RECONNAISSANCE SOIL STUDIES TO DETERMINE OPTIMUM SURVEY SCALES AND MAPPING LEGEND FOR SOIL MOISTURE RESEARCH IN THE HUPSELSE BEEK HYDROLOGICAL CATCHMENT: OOST GELDERLAND

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RECONNAISSANCE SOIL STUDIES TO DETERMINE OPTIMUM SURVEY SCALES AND MAPPING LEGEND FOR SOIL MOISTURE RESEARCH IN THE HUPSELSE BEEK HYDROLOGICAL CATCHMENT; OOST GELDERLAND

by

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1 INTRODUCTION

The Hupselse Beek has long been subject to hydrological and geological studies (Bron 1982). Underlain by water tight Miocene clay, its valley in Oost Gelderland appears to be ideal for catchment studies of inputs and runoff. The geomorphological and soil patterns of the surface layers in the catchment are much more complex than the underlying geology, however, because of the events occurring throughout the Pleistocene period. Eroded by meltwaters, covered respectively by boulder clay and fluvio-glacial sand, and later, aeolian sands, the present landscape bears the traces of many extreme changes.

The external appearance of the present landscape is a gently undulating valley whose smooth outer forms belies the complexity of the geomorphology under the thin covering of aeolian sands. These sands are very homogenous and their physical properties can easily be measured. The physical behaviour of the soil, however, is also strongly affected by the presence of boulder clay (keileem), fluvio-glacial sands, and the Miocene clay, all of which occur close enough to the surface of the ground to affect the movement of water in the soil profile, and thus the behaviour of plants.

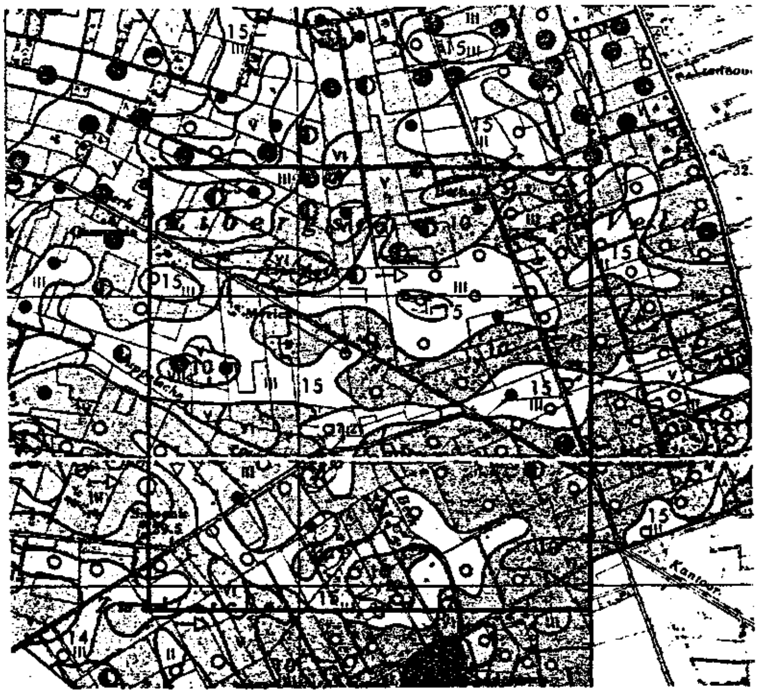
Because the major aim of the Hupselse Beek study is to model the supply of moisture to a crop in the catchment, this study was first undertaken to characterize the kinds of soil occuring there, and to estimate how they varied spatially.

An earlier survey (STIBOKA, 1963) at a scale of 1:25.000 (Figure 1.1) mapped the soil according to the Netherlands Soil Classification (De Bakker and Schelling 1966). Two main classes were distinguished - Veldpodzolen and Beekeerdgronden. But this map also showed that in many places within the catchment clay subsoils were found within 40-120 cm of the surface, though the exact distributions of the clay were not mapped.

The aims of this study were therefore to:

1. Determine the scales of variation of the important soil parent materials occurring within c. 1.5 m of the present ground surface.
2. Check the degree of success of the earlier soil map
3. Devise an optimum soil classification
4. Determine the most discriminating soil properties for hydrological studies.

Figure 1.1



1 : 25,000 Soil Map of the Hupselse Beek Area
(Stiboka 1963)

Legend:

10: Hn21 Veldpodzol gronden
15: pZn21 Beekeerd gronden — Zandgronden
0: "oude" clay found within 40-120 cm.
●: grind/coarse sand/gravel 40-120 cm.

2 GEOLOGY AND GEOMORPHOLOGY

The Hupselse Beek area is underlain by Miocene clay sediments that vary in depth from c. 1 m to 10 m under the present land surface (Figure 2.1) (Stuip and Boekelman 1976). The Miocene clay is a well-sorted, silty, humic clay deposited in a coastal environment.

The stratigraphic sequence is discontinuous and the Miocene clay is covered by various middle Pleistocene deposits (Table 2.1 - STIBOKA 1979). It is thought that the upper layer of the Tertiary deposits are possibly Pliocene in origin because of the presence of an up to 4 m thick layer of fine sandy - silty fine sandy material, rich in glauconite that shows some effects of glacial reworking. Deposits from the early Pleistocene are not found.

Middle Pleistocene deposits consist of a sandy and gravelly upper Rhine terrace. In the Elsterian period, west of the line from Aalten-Neede, this terrace was largerly eroded. Near the end of the Elsterian, a 20-30 m deep valley was eroded through to the Miocene clay, close to the line of the present Hupselse Beek (Figure 2.1). This valley was refilled in the Holsteinien period with fluvial Rhine sediments that have been classified as the "Formatie van Urk" (Figure 2.2).
In the Salian, the area was strongly affected by the glaciers that covered the entire Achterhoek area. This period saw the deposition of the ground moraine (Formatie van Drente), or keileem. This material is very variable in composition and is badly sorted and silty. To the north of the Hupselse Beekdal the material is coarse sandy with fine and coarse gravel. In the valley itself, the composition is very variable, and to the south of the valley there is mostly little gravel. As the glacier retreated, the meltwater deposited a layer of poorly sorted fine to coarse sand, particularly in the lower parts of the (then) landscape. These lower parts received deposits of silty, peaty material in the Eemien interstadial.
The last ice period, the Weichselien, was characterised by long, cold and dry periods. The area was covered by aeolian sand deposits (oude dekzand) of the Twente Formation in the Upper Pleniglacial (Middle Weichselian) - Table 2.2.
The deposit consists of varous layers having different amounts of silt. The "oude dekzand" is often split into two main layers, oud dekzand I and II, by the "layer of Beuningen" - a thin layer of cryoturbation and niveo-fluviatile deposits less than 1 m thick.
Finally, more aeolian deposits (Young dekzand 1 and II) occurred in the old and young Dryas period. These are well sorted fine sands with a particle size lying between 105 and 210 μm.
The geology of the area can be summarized as a water-tight Miocene clay surface with a deep erosion valley. This valley has been filled with fluvio-glacial sediments. The area is covered in keileem which in turn is covered by aeolian sands. The keileem varies in thickness and composition, and is thicker to the north of the Hupselse Beek than to the south where the difference between the Miocene surface and the present land surface is only c. 1 m.

Figure 2.1 The surface of the Miocene clay (meters N.A.P.). The black-lined square shows the position of the study area.

Source: Stuip and Boekelman 1976.

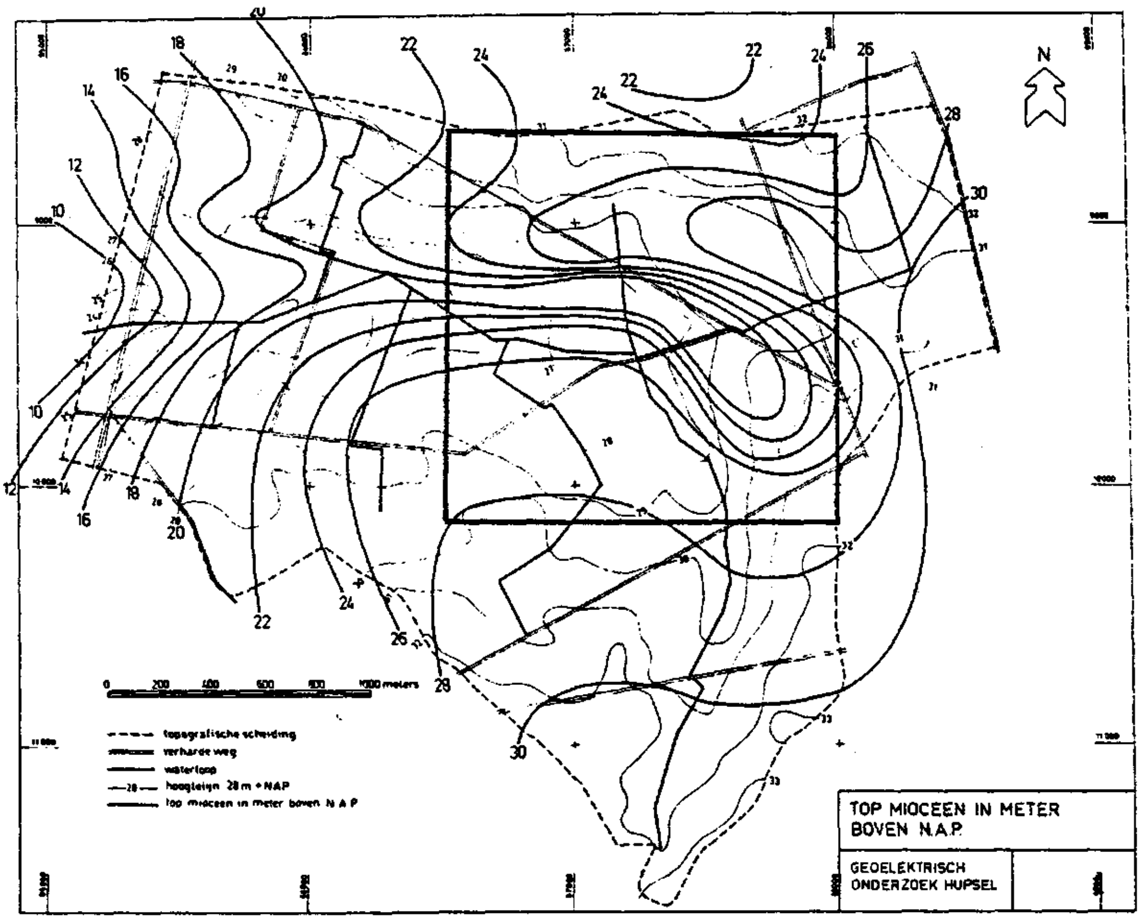


Figure 2.2 Rhine sediments of the Urk Formation deposited in gullies in the Miocene surface.

Source: Stuip and Boekelman 1976.

