2	163.7	168.3	2.24	2.21	2.23
8	-1	-1	-1	* *	* *	* *
10	149.1	124.8	125.8	2.17	2.10	2.10
12	139.3	-1	-1	2.14	* *	* *
14	138.1	-1	-1	2.14	* *	* *
16	114.0	84.7	67.2	2.06	1.93	1.83
18	78.7	-1	-1	1.90	* *	* *
20	-1	75.5	-1	* *	1.88	* *

h (-cm)	avg K (cm/day)	avg log K	σn
ksat	374.6	2.56	106.8
k(sat)	216.3	2.33	8.6
1	210.9	2.32	6.6
2	196.8	2.29	10.0
4	179.8	2.25	9.9
6	169.7	2.23	5.6
8	* *	* *	* *
10	133.2	2.12	11.2
12	139.3	2.14	* *
14	138.1	2.14	* *
16	88.6	1.94	19.3
18	78.7	1.90	* *
20	75.5	1.88	* *

-1 : not measured
* * : not possible

EUTRIC HAPLUDAND
FOREST: DEPTH 0-30 CM

h (-cm)	K (cm/day)			log K		
ksat	402.5	431.3	708.9	2.60	2.63	2.85
k(sat)	326.6	256.4	271.2	2.51	2.41	2.43
1	317.8	234.3	261.3	2.50	2.37	2.42
2	287.5	211.9	226.7	2.46	2.33	2.36
4	262.5	169.4	187.0	2.42	2.23	2.27
6	235.8	111.4	143.4	2.37	2.05	2.16
8	-1	30.8	-1	* *	1.49	* *
10	43.0	-1	49.9	1.63	* *	1.70
12	13.6	-1	-1	1.14	* *	* *
14	-1	-1	-1	* *	* *	* *
16	-1	-1	-1	* *	* *	* *
18	-1	-1	-1	* *	* *	* *
20	-1	-1	-1	* *	* *	* *

h (-cm)	avg K (cm/day)	avg log K	σn
ksat	514.2	2.69	138.2
k(sat)	284.7	2.45	30.2
1	271.1	2.43	34.8
2	242.0	2.38	32.7
4	206.3	2.31	40.4
6	163.5	2.19	52.7
8	30.8	1.49	* *
10	46.5	1.67	3.4
12	13.6	1.14	* *
14	* *	* *	* *
16	* *	* *	* *
18	* *	* *	* *
20	* *	* *	* *

-1 : not measured
* * : not possible

EUTRIC HAPLUDAND
FOREST: DEPTH 30-60 CM

h (-cm)	K (cm/day)		log K	
ksat	526.8	531.7	2.72	2.73
k(sat)	355.3	340.8	2.55	2.53
1	346.3	332.1	2.54	2.52
2	328.0	319.8	2.52	2.50
4	306.8	307.6	2.49	2.49
6	294.7	289.3	2.47	2.46
8	-1	-1	* *	* *
10	254.4	256.4	2.41	2.41
12	241.9	220.9	2.38	2.34
14	-1	-1	* *	* *
16	149.7	129.8	2.18	2.11
18	-1	-1	* *	* *
20	-1	-1	* *	* *

h (-cm)	avg K (cm/day)	avg log K	σn
ksat	529.3	2.73	2.5
k(sat)	348.1	2.54	7.2
1	339.2	2.53	7.1
2	323.9	2.51	4.1
4	307.2	2.49	0.4
6	292.0	2.47	2.7
8	* *	* *	* *
10	255.4	2.41	1.0
12	231.4	2.36	10.5
14	* *	* *	* *
16	139.8	2.15	9.9
18	* *	* *	* *
20	* *	* *	* *

-1 : not measured
* * : not possible

ANDIC HUMITROPEPT
PASTURE: DEPTH 0-30 CM

h (-cm)	K (cm/day)			log K		
ksat	385.9	647.8	613.2	2.59	2.81	2.79
k(sat)	193.8	252.6	188.2	2.29	2.40	2.27
1	168.2	239.4	174.6	2.23	2.38	2.24
2	142.0	216.1	161.6	2.15	2.33	2.21
4	102.6	165.7	124.8	2.01	2.21	2.10
6	78.3	114.6	98.6	1.89	2.06	1.99
8	-1	69.0	59.3	* *	1.84	1.77
10	-1	40.7	33.3	* *	1.61	1.52
12	-1	-1	-1	* *	* *	* *
14	-1	-1	-1	* *	* *	* *
16	-1	-1	-1	* *	* *	* *
18	-1	-1	-1	* *	* *	* *
20	-1	-1	-1	* *	* *	* *

h (-cm)	avg K (cm/day)	avg log K	σn
ksat	549.0	2.73	116.2
k(sat)	211.5	2.32	29.1
1	194.1	2.28	32.2
2	173.2	2.23	31.3
4	131.0	2.11	26.1
6	97.2	1.98	14.9
8	64.2	1.81	4.8
10	37.0	1.57	3.7
12	* *	* *	* *
14	* *	* *	* *
16	* *	* *	* *
18	* *	* *	* *
20	* *	* *	* *

