ATLANTIC ZONE PROGRAMME

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SOIL PHYSICAL CHARACTERIZATION OF TWO SOIL TYPES UNDER FOUR DIFFERENT LAND USE FORMS IN THE ATLANTIC ZONE OF COSTA RICA

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GANADERIA DE COSTA RICA - MAG

Location of the study area.

PREFACE

General description of the research programme on sustainable Landuse.

The research programme is based on the document "elaboration of the VF research programme in Costa Rica" prepared by the Working Group Costa Rica (WCR) in 1990. The document can be summarized as follows:
To develop a methodology to analyze ecologicaly sustainable and economically feasible land use, three hierarchical levels of analysis can be distinguished.
1. The Land Use System (LUS) analyses the relations between soil type and crops as well as technology and yield.
2. The Farm System (FS) analyses the decisions made at the farm household regarding the generation of income and on farm activities.
3. The Regional System (RS) analyses the agroecological and socio-economic boundary conditions and the incentives presented by development oriented activities.

Ecological aspects of the analysis comprise comparison of the effects of different crops and production techniques on the soil as ecological resource. For this comparision the chemical and physical qualities of the soil are examined as well as the polution by agrochemicals. Evaluation of the groundwater condition is included in the ecological approach. Criterions for sustainability have a relative character. The question of what is in time a more sustainable land use will be answered on the three different levels for three major soil groups and nine important land use types.

Combinations of crops and soils

	Maiz	Yuca	Platano	Piña	Palmito	Pasto	Forestal I II III
Soil I	x	x	x		x	x	x
Soil II						x	x
Soil III	x			x	x	x	x

As landuse is realized in the socio-economic context of the farm or region, feasibility criterions at corresponding levels are to be taken in consideration. MGP models on farm scale and regional scale are developed to evaluate the different ecological criterions in economical terms or visa-versa.

Different scenarios will be tested in close cooperation with the counter parts.

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 Ganadería (MAG) of Costa Rica. The Programme, that was started in April 1986, has a long-term objective multidisciplinary research aimed at rational use of the natural resources in the Atlantic Zone of Costa Rica with emphasis on the small landowner.

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SUMMARY

To determine soil water retention functions and hydraulic conductivity functions of two (2) soil types under four (4) land use forms, laboratory and field measurements were done using the 1-step-outflow apparatus and the modified crust test, respectively. Measured data were used in the SFIT model to estimate the van Genuchten parameters, which were used to calculate pF- and K-functions.

For each site and measurement depth at least two pF- and corresponding K- functions are given (Fig. 1 & 2) as a selection out of all received estimations. Each presented functions represents the best result of running the SFIT model (compare Fig. 4). The van Genuchten parameters, used to calculate these functions are listed in Table 2 & 3.

Problem description

For the atlantic zone of Costa Rica since 1992 a soil map is available in a GIS, But there still is a lack on information on soil physical model parameters as soil water retention functions and soil hydraulic conductivity functions. The present report shall give some information on the soil physical parameters of two major soil types under four different land use types, as they are necessary for several deterministic models of crop growth and water balance. The parameters were estimated on each soil type/land use combination in two or three depths. We present the measured data and the first results of pF and K estimation per site and depth graphically as functions and as lists of 'van Genuchten' model parameters. A discussion on these results is given, explaining the limitations of the data as presented.

Material

The soil types distinguished by the soil map of the atlantic zone were classified by the PZA (Programa Zona Atlantica) into the following classes and subclasses, respectively:
main class: well drained - poorly drained
sub class: fertile - low fertile

We did field and laboratory measurements on two soil types of the main class 'well drained'. Each soil type represents one sub class. Using the USDA soil taxonomy, the well drained, fertile soil is classified as an eutric Hapludand (eH; local name: suelo Los Diamantes), the well drained low fertile soil is classified

as an andic Humitropept (aH; local name: suelo Neguev). Sites were chosen on land use types important for the Atlantic Zone of Costa Rica:
forest, grassland, annual crop and perennial crop.

Site location is given for latitude (la) and longitude (lo) as follows:

eH forest	la: 56 08 77	lo: 24 50 26
eH pasture	la: 56 10 10	lo: 24 84 38
eH annual crop	la: 56 08 47	lo: 24 85 73
eH perennial crop	la: 55 72 47	lo: 24 50 26
aH forest	la: 58 75 85	lo: 24 03 50
aH pasture	la: 58 72 64	lo: 24 01 00
aH annual crop	la: 58 61 80	lo: 24 07 48
aH perennial crop	la: 58 74 06	lo: 24 07 29

Profile description and general site information for both soil types under forest are given by Weerts 1991. Descriptions of grassland and the cropped sites are not available at the moment. Sites were chosen close to those presented by Weerts, in order to provide comparable basic soil conditions in parent material.

Methods

During a field period in Costa Rica field and laboratory measurements were done to determine bulk density, soil water retention data, soil water outflow data and hydraulic conductivity data. Additional laboratory work and first data processing by running the SFIT model was done at the AUW (Agricultural University Wageningen) in Holland.

Bulk density

Undisturbed soil samples were taken using 300 ccm metal cylinders, oven dried for 24 hours by 105 grad celsius and dry weighted. Bulk density is calculated as g/ccm.

pF data

Saturated water content and volumetric water content at h= 30 hPa and at h= 60 hPa were calculated from desaturation data measured at undisturbed 300 ccm samples using the 1-step-outflow equipment. In this apparatus a sample first is completely saturated. Retention values are calculated from total water outflow by known pressure applications, until equilibrium conditions are reached. Related water contents at high pF ranges were calculated from independent measurements at field moist, disturbed soil material using high pressure pots. Values of pF 3 an 4.2 were partly measured in Costa Rica at the CORBANA laboratory, partly in the AUW laboratory in Wageningen.

Outflow data

According to the 1-step-outflow procedure we measured from undisturbed 300 ccm soil samples after termination of the last pF determination, the time depending outflow characteristic by application of 660 hPa pressure using the 1-step-outflow apparatus. The outflow was measured during 5 days of desaturation.

Conductivity data

Saturated and unsaturated hydraulic conductivity was measured in the field by using the modified crust test (Booltink et al. 1991). On undisturbed soil columns of 30 cm diameter and 30 cm height infiltration of water with and without a negative suction is measured. With the method soil water suction up to -20 hPa were measured. Conductivity is calculated as cm/hour for the measured suction conditions.

SFIT simulations

The pF and outflow data received from the described methods were used to fit retention and outflow functions on measured data and to estimate corresponding conductivity functions. The SFIT model is based on the van Genuchten model using the Mualem strategy to describe the conductivity function from retention data. Fitted pF functions are expressed by four parameters (van Genuchten parameters), estimated conductivity functions by those parameters plus one, resulting in a five parameter model described in formula (1) and (2).

$$K(h) = \frac{K(sat) * (((1+(\alpha * h)^{n})^{m}) - (\alpha * h)^{(n-1)})^{2}}{(1+(\alpha * h)^{n})^{(m*(\gamma+2))}} \quad (1)$$

with the relation to Mualem's concept by

$$m = (1-\frac{1}{n})$$

$$\Theta(h) = \Theta r + \frac{(\Theta s - \Theta r)}{(1+(\alpha * h)^{n})^{m}} \quad (2)$$

The theoretical background is given by Kool et al. 1985, Van Genuchten 1980 and Kool & Parker 1987.