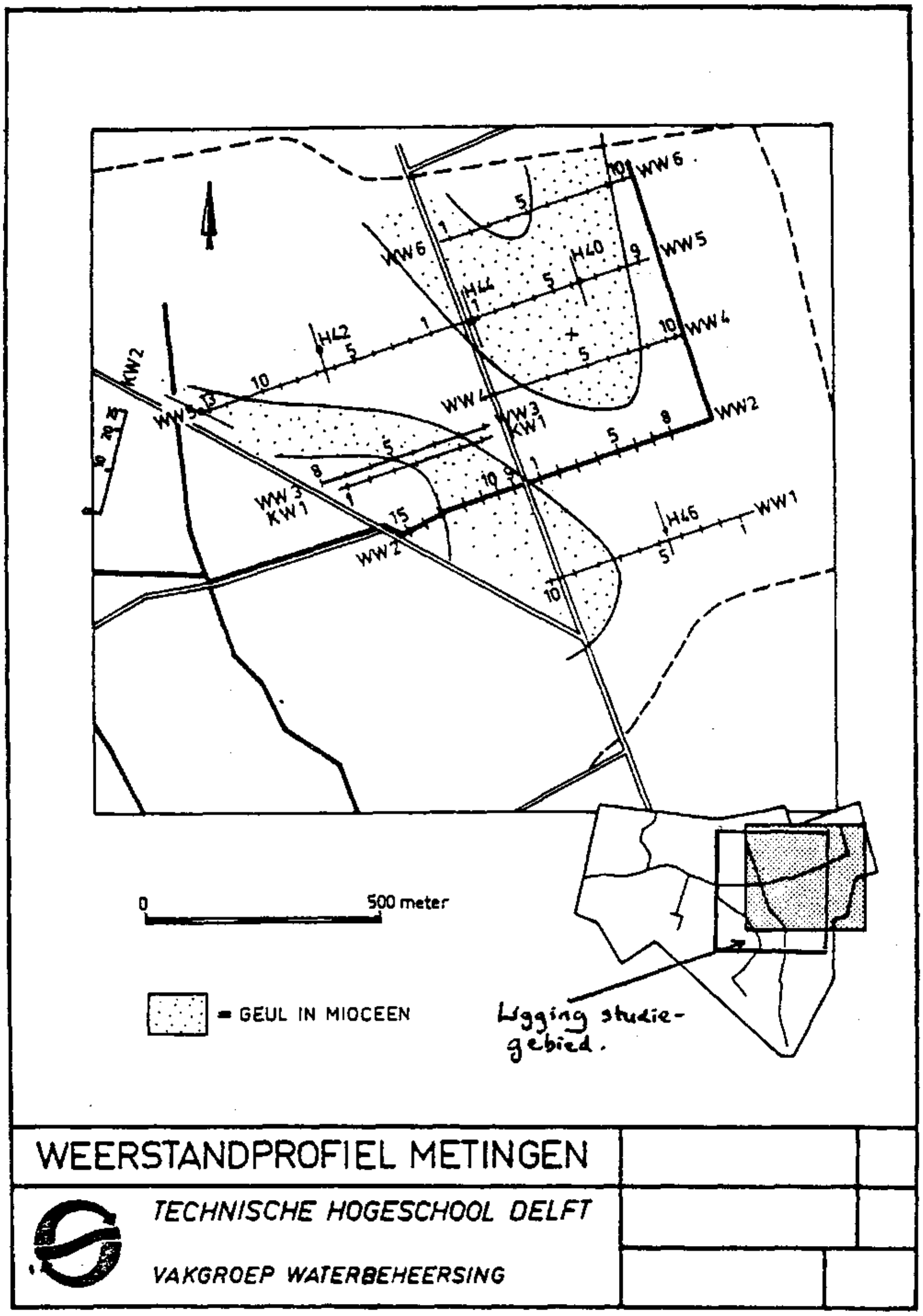


Table 2.1 Stratigraphy of deposits in the Hupselse Beek region

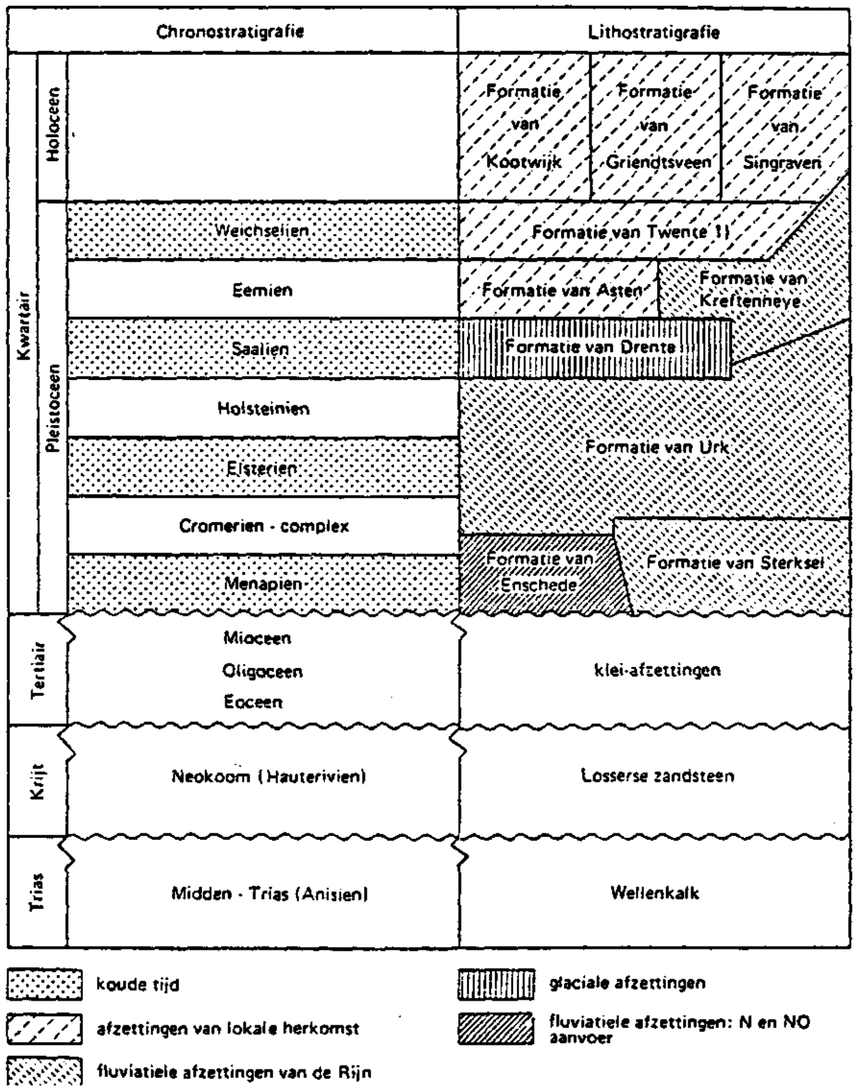


Table 2.2 Deposits of the Twente Formation.

Chronostratigrafie			Afzettingen
WEICHSELIEN	Laat	Late Dryas Stadiaal	jong dekzand II
		Allerød Interstadiaal	veen of laag van Usselo
		Vroege Dryas Stadiaal	jong dekzand I
		Bølling Interstadiaal	veen of leemlaagje
	Midden	Pleniglaciaal	oud dekzand II
			laag van Beuningen
			oud dekzand I veenlagen smeltwaterzanden
	Vroeg		dekzanden met veenlagen

Source (both tables): STIBOKA 1979.

3 DATA COLLECTION AND PREPARATION

3.1 The survey area and sampling strategy

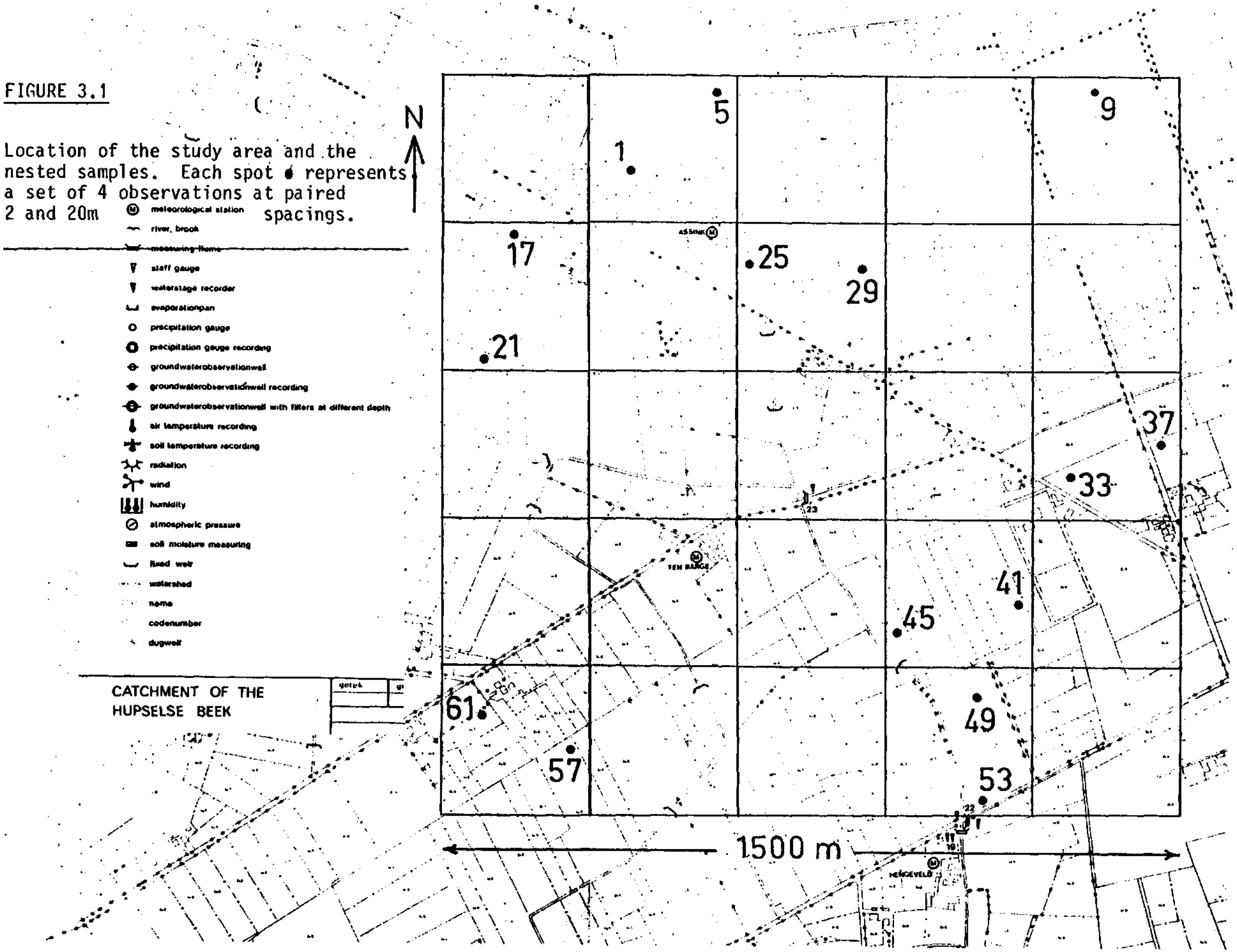
Because the previous surveys undertaken by STIBOKA (STIBOKA 1963, STIBOKA 1979) gave only a general description of the soil of the Hupselse Beek area, there was little information available about the magnitude of the soil variability at a field scale.
Examination of aerial photos and remotely sensed imagery also failed to give any clear indication of the nature of the soil pattern (Oerlemans 1982).
The Geological literature, and the presence of "oude" clay or gravel within 40-120 cm indicated at many places on the STIBOKA (1963) 1:25,000 map, however, suggested that short range variations in the soil might be extreme, particularly for those physical properties associated with water movements. So, before choosing an ad-hoc large map scale for detailed survey, it was thought reasonable to conduct pre-survey investigations of the scale and nature of the short range variations. Such a study might well enable time and money to be saved by subsequent survey by indicating the scale of soil patterns, approximate sampling intervals for mapping or detailed study (Nortcliff 1978), and an appropriate classification scheme. This reconnaissance study was carried out in a 1500 m x 1500 m sample area located approximately in the middle of the catchment (fig. 3.1). The field survey of 64 profiles was undertaken in November 1981 and took 2½ days.
In order to estimate the scales at which the soil pattern changed and so suggest the most efficient mapping scale, a technique was required that could give information about how the variance of soil properties varied with distance. In principle, this can be done by laying a number of regular transects over the area, and computing how the semivariance, or half the variance of differences

$$2\gamma(h) = \mathrm{Var}\ [(Z(x) - Z(x + h)]$$

varies with sample spacing h. In principle, one may expect that $\gamma(h)$ may rise from a low value calculated over the smallest sampling interval to a constant value or sill that is reached at a critical distance known as the range. Sampling points located further apart than the range cannot be used for interpolation of soil bounderies without the help of external features because, statistically, they are independent from each other. Experience suggests that a sample spacing of approximately a quarter to one third of the range is the minimum that can be used for interpolation.

FIGURE 3.1

Location of the study area and the nested samples. Each spot ● represents a set of 4 observations at paired 2 and 20m spacings.



To estimate over an area of 1.5 x 1.5 km how variance increases with distance requires a large number of samples along transects if one is interested in all scales of variation corresponding to sample spacings from a few meters to several 100 meters. Alternatively, one can sample on a regular grid, or in a stratified random manner (eq. Webster 1977), but even though fewer samples may be needed (a 100 m x 100 m grid would require 225 sample points) one cannot estimate the variance over shorter distances than the average inter-sample spacing. When the scale of spatial variation is not known, it is not sensible to invest expensive manpower in intensive sampling programmes but more reasonable to begin by using a simple technique that may give an estimate of how the variance changes over roughly logarithmically increasing scales (Webster 1977, Nortcliff 1978). Such a system may be more efficient for guessing spatial structure scales than the use of the semivariogram computed from linear transects (Burrough and Kool, 1981).

Once the scales of variation have been estimated, accurate determination of the autocorrelation structure of the area can be obtained from transects whose sample interval has been adjusted to make optimal use of the knowledge gained (Burgess et al 1981).

The technique of nested sampling, backed up by nested analysis of variance (Cochran 1963, Webster 1977) was used to estimate how level of variation altered with sample spacing. The results were compared with those obtained by variogram analysis of the same data (see next section).

The 1500 x 1500 m area was divided into 25 300 x 300 m squares. Eight of these squares were chosen at random using a table of random numbers (Snedecor 1956).

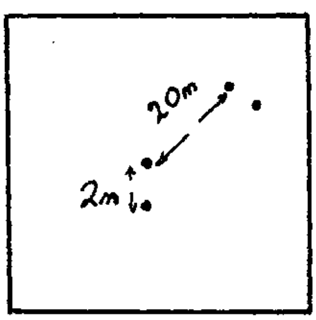


Fig. 3.2 Layout of the sampled points

The resulting set of 64 sample points consisted of 32 replicates over 2 m, 16 over 20 m, 8 over 200 m, and 8 over 1000 m (the average spacing of the 300 x 300 m squares, nested as shown in figure 3.3. The locations of the groups of points over the whole study are shown on Figure 3.1.

Each square was further divided into 25 subsquares measuring 60 x 60m. For each square, 2 subsquares were selected at random, with the constraint that subsquares were approximately 200 m from each other.
The mid-point of each sub-square was visited, and a soil boring made. The surveyor then moved 2 m in a randomly chosen direction and made a second boring. He then moved 20 m in another randomly chosen direction, made a third boring; thereafter a fourth boring was made another 2 m away, also in a random direction (Figure 3.2). The random directions were decided beforehand.
In one instance, a sub-square could not be sampled because the farmer refused permission. The sites were transferred to another site within the square in accordance with the sampling design (sites 49 to 52).

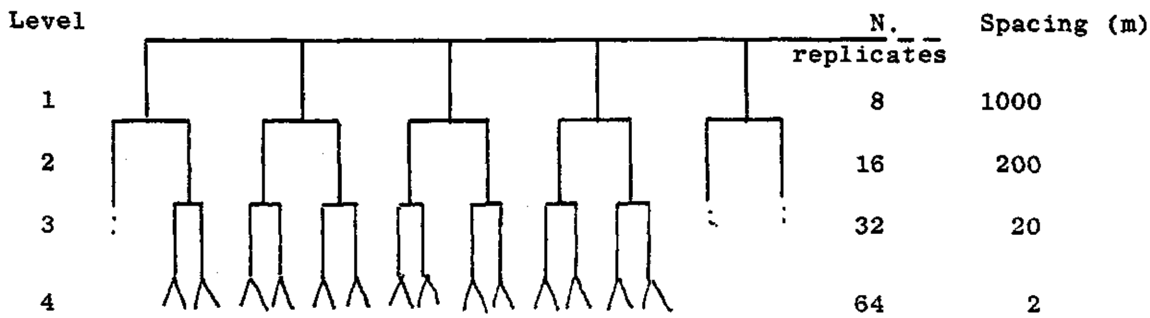


Figure 3.3 The sample pattern hierarchy

The advantage of this nested system of sampling is that it returns information over several distinct scales of soil variation (Webster 1977, Nortcliff 1978). Locating the same number of points on a regular grid would take longer and would only allow resolution of features some 200 m across. The disadvantages are that sampling is unequally spread over the various distances; the choice of sample spacing is regrettably somewhat arbitrary (why 2 m, 20 m, 200 m and not 5 m, 50 m, 500 m?) and the use of logarithmically increasing differences gives large gaps in sample spacing.

3.2 Soil profile sampling

Each profile was bored to a depth of 130 cm. The following data were recorded:

Profile number	- sequential 1-64
Profile classification	- STIBOKA code for profile
Bodemeenheid	- STIBOKA map unit class
Landuse	- Cropland 1, Grassland 2.
Effective rootable depth	- depth (from surface in which 80% of roots occur) (cm)
Depth to rust mottles	(cm)
Depth to grey, reduced layer	(cm)
Depth to an impermeable layer	(cm)
Thickness of an impermeable layer	(cm)
Depth to clay	(cm)
Number of pedological horizons	(cm)
Actual groundwater level (at the end of the survey day)	(cm)

For each horizon:

Horizon code

Beginning depth (cm)

End depth (cm)

Thickness (cm)

% clay (lutum < 2µm)

% silt (2 - 50µm)

M 50 Sand. Median particle size (µm)

Boorweerstand (resistance to boring) Class: 0 - 4

Gelaagdheid (degree of layering) Class: 0 - 4

Organic matter content %

The data were recorded on special form (Appendix 2) for ease of computer input. Appendix 1 contains these data.
If a particular property could not be measured, its missing value was indicated by -1.

Certain properties (depth to gley, depth to clay) could not be properly estimated because the gley or clay were not reached within 130 cm. These "missing values" were indicated by entering the value 130. This is not an ideal solution, but represents a pragmatic compromise to make the best use of the information available.

Such a compromise allows one to compute new variables such as "Thickness of keileem found within the bored profile" = 130 - Depth to keileem.

The actual groundwater level was measured by leaving the auger holes open for a few hours to allow the groundwater to reach equilibrium before the depths were measured.