-1 : not measured
* * : not possible

ANDIC HUMITROPEPT
PASTURE: DEPTH 30-60 CM

h (-cm)	K (cm/day)			log K		
ksat	352.0	443.4	369.6	2.55	2.65	2.57
k(sat)	224.3	267.4	180.8	2.35	2.43	2.26
1	218.8	253.6	168.4	2.34	2.40	2.23
2	211.9	241.4	160.6	2.33	2.38	2.21
4	196.8	216.4	143.8	2.29	2.34	2.16
6	186.2	190.7	128.5	2.27	2.28	2.11
8	-1	-1	-1	* *	* *	* *
10	160.3	160.9	86.5	2.20	2.21	1.94
12	147.9	137.9	-1	2.17	2.14	* *
14	-1	-1	-1	* *	* *	* *
16	118.2	95.7	-1	2.07	1.98	* *
18	-1	-1	-1	* *	* *	* *
20	-1	-1	-1	* *	* *	* *

h (-cm)	avg K1 (cm/day)	avg log K1	σn K1	avg K2 (cm/day)	σn K2
ksat	388.3	2.59	39.6	397.7	45.7
k(sat)	224.2	2.35	35.4	245.9	21.6
1	213.6	2.32	35.0	236.2	17.4
2	204.6	2.31	33.4	226.7	14.8
4	185.7	2.26	30.7	206.6	9.8
6	168.5	2.22	28.3	188.5	2.3
8	* *	* *	* *	* *	* *
10	135.9	2.12	34.9	160.6	0.3
12	142.9	2.15	5.0	142.9	5.0
14	* *	* *	* *	* *	* *
16	107.0	2.03	11.2	107.0	11.2
18	* *	* *	* *	* *	* *
20	* *	* *	* *	* *	* *

-1 : not measured
* * : not possible

ANDIC HUMITROPEPT
FOREST: DEPTH 0-30 CM

h (-cm)	K (cm/day)		log K	
ksat	321.4	513.4	2.71	2.51
k(sat)	257.8	284.0	2.45	2.41
1	235.3	259.6	2.41	2.37
2	206.0	253.1	2.40	2.31
4	171.9	232.7	2.37	2.24
6	138.2	211.0	2.32	2.14
8	-1	-1	* *	* *
10	56.6	163.0	2.21	1.75
12	18.9	30.6	1.49	1.28
14	-1	-1	* *	* *
16	-1	-1	* *	* *
18	-1	-1	* *	* *
20	-1	-1	* *	* *

h (-cm)	avg K (cm/day)	avg log K	σn
ksat	417.4	2.61	96.0
k(sat)	270.9	2.43	13.1
1	247.5	2.39	12.2
2	229.6	2.36	23.5
4	202.3	2.31	30.4
6	174.6	2.23	36.4
8	* *	* *	* *
10	109.8	1.98	53.2
12	24.8	1.39	5.9
14	* *	* *	* *
16	* *	* *	* *
18	* *	* *	* *
20	* *	* *	* *

-1 : not measured
* * : not possible

ANDIC HUMITROPEPT
FOREST: DEPTH 30-60 CM

h (-cm)	K (cm/day)		log K	
ksat	484.2	579.4	2.68	2.76
k(sat)	280.5	298.1	2.45	2.47
1	275.3	282.3	2.44	2.45
2	264.8	275.3	2.42	2.43
4	241.4	255.5	2.38	2.40
6	207.8	227.7	2.32	2.35
8	-1	-1	* *	* *
10	167.7	182.2	2.22	2.26
12	117.8	165.0	2.07	2.21
14	-1	-1	* *	* *
16	74.5	120.1	1.87	2.07
18	-1	-1	* *	* *
20	-1	76.2	* *	1.88

h (-cm)	avg K (cm/day)	avg log K	σn
ksat	531.8	2.72	47.6
k(sat)	289.3	2.46	8.8
1	278.8	2.45	3.5
2	270.1	2.43	5.2
4	248.5	2.39	7.0
6	217.8	2.34	10.0
8	* *	* *	* *
10	175.0	2.24	7.2
12	141.4	2.14	23.6
14	* *	* *	* *
16	97.3	1.97	22.8
18	* *	* *	* *
20	76.2	1.88	* *

-1 : not measured
* * : not possible

CORRESPONDING TENSIOMETER READINGS (in cm) BELONGING TO THE K MEASUREMENTS

EUTRIC HAPLUDAND
PASTURE DEPTH: 0-30 CM

h (-cm)	first	second	first	second	first	second
0	-4	-6/-7	-3/-4	-5/-6	-7	***
1	-5	-7/-8	-3/-4	-6/-7	-8 leak -6	***
2	-6/-7	-9/-10	-4/-5	-6/-7	-6/-7	***
4	-8/-9	-9/-10	-6	-8/-9	-7/-8	***
6	-9/-10	-10/-11	-6/-7	-9/-10	-10	***
8	***	***	***	***		***
10	-11	-13	-12	-14/-15	-13	***
12	-14	-15/-16	-13	-15	-14/-15	***
14	***	***	***	***	-16/-17	***
16	(-15/-16)	-19(-16/-17)	(-11/-12)	(-12/-13)		
20	***	***	***	***	***	***