Results and discussion

Each site represents a combination of soil type and land use type. Per site and measurement depth we did laboratory measurements on two, in some cases three undisturbed soil samples of 300 ccm, here labled as A, B and C (see tab.1). Measurement values and estimated functions are presented graphically in figure 1a - 1d for the fertile soil (eutric Hapludand) and in figure 2a - 2d for the unfertile soil (andic Humitropept). SFIT gives three estimations on one measured data set. Here we only present the best estimation per sample. The van Genuchten parameters of these functions are given in table 2 and 3, respectively. The quality of the fit on as well retention as outflow data is given by R^2.

The SFIT estimation procedure uses laboratory retention and outflow data received from one soil sample in combination with the average field measurement value of saturated hydraulic conductivity for the measurement depth. We only used the K(sat) value, which characterizes the hydraulic conductivity at pressure head zero but with crust, eliminating bypass flow during measurement. From these data SFIT derives the van Genuchten parameters, which were used to calculate retention and conductivity functions. The conductivity measurement values presented in figure 1 and 2 are averages, each from three field measurements. Therefore they are independent data, which can be used to evaluate the reliability of the SFIT estimations. All saturated conductivity values given in figure 1 and 2 are K(sat) values.

As can be seen in figure 1 and 2, there are some problems in basic pF data. First most of the saturated water contents measured are too high compared with the following water content value for corresponding pressure head of 30 mbar. For example see figures 1a 0-10cm, 1b 30-40 cm, 1d 0-10cm, 2a 0-10 cm, 2c 0-10 cm, 2d 0-10 cm. This effect of soil structure and related macroporosity is measurable with the 1-step-apparatus, because it starts measurements with total saturated samples. Traditional pF measurement procedures saturate a sample by putting a pressure head of zero at its bottom, while in the 1-step-apparatus zero head is located at the sample top. In the 1-step-apparatus big pores and spaces are water filled, which actually have no capillarity in the soil. Therefore this porespacevolume is not involved in the basic assumptions of the theoretical model of soil water retention. For saturated conditions in strongly aggregated soils, the 1-step-measurement concept does not fit with the theory of the pF model. We are going to do some calibration runs, using saturated water contents of soil samples taken as replicates, on which a traditional pF measurement procedure was applied (capillary saturation by pressure head h = -3,5 cm for a sample of 7 cm height, stepwise desaturation by hanging water column), an example is given in figure 3.

A second problem with pF values occurs in high pressure ranges. Water contents calculated for a pressure head of 1.24 bar very often are too high, compared with those of the moist range of the retention curve. For examples see figures 1a 0-10 cm, 1c 20-30 cm, 2a 30-40 cm, 2c 15-25 cm. For the cropped sites of the andic Humitropept even the water contents of 15.5 bar are very high. As a result estimated retention functions are very flat, but on a high level. The volume of plant available water content is very low, even for a clay soil. This is probably an effect of measurement technique and/or of andic properties of our samples. Here some additional laboratory work will be done. The result has to be checked by literature study.

Estimated hydraulic conductivity functions of 0-10 cm depth often show worse relation to corresponding crust measurement data than those of 15-25 and 30-40 cm depth. Estimated conductivities generally are lower than measured ones and the functions start falling at higher pressure heads as compared with measured values. The later effect is smaller by second and third measurement depth. For example the shape of the estimated function fits good to measured data for aHa 15-25 cm (fig. 1c), aHf 30-40 cm (fig. 1a), eHf 30-40 cm (fig. 2a), eHpe 15-25 cm (fig.2d), also the conductivity values generally are too low. Fig. 2b 30-40 and fig. 2c 15-25 cm show the point of inflection of the estimated function at too low or too high pressure heads compared with measured data.

Best estimation results for hydraulic conductivity shows fig. 2c 0-10 cm depth. Even if generally the shape of estimated functions fits acceptably to that the measurement values are indicating, the physical property of the soil isn't described well, because absolute values are too low. The effect of this underestimation definitely can be determined by inserting the fitted functions in a soil water model and comparing results of simulations with field measurements in time. These simulations will be done for sites eHf, eHp, aHf and aHp in 1993.

Finally we want to highlight a problem implicit in the data set, but not demonstrated here widely. All parameter estimations are based as well on pF measurement data as on outflow measurements in time. Those outflow characteristics normally have to be maximum functions as can be seen in fig.4 for depth 30-40 cm. For the andic Humitropept we found some different outflow behaviour, correlated to soil structure (see fig. 4 depth 0-10 cm). These outflow characteristics also influence SFIT estimation results, but we still have to do some model runs to analyze the sensitivity of the estimation procedure on abnormal outflow behaviour.
In figure 4 the best fit for each depth marked by a circle arround the fit number. Those functions are given in fig. 2d as function B in each depth.

Summary and conclusion

To determine soil waterretention functions and hydraulic conductivity functions of 2 soil types under 4 land use forms, laboratory and field measurements were done using the 1-step-outflow apparatus and the modified crust test, respectively. Measured data were used in the SFIT model to estimate the van Genuchten parameters, which were used to calculate pF- and K-functions.

For each site and measurement depth at least two pF- and corresponding K-functions are given (fig. 1 & 2) as a selection out of all received estimations. Each presented function represents the best result of running the SFIT model (compare fig. 4). The van Genuchten parameters, used to calculate these functions are listed in table 2 & 3.

Problems occur in soil waterretention data (saturated water content, water content at high pressure values) and in some cases in measured outflow characteristics. There is additional laboratory work necessary, and in a reliable range some calibrations on input variables of SFIT model in order to improve estimation results. This work will be done at the WAU.

Presented first results of SFIT estimation procedures on basic data, as given in tab. 2 and 3 can be used to calculate input tables of pF and K values as needed for simulation models. But the problems discussed above, have to be recognized during use and interpretation of simulation runs.

Literature

Booltink H.W.G., J. Bouma & D. Giménez 1991: Suction crust infiltrometer for measuring hydraulic conductivity of unsaturated soil near saturation. Soil Sci. Soc. Am. J. 55, 566-568.

Kool J.B., J.C. Parker & M.T. van Genuchten 1985: Determining soil hydraulic properties from one-step outflow experiments by parameter estimation: I. Theory and numerical studies. Soil Sci. Soc. Am. J., 49, 1348-1354.

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Van Genuchten M.T. 1980: A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Sci. Soc. Am. J., 44, 892-898.

Weerts G.J. 1991: Soil hydraulic conductivity on two tropical soil types under forest and a 25 year old pasture. Afstudeerverslag WAU, Wageningen, The Netherlands.