Topographic heights at each borehole were estimated from contours plotted on a 1 : 10,000 map of the area.

3.3 Data preparation

During the survey, the surveyor recorded the data according to the number of horizons he perceived. This meant that the number of horizons per profile differed (range 3-6), with a consequent variation of the number of variables per profile. The data were first examined to see how great differences between horizons were when more than 4 had been recorded. In every case, the extra divisons had been apparently made on colour criteria that were not reflected in the texture, boorweerstand or gelaagdheid criteria. For profiles with only 3 horizons, examination revealed the presence of a very deep, homogenous C layer that could equally well have been split in two. On the basis of this examination it was decided to reduce all profiles to 3 "textural layers" for the subsequent analysis. The A horizons reamined the same overall, as did the lowest horizon. The reorganisation was performed using the HAKFIL Data Base Management program (Burrough 1981). At the same time, the data were examined for input errors and inconsistencies; those found were corrected. The actual horizons analysed were the plough layer (A horizon) the B horizon (upper layer, dominantly aeolian sand (c. 20-60cm), the D horizon (lowest layer, often clay from 80-130 cm).

Initially, 40 properties were analysed. Inspection of the results revealed that of these, only 21 showed sufficient variation to warrant further analysis.

These were:

Property number	Property code	Description
P1	BWD	Rootable depth (cm)
P2	DMOT	Depth to iron mottles (cm)
P3	DRED	Depth to reduced (gleyed) zone (cm)
P4	DSL	Depth to a more compact layer (cm)
P5	DIKSL	Thickness of a compact layer (cm)
P6	DCLAY	Depth to a clay layer (cm)
P7	AGW	Actual groundwater level (cm)
P8	ADIK	Thickness of the A horzon (cm)
P9	ALUT	Clay content (2 m %) A horizon
P10	ALEEM	Silt " (2-50 m %) A horizon
P11	AM50	Median sand size fraction A " (µm)
P12	AORG	Organic matter content (%) A horizon
P13	BDIKTE	Thickness of the B horizon (cm)
P14	BLUT	Clay content (2 m %) B horizon
P15	BM50	Median size sand fraction (µm) B horizon
P16	BBW	Compactness, B horizon (qualitative scale)
P17	BGLAG	Degree of layering, B horizon (qual. scale)
P18	DLUT	Clay content (2 m %) D horizon
P19	DM50	Median size sand fraction D horizon (µm)
P20	DBW	Compactness, D horizon (qual. scale)
P21	DGLAG	Degree of layering, D horizon (qual. scale).

Figure 3.4 shows the histograms, together with the means, standard deviations, minima and maxima of these data. Many of these show roughly unimodal normal distributions, but some, such as the depths to iron mottles, reduced gleyed layer, impermeable layer and clay and %clay of the D layer show multimodal distributions. The M50 layer of the B horizon is extremely skew, owing to the presence of coarse sand in one or two profiles. This variable was transformed to logarithms for the subsequent analysis.

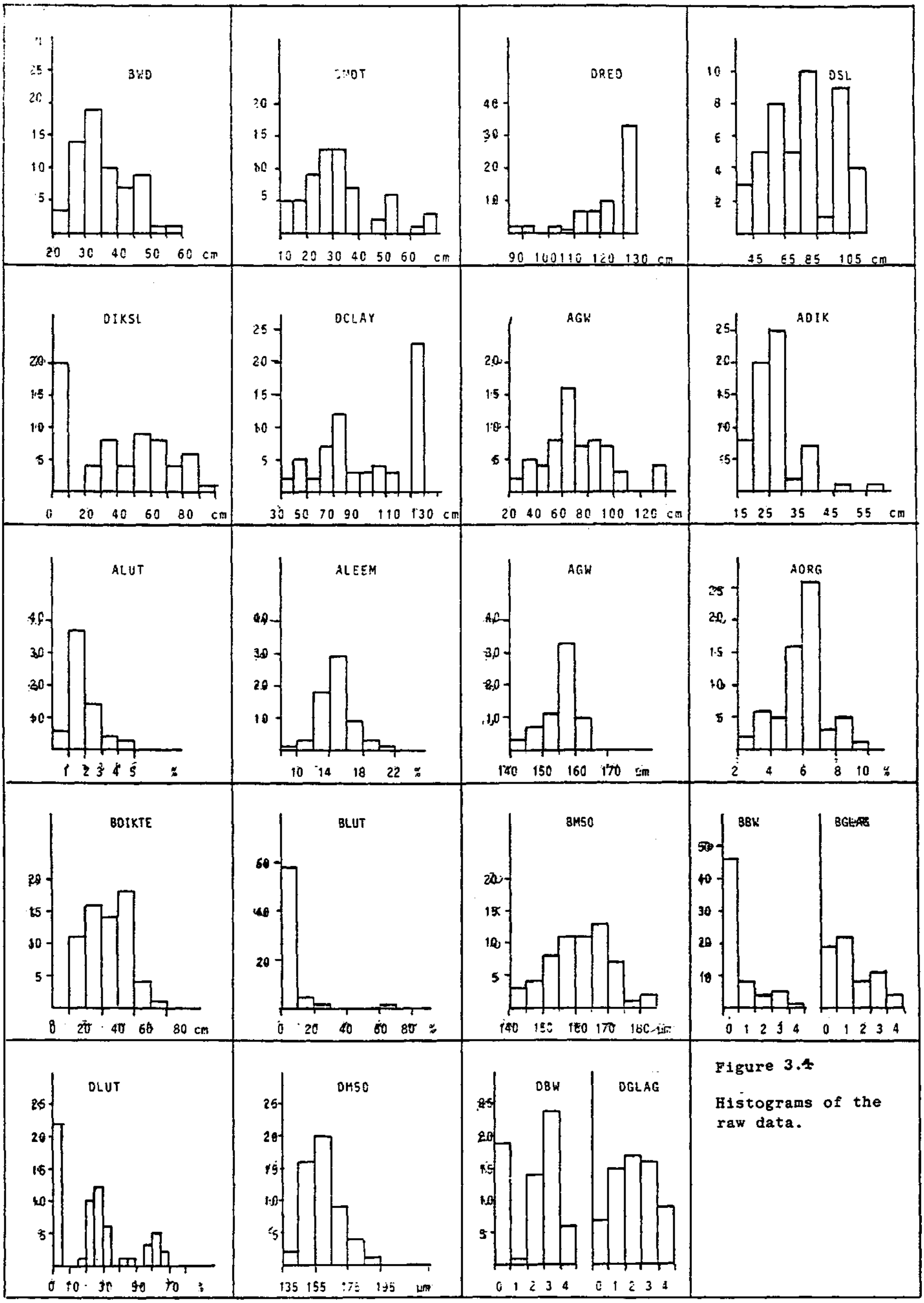


Figure 3.4

Histograms of the raw data.

TABULATED SUMMARY OF FILE HUP.GEG

N OF POINTS = 64 N OF VARIABLES = 22

PROPERTY	MEAN	SDEV.	MIN.	MAX.	RANGE	NMIS
BWD	33.31	7.98	20.00	55.00	35.00	0.00
DMOT	29.88	13.75	10.00	65.00	55.00	0.00
DRED	120.67	12.10	85.00	130.00	45.00	0.00
DSL	73.69	21.79	35.00	110.00	75.00	19.00
DIKSL	37.16	30.06	0.00	92.00	92.00	0.00
DCLAY	93.22	32.23	38.00	130.00	92.00	0.00
AGW	70.97	25.63	20.00	130.00	110.00	0.00
ADIK	25.58	6.77	15.00	55.00	40.00	0.00
ALUT	2.39	0.92	1.00	5.00	4.00	0.00
ALEEM	14.13	2.04	9.00	20.00	11.00	0.00
AM50	153.13	5.16	140.00	160.00	20.00	0.00
AORG	5.57	1.35	2.50	9.00	6.50	0.00
BDIK	31.34	13.20	10.00	60.00	50.00	0.00
BLUT	4.01	9.28	0.00	65.00	65.00	0.00
BM50	151.35	35.31	0.00	180.00	180.00	1.00
BBW	0.55	1.02	0.00	4.00	4.00	0.00
BGLAG	1.36	1.25	0.00	4.00	4.00	0.00
DLUT	20.17	20.18	0.00	65.00	65.00	0.00
DM50	157.40	10.12	135.00	185.00	50.00	12.00
DBW	1.95	1.41	0.00	4.00	4.00	0.00
DGLAG	2.08	1.23	0.00	4.00	4.00	0.00

Figure 3.4 continued:

4 UNIVARIATE STATISTICAL SPATIAL ANALYSIS: THEORY AND RESULTS

As pointed out in the previous section (3.1) the scales of variation of a pattern can be sought from interpretation of either the semivariogram or from a nested, or hierarchial analysis of variance. Although semivariograms are most easily estimated from regularly spaced samples, they can also be calculated from irregularly spaced samples by replacing the fixed "lag" or sampling interval by a search radius. In this way the semivariance can be calculated using every pair of points to maximum advantage: far more replicates are possible at each scale than are allowed by the nested analysis of variance. One must not forget, however, that in both cases the overall degrees of freedom are governed by the number of observations.

Although the technique of nested analysis and semivariogram analysis should yield similar results when applied to the same data set (see for example, Miesch 1975), there seem to be few published examples comparing their merits. So an attempt was made here to examine the results of applying both techniques to the set of data from the 64 nested points.

4.1 The estimation of semi-variances

For a regionalized variable $Z(x)$, which takes a value at every point x of coordinates (x_1,x_2) in two-dimensional space, the semi-variogram $\gamma(h)$ is defined by:

$$\gamma(h) = \tfrac{1}{2}\,\mathrm{Var}[Z(x)-Z(x+h)] \qquad (1)$$

where h is distance.

If the 'intrinsic hypothesis' holds:

$$E[Z(x)-Z(x+h)] = 0 \qquad (2a)$$

$$\mathrm{Var}[Z(x)-Z(x+h)] = 2\gamma(h) \qquad (2b)$$

The population semi-variogram $\gamma(h)$ is estimated without bias by the sample semi-variogram $\hat{\gamma}(h)$:

$$\hat{\gamma}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i)-z(x_i+h)]^2 \qquad (3)$$

where $z(x_1)$ are the experimental values ('realizations of $Z(x)$') at points x_i such that data are available at x_i and x_i+h, and N(h) is the number of pairs of data points separated by a gap equal to h. In case of a random or nested design the paired data are grouped according to distance classes.

The semi-variogram is a tool of great use:

(a) to obtain insight in the structural properties of the regionalized variable $Z(x)$

(b) to calculate estimation variances and to compare various interpolation schemes

(c) in the application of kriging.

The influence of random errors on the estimation of the semi-variogram is given by GANDIN (1965) and will not be discussed here. The following practical rules may be given concerning the estimation of the semi-variogram (JOURNEL and HUIJBREGTS; 1978): $N(h) > 30$ pairs, and the experimental semi-variogram should only be considered for small distances ($h<L/2$) in relation to the dimension L of the domain on which it has been computed. The first rule follows from the well-known property (KENDALL and STUART; 1958. p.235) that in the case of Normally distributed increments $[Z(x_i - Z(x_i+h)]$ the variance of the estimator $\underline{s}^2$ of the population variance σ^2 equals:

$$\text{var } \underline{s}^2 \approx 2\sigma^4/N(h)$$

so that: (4)

$$\frac{\text{var } \underline{s}^2}{(\sigma^2)^2} \approx \frac{2}{N(h)}$$

So for a relative variance less than 5%, $N(h)$ should exceed 40. The second practical rule follows from the fact that only one realization of $Z(x)$ is known. In case of a linear population semi-variogram

$\gamma(h) = \alpha h$

, where α is a coefficient, and in the case the realization $z(x)$ is known on all points of V, and with the help of all this information $\gamma(h)$ was estimated by the estimator $\hat{\gamma}'(h)$, it can be shown (MATHERON; 1971) that the relative variance of this estimator equals:

$$\frac{\text{var}(\hat{\gamma}'(h))}{[\gamma(h)^2]} = \begin{cases} \left(\frac{4}{3}\frac{h^3}{L-h} - \frac{1}{3}\frac{h^4}{(L-h)^2} \right) \alpha^2 & (h<L/2) \quad (5a) \\ \left(2h^2 + \frac{1}{3}(L-h)^2 - \frac{4}{3}h(L-h)\right) \alpha^2 & (h>L/2) \quad (5b) \end{cases}$$

So as soon as h is not very small compared with L, the relative variance becomes very large and statistical inference is no longer possible.

According to (3), the semi-variogram was estimated for quantitative physical properties, measured on a linear scale and with clearly marked missing values,

if they occurred. So properties DRED, DCLAY, AGW, BBW and DBW were discarded. Pairs of data were grouped in distance classes 0-150m, 150-300m,.... (fig. 3.1 shows the configuration of sample points). The calculated semi-variograms $\hat{\gamma}(h)$ are presented in fig. 4.1. Please note that the sample scheme used prevented the estimation of semi-variances for distances between 20 and 200 m.
Visual inspection showed that each of the semi-variograms has a range $b<L$. An exponential model was chosen for $\gamma(h)$:

$$\gamma(h) = C\delta + \lambda_1(1-\exp(-h/\lambda_2)) \qquad (6)$$

where:

C = 'nugget-effect'

$\delta = 0(h=0)$ or 1 $(h\neq 1)$

λ_1, λ_2: coeffcients (note: the range $b\approx 3\lambda_2$)

However, for soil properties ALUT, BLUT and DLUT a linear model was chosen according to:

$$\lambda(h) = C\delta + \lambda_3 h \qquad (7)$$

Estimation of the coefficients in (6) and (7) should not be done by 'blind' application of some criterion. Here it was felt that due attention should be given to the estimation of C.
The 30 pairs of data at the very small distance (relative to the working scale and to the dimension L of the domain) of 2 meter were used for a direct calculation of C, equal to $\hat{\gamma}(h=2m)$. The coefficients λ_1 and λ_2 were optimized for distances $2<h<750$m, using the Levenberg-Marquardt version of the non-linear least-squares procedure (ABDY and DEMPSTER; 1974). The coefficient λ_3 was calculated by simple regressions, also for distances $2 < h < 750$ m.
The resulting fitted semi-variograms are also shown in fig. 4.1. In table 4.1 the parameters of the fitted semi-variogram for each of the soil properties are listed. Values of the semi-variogram and of the parameters λ_1 and C are expressed in squares of measurement units [mu^2].