EUTRIC HAPLUDAND
PASTURE DEPTH: 30-60 CM

h (-cm)	first	second	first	second	first	second
0	-9	-15/16	-5	-10/-11	-10/-11	-13
1	-9/-10	-16	-7	-11/-12	-11	-13
2	-10	-16/-17	-7	-12/-13	-12/-13	-16
4	-11	-18	-7	-12/-13	-12/-13	-14/15
6	-12	-19	-10	-14	-12	-14
8	***	***	***	***	***	***
10	-13/-14	-19	-11/-12	-19	-14	-16/-17
12	-14	-21	***	***	***	***
14	-15/-16	-20/-21	***	***	***	***
16	***	***	-16/-17	-23	-16/-17	***
18	-16/-17	-21	***	***	***	***
20	***	***	-17/-18	***	***	***

*** : not measured
( ) : next day
first : tensiometer at ±4-6 cm depth
second : tensiometer at ±6-8 cm depth

EUTRIC HAPLUDAND
FOREST DEPTH: 0-30 CM

h	first		second		first		second		first	
(-cm)	1	2	1	2	1	2	1	2	1	2
0	-9	-9	-9	-10	-4	-4	-8	-7	-10	-10
1	-9/-10	-9	-9	-10/-11	-4	-4	-7	-7	-10/-11	-10
2	-8	-9	-9	-9	-5	-4	-8	-7	-10	-10
4	-9	-9	-9	-9/-10	-5/-6	-6/-7	-8/-9	-8	-10	-11
6	-9/-10	-9/-10	-9/-10	-10	-7	-6/-7	-9	-9	-11	-11
8	***		***		-8		-10		***	
10	-9		-13/-14		***				-13	
12	***		leak -15		***				***	
14	***				***				***	
16	***				***				***	
18	***				***				***	
20	***				***				***	

h	second	
(-cm)	1	2
0	-13/-14	-14
1	-13/-14	-14
2	-14	-14
4	-14	-14
6	-15	-15
8	***	
10	-16/-17	
12	***	
14	***	
16	***	
18	***	
20	***	

*** : not measured
first : tensiometer at ±4-6 cm depth
second : tensiometer at ±6-8 cm depth

EUTRIC HAPLUDAND
FOREST DEPTH: 30-60 CM

h	first		second		first		second	
(-cm)	1	2	1	2	1	2	1	2
0	-15	-15	-18	-19	-13	-13	-16	-15
1	-16	-16	-20	-19	-14	-14	-16	-16
2	-17	-16	-19	-20	-14	-14	-16/-17	-16
4	-16	-16/-17	***	-20/-21	***	-15/-16	-17	-17/-18
6	-18	-18	-21	-22	-16	-16	-18	-18
8	***	***	***	***	***	***	***	***
10	-20		-25		-17/-18		-19/-20	
12	-22	-22	-25	-26	-19		-21	
14	***		***		***		***	
16	-22		-26		-20		-23	
18	***		***		***		***	
20	***		***		***		***	

ANDIC HUMITROPEPT
FOREST DEPTH: 0-30 CM

h	first		second		first		second	
(-cm)	1	2	1	2	1	2	1	2
0	-9	-9	-13	-12	-9	-9	-11	leak
1	-9/-10	-10	-13	-13	-7	-7	-10	-10
2	-10	-10	-13	-13	-8	-8/-9	-11	-10/-11
4	-10	-10	-15	-14	-9	-9	-11/-12	-11
6	-11	-12	-15	-15	-10/-11	-10	-12	-12
8	***	***	***	***	***	***	***	***
10	-14		-19		***		***	
12	-15/-16		-21/22		***		***	
14	***		***		***		***	
16	***		***		***		***	
18	***		***		***		***	
20	***		***		***		***	

*** : not measured
first : tensiometer at ±4-6 cm depth
second : tensiometer at ±6-8 cm depth

ANDIC HUMITROPEPT
FOREST DEPTH: 30-60 CM

l	first		second		first		second	
-cm)	1	2	1	2	1	2	1	2
)	-13	-12	-10	-13	-12	-12	-14	-15
.	-12	-13	-13/-14	-13/-14	-14	-14	-17	-19
!	-13	-13	-14	-14	-15	***	-19	-19
!	-13	-14	-15	-15	-16	-16	-20	-20/-21
;	-15	-15	-16	-16	-17	-17	-21	-21
!	***		***		***		***	
.0	-16/-17		-18		-19		-24	
.2	-17		-17		-20		-25	
.4	***		***		***		***	
.6	-20/-21		-9		-23		-27	
.8	***		***		***		***	
:0	***		***		-26		-31	