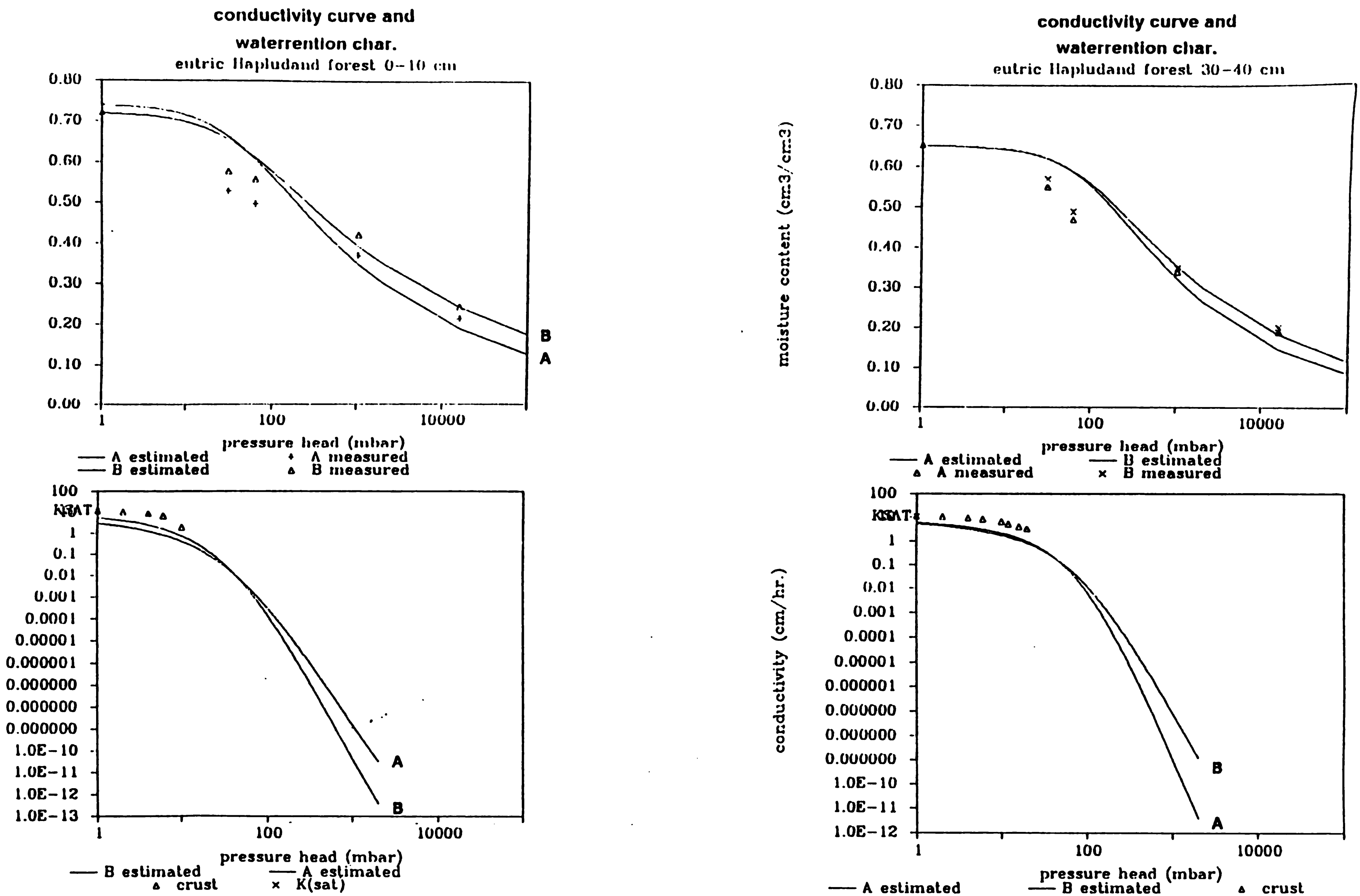

Fig. 1a: Soil waterretention and conductivity functions

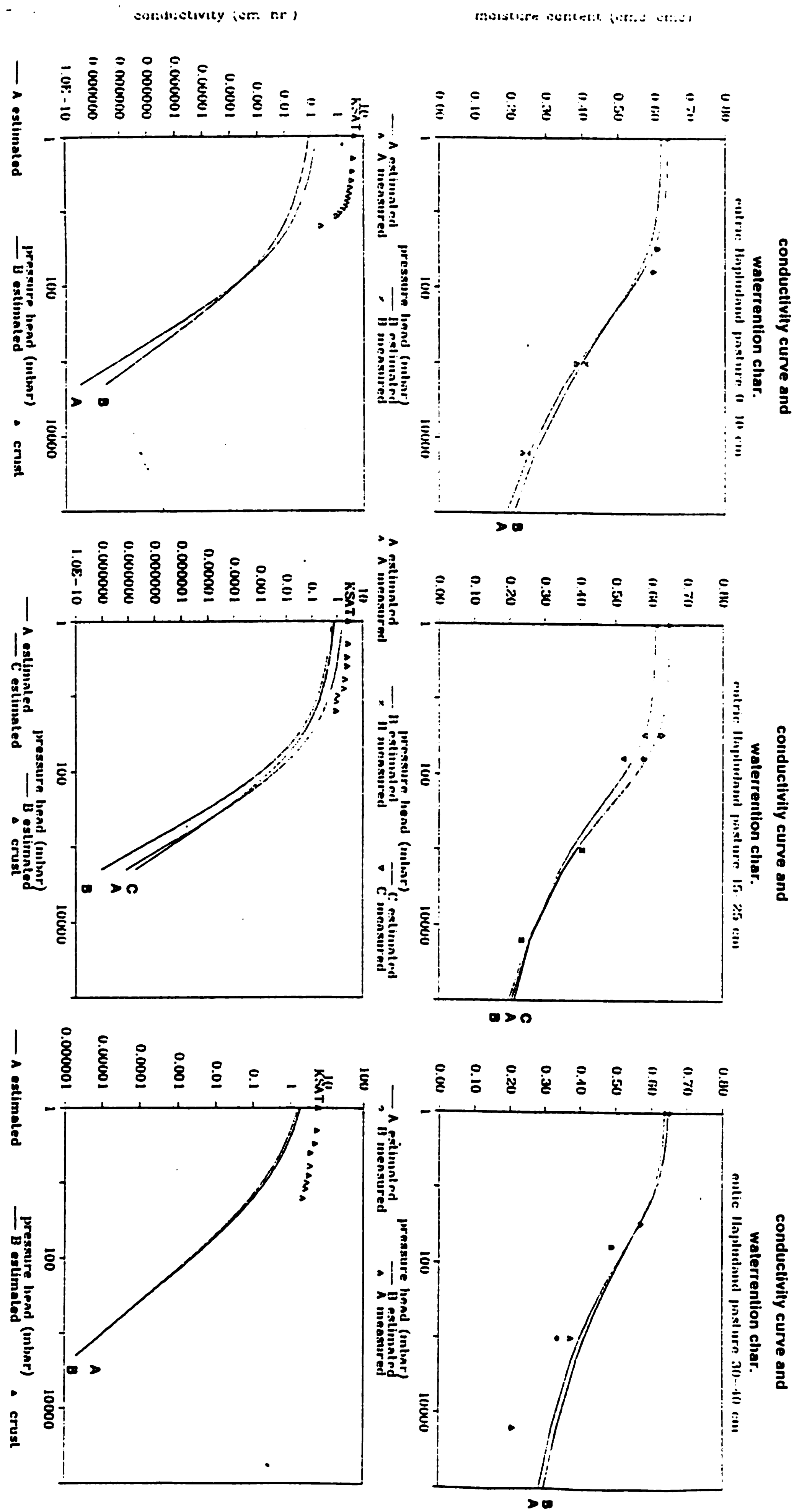

Fig. 1b: Soil waterretention and conductivity functions soil