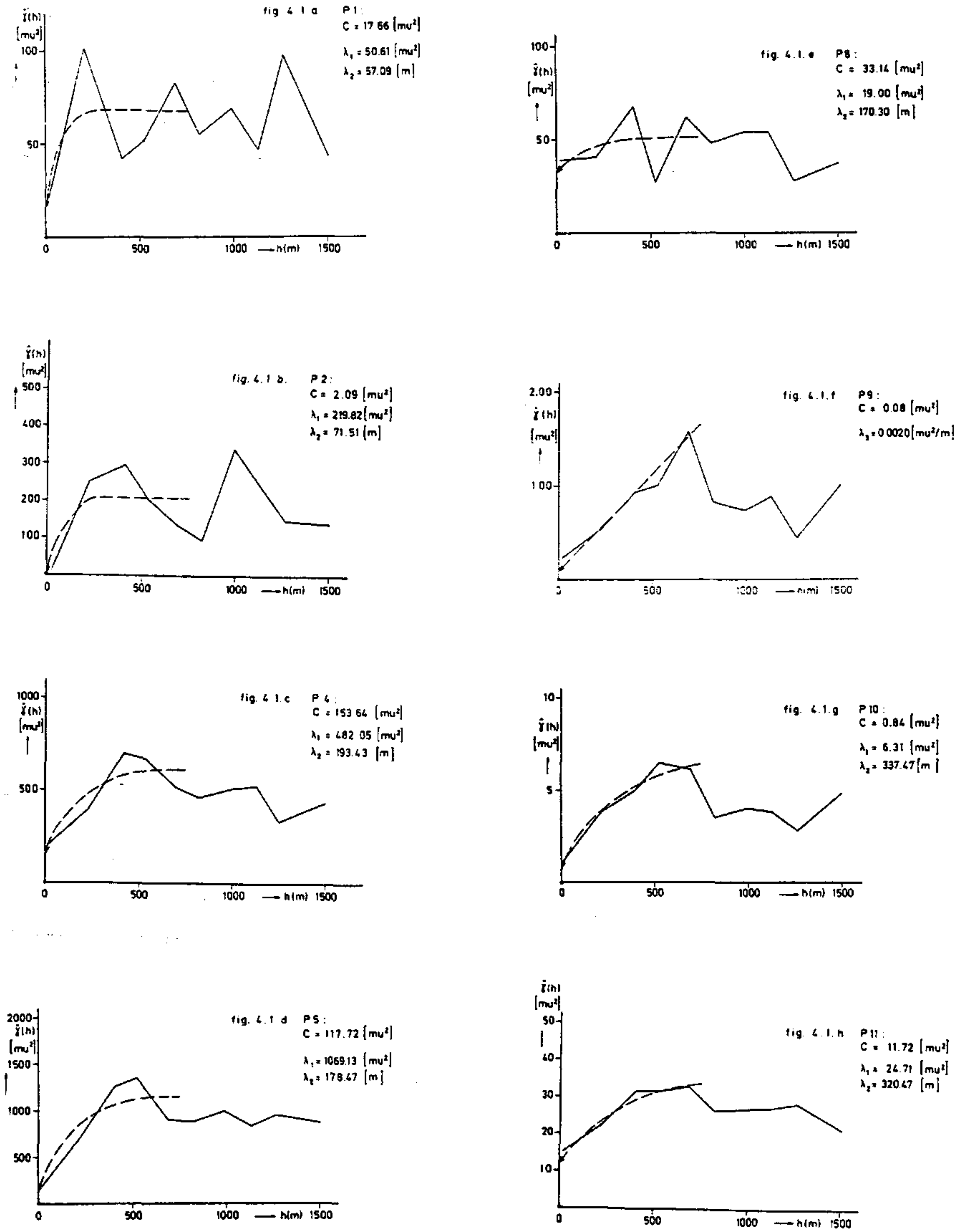


Figure 4.1 Semivariograms

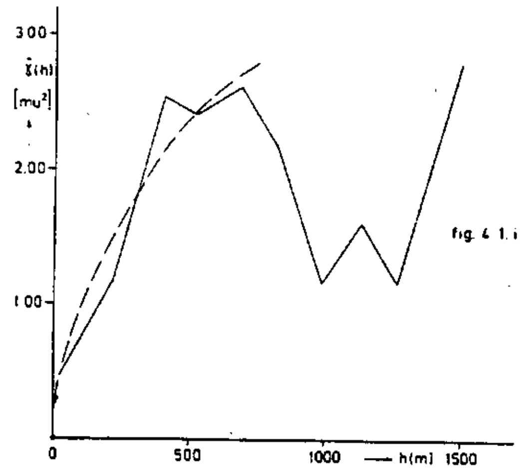


fig. 4.1.i P12:
$C = 0.27$ [mu^2]
$\lambda_1 = 3.06$ [mu^2]
$\lambda_2 = 424.68$ [m]

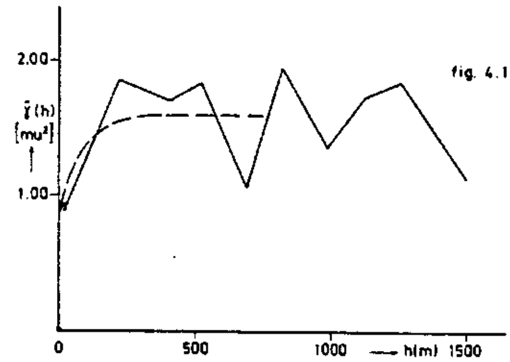


fig. 4.1.m P17:
$C = 0.86$ [mu^2]
$\lambda_1 = 0.75$ [mu^2]
$\lambda_2 = 68.23$ [m]

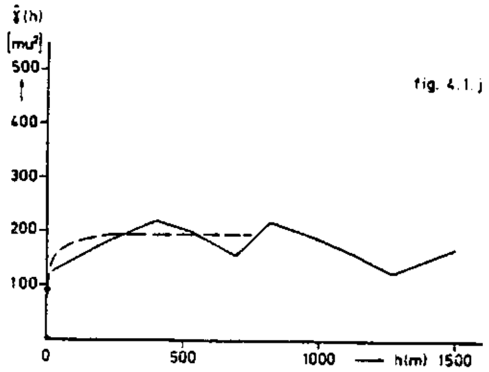


fig. 4.1.j P13:
$C = 73.84$ [mu^2]
$\lambda_1 = 115.14$ [mu^2]
$\lambda_2 = 19.11$ [m]

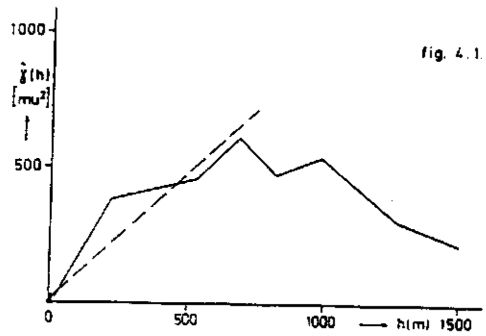


fig. 4.1.n P18:
$C = 10.36$ [mu^2]
$\lambda_3 = 0.95$ [mu^2/m]

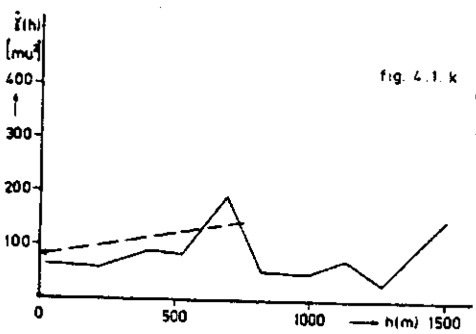


fig. 4.1.k P14:
$C = 79.96$ [mu^2]
$\lambda_3 = 0.086$ [mu^2/m]

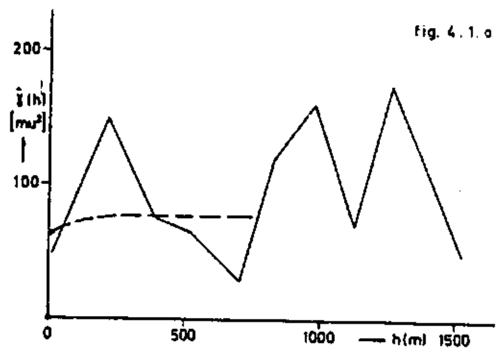


fig. 4.1.o P19:
$C = 61.06$ [mu^2]
$\lambda_1 = 16.12$ [mu^2]
$\lambda_2 = 55.31$ [m]

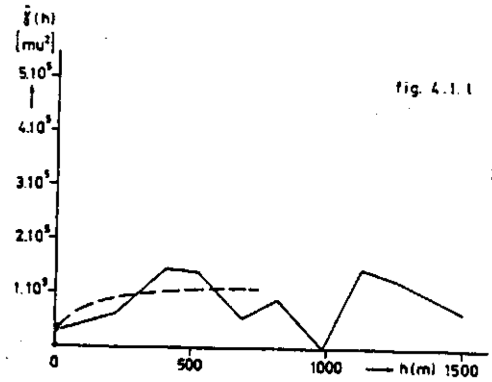


fig. 4.1.l P15:
$C = 0.25 \times 10^5$ [mu^2]
$\lambda_1 = 0.85 \times 10^5$ [mu^2]
$\lambda_2 = 158.42$ [m]

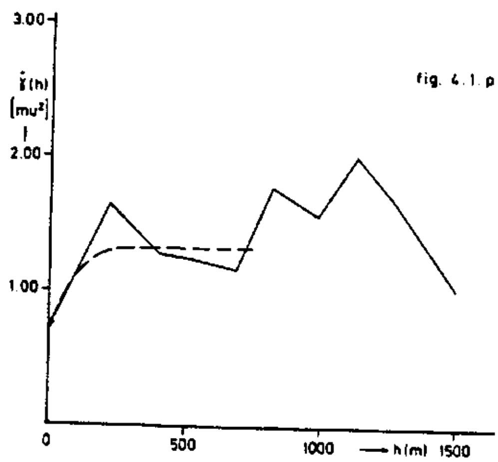


fig. 4.1.p P20
$C = 0.67$ [mu^2]
$\lambda_1 = 0.66$ [mu^2]
$\lambda_2 = 51.87$ [m]

Table 4.1 Parameters of the fitted semi-variograms

Exponential semi-variogram

Soil property	$C[mu^2]$	$\lambda_1[mu^2]$	$\lambda_2[m]$
P1-BWD	17.66	50.61	57.09
P2-DMOT	2.09	219.82	71.51
P4-DSL	153.64	482.05	193.43
P5-DIKSL	117.72	1069.13	178.47
P8-ADIK	33.14	19.00	170.30
P10-ALEEM	0.84	6.31	337.47
P11-AM50	11.72	24.71	320.47
P12-AORG	0.27	3.06	424.68
P13-BDIKTE	73.84	115.14	19.11
P15-BM50	$0.25*10^5$	$0.85*10^5$	158.42
P17-BGLAG	0.86	0.75	68.23
P19-DM50	61.06	16.12	55.31
P20-DBW	0.67	0.66	51.87

Linear semi-variogram

Soil property	$C[mu^2]$	$\lambda_3[mu^2/m]$
P9-ALUT	0.08	0.0020
P14-BLUT	79.96	0.086
P18-DLUT	10.36	0.95

The following comments are made:

1. only physically plausible structural properties may be concluded from the semi-variogram.
2. the semi-variograms exhibit strong pseudo-periodic fluctuations beyond 200-500 m. The assumption of periodicity of the soil properties is, however, not very plausible, because the phases of the fluctuations differ for different soil properties. Most likely the fluctuations are a consequence of the discrete sampling and of the very skew distributions of some of the soil properties.
3. none of the sampled properties exhibits a spatial trend (drift).
4. some of the properties have a small short-distance variability: DMOT, AORG, DLUT.
5. some properties exhibit a spatial behaviour like that of 'white noise': e.g. ADIK, DM50.

4.2 Nested analysis of variance

4.2.1 Theory

The aim of nested analysis of variance is to partition the variance of a set of samples into a number of hierarchically arranged levels. The technique is an extension of the more familiar one-way analysis of variance to more than 2 levels; i.e. groups are split into a number of subgroups which are then sampled.

The terms for estimating the variance components at each level are given in Table 4.2.

Table 4.2

Source	Degrees of freedom	Sums of squares	Components of variance estimated by mean square
Stage 1 Between stations	$n_1 - 1$	$\sum_{i=1}^{n_1} n_2 n_3 n_4 (\bar{x}_i - \bar{x})^2$	$\sigma_4^2 + n_4\sigma_3^2 + n_3 n_4 \sigma_2^2 + n_2 n_3 n_4 \sigma_1^2$
Stage 2 Between sub-stations within stations	$n_1(n_2 - 1)$	$\sum_{i=1}^{n_1}\sum_{j=1}^{n_2} n_3 n_4 (\bar{x}_{ij} - \bar{x}_i)^2$	$\sigma_4^2 + n_4\sigma_3^2 + n_3 n_4 \sigma_2^2$
Stage 3 Between areas within sub-stations	$n_1 n_2 (n_3 - 1)$	$\sum_{i=1}^{n_1}\sum_{j=1}^{n_2}\sum_{k=1}^{n_3} n_4 (\bar{x}_{ijk} - \bar{x}_{ij})^2$	$\sigma_4^2 + n_4\sigma_3^2$
Stage 4 Between sampling points within areas	$n_1 n_2 n_3 (n_4 - 1)$	$\sum_{i=1}^{n_1}\sum_{j=1}^{n_2}\sum_{k=1}^{n_3}\sum_{l=1}^{n_4} (x_{ijkl} - \bar{x}_{ijk})^2$	σ_4^2
Total	$n_1 n_2 n_3 n_4 - 1$	$\sum_{i=1}^{n_1}\sum_{j=1}^{n_2}\sum_{k=1}^{n_3}\sum_{l=1}^{n_4} (x_{ijkl} - \bar{x})^2$	

For each stage g, n_g is the number of subdivisions within each class of stage $g - 1$, and σ_g^2 is the component of variance. Group means at each stage are indicated by appropriate subscripts, and the general mean by $\bar{x}$.

Quite early on in spatial studies of soil and geology (see Miesch, 1975 and Webster 1977 for references) it was realised that if each level in the hierarchy were associated with a different sampling interval, the analysis would estimate how variance changed with sample spacing. If an abrupt change in variance occurred from one sampling interval to the next, this would indicate that the smaller sample spacing had resolved a pattern that had not been detected by the less intensive survey. Alternatively, if the variance did not increase with sampling interval, the increased sampling effort and costs would be to no advantage. Clearly, nested or hierarchical sampling appears to have something to offer in terms of a pre-survey reconnaissance technique (cf Webster 1977, Nortcliff 1978).

As can be seen from Table 4.2, nested analysis of variance estimates the deviations from group/subgroup etc. means in a classical manner. Because variance is cumulative, the total variance at a given level is the sum of all the variance components at lower levels plus the variance of the level itself. When the samples are arranged in a spatial hierarchy according to distance, the total variance at a certain level is the variance of a block of land having dimensions corresponding to the sample spacing at that level. Therefore if at level 1 the spacing averages 1000m, at level 2, 200m, at level 3, 20m and at level 4, 2m, the cumulative variance at level 2, (built up out of contributions from levels 2, 3 and 4) equates the variance within blocks of land corresponding to 200m across.

The Nested Analysis of variance was carried out using program NESTAN written in FORTRAN-10 by P.A.B. The program reports the overall means and standard deviations per variate, the sums of squares, degrees of freedom mean square, F-value of variance ratio for (Level n/level n+1), and the estimated variance per level. Cumulative variances are reported as percentages of the variance estimated for the whole area.