NDIC HUMITROPEPT
ASTURE DEPTH: 0-30 CM

.	first		second		fir	sec	first		second	
-cm)	1	2	1	2			1	2	1	2
	-9/-10	-9/-10	-20	-20	***	***	-5/-6	***	-10/-11	-10/-11
	-6/-9	-6/-8	-9	-15/-17	***	***	-6/-7	-6	-13	-13
	-6/-7	-6/-7	-15/-18	-14/-17	***	***	-6	-6	-12	-13
	-8	-6/-7	-16/-17	-14/-17	***	***	-5	-5	-11	-10/-11
	-4/-7	-4/-7	-10/-11	-9/-11	***	***	-5	-5	-12/-13	-11
	***		***		***	***	-5	-5	-11	-11
0	***		***		***	***	***		***	
2	***		***		***	***	***		***	
4	***		***		***	***	***		***	
6	***		***		***	***	***		***	
8	***		***		***	***	***		***	
0	***		***		***	***	***		***	

** : not measured
irst : tensiometer at ±4-6 cm depth
econd : tensiometer at ±6-8 cm depth

ANDIC HUMITROPEPT
PASTURE DEPTH: 30-60 CM

h	first		second		first		second	
(-cm)	1	2	1	2	1	2	1	2
0	-2	***	-4	***	-6/-7	-6/-7	-10/-11	-10/-11
1	-2/-3	-2/-3	-4/-5	-5	-6/-7	-6	-10/-11	-10
2	-4/-5	-4	-6	-6/-7	-6	-6/-7	-9	-9
4	-6/-7	-6	-7/-8	-9	-7	-7	-11	-11
6	-9	-9	-10/-11	-10/-11	-8	-8	-11	-11
8	***		***		***		***	
10	-12		-14/-15		-10		-12	
12	-14		-18/-19		-11		-14/-15	leak
14	***		***		***		***	
16	-17		-20		-13/-14	-13/-14	-16/-17	-16/-17
18	***		***		***		***	
20	***		***		***		***	

h (-cm)	first		second	
	1	2	1	2
0	-4/-5	-4/-5	-10	-10
1	-5	-5	-9	-9
2	-6	-6	-8/-9	-8/-9
4	-6/-7	-6/-7	-10/-11	-10/-11
6	-8/-9	-8/-9	-12	***
8	***		***	
10	-10/-11		-14/-15	
12	-12/-13 leak and stop		***	
14	***		***	
16	***		***	
18	***		***	
20	***		***	

first : tensiometer at ±4-6 cm depth
second : tensiometer at ±6-8 cm depth
*** : not measured

Appendix 3 BULK DENSITY RESULTS

EUTRIC HAPLUDAND 25 YEAR OLD PASTURE

Soil layer (cm)	Bulk density (g/cc)
0-5	0.84
0-5	0.84
0-5	0.88
0-5	0.83
0-5	0.89
0-5	0.84
0-5	0.87
0-5	0.88
0-5	0.85
0-5	0.93
12-17	0.82
12-17	0.87
12-17	0.83
12-17	0.85
12-17	0.81
12-17	0.88
12-17	0.84
12-17	0.90
28-33	0.79
28-33	0.79
28-33	0.84
28-33	0.84
28-33	0.83
28-33	0.86
28-33	0.78
28-33	0.82
43-48	0.85
43-48	0.89
43-48	0.91
43-48	0.84
43-48	0.89
43-48	0.83
43-48	0.86
43-48	0.85
58-63	1.25
58-63	1.16
58-63	1.17
58-63	1.12
58-63	1.18
58-63	1.20
58-63	1.08
58-63	1.11

EUTRIC HALPUDAND FOREST

Soil layer (cm)	Bulk density (g/cc)
3-8	0.69
0-5	0.69
0-5	0.70
3-8	0.73
0-5	0.60
14-19	0.72
14-19	0.73
14-19	0.73
30-35	0.73
30-35	0.78
30-35	0.81
30-35	0.76
45-50	0.82
45-50	0.85
45-50	0.81
45-50	0.86
65-70	0.95
65-70	0.89
65-70	0.89
65-70	0.93
65-70	1.02
82-87	1.06
82-87	1.04
82-87	1.02
82-87	1.06
82-87	1.03
92-97	1.12
92-97	1.07
92-97	1.15
92-97	1.14
92-97	1.19

ANDIC HUMITROPEPT 25 YEAR OLD PASTURE

Soil layer (cm)	Bulk density (g/cc)
1-6	0.72
1-6	0.80
1-6	0.69
1-6	0.75
1-6	0.64
1-6	0.65
1-6	0.72
1-6	0.70
1-6	0.77
15-20	0.89
15-20	0.85
15-20	0.87
15-20	0.86
15-20	0.87
15-20	0.95
15-20	0.93
30-35	0.71
30-35	0.75
30-35	0.84
30-35	0.80
30-35	0.83
30-35	0.80
30-35	0.80
45-50	0.82
45-50	0.78
45-50	0.77
45-50	0.84
45-50	0.80
45-50	0.78
45-50	0.74
65-70	0.78
65-70	0.84
65-70	0.78
65-70	0.83
65-70	0.80
65-70	0.82