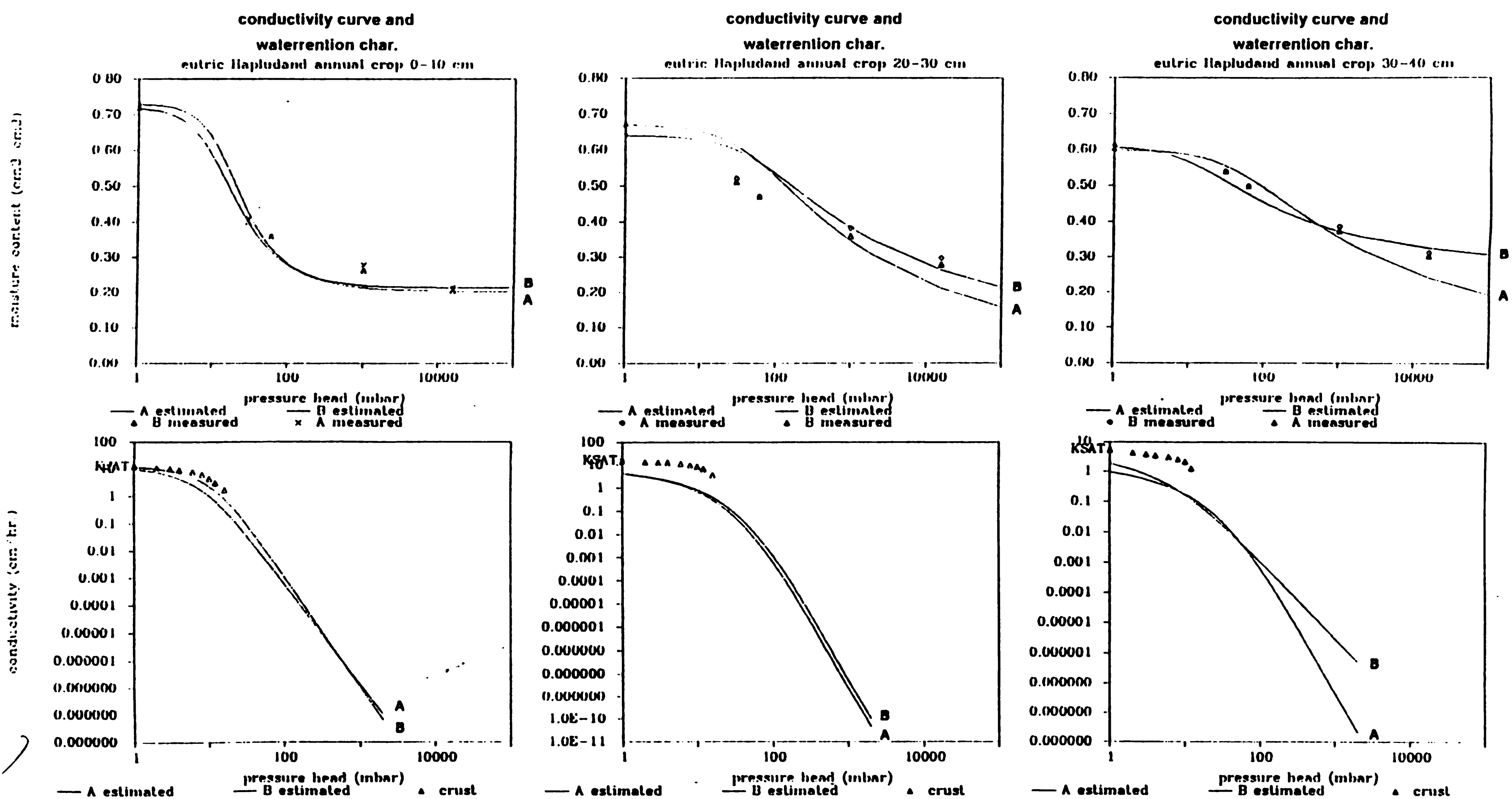

Fig. 1c: Soil waterretention and conductivity functions soil

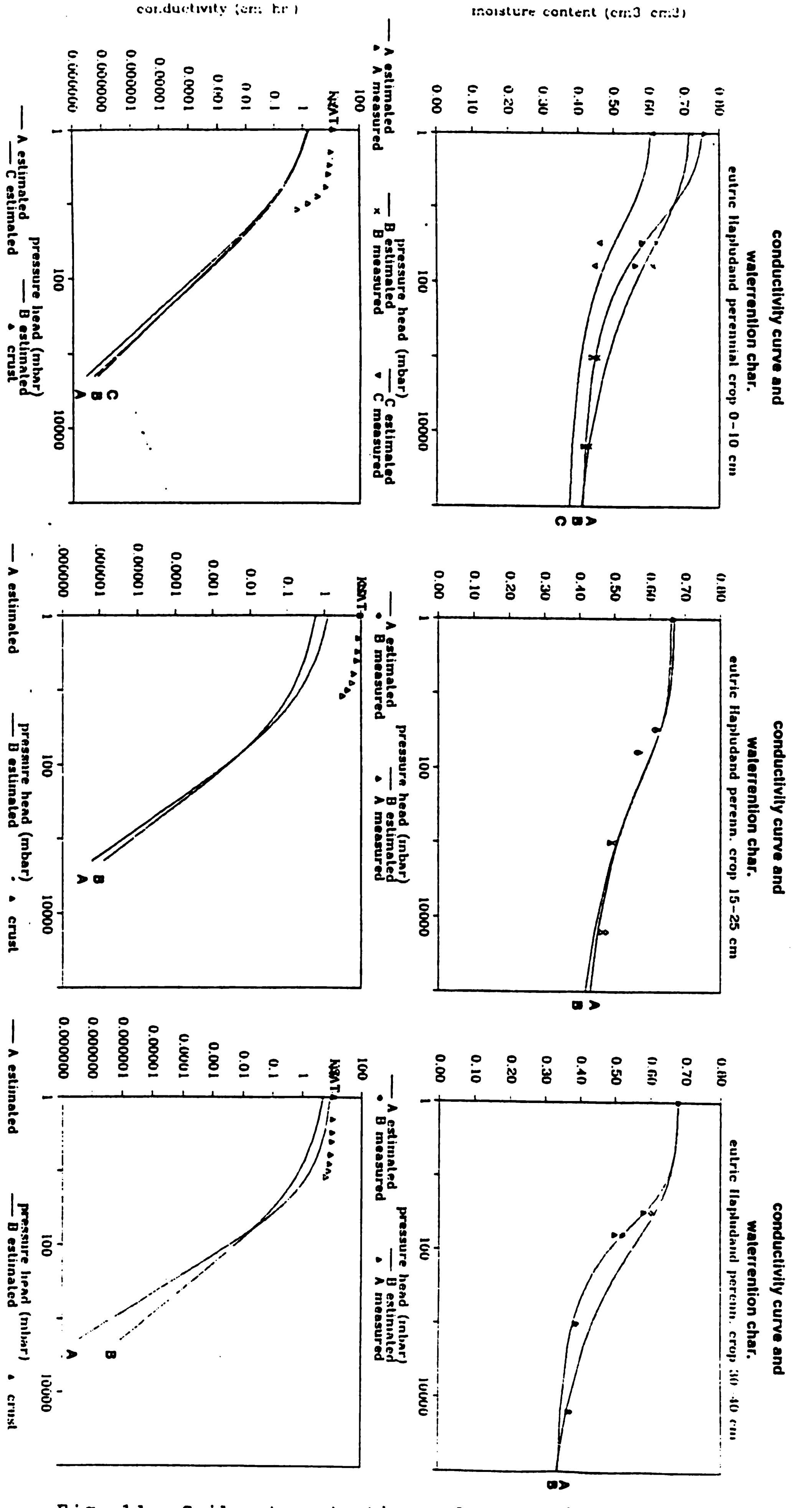

Fig. 1d: Soil waterretention and conductivity functions soil