The variance at any level must be greater or equal to zero, but it can happen that the estimated mean square at a higher level is less than that estimated at a lower level. This is caused by sampling variations or by the model being invalid; it most commonly occurs when differences at the higher levels are unimportant compared with those at lower levels. In these cases, F-values are less than 1, and the program automatically sets the variance of the level to zero. In these cases the ANOVAR table can be recomputed as follows: (J.B. Kool, 1981). The "negative" components are set equal to zero, and the other variance components are recomputed. The sum of squares of the level that originally had "negative" variance is added to the sum of squares of the next lower level. The degrees of freedom of both levels are summed and a new mean square is calculated for the two levels jointly.

For example:
variate: ADIK

level	SS	df	MS	S^2
1	695.5	7	99.35	7.48
2	316.4	8	39.55	0.00
3	817.3	16	51.08	9.97
4	1060.5	32	33.14	33.14
total	2889.6	63	45.87	

The MSquare of level 2 is lower than that of level 3 implying "negative" variance. The variance is reworked as

$$S^2 = (SS_2 + SS_3) / (df_2 + df_3)$$
$$(316.4 + 817.3)/(8 + 16)$$
$$= 1133.7/24$$
$$= 47.22$$

The new anova table is therefore

level	SS	df	MS	S^2
1	695.5	7	99.35	6.54
2	---	-	---	---
3	1133.7	24-	47.22	7.04
4	1060.5	32	33.14	33.14
total	2889.6	63		

The results are equivalent to that from an analysis in which level 2 was not sampled.

4.2.2 Results

All 21 variables were submitted for analysis; table 4.2 presents results, which are also presented graphically in Figure 4.2.

These results can be summarised as follows:

a. There are several properties, mainly associated with the A and B horizons (A thickness, AM50, B thickness, B%clay, B boorweerstand, B degree of layering) that have more than 60% of the variance reached within 20m; often the variance within 2M is more than 50% of the total for the area. These are mainly very homogenous properties (to judge by their low, overall standard deviation) that vary little over the area. They would not be useful as mapping criteria.

b. There is a large group of properties including many profile characteristics and D-horizon properties (rootable depth, depth to iron mottles, depth to reduced zone, thickness of impermeable layer, depth to clay, D%clay, DM50, D Boorweerstand and D degree of layering) that shows little increase of variance from 2-20m, but then shows a large jump, often to 100% by 200m. 2m variances are usually small. This behaviour is to be interpreted as reflecting a pattern of subsoil variation, important for profile drainage, that changes on average between 20 and 200m. It reflects possibly, an al-

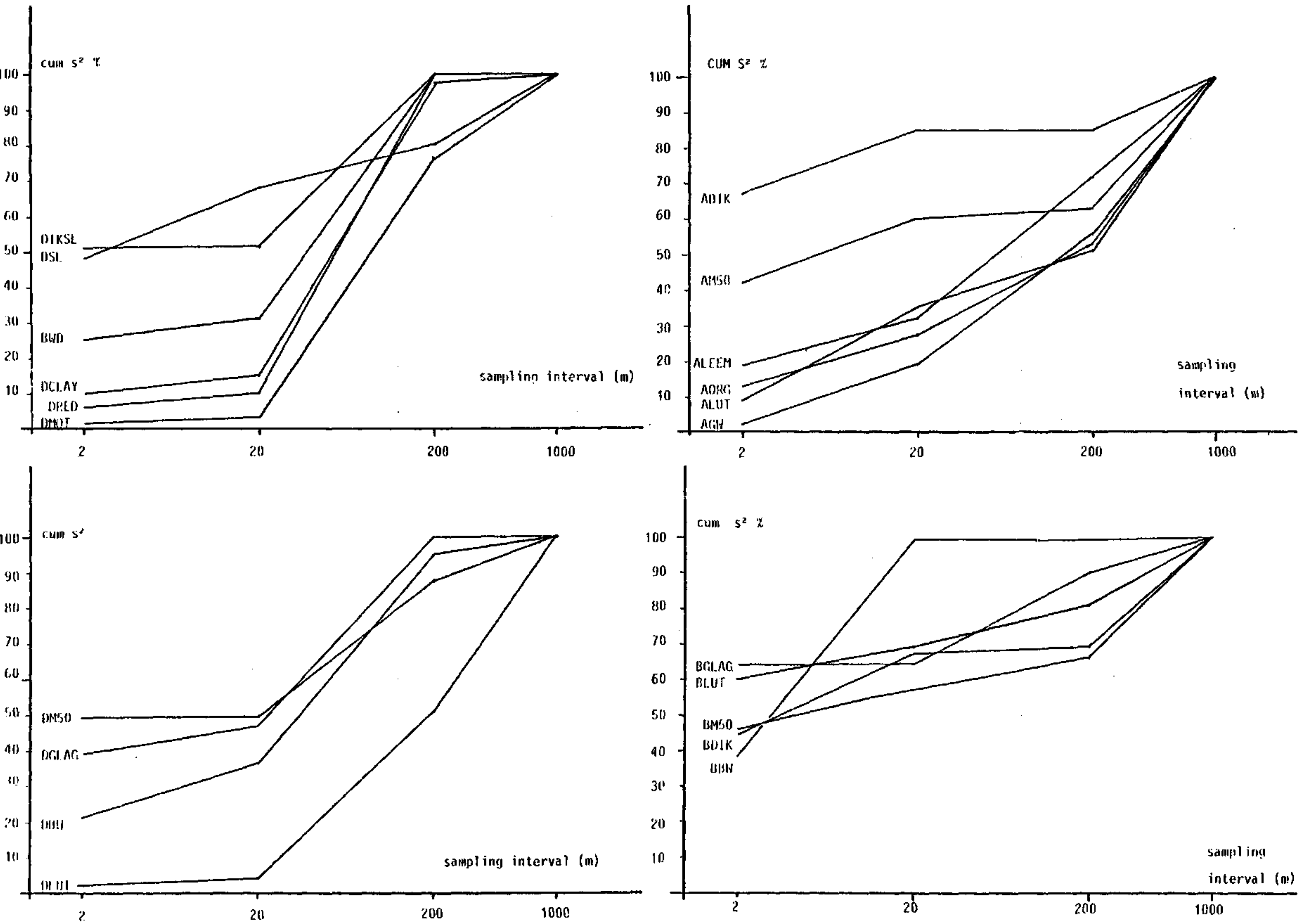


Figure 4.2 Variograms resulting from the nested analysis of variance

Table 4.2 Summary of nested variance analysis results

Property	Overall Mean	Overall Sd.	Variance contributions 2m	20m	200m	100m
Rootable depth	33.3	8.4	25	6	69	0
Depth iron mottles	29.8	14.2	1	2	73**	24
Depth gley	120.7	12.5	6	4	90**	0
Depth imperm.	73.7	18.2	48	20	12	20
Thickness layer	41.4	44.5	51	0	49**	0
Depth to clay	93.2	32.2	10	5	83**	2
AGW	71.0	25.6	2	17**	37**	44
A thickness	25.5	6.8	67	18	0	15
A%clay	2.4	0.9	9	26**	16	49
A%silt	14.1	2.0	19	13	40**	28
AM50	153.1	5.1	42	18	2	37
A Org. matter	5.6	1.4	13	14**	26	47
B thickness	21.7	13.6	44	23	1	31
B%clay	1.5	0.7	60	9	11	19
BM50	157.9	8.3	46	8	12	34
B Boorweerstand	0.2	0.7	38	61**	0	1
B Gelaagd	0.5	0.8	64	0	26	10
D%clay	20.2	20.1	2	2	47**	49
DM50	157.5	9.1	49	0	38**	12
D Boorweerstand	2.0	1.4	21	15	59**	5
D Gelaagd	2.1	1.2	39	8	53**	0

**Indicates variance ratio F is larger than tabulated $F_{0.01}$ for these degrees of freedom.

$$\frac{\text{level 1}}{\text{level 2}} \quad \text{Table } F_{7,8} = 6.19$$

$$\frac{\text{level 2}}{\text{level 3}} \quad \text{Table } F_{8,16} = 3.89$$

$$\frac{\text{level 3}}{\text{level 4}} \quad \text{Table } F_{16,32} = 2.62$$

ternating pattern of deep profiles on aeolian sand ridges alternating with profiles overlying shallow clay that could be mapped using a sample spacing of 20m; possibly 50m might also be adequate if these features were related to external aspects of the landscape.

c. the third group represents properties that vary over all spatial scales. These properties are those related to the present topography - ground water depth, A%clay, A%silty, A% organic matter - yet they may also be partially dependent on the subsoil controls. The %clay of the D horizon, though following the general behaviour of class b above, also shows a variation between 200 - 1000m. Inspection of the data values on the map reveals that all the profiles on clay in the south-east third of the area have subsoil textures of 45 - 65%clay, while for the rest of the area the %clay recorded lies between 15 - 25% for profiles with heavy subsoils, or 0 - 2% for profiles totally in aeolian sand.

Comparison of the results of the Nested analysis of variance with those of the semi-variogram analysis leads to the conclusion that both methods give a similar picture of the spatial structure of the data up to a range of 200 m.

5 COMPARISONS OF THE DEGREE OF SUCCESS OF EARLIER SOIL CLASSIFICATIONS; THE SEARCH FOR IMPROVEMENT

5.1 Soil map classes on the STIBOKA maps

During the survey, the surveyor (G.S.) classified each profile according to the map legend class used in the STIBOKA surveys (STIBOKA 1963, 1979). Two main classes of soil were discerned according to this system: Hn21 (Veldpodzolen) and Zg or Zn21 (Beekeerdgronden).

The soil maps and their classifications would only have been useful in the present study if they had distinguished adequately the kinds of soil present. To check this, the relative variance statistic RV%

where

$$RV\% = \frac{\text{within class variance}}{\text{total variance}} \times 100$$

(Beckett and Burrough 1971) was calculated for each of the 21 soil properties when the sample sites were classified according to the soil classification. Table 5.1, column 1 presents the results.

The successful classification should have a lower within-class or residual variance compared with the total; conversely, if the RV is near 100%, the classification has achieved little. The results in Table 5.1 show that on average, the soil classification has not performed well and makes little discrimination between the profiles.

5.2 Classification based on presence/absence of subsoil clay

Because the Nested variance analysis showed that many soil properties apparently co-varied with the presence or absence of clay within 130cm (auger depth) it was decided to use this property as an alternative to the STIBOKA classification. Two classes resulted, and the RV% was recalculated. As Table 5.1 shows, this was a considerable improvement overall, but particularly so for the soil drainage properties of the profile and for those of the D horizon.

5.3 Classification according to presence/absence subsoil clay and soil class

The next strategy was to classify the profiles according to both the soil map class and the presence of clay in the subsoil. The results are in column 3 of Table 5.1. These results are only a slight improvement on average, but for some properties the improvement is considerable: eg depth to iron mottles, actual groundwater level, %clay and %silt of the A horizon, thickness of the B, the %clay and degree of layering of the D.

Table 5.1 Comparison of profile classifications by relative variance %

	CLASSIFICATION SYSTEM			
Soil property	STIBOKA classification	Presence/absence of clay subsoil	STIBOKA and presence/absence of of clay subsoil	STIBOKA and texture of clay subsoil
BWD	100	79*	75*	73*
DMOT	81*	63*	44*	42*
DRED	94	86*	82*	84
DSL	100	100	100	100
DIKSL	100	33*	35*	34*
DCLAY	100	26*	28*	27*
AGW	89*	81*	73*	68*
ADIK	98	99	93	91
ALUT	81*	91*	71*	47*
ALEEM	75*	83*	61*	48*
AM50	89*	96	89*	78*
AORG	95	100	100	94
BDIKTE	96	100	85*	87
BLUT	99	96	96	96
BM50	100	100	99	100
BBW	100	88*	90*	89
BGLAG	100	93	85*	85
DLUT	76*	48*	23*	4*
DM50	100	68*	67*	85
DBW	100	38*	39*	39*
DGLAG	99	93	79*	68*
AVERAGE	93	79	72	69

*Variance ratio > table F0.01

5.4 Classification according to textural class of clay and soil class

The histogram of the texture of the deepest layer in the profile (DLUT) showed a clear trimodal distribution (figure 3.1) Re-examination of the field sheets and the location of the profiles suggested strongly that two kinds of clay were present at depth. These are presumably keileem which has a % clay content ranging between 15-25% and the old Miocene clay, between 45-65%. The Miocene clay profiles had no keileem and occurred in the eastern part of the study area where the Miocene surface comes within 1m of the present topographic surface. The 64 profiles were split into 6 groups according to soil type (Hn21 or Zn21/Zg21) and the texture of the "D" horizon (< 10% = dekzand, 15-35% = "Keileem", > 35% = Miocene clay).

Table 5.2 shows the number of profiles in each class.

Table 5.2 Grouping of profiles by soil class and subsoil texture class

Soil type	Sub soil texture (D)	Number of profiles
Hn21	<10%	18
"	10-35%	26
"	>35%	2
Zn21/Zg21	<10%	5
"	10-35%	3
"	>35%	10

These results show clearly how the podzols are concentrated on the deep sand and sand over keileem. The Beekeerd soils occur dominantly over the more impervious heavy Miocene clay. Table 5.1 shows the relative variances for all data according to this classification. This is overall the best, but is only a marked improvement over the two-way classification for the texture of the A and the D horizons and also partly for the degree of layering in the D. The keileem is layered but the Miocene clay is not.

5.5 Conclusions concerning an optimum classification for the area

The original STIBOKA classification is not suitable for making a detailed soil map of the Hupselse Beek. More attention must be paid to the effect of the underlying sediments in controlling the behaviour of the whole soil profile. It is interesting to note that this result is in accord with studies of the success of German soil classification (Lamp, 1981). Lamp showed that soil parent material provided a better basis for classifying German soil than a classification based on pedogenetic aspects of the soil. This is surely because in most northern European soils there has been insufficient time for weathering effects to dominate over the Pleistocene sediments and rock surfaces. Although it appeared that a single variable, (namely the texture of the subsoil at depths of c80-120cm) could be used as a classification criterion that is easy to recognise and use in the field, it was considered possible that it was only a representative of a more complex, multivariate interaction. Examination of multivariate relations might provide more insight into the soil pattern of the study area and further refine the classification. These studies are reported in the next section.

6 MULTIVARIATE STUDIES OF THE SOIL DATA

The results of the spatial and classification analysis (see previous sections) suggested that many soil properties were strongly correlated with each other. If this could be shown to be so, more information about the way in which soil properties co-varied might lead to further improvements in the suggestions for optimum map scale and map legend for the area. Principal component analysis (Davis 1973, Webster 1977, Webster and Burrough 1972) was used to examine the interrelations between all 21 soil properties. Cluster analysis (Webster and Burrough 1972, Webster 1977) was also used to attempt to improve upon the classification criteria examined in part 5.