ANDIC HUMITROPEPT FOREST

Soil layer (cm)	Bulk density (g/cc)
1-6	0.59
1-6	0.62
1-6	0.62
1-6	0.57
1-6	0.63
1-6	0.63
1-6	0.60
1-6	0.66
1-6	0.57
16-21	0.75
16-21	0.72
16-21	0.75
16-21	0.76
30-35	0.78
30-35	0.70
30-35	0.74
30-35	0.76
45-50	0.78
45-50	0.80
45-50	0.72
75-80	0.82
75-80	0.86
75-80	0.82
75-80	0.82

Appendix 4 FIELD pF MEASUREMENTS

Measurement 1

depth	tarra	wet	dry	diff	bulk d	theta	pF
cm	gr	gr	gr	gr	gr/ccm	cm/cm	
15.00	158.76	286.14	242.23	43.91	0.85	0.45	2.42
30.00	155.53	252.18	219.53	32.65	0.82	0.42	2.21
50.00	161.55	273.14	240.00	33.14	0.87	0.37	2.09
65.00	156.43	286.06	250.99	35.07	1.16	0.43	2.00

Measurement 2

depth	tarra	wet	dry	diff	bulk d	theta	pF
cm	gr	gr	gr	gr	gr/ccm	cm/cm	
15.00	158.82	276.90	239.04	37.86	0.85	0.40	2.77
30.00	155.58	272.10	234.13	37.97	0.82	0.40	2.65
50.00	161.61	303.42	262.64	40.78	0.87	0.35	2.64
65.00	156.49	272.37	245.21	27.16	1.16	0.36	2.59

Measurement 3

depth	tarra	wet	dry	diff	bulk d	theta	pF
cm	gr	gr	gr	gr	gr/ccm	cm/cm	
15.00	158.71	240.79	218.76	22.03	0.85	0.31	2.51
30.00	153.76	229.25	208.99	20.26	0.82	0.30	2.46
50.00	161.62	286.08	257.71	28.37	0.87	0.26	2.32

Measurement 4

depth	tarra	wet	dry	diff	bulk d	theta	pF
cm	gr	gr	gr	gr	gr/ccm	cm/cm	
15.00	158.71	264.92	234.62	30.30	0.85	0.34	2.47
30.00	153.76	277.51	239.83	37.68	0.82	0.36	2.55
50.00	161.62	255.13	231.00	24.13	0.87	0.30	2.68
65.00	156.48	295.68	270.98	24.70	1.16	0.25	2.83

Measurement 5

depth	tarra	wet	dry	diff	bulk d	theta	pF
cm	gr	gr	gr	gr	gr/ccm	cm/cm	
30.00	156.40	269.08	235.58	33.50	0.82	0.35	2.57
65.00	160.54	265.44	240.62	24.82	1.16	0.36	2.73

Appendix 5 Climate data of CORBANA S.A.

MES: NOVIEMBRE   AÑO: 1990

	Hum. Relativa			Temperatura			Lluvia - mm		Evaporac.- mm	
	Prom	Max.	Min.	Prom	Max.	Min.	Diaria	Acum.	Diaria	Acum.
1	76.3	86	63	23.9	27	22	2.9	2.9	2.0	2.0
2	81.8	88	69	23.6	28	21	0.5	3.4	2.3	4.3
3	81.3	88	64	23.1	27	21	13.5*	16.9	3.6*	7.9
4	81.8	88	68	23.1	28	20				
5	82.5	88	64	22.5	28	20	20.0	36.9	1.7	9.6
6	79.6	88	55	22.9	29	19	12.2	49.1	2.5	12.1
7	74.9	87	53	23.9	29	20	0.0	49.1	3.8	15.9
8	76.8	87	57	23.6	28	20	18.2	67.3	2.9	18.8
9	83.0	89	72	23.4	27	21	4.0	71.3	2.2	21.0
10	80.9	88	65	24.3	30	21	8.2*	79.5	5.2*	26.2
11	79.6	88	62	23.2	26	21				
12	81.4	88	67	22.4	26	20	2.2	81.7	2.1	28.3
13	81.8	88	70	22.9	26	21	36.3	118.0	1.9	30.2
34	85.1	88	77	22.5	25	21	17.9	135.9	0.9	31.1
15	86.5	88	81	22.2	25	21	29.0	164.9	1.0	32.1
16	86.7	89	83	21.9	24	21	35.2	200.1	0.6	32.7
17	82.2	88	71	22.2	26	20	0.2*	200.3	3.0*	35.7
18	79.8	87	62	22.4	27	19				
19	76.5	87	55	23.4	28	20	17.4	217.7	4.2	39.9
20	82.2	88	64	23.2	27	21	26.0	243.7	2.7	42.6
21	77.9	88	59	23.7	29	20	1.8	245.5	3.7	46.3
22	72.8	87	50	23.0	28	19	0.0	245.5	4.4	50.7
23	82.4	87	70	20.9	25	19	17.9	263.4	1.3	52.0
24	86.0	88	77	20.9	24	20	109.5*	372.9	2.5*	54.5
25	82.2	88	65	22.2	27	19				
26	78.1	89	62	23.2	28	20	15.6	388.5	3.5	58.0
27	80.0	88	65	22.9	27	20	4.4	392.9	2.2	60.2
28	79.6	86	63	22.5	27	20	3.0	395.9	1.7	61.9
29	77.8	86	60	22.6	27	19	0.0	395.9	2.6	64.5
30	73.8	86	53	23.5	29	18	0.0	395.9	3.2	67.7
31										