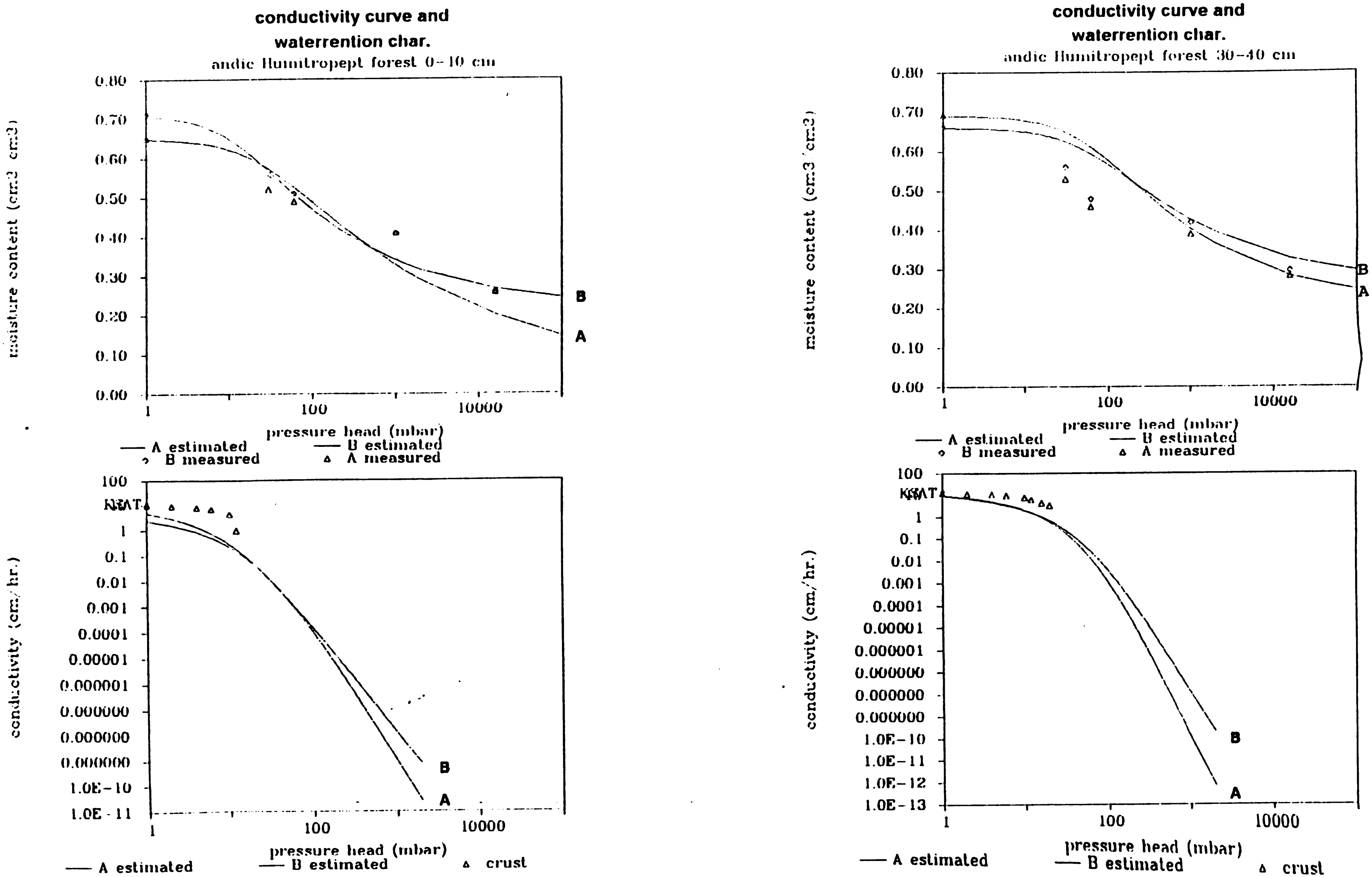

Fig. 2a: Soil waterretention and conductivity functions soil

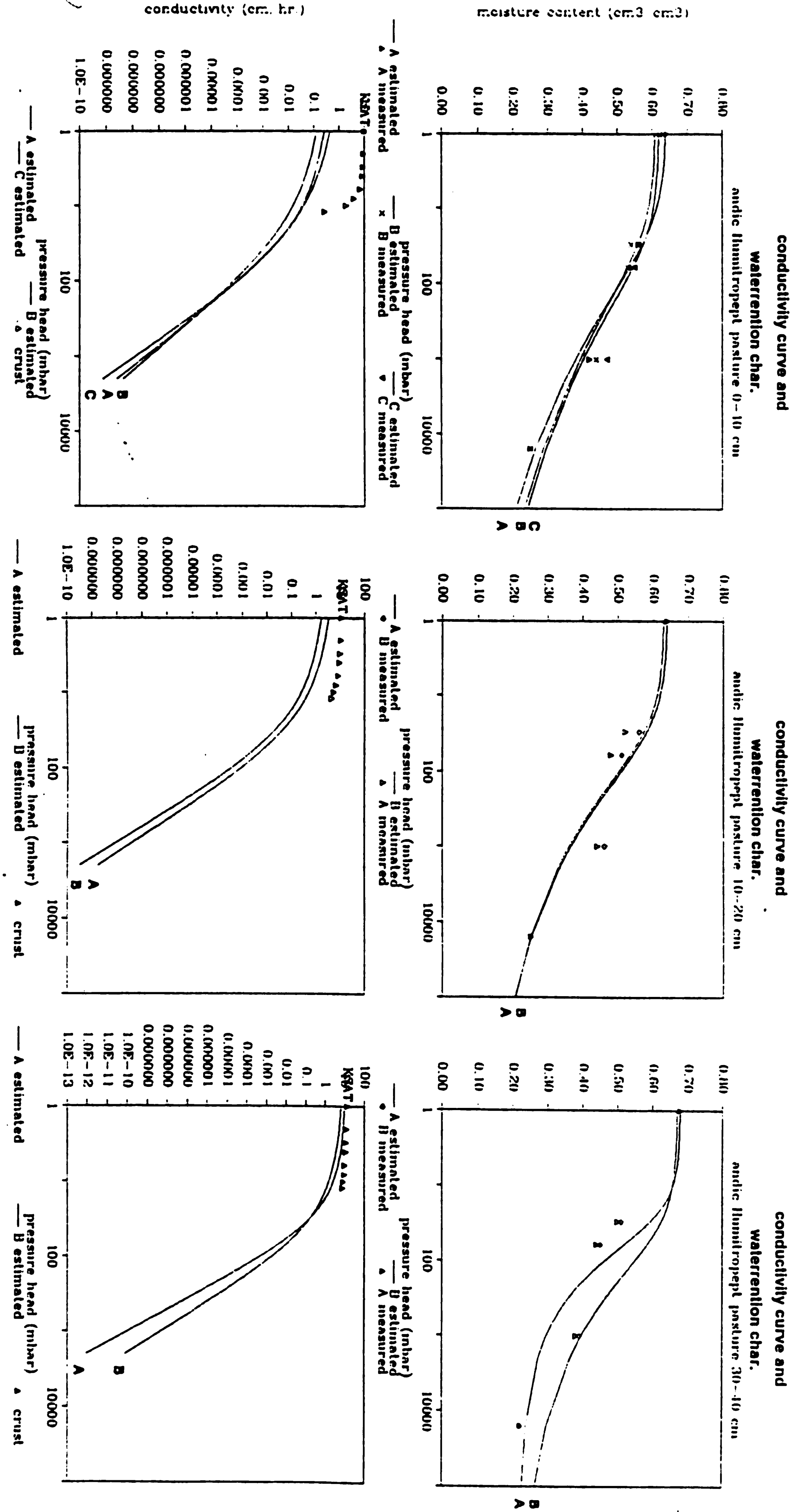

Fig. 2b: Soil waterretention