6.1 Principal component analysis

6.1.1

The object of principal component analysis is to reduce a complex data set containing many variables to a simpler, smaller set of independent principal components, in such a way that the variance, or information content of the original data, is expressed by far fewer principal components than variables.
Each principal component is a linear combination of the original variables; the greater the correlation between two or more properties, the more nearly equal will be the way in which they contribute to the same component. Full descriptions of the theory can be found in Davis (1973) or Webster (1977). The steps in the analysis are as follows. The M50 property of the B horizon, which showed strong, apparent lognormality, was first transformed.
Second, the variance-covariance matrix is computed. In the SPSS program, the standardised correlation matrix is computed. This results in each property delivering an equal amount of variance (1 unit) to the data set, and circumvents problems when comparing data measured on different scales. The eigenvectors (principal components) and eigenvalues of the correlation matrix describe how groups of variables contribute to independent, or orthogonal, axes of variation. These new axes are automatically chosen so that the first principal component expresses the maximum amount of variance (indicated by the eigenvalue) the second expresses the maximum of the remainder, and so on.
The contributions of the original variable to the principal components can be seen from tables of vector loading scores. Variables with loadings near +1 or -1 make important contributions to a given component. Sometimes there are good physical reasons to link a group of variables giving large contributions and thus interpret the principal component as representing a soil "effect".

Finally, the original sites can be ordered according to their position in the multivariate space defined by the principal component axes. These new coordinates are called principal component scores. They are all standardized to zero mean and variance σ^2.

6.1.2

The data from the 64 sites and 22 variables (topographical height was now included) were submitted for principal component analysis. Examination of the correlation matrix (table 6.1 shows that the properties do fall into several groups. Rootable depth is only weakly correlated with other properties, but correlations between the properties of the profile, the A horizon and the D layer are higher. The properties of the B horizons (=dekzand layer) are generally only correlated with each other.
The first six principal components (Table 6.2) take up 77.1% the total variance; table 6.3 lists the vector loading scores.

6.1.3 Interpretation of the vector loading scores and diagrams (Figure 6.1)

The first two components are dominated by those properties associated with the internal drainage of the profile, while the rest take up variation resulting from only one or two properties acting together. Component 3 expresses mainly the variation of the depth to a impermeable layer (variously the underlying clay or a B_2hfe horizon); component 4 is a relation between the organic content of the A horizon and the thickness of the B horizon; component 5 is almost completely the logarithm of the texture of the B horizon, a variable that is governed by the occasional presence of coarse fluvio-glacial sand in place of dekzand; component 6 shows a relation between the organic content of the A horizon and topography. It is important to note that topographic position appears to have little correlation with most soil properties.
The vector loading diagrams show how the variables loading into the first two components fall into two groups, aligned on axes that are approximately 45 degrees to the principal component axes. The contributing variables are: Group 1, positive: DIKSL, BBW, BGLAG, DBW, DGLAG, BLUT; negative: DSL, BWD.
Group 2, positive: ALUT, ALEEM, AORG, DLUT; negative: DMOT, AGW, AM50, LGBM50, LGDM50.
This suggests again the presence of two main controls, first the thickness of sand deposit over a clay subsoil, second, the texture of the subsoil and its

TABLE 6.1 Correlation matrix

File NONAME (Creation date = 1-Mar-82)

Correlation coefficients:

	TOPO	BUD	DMOT	DRED	DSL	DIKSL	DKEILN	AGW	ADIK	ALUT
TOPO	1.00000	0.06869	-0.01646	0.08084	-0.21990	0.06324	-0.07683	-0.16684	-0.15040	-0.36079
BUD	0.06869	1.00000	0.36512	0.17393	-0.19119	-0.37394	0.33802	0.13348	0.41171	-0.10782
DMOT	-0.01646	0.36512	1.00000	0.53627	0.05424	-0.61468	0.60012	0.62901	0.11072	-0.37907
DRED	0.08084	0.17393	0.53627	1.00000	-0.06987	-0.26635	0.30925	0.32440	0.02754	-0.09249
DSL	-0.21990	-0.19119	0.05424	-0.06987	1.00000	-0.80898	0.79273	0.02057	0.30705	-0.13395
DIKSL	0.06324	-0.37394	-0.61468	-0.26635	-0.80898	1.00000	-0.96805	-0.40003	-0.28151	0.30563
DKEILN	-0.07683	0.33802	0.60012	0.30925	0.79273	-0.96805	1.00000	0.40533	0.27850	-0.30885
AGW	-0.16684	0.13348	0.62901	0.32440	0.02057	-0.40003	0.40533	1.00000	-0.14592	-0.25008
ADIK	-0.15040	0.41171	0.11072	0.02754	0.30705	-0.28151	0.27850	-0.14592	1.00000	0.06769
ALUT	-0.36079	-0.10782	-0.37907	-0.09249	-0.13395	0.30563	-0.30885	-0.25008	0.06769	1.00000
ALEEN	-0.23245	-0.09433	-0.59490	-0.30322	-0.16449	0.35610	-0.41466	-0.35315	0.00964	0.79640
AM50	0.21141	0.13988	0.41303	0.32587	0.03873	-0.28429	0.25513	0.10223	0.13153	-0.51279
AORG	-0.06542	0.09568	-0.11635	0.25927	-0.22989	0.03405	-0.10532	-0.01641	-0.17246	0.51974
BDIKTE	-0.08342	-0.22216	-0.28686	-0.20564	0.44221	-0.12526	0.17574	-0.17552	-0.11430	-0.07796
BLUT	-0.14851	-0.35008	-0.27454	-0.05046	-0.35278	0.41280	-0.38992	-0.17782	-0.23649	0.45650
LGBM50	0.06422	0.15855	0.12920	0.08954	0.10765	-0.11285	0.07303	0.30073	0.03898	-0.37009
BBW	-0.19052	-0.34626	-0.24456	-0.01734	-0.31300	0.45420	-0.46850	0.08909	-0.35584	0.22509
BGLAG	-0.07475	-0.36743	-0.41596	-0.15454	-0.09202	0.33379	-0.34581	-0.02240	-0.26266	0.05539
DLUT	-0.08006	-0.20825	-0.58177	-0.44020	-0.05727	0.60613	-0.61719	-0.40867	-0.02754	0.62434
LGDM50	0.04011	0.05804	0.41440	0.24967	0.00551	-0.31823	0.30374	0.27470	0.00301	-0.71758
DBW	-0.01393	-0.45093	-0.57918	-0.39143	-0.02886	0.74616	-0.72986	-0.19183	-0.22852	0.22289
DGLAG	0.00061	-0.33212	-0.20758	0.09812	-0.00239	0.24224	-0.24920	-0.04793	-0.33640	-0.12616

	ALEEN	AM50	AORG	BDIKTE	BLUT	LGBM50	BBW	BGLAG	DLUT	LGDM50
TOPO	-0.23245	0.21141	-0.06542	-0.08342	-0.14851	0.06422	-0.19052	-0.07475	-0.08006	0.04011
BUD	-0.09433	0.13988	0.09568	-0.22216	-0.35008	0.15855	-0.34626	-0.36743	-0.20825	0.05804
DMOT	-0.59490	0.41303	-0.11635	-0.28686	-0.27454	0.12920	-0.24456	-0.41596	-0.58177	0.41440
DRED	-0.30322	0.32587	0.25927	-0.20564	-0.05046	0.08954	-0.01734	-0.15454	-0.44020	0.24967
DSL	-0.16449	0.03873	-0.22989	0.44221	-0.35278	0.10765	-0.31300	-0.09202	-0.05727	0.00551
DIKSL	0.35610	-0.28429	0.03405	-0.12526	0.41280	-0.11285	0.45420	0.33379	0.60613	-0.31823
DKEILN	-0.41466	0.25513	-0.10532	0.17574	-0.38992	0.07303	-0.46850	-0.34581	-0.61719	0.30374
AGW	-0.35315	0.10223	-0.01641	-0.17552	-0.17782	0.30073	0.08909	-0.02240	-0.40867	0.27470
ADIK	0.00964	0.13153	-0.17246	-0.11430	-0.23649	0.03898	-0.35584	-0.26266	-0.02754	0.00301
ALUT	0.79640	-0.51279	0.51974	-0.07796	0.45650	-0.37009	0.22509	0.05539	0.62434	-0.71758
ALEEN	1.00000	-0.53691	0.60169	0.09645	0.36134	-0.21381	0.28698	0.28110	0.63967	-0.64802
AM50	-0.53691	1.00000	-0.26509	-0.09649	-0.25763	0.26466	-0.08844	-0.21363	-0.43317	0.45261
AORG	0.60169	-0.26509	1.00000	0.03949	0.29599	-0.17897	0.17822	0.20498	0.17971	-0.33136
BDIKTE	0.09645	-0.09649	0.03949	1.00000	0.12413	-0.22449	-0.02591	0.23928	-0.03727	-0.00061
BLUT	0.36134	-0.25763	0.29599	0.12413	1.00000	-0.75647	0.64369	0.38373	0.23795	-0.25778
LGBM50	-0.21381	0.26466	-0.17897	-0.22449	-0.75647	1.00000	-0.09232	0.03775	-0.15547	0.28606
BBW	0.28698	-0.08844	0.17822	-0.02591	0.64369	-0.09232	1.00000	0.56328	0.18842	-0.05978
BGLAG	0.28110	-0.21363	0.20498	0.23928	0.38373	0.03775	0.56328	1.00000	0.06340	0.04258
DLUT	0.63967	-0.43317	0.17971	-0.03727	0.23795	-0.15547	0.18842	0.06340	1.00000	-0.88041
LGDM50	-0.64802	0.45261	-0.33136	-0.00061	-0.25778	0.28606	-0.05978	0.04258	-0.88041	1.00000
DBW	0.31783	-0.31843	0.03091	0.00259	0.24001	0.05590	0.42611	0.47805	0.52989	-0.22247
DGLAG	-0.01670	0.11147	0.21194	0.22794	0.08580	0.14018	0.29474	0.43666	-0.18547	0.35629

	DBW	DGLAG
TOPO	-0.01393	0.00061
BUD	-0.45093	-0.33212
DMOT	-0.57918	-0.20758
DRED	-0.39143	0.09812
DSL	-0.02886	-0.00239
DIKSL	0.74616	0.24224
DKEILN	-0.72986	-0.24920
AGW	-0.19183	-0.04793
ADIK	-0.22852	-0.33640
ALUT	0.22289	-0.12616
ALEEN	0.31783	-0.01670
AM50	-0.31843	0.11147
AORG	0.03091	0.21194
BDIKTE	0.00259	0.22794
BLUT	0.24001	0.08580
LGBM50	0.05590	0.14018
BBW	0.42611	0.29474
BGLAG	0.47805	0.43666
DLUT	0.52989	-0.18547
LGDM50	-0.22247	0.35629
DBW	1.00000	0.43459
DGLAG	0.43459	1.00000

PC	Eigenvalue	% of var	Cum %
1	6.65849	30.3	30.3
2	3.06417	13.9	44.2
3	2.27122	10.3	54.5
4	2.18960	10.0	64.5
5	1.51340	6.9	71.3
6	1.27088	5.8	77.1
7	1.04446	4.7	81.9
8	0.88152	4.0	85.9
9	0.70143	3.2	89.1
10	0.58525	2.7	91.7
11	0.46914	2.1	93.9
12	0.43218	2.0	95.8
13	0.30167	1.4	97.2
14	0.25442	1.2	98.4
15	0.18345	0.8	99.2
16	0.15398	0.7	99.9
17	0.13038	0.6	100.5
18	0.08163	0.4	100.9
19	0.03339	0.2	101.0
20	0.02801	0.1	101.1
21	0.00857	0.0	101.2
22	-0.25725	-1.2	100.0

TABLE 6.2 Eigenvectors and eigenvalues

Property	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
TOPO	-0.11266	0.22009	0.16527	-0.40867	-0.34145	0.47808
BWD	-0.43314	-0.37853	0.41951	-0.13266	0.12743	0.24174
DMOT	-0.77513	0.00702	0.37187	0.23730	0.03255	-0.21146
DRED	-0.42180	0.12261	0.45307	0.40047	0.06368	0.24352
DSL	-0.37491	-0.31357	-0.82695	0.16144	0.15509	-0.05711
DIKSL	0.82081	0.34291	0.26052	-0.34676	-0.06453	-0.05720
DKEILM	-0.82247	-0.33332	-0.27999	0.35075	0.01082	0.01306
AGW	-0.45884	0.19359	0.22426	0.36380	0.42244	-0.37674
ADIK	-0.27762	-0.50819	-0.06062	-0.21089	0.05757	-0.03065
ALUT	0.65851	-0.54190	0.17339	0.27213	0.15520	-0.01170
ALEEM	0.74810	-0.41601	0.01738	0.17522	0.23888	0.22059
AM50	-0.55289	0.32437	0.10547	-0.12940	-0.15444	0.11074
AORG	0.34948	-0.19701	0.29657	0.53892	0.24230	0.55393
BDIKTE	0.08249	0.00077	-0.69437	0.29630	-0.26125	0.24969
BLUT	0.61283	0.08142	0.16938	0.51663	-0.46749	-0.20405
LGBM50	-0.33773	0.28324	-0.04547	-0.38930	0.73758	0.10721
BBW	0.52936	0.44709	0.14532	0.37746	0.09177	-0.27804
BGLAG	0.46734	0.47928	-0.24361	0.29805	0.19006	0.06330
DLUT	0.76846	-0.38822	-0.02731	-0.29935	0.13655	-0.09578
LGDM50	-0.61028	0.62157	-0.06706	0.06894	-0.07012	0.00763
DBW	0.69925	0.35861	-0.23135	-0.22576	0.26887	-0.10063
DGLAG	0.18172	0.66464	-0.24232	0.21752	0.17438	0.38241

TABLE 6.3 Vector loading scores (relative contributions of each property to each principal component).