x Diario: 80.4	x Diario: 22.9	Tot: 395.9	Tot: 67.7
x Máxima: 87.6	x Máxima: 27.0	x Diario:	x Diario:
x Mínima: 64.8	x Mínima: 20.1	13.2	2.26

LOCALIDAD: LA RITA

* Incluye el Sábado y Domingo.

CORBANA S.A.
FITOPATOLOGIA

MES: DICIEMBRE AÑO: 1990

	Hum. Relativa			Temperatura			Lluvia - mm		Evaporac.- mm	
	Prom	Max.	Min.	Prom	Max.	Min.	Diaria	Acum.	Diaria	Acum.
1	76.0	88	61	23.8	28	19	2.3*	2.3	4.8*	4.8
2	80.8	88	66	22.7	27	20				
3	81.1	88	65	22.5	28	19	2.6	4.9	1.7	6.5
4	83.7	89	71	22.3	26	20	45.2	50.1	1.3	7.8
5	86.2	88	79	20.9	23	19	42.2	92.3	0.4	8.2
6	81.2	87	69	22.0	27	18	0.2	92.5	2.0	10.2
7	83.2	87	73	22.5	27	20	3.0	95.5	0.9	11.1
8	77.6	86	77	20.4	27	17	40.3*	135.8	3.3*	14.4
9	63.7	73	49	23.0	30	20				
10	83.2	87	70	19.1	20	18	22.0	157.8	0.7	15.1
11	84.7	87	72	19.6	23	18	19.3	177.1	1.0	16.1
12	82.1	87	67	21.0	25	19	0.0	177.1	1.4	17.5
13	78.9	87	63	22.2	26	18	0.5	177.6	3.0	20.5
14	84.3	88	75	22.2	26	20	12.0	189.6	1.5	22.0
15	84.5	87	75	22.9	27	21	65.5*	255.1	3.0*	25.0
16	83.3	87	72	22.9	26	21				
17	81.5	87	68	23.0	27	21	0.4	255.5	2.5	27.5
18	84.2	87	75	21.6	24	19	8.1	263.6	0.9	28.4
19	83.5	88	68	21.6	25	19	1.7	265.3	1.2	29.6
20	80.3	87	65	21.7	26	18	1.5	266.8	2.9	32.5
21	81.7	86	60	19.2	26	16	0.0	266.8	4.8	37.3
22	73.5	87	54	21.3	27	17	0.0*	266.8	7.8*	45.1
23	78.7	87	68	20.2	26	16				
24	73.2	85	60	21.7	28	14				
25	74.9	87	60	22.0	26	19	5.0**	271.8	8.9*	54.0
26	76.2	87	60	21.9	27	18	0.0	271.8	4.9	58.9
27	76.8	87	60	21.2	28	15	0.0	271.8	3.8	62.7
28	83.1	88	70	18.6	26	15	0.0	271.8	3.7	66.4
29	72.1	87	57	21.9	27	16	0.5*	272.3	8.2*	74.6
30	77.6	87	61	22.2	28	18				
31	78.2	87	65	22.5	28	17				

x Diario: 79.7	x Diario: 21.6	Tot: 272.3	Tot: 74.6
x Máxima: 86.7	x Máxima: 26.2	x Diario: 9.07	x Diario: 2.49
x Mínima: 65.9	x Mínima: 18.2		

LOCALIDAD: LA RITA

* Incluye el dia posterior
** Incluye el dia anterior.

CORBANA S.A.
FITOPATOLOGIA

MES: ENERO AÑO: 1991.