and conductivity functions soil

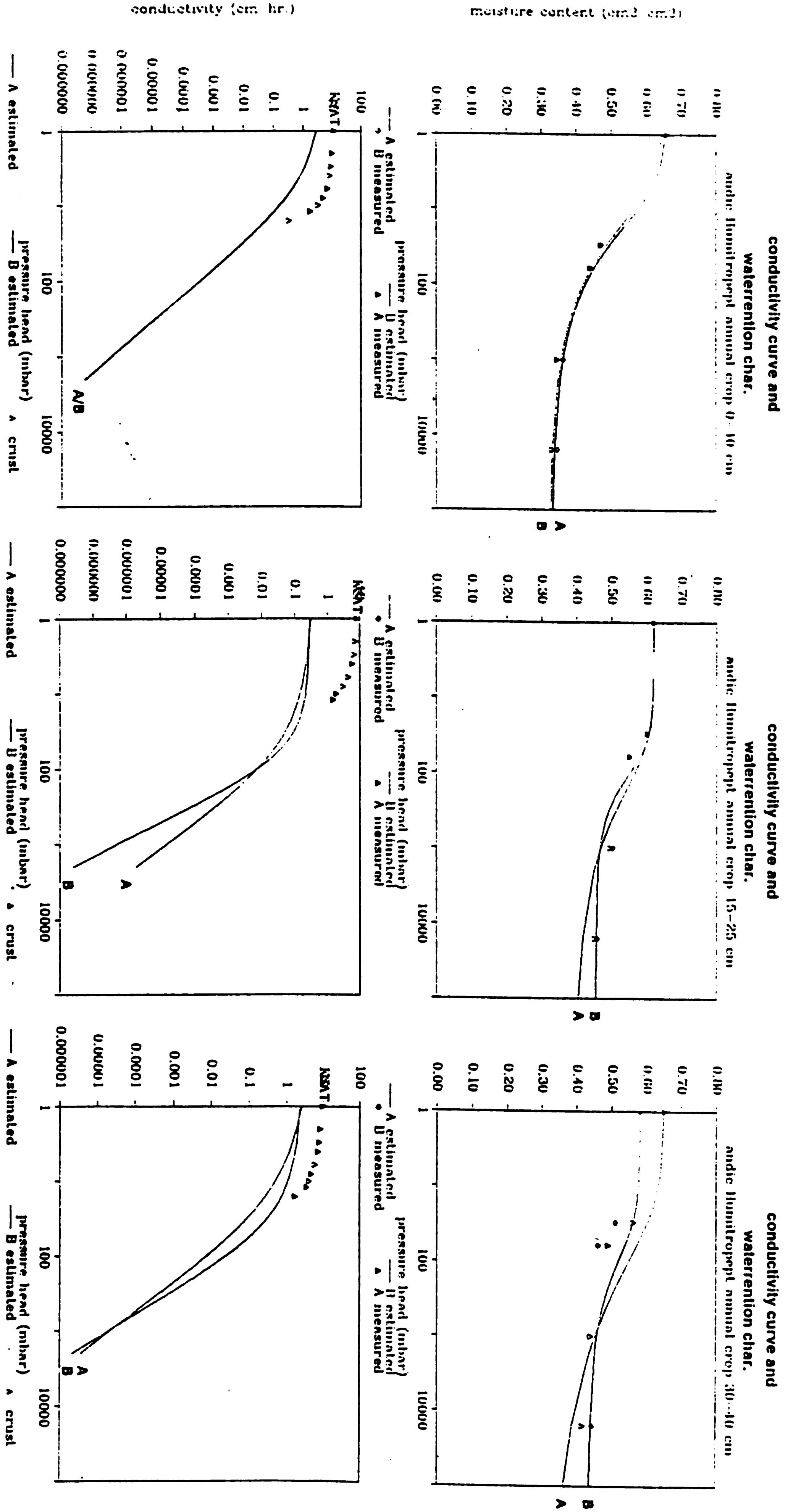

Fig. 2c: Soil waterretention and conductivity functions soil

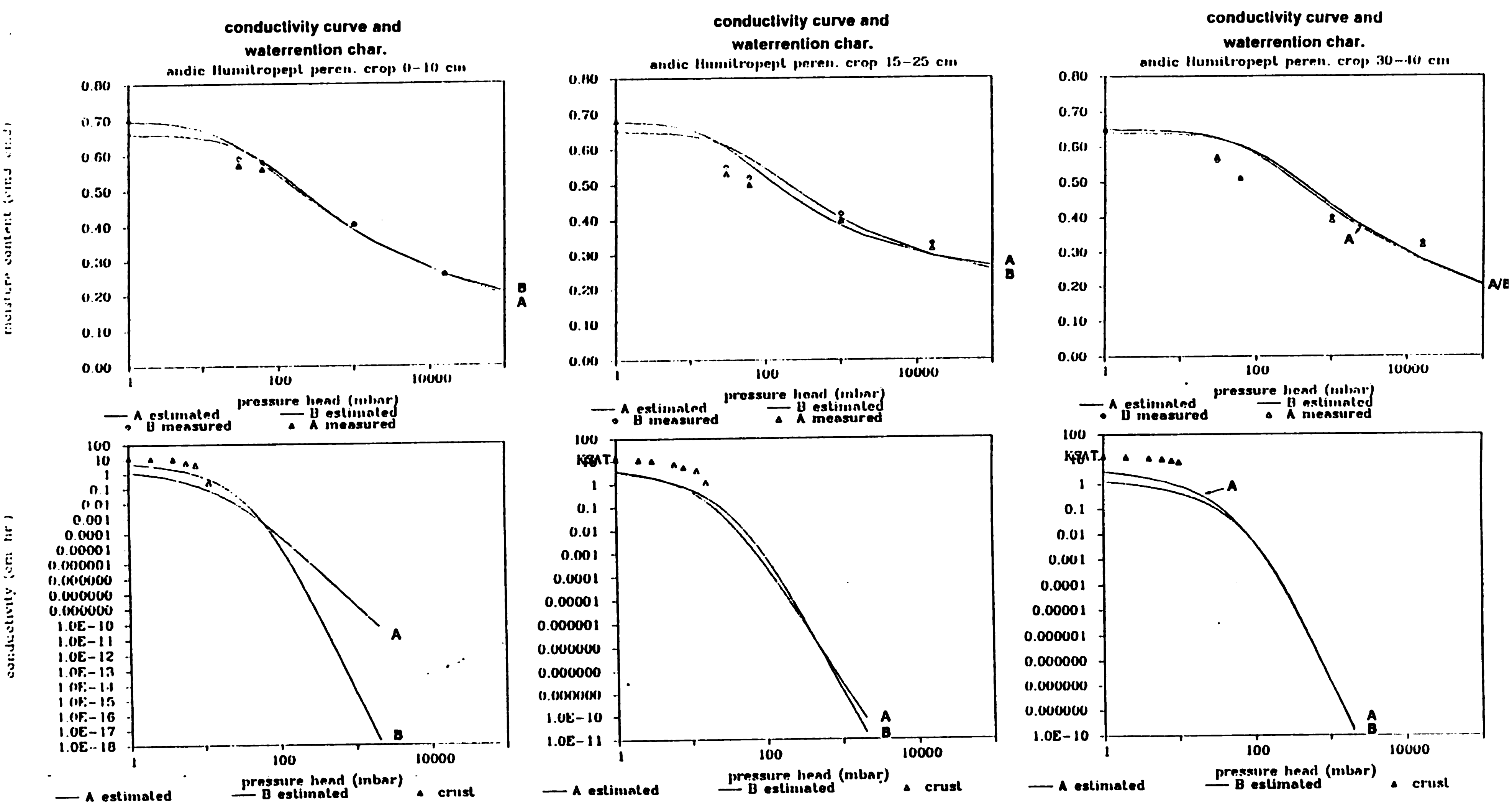