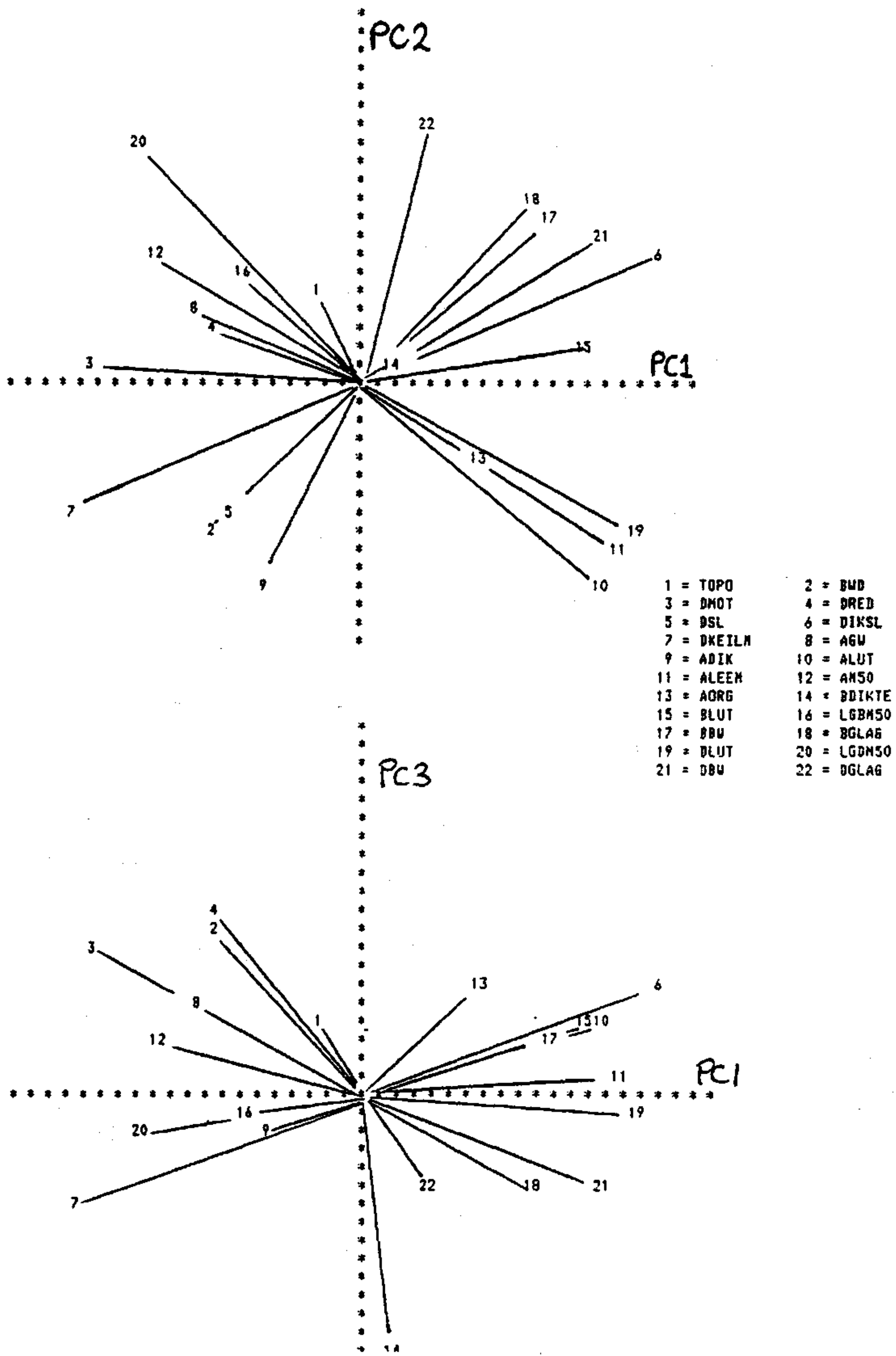


Figure 6.1 Vector loading diagrrams for the first 3 principal components.

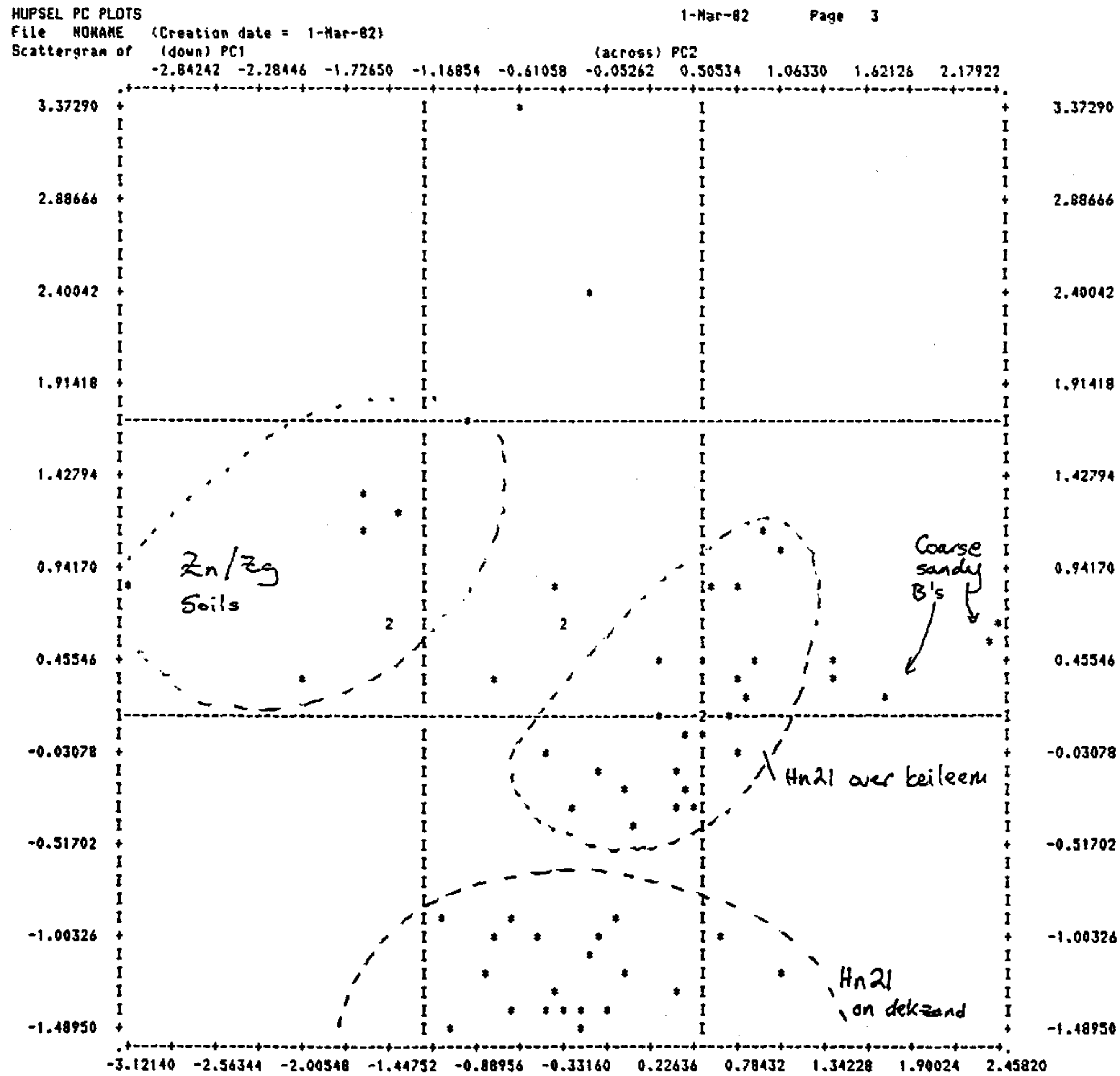


Figure 6.2 Scattergram of profiles in the space defined by the first two principal components.

control over groundwater levels, mottling and the amount of organic matter in the surface horizons.

Figure 6.2 is a scattergram of the original data points in the space defined by the first principal components. Several clusters are apparent, enhanced by the hand-drawn boundaries(!). Podzol profiles without clay from a definite group apart from those podzols (Hn21) in which clay was found. The latter overlap somewhat with the Zg/Zn classified profiles, though these fall dominantly in the area of the plot corresponding with lower values of the second component. It seems therefore, that the presence or absence and texture of subsoil clay is most important, followed by the criteria used to recognize the two soil classes. This supports the classification proposed in section 5. Because the first component also includes contributions from the A-horizon properties, it seems likely that the chances of encountering clay are greatest where the texture of the A horizon is heaviest. The reason for this could be due to biological mixing, but what is more likely is that the lower parts of the present landscape have thinner dekzand deposits. These would have been the lowest parts of the clay landscape which are today still part of the lower landscape. Here normal erosional processes have deposited more clay. In the higher parts of the landscape (by the meteorological station), no clay is found, and A horizon textures are also low due to the combination of a thick sand ridge plus possible anthropogenic activity.

6.2 Numerical classification

The aim of numerical classification, or cluster analysis, is to reveal structure, or groupings of points, in multivariate data. Many different methods have been tried (e.g. see Sneath and Sokal 1973,); to a certain extent the results obtained may depend on the method used, particularly in data containing much overlap. The agglomerative, hierarchical clustering technique used here has several phases. First, the similarity between all individuals is estimated. Here the Euclidean distance was used as an estimate of dissimilarity δ

$$\delta ij = \Sigma_{i=1}^{n} (x_{ij} - x_{ik})^{2 \ \frac{1}{2}}$$

between all pairs of sample points. (N x N matrix).

The dissimilarity matrix is then examined so that points are joined together according to their increasing dissimilarity. Many strategies are possible: here we used Ward's method, which has the advantage of producing well-defined groups with minimum variance. The first six principal component scores from the 64 pro-

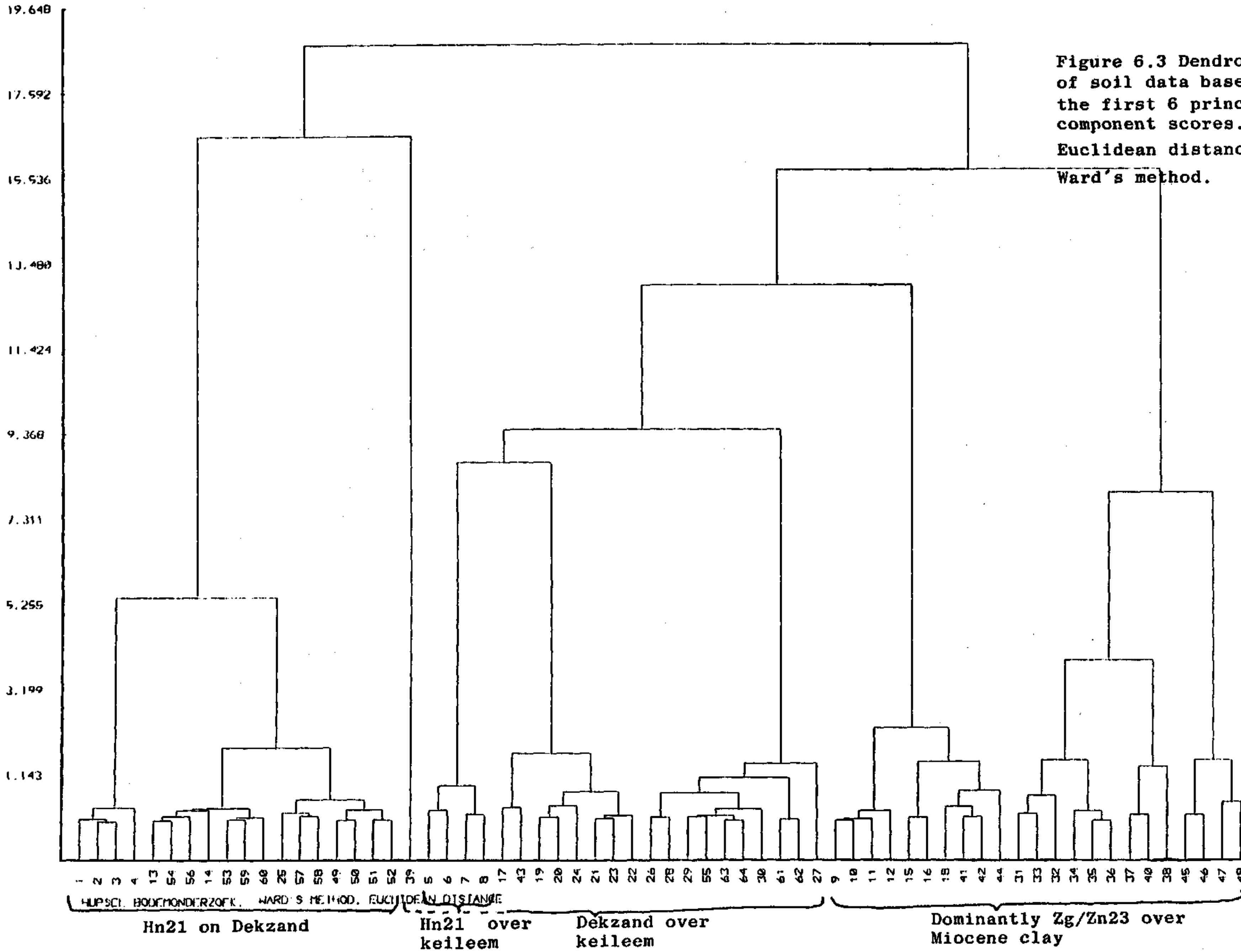


Figure 6.3 Dendrogram of soil data based on the first 6 principal component scores. Euclidean distance/ Ward's method.

files were submitted for Numerical classification using the library program CLUSTAN (Wishart 1977). Figure 6.3 shows the resulting dendrogram.
Inspection of the dendogram together with the field data shows that, with the exception of profile 39, the profiles fall into two main groups; those classified as Hn21 on dekzand, and those having a clay layer within 130 cm of the surface. The clay profiles are then further split according to the nature of the underlying clay, with those developed over the Miocene clay forming a well-defined group. By contrast, the profiles developed in dekzand overlying keileem are more variable, which corresponds partly with the heterogenous nature of the keileem. Profile 39 is a dekzand/Miocene clay profile that is unusual in that it is the only one where the clay comes within 40 cm of the surface. Pedologically, therefore, it belongs to the group of shallow dekzand over clay soils.
These results support the division of the profiles into groups based on the presence/absence of clay at depth, and on the type of clay, described in section 5.

7 ESTIMATING THE RELATIVE MAPPING EFFICIENCY AT DIFFERENT SCALES

One of the aims of this study was to give an idea of an optimum mapping scale for the Hupselse Beek area. As discussed in Section 4, there appeared to be at least two main kinds of variation, ie. that associated with the presence or absence of subsoil clay, and that associated with variations in the texture of that clay. The first set of variations had range of between 20 - 200 m, (probably in the order of 50 - 100 m), the second were longer range (probably c500 m). Other variations, such as the presence or absence of fluvioglacial material occurred over very short distances.
A spatial analysis of the variation in principal component scores, linked to the weights of each component, can give an estimate of the relative amount of variance that can be resolved at any given scale. Let w_1, w_2, w_3.. represent the amount of variance expressed by the Principal components over the whole area. Then the variance perceived by a survey of the M properties submitted to the PCA will at any scale be estimated by

$$s_h^2 = \sum_{i=1}^{m} wi \; S_{PC_{hi}}^2$$

where s_{PCi}^2 is the variance (or semivariance) of PC_i at distance h,
wi is the relative weight of the P.C.