	Hum. Prom	Relativa Max.	Min.	Temperatura Prom	Max.	Min.	Lluvia - mm Diaria	Acum.	Evaporac.- mm Diaria	Acum.
1	79.8	87	64	22.8	28	20				
2	77.0	87	57	21.9	26	18	32.5**	32.5	5.8**	5.8
3	77.3	87	61	22.0	28	17	0.0	32.5	2.6	8.4
4	82.0	87	74	21.5	27	17	0.0	32.5	4.0	12.4
5	79.3	87	67	21.9	28	18	12.5*	45.0	3.8*	16.2
6	79.6	87	67	21.7	27	18				
7	81.0	87	69	21.5	27	19	1.0	46.0	1.8	18.0
8	81.3	87	67	22.0	26	18	2.1	48.1	2.0	20.0
9	74.0	87	59	21.3	26	17	5.3	53.4	2.4	22.4
10	79.3	87	65	22.0	26	19	1.3	54.7	2.6	25.0
11	80.0	87	69	22.4	27	18	0.0	54.7	3.9	28.9
12	75.8	87	60	22.4	28	16	5.1*	59.8	7.0*	35.9
13	73.3	86	61	21.9	28	17				
14	77.7	87	66	21.8	29	19	0.0	59.8	2.5	38.4
15	81.2	87	72	22.0	26	19	4.8	64.6	2.5	40.9
16	79.8	88	69	21.7	26	19	0.0	64.6	2.4	43.3
17	77.5	87	66	21.6	27	16	0.3	64.9	3.7	47.0
18	81.6	87	75	21.8	27	16	0.4	65.3	3.5	50.5
19	82.7	87	78	21.4	24	18	0.0*	65.3	6.0*	56.5
20	77.7	87	64	21.9	28	17				
21	75.2	87	62	21.9	28	16	5.1	70.4	3.4	59.9
22	79.5	87	67	21.7	26	18	0.0	70.4	5.3	65.2
23	77.8	88	65	22.3	28	17	0.0	70.4	3.5	68.7
24	80.7	87	73	21.1	26	17	0.5	70.9	3.2	71.9
25	83.3	89	73	20.8	24	18	0.0	70.9	1.7	73.6
26	81.6	89	66	22.7	28	19	6.7*	77.6	6.3*	79.9
27	80.9	88	72	21.2	25	17				
28	84.3	87	78	23.2	28	18	0.9	78.5	2.7	82.6
29	84.9	88	77	22.3	25	21	7.1	85.6	3.0	85.6
30	86.4	88	79	22.1	26	18	0.0	85.6	2.6	88.2
31	83.0	87	75	21.2	26	18	13.1	98.7	2.3	90.5

x Diario: 79.9 x Diario: 21.9 Tot: 98.7 Tot: 90.5
x Máxima: 87.2 x Máxima: 26.6 x Diario: x Diario:
x Mínima: 68.2 x Mínima: 17.8 3.18 2.92

LOCALIDAD: LA RITA.

* Incluye Sábado y Domingo.
(10 Enero)

CORBANA S.A.
FITOPATOLOGIA

ES: FEBRERO AÑO: [illegible]

	Hum. Relativa			Temperatura			Lluvia - mm		Evaporac.- mm	
	Prom	Max.	Min.	Prom	Max.	Min.	Diaria	Acum.	Diaria	Acum.
1	**	**	**	20.8	23	19	22.8	22.6	2.6	2.6
2				20.5	26	18	31.2*	57.0	3.9*	6.5
3				20.3	24	17				
4				20.6	25	18	2.4	59.4	2.3	8.8
5				21.5	28	17	1.4	60.8	4.6	13.4
6				21.3	27	17	0.0	60.8	6.3	19.7
7				21.3	27	16	0.0	60.8	4.6	24.3
8				20.0	24	16	1.5	62.3	3.3	27.6
9				20.8	26	16	5.0*	67.3	9.0*	36.6
0				20.3	25	17				
1				19.7	22	18	7.5	74.8	1.1	37.7
2				19.6	22	18	2.5	77.3	1.3	39.0
3				19.3	21	18	0.0	77.3	1.6	40.6
4				21.7	26	17	0.0	77.3	3.6	44.2
5				21.0	25	17	0.0	77.3	3.5	47.7
6				20.8	25	17	4.7*	82.0	7.1*	54.8
7				19.9	26	15				
8				21.8	27	18	0.0	82.0	5.9	60.7
9				21.1	28	15	0.0	82.0	6.4	67.1
0				21.2	26	15	0.0	82.0	4.6	71.7
1				21.0	26	18	2.0	84.0	2.4	74.1
2				22.4	27	17	0.0	84.0	3.8	77.9
3				23.5	29	19	12.4*	96.4	7.9*	85.8
4				24.0	29	21				
5				23.1	26	21	7.8	104.2	1.9	87.8
6				22.6	25	22	24.2	128.4	1.3	89.1
7				23.1	27	21	49.2	177.6	1.2	90.3
8				22.4	26	19	37.2	214.8	1.2	91.5
9										
0										
1										

x Diario: 00.0 x Diario: 21.3 Tot: 214.8 Tot: 91.5
x Máxima: 00.0 x Máxima: 25.6 x Diario: x Diario:
x Mínima: 00.0 x Mínima: 17.7 7.67 3.2

OCALIDAD: LA RITA

Incluye Sábado y Domingo.
* Los datos de Humedad R. no se tabularon las bandas no estaban legibles.