Fig. 2d: Soil waterretention and conductivity functions soil

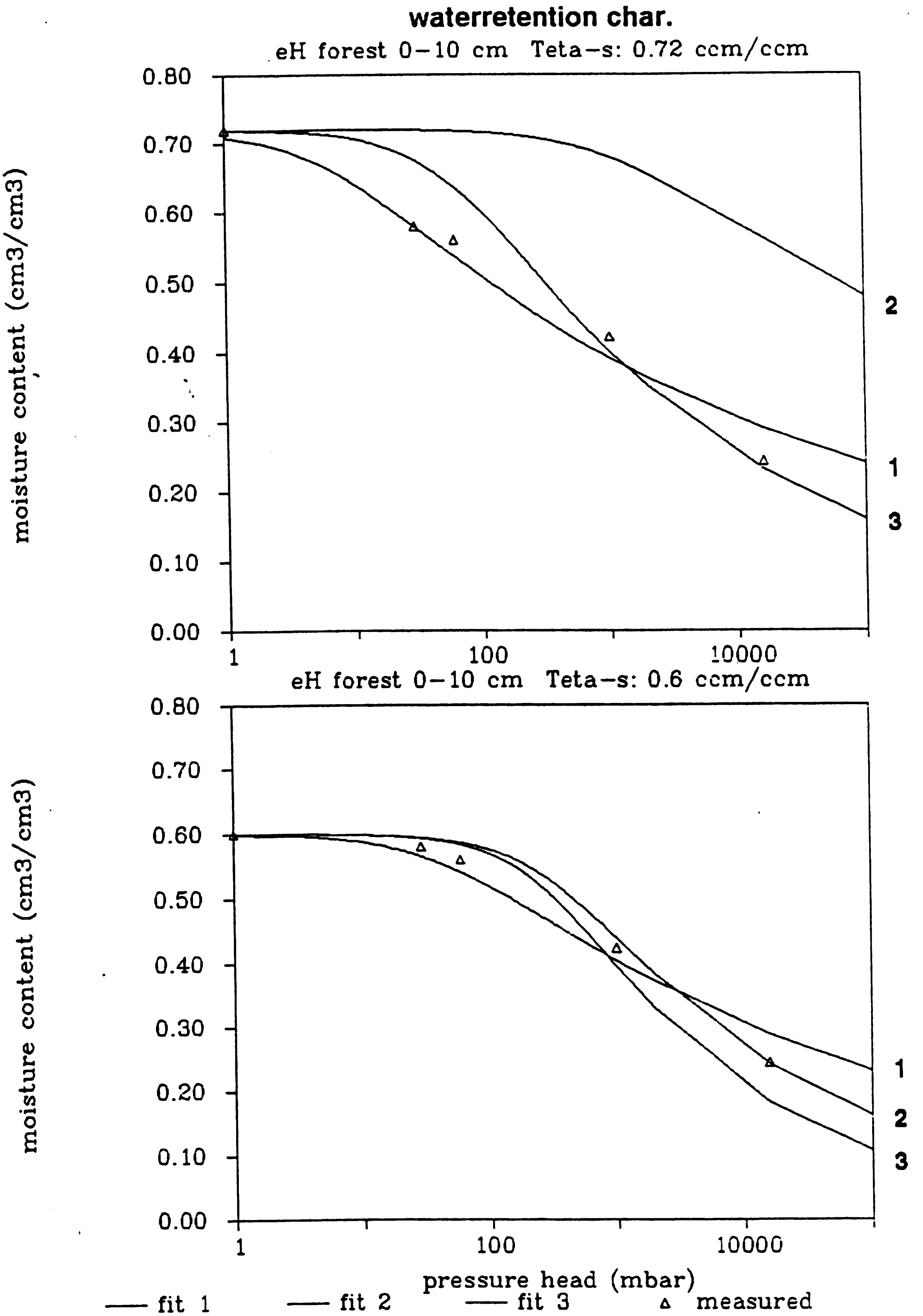

Fig.3: Example of SFIT results by changed saturated water content for eutric Hapludand forest 0–10 cm depth