Appendix 6 Listing of the program HKGENU (Fortran)

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C      PROGRAM HKGENU
C*******DECLARATIES*********

      REAL          TETAR,TETAS,TETA,TEREL,H,K,K10,C10,N,M,A
      REAL          HTAB(8,8),KTAB(8,8)
      REAL          F1
      DOUBLE PRECISION F2,F3
      CHARACTER*10 FNIN,FNOUT
C********FUNCTIE DEFINITIES********

      F1(TETA,TETAR,TETAS)=(TETA-TETAR)/(TETAS-TETAR)
      F2(TEREL,A,N,M)    =(((TEREL**(-1/M))-1)**(1/N))/A
      F3(TEREL,C10,K10,M) =(((1-((1-(TEREL**(1/M)))**M))**2)
     $*SQRT(TEREL)*K10)/C10

      WRITE(*,1)
1     FORMAT(' GIVE INPUT FILENAME: '$)
      READ(*,2) FNIN
2     FORMAT(A10)
      WRITE(*,3)
3     FORMAT(' GIVE OUTPUT FILENAME: '$)
      READ(*,2) FNOUT

C******OPEN-OPDRACHTEN********

      OPEN(UNIT=21,FILE=FNIN)
      OPEN(UNIT=22,FILE=FNOUT,STATUS='NEW')

C******INLEZEN PARAMETERS*******

      READ(21,*) TETAS,TETAR,A,N,K10
C10   FORMAT(5F)

C********BEREKENING AANTAL TETA-STAPPEN,M,C10********

      MS=TETAS+1

      M =1-(1/N)

      H=10
      TEREL=(1/(1+((A*H)**N)))**M

      C10=1
      C10=(F3(TEREL,C10,K10,M))/K10

C*******BEREKENING H(TETA) EN K(TETA) VOOR TETA=1,MS********

      J1=0
      J2=1
      J3=8

      DO 100 I=0,MS

         TETA=I
           IF(TETA.LE.TETAR) GO TO 100
         TEREL=F1(TETA,TETAR,TETAS)
           IF(I.EQ.MS) TEREL=1.

         H=F2(TEREL,A,N,M)
           IF(H.GT.100000000000000.) GO TO 100
           IF(J1.EQ.0.AND.J2.EQ.1) ISTART=I

         J1=J1+1
         HTAB(J2,J1)=H
         KTAB(J2,J1)=F3(TEREL,C10,K10,M)

           IF(J1.NE.J3) GO TO 100
         J1=0
         IF(I.NE.MS) J2=J2+1

100   CONTINUE

C*******WEGSCHRIJVEN H(TETA) EN K(TETA) NAAR UITVOER********

      WRITE(22,150) ((HTAB(I,J),J=1,8),I=1,J2)
      WRITE(22,150) ((KTAB(I,J),J=1,8),I=1,J2)
150   FORMAT(8E10.2)

      WRITE(*,160) ISTART,MS
160   FORMAT(' START TETA=',I2,' EIND TETA=', I2)
```

Appendix 7 VAN GENUCHTEN PARAMETERS FOR THE DIFFERENT SOIL LAYERS AND FOR THE DIFFERENT RUNS

Layer 1

Run	α	N	θsat	θdry	RSQ
1	0.00977	1.32579	0.6618	0.0000	0.95
2	0.01016	1.32961	0.6479	0.0000	0.955
3	0.01689	1.39203	0.6234	0.0000	0.963
4	0.01288	1.35574	0.6333	0.0000	0.959
5	0.01288	1.35574	0.6333	0.0000	0.959
6	0.02574	1.26593	0.6449	0.0000	0.998

Layer 2

Run	α	N	θsat	θdry	RSQ
1	0.01129	1.34172	0.6311	0.0000	0.96
2	0.01091	1.33717	0.6337	0.0000	0.956
3	0.01663	1.38827	0.6064	0.0000	0.962
4	0.01324	1.35857	0.6182	0.0000	0.959
5	0.01324	1.35857	0.6182	0.0000	0.959
6	0.03199	1.25442	0.6349	0.0000	0.998

Layer 3

Run	α	N	θsat	θdry	RSQ
1	0.00672	1.31116	0.5248	0.0000	0.93
2	0.00940	1.34302	0.5841	0.0000	0.932
3	0.01772	1.41629	0.5497	0.0000	0.921
4	0.01242	1.37126	0.5632	0.0000	0.928
5	0.01242	1.37126	0.5632	0.0000	0.928
6	0.06583	1.24479	0.6159	0.0000	0.997

Layer 4

Run	α	N	θsat	θdry	RSQ
1	0.00663	1.30988	0.4315	0.0000	0.93
2	0.00435	1.2769	0.4977	0.0000	0.933
3	0.00816	1.32459	0.4685	0.0000	0.929
4	0.00581	1.29666	0.4812	0.0000	0.932
5	0.00581	1.29666	0.4812	0.0000	0.932
6	0.01693	1.22566	0.5013	0.0000	0.993

ppendix 9 THE FUNCTIONS FOR THE K ESTIMATION OF RUN 6

he used function: $\ln(\ln(K)) = -\alpha h + \underbrace{\ln(K_0)}_{= B}$

ayer 1+2 : $\alpha = -0.0317$
$B = 1.617$

ayer 3+4 : $\alpha = -0.011$
$B = 1.687$