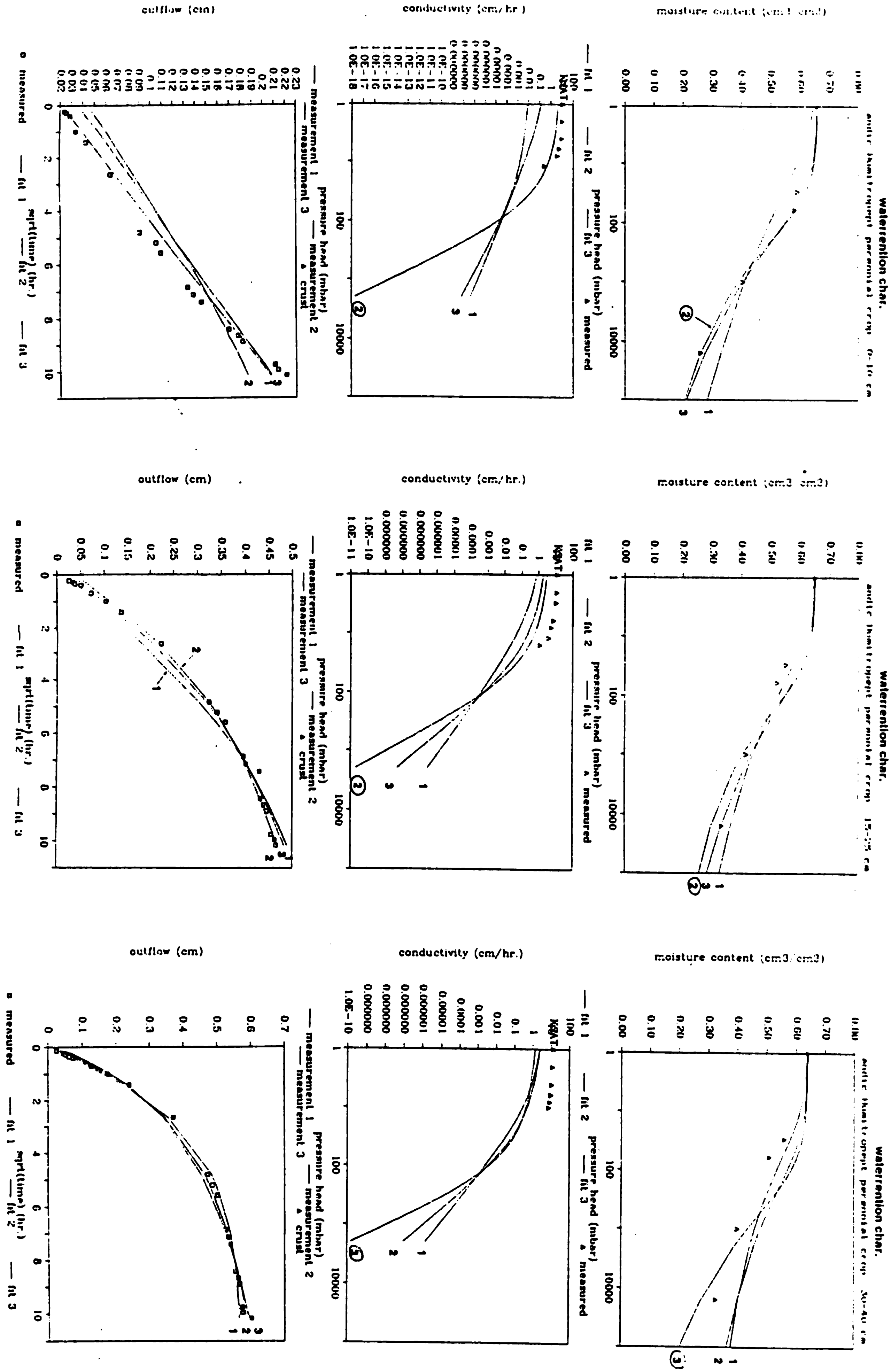

Fig. 4: Comparison of basic SFIT results for 3 measurment

soil type / depth / land use	eutric Hapludand 0-10 cm	15-25 cm	30-40 cm
forest	eHf A/B		eHf A/B
pasture	eHp A/B	eHf A/B/C	eHf A/B
annual crop	eHa A/B	eHa A/B *)	eHa A/B
perennial crop	eHpe A/B/C	eHpe A/B	eHpe A/B

soil type / depth / land use	andic Humitropept 0-10 cm	15-25 cm	30-40 cm
forest	aHf A/B		aHf A/B
pasture	aHp A/B/C	aHf A/B/C	aHf A/B
annual crop	aHa A/B	aHa A/B	aHa A/B
perennial crop	aHpe A/B	aHpe A/B	aHpe A/B

*) depth 20-30 cm

tab.1: Table of samples per site

name	depth	R2	alpha	n	Teta-r	Ksat	gamma	m
eHf A	0-10	0.8958	0.0277	1.224	0.001	20	20.43	0.183
eHf B	0-10	0.964	0.028	1.1791	0.001	14	18.683	0.151
eHf A	30-40	0.9619	0.0701	1.2091	0.189	12.4	0.0001	0.172
eHf B	30-40	0.9783	0.0449	1.2252	0.202	12.4	0.0001	0.183
eHp A	0-10	0.9688	0.0217	1.16	0.0033	0.8201	14.6741	0.127
eHp B	0-10	0.9756	0.0212	1.1418	0.001	0.4864	11.5734	0.124
eHp A	15-25	0.9953	0.016	1.2339	0.1087	1.5959	9.3583	0.189
eHp B	15-25	0.9901	0.016	1.2241	0.0914	1.7121	12.1123	0.183
eHp C	15-25	0.9956	0.0171	1.233	0.1278	2.0873	7.8325	0.188
eHp A	30-40	0.98	0.0741	1.1917	0.204	11.7	0.0001	0.160
eHp B	30-40	0.9755	0.075	1.1737	0.208	11.7	0.0001	0.147
eHa A	0-10	0.9929	0.0974	1.8367	0.202	12.96	0.0001	0.455
eHa B	0-10	0.9913	0.0716	2.0169	0.214	12.96	0.0001	0.504
eHa A	20-30	0.9727	0.0259	1.2301	0.0596	13.3811	14.6557	0.187
eHa B	20-30	0.9597	0.0235	1.231	0.1126	13.8874	14.6852	0.187
eHa A	30-40	0.9867	0.0263	1.1886	0.0725	4.0228	11.047	0.158
eHa B	30-40	0.9912	0.0979	1.2821	0.2845	7.89	0.0088	0.220
eHpe A	0-10	0.9714	0.1159	1.1532	0.2463	12.32	4.4795	0.132
eHpe B	0-10	0.9916	0.1323	1.2257	0.3667	12.32	1.7359	0.184
eHpe C	0-10	0.9845	0.1577	1.3536	0.3662	6.0407	0.0001	0.261
eHpe A	15-25	0.9944	0.0428	1.2306	0.3906	4.8487	1.5104	0.187
eHpe B	15-25	0.9933	0.0308	1.216	0.3641	2.118	0.9686	0.177
eHpe A	30-40	0.9979	0.0451	1.5446	0.3336	12.8476	1.5699	0.352
eHpe B	30-40	0.9939	0.0466	1.2631	0.2906	16.0355	1.8172	0.208

tab.2: Van Genuchten parameters soil type eutric Hapludand.

name	depth	R2	alpha	n	Teta-r	Ksat	gamma	m
aHf A	0-10	0.9654	0.0404	1.191	0.0177	12.1974	15.2604	0.160
aHf B	0-10	0.8409	0.0809	1.3087	0.2142	17.39	4.9111	0.235
aHf A	30-40	0.9435	0.0187	1.2666	0.1649	22.16	19.4521	0.210
aHf B	30-40	0.9777	0.0197	1.2535	0.2225	22.16	13.9249	0.202
aHp A	0-10	0.9902	0.0512	1.1327	0.0034	4.1775	10.4679	0.117
aHp B	0-10	0.9908	0.0439	1.1152	0.001	1.4474	9.8085	0.103
aHp C	0-10	0.9817	0.0332	1.1424	0.069	1.8084	13.0874	0.124
aHp A	15-25	0.9761	0.0324	1.2059	0.1036	9.1836	13.7185	0.170
aHp B	15-25	0.984	0.0313	1.2169	0.1175	6.1955	11.3186	0.178
aHp A	30-40	0.9542	0.0296	1.5303	0.22	14.15	7.3313	0.346
aHp B	30-40	0.9587	0.0222	1.3025	0.22	14.15	11.4416	0.232
aHa A	0-10	0.9953	0.1329	1.4717	0.331	7.3717	0.002	0.320
aHa B	0-10	0.9981	0.1437	1.4477	0.3224	8.53	0.0048	0.309
aHa A	15-25	0.9928	0.0136	1.4204	0.3945	0.4287	0.3288	0.295
aHa B	15-25	0.9974	0.0142	1.9728	0.4548	0.2865	0.4978	0.493
aHa A	30-40	0.9867	0.0398	1.2483	0.3222	8.3187	0.4543	0.198
aHa B	30-40	0.88	0.0217	1.6078	0.4364	2.8362	0.012	0.378
aHpe A	0-10	0.9726	0.0458	1.1594	0.0205	9.8888	15.71	0.137
aHpe B	0-10	0.983	0.0198	1.2217	0.1034	15.831	38.1112	0.181
aHpe A	15-25	0.9796	0.0402	1.2788	0.2205	11.3168	9.3579	0.216
aHpe B	15-25	0.9837	0.0226	1.2324	0.1763	9.5695	16.0286	0.188
aHpe A	30-40	0.9766	0.0127	1.1654	0.002	12.6009	25.0519	0.141
aHpe B	30-40	0.9757	0.0323	1.1657	0.255	15.624	6.7605	0.142

tab.3: Van Genuchten parameters soil type andic Humitropept.