Table 7.1 shows the components of variance for various distances as computed using nested analysis of variance (semivariance could also have been used) for the first 6 components. It was assumed that higher components would reveal no spatial structure, and the 21.4% of the total variance taken up by them has been considered to be always present as "noise" or a nugget effect. The results are presented graphically in Fig. 7.1. The map scales are based on a density of 4 observations/cm^2 published map (Vink 1963).
Figure 7.1 suggests that even with an optimum legend, a map scale of 1:25000 would not remove more than 30% of the variance found in the sample area; given a legend that failed to recognise the importance of subsoil clay the map would be much worse. On the other hand, mapping at scales of greater than 1:400 would have no sense, except for very local areas or for detecting specific changes. Figure 7.1 suggests that a map scale of 1:10000 (sample interval 50 m) would allow removal of half the variance of the study area, which is quite reasonable. (Beckett and Burrough 1971). The effort required would be considerable, however; some 900 observations on a 50 m grid would be needed for the 1500 x 1500 m study area. This would cost approximately 30 man days survey. Doubling the sampling interval to 100 m would result in a relative extra loss of resolution of 12-14%, but would save 675 borings or 22.5 man days. Because the present landscape is little help in detecting the subsoil patterns (topography has very little relation to soil pattern and remotely sensed imagery is also of little help) these estimates of sample numbers could not easily be reduced by interpolation from external features.

Table 7.1 Nested analysis of principal component scores

Property	Variance contributions (in %) 2	20	200	1000 m
PC1	9	1	54**	35
PC2	17	8	53**	22
PC3	18	21*	20	40
PC4	20	13*	67**	0
PC5	51	1	48**	0
PC6	13	26**	19	42

* Variance ratio exceeds Table F0.05
** " " " " F0.01

Estimation of mapping efficiency

Distance m	Cumulative variance per component % PC1	PC2	PC3	PC4	PC5	PC6	Rest	weighted average cumulative Variance%
	31.4	15.4	11.1	9.4	5.8	5.5	21.4	
1000	100	100	100	100	100	100		100
200	64	78	60	100	100	58		78.6
20	10	25	39	33	52	39		41.0
2	9	17	18	20	51	13		34.4

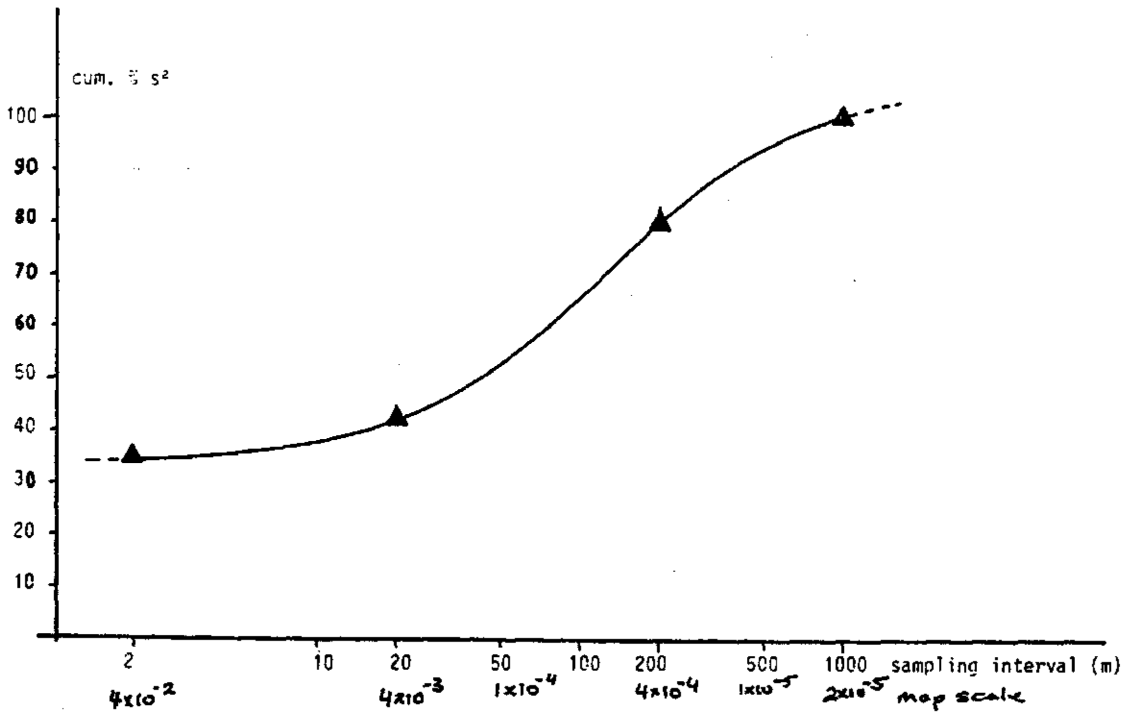


Figure 7.1 Relation between weighted average variance resolved versus sampling interval/map scale.

8 DISCUSSION AND CONCLUSIONS

The combined results of the spatial analysis and principal component analysis reflect clearly the complex soil pattern of the sample area that is the result of several independent geological, geomorphological and pedological phases. The Pleistocene glaciers brought the keileem, which was deposited over older, Miocene clay now deeply buried except in the southern part of the area. As the glaciers melted, the keileem was eroded, leading to a complex pattern of ridges and gullies and deposits.

The aeolien deposits swept over this eroded clay landscape, filling up the gullies, smothering the existing relief, and replacing it with a landscape of gently varying topography. This gentle landscape has itself been eroded, and reworked. The lower levels, possibly including also lower levels in the keileem landscape, have functioned as water carrying areas because the combined effect of the keileem and Miocene clay has allowed little percolation. These lower areas have received clay deposits, and have gained accumulations of organic matter. On the other hand, the higher and drier parts of the landscape have been used for cropland and have received additons of manure. The most important controls on the soil pattern are not the present topography, but the depth of sand over a clay subsoil and the type of clay subsoil. The soil is likely to be more variable when there are thin deposits of dekzand on keileem than when the deposits of dekzand are thick (>130 cm) or the dekzand is above Miocene clay. Keileem is widespread north of the Hupselse Beek, but is thinner or non-existing in the south and east of the area. In the south and east the soil appears to be formed on dekzand deposits above heavier, possibly Miocene clay. The results suggest that soil investigations should pay more attention to the nature of the sub-strata in the area. Observations should not be restricted to the upper 1m of the soil but should be deep enough to investigate all sub-soil factors influencing the movement of water in the upper soil volume.

Generalised soil classifications based on notions of pedogenesis are insufficient; they must be supplemented by detailed information about the nature of the soil parent materials. Although none of the examined soil properties showed a trend across the area, their spatial behaviour was strongly related to the spatial variation of the parent material. For example, the properties of the aeolian sand (the dekzand, and B horizon) are homogenous over the area. Properties controlled by subsoil texture are strongly dependent on the pattern of keileem, fluvio-glacial deposits and deep dekzand. Particularly for keileem-associated properties, short range variations (c.20 m) make mapping difficult. The nested sampling design is an efficient way of obtaining information quickly about several scales. Future applications should choose distance classes that are more evenly spread; the logarithmic distance classes of 2, 20, 200 m leave a large gap in the distance spectrum from 20 - 200 m which was particularly regrettable in this area.

Estimates of mapping efficiency suggest that a sample spacing of 50 m on a regular grid (equivalent scale 1:10000) is necessary to resolve 50% of the variance of the soil pattern. Sub-soil features may require even more intensive sampling for their resolution. Because of land use differences and the blanketing dekzand, remotely sensed imagery and landform are unsure guides to soil pattern.

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Appendix 1. Field recording form.

GEBIED		DATUM		KAARTEERDER	

PROFIEL #	PROFIEL CLASSIFCN	BODEM EENHEID	BODEM GEBRUIK	EFF. BWD	DIEPTE TOT MOTTLES	DIEPTE TOT REDUCTIE	DIEPTE TOT STORENDE LAAG	DIKTE STORENDE LAAG	DIEPTE TOT KEILEEM	AANTAL HORIZONTEN	ACTUELE GWS.	

HORIZONT	BEGIN D (cm)	EINDE DIEPTE	DIKTE (cm)	%LUTUM <2µ	%LEEM 2-50µ	M50	BOORWEERSTAND	GELAAGDHEID	OPMERKINGEN
A									
A									
B/C									
B/C									
C									
C									

CODES: Dieptes / Diktes in cm.
Textuur in %
M50 – Mediaan zand grootheid.
Bodem eenheid – STIBOKA code
Bodem gebruik – Akkerbouw 1, Grasland 2, Bos 3,
Boorweerstand, Gelaagheid } 0, 1, 2, 3, 4.

Appendix 2. Raw data.

SITE	BWD	DMOT	DRED	DSL	DIKSL	DCLAY	AGW	ADIK	ALUT	ALEEM	AM50	AORG	BDIK	BLUT	BM50	BBW	BGLAG	DLUT	DM50	DBW	DGLAG
1.0	40.0	65.0	130.0	-1.0	0.0	130.0	130.0	28.0	2.0	12.0	155.0	5.0	12.0	1.0	155.0	0.0	0.0	0.0	160.0	2.0	1.0
2.0	35.0	65.0	130.0	-1.0	0.0	130.0	130.0	18.0	2.0	11.0	150.0	6.0	14.0	1.0	155.0	0.0	0.0	0.1	160.0	1.0	1.0
3.0	40.0	60.0	130.0	-1.0	0.0	130.0	130.0	25.0	2.0	12.0	150.0	6.0	16.0	1.0	150.0	1.0	0.0	0.0	155.0	0.0	1.0
4.0	35.0	65.0	130.0	35.0	9.0	130.0	130.0	22.0	2.0	12.0	155.0	6.0	14.0	1.0	145.0	0.0	0.0	0.0	155.0	0.0	3.0
5.0	34.0	25.0	130.0	55.0	65.0	55.0	95.0	25.0	2.0	14.0	155.0	8.0	21.0	1.0	1400.0	1.0	3.0	20.0	150.0	4.0	3.0
6.0	34.0	25.0	130.0	60.0	60.0	60.0	95.0	15.0	2.0	15.0	155.0	8.0	26.0	1.0	165.0	1.0	2.0	16.0	155.0	4.0	4.0
7.0	26.0	22.0	130.0	38.0	62.0	38.0	105.0	20.0	2.0	14.0	160.0	7.0	12.0	3.0	1600.0	2.0	4.0	22.0	150.0	4.0	4.0
8.0	35.0	25.0	130.0	60.0	60.0	60.0	108.0	15.0	2.0	15.0	155.0	6.0	20.0	3.0	1600.0	4.0	4.0	14.0	165.0	4.0	4.0
9.0	30.0	20.0	88.0	75.0	45.0	75.0	68.0	24.0	1.0	14.0	155.0	4.0	43.0	1.0	155.0	0.0	2.0	22.0	150.0	3.0	2.0
10.0	30.0	25.0	90.0	75.0	45.0	75.0	64.0	25.0	1.0	14.0	155.0	3.5	40.0	1.0	165.0	0.0	1.0	25.0	150.0	3.0	2.0
11.0	30.0	20.0	90.0	70.0	50.0	70.0	35.0	22.0	1.0	13.0	155.0	3.5	35.0	1.0	160.0	0.0	2.0	25.0	155.0	3.0	2.0
12.0	30.0	20.0	85.0	60.0	60.0	60.0	30.0	25.0	1.0	12.0	150.0	3.0	25.0	0.5	165.0	0.0	3.0	25.0	155.0	3.0	1.0
13.0	30.0	35.0	130.0	-1.0	0.0	130.0	78.0	25.0	2.0	13.0	155.0	6.0	48.0	1.0	165.0	0.0	1.0	1.0	170.0	0.0	2.0
14.0	35.0	35.0	130.0	-1.0	0.0	130.0	78.0	28.0	2.0	12.0	155.0	4.0	35.0	1.0	170.0	0.0	1.0	1.0	160.0	0.0	2.0
15.0	25.0	35.0	130.0	100.0	30.0	130.0	95.0	22.0	1.0	9.0	160.0	2.5	25.0	1.0	170.0	0.0	1.0	1.0	170.0	2.0	2.0
16.0	30.0	30.0	130.0	95.0	45.0	130.0	88.0	25.0	1.0	10.0	155.0	2.5	55.0	0.0	160.0	0.0	1.0	0.0	160.0	2.0	1.0
17.0	20.0	30.0	120.0	45.0	85.0	45.0	64.0	18.0	3.0	14.0	150.0	5.0	30.0	16.0	155.0	2.0	1.0	25.0	155.0	4.0	2.0
18.0	30.0	30.0	115.0	65.0	65.0	65.0	64.0	25.0	3.0	12.0	155.0	4.0	10.0	1.0	165.0	0.0	0.0	22.0	155.0	3.0	3.0
19.0	30.0	30.0	130.0	70.0	60.0	70.0	85.0	25.0	2.0	14.0	140.0	4.5	20.0	5.0	155.0	1.0	3.0	16.0	155.0	3.0	2.0
20.0	25.0	30.0	120.0	75.0	55.0	75.0	85.0	20.0	2.0	15.0	150.0	5.0	25.0	4.0	155.0	1.0	3.0	24.0	150.0	3.0	3.0
21.0	30.0	25.0	110.0	70.0	60.0	70.0	80.0	22.0	3.0	15.0	155.0	5.0	40.0	18.0	155.0	2.0	3.0	26.0	150.0	3.0	3.0
22.0	30.0	25.0	110.0	80.0	50.0	80.0	90.0	24.0	3.0	16.0	150.0	5.5	30.0	16.0	155.0	3.0	3.0	20.0	155.0	3.0	3.0
23.0	25.0	25.0	115.0	60.0	70.0	60.0	80.0	26.0	3.0	16.0	155.0	6.0	45.0	18.0	150.0	3.0	3.0	20.0	150.0	3.0	3.0
24.0	30.0	25.0	115.0	75.0	55.0	75.0	88.0	24.0	3.0	15.0	150.0	6.0	49.0	2.0	170.0	0.0	3.0	16.0	155.0	3.0	3.0
25.0	45.0	15.0	120.0	-1.0	0.0	130.0	65.0	35.0	2.0	14.0	155.0	6.0	15.0	1.0	150.0	0.0	0.0	1.0	145.0	0.0	1.0
26.0	35.0	15.0	120.0	-1.0	0.0	130.0	65.0	24.0	2.0	15.0	150.0	6.0	40.0	4.0	140.0	0.0	4.0	1.0	155.0	0.0	1.0
27.0	35.0	15.0	110.0	110.0	20.0	130.0	85.0	28.0	2.0	14.0	140.0	6.0	60.0	4.0	145.0	0.0	4.0	1.0	180.0	4.0	4.0
28.0	25.0	15.0	100.0	-1.0	0.0	130.0	90.0	15.0	3.0	16.0	145.0	6.0	55.0	1.0	165.0	0.0	0.0	3.0	135.0	0.0	3.0
29.0	35.0	25.0	120.0	100.0	30.0	100.0	60.0	25.0	2.0	14.0	150.0	6.0	45.0	0.0	160.0	0.0	0.0	20.0	150.0	3.0	3.0
30.0	35.0	20.0	110.0	95.0	35.0	95.0	55.0	20.0	2.0	14.0	155.0	5.0	40.0	0.0	165.0	2.0	1.0	22.0	150.0	3.0	3.0
31.0	38.0	15.0	115.0	70.0	60.0	70.0	20.0	38.0	3.0	16.0	150.0	5.0	32.0	2.0	140.0	1.0	1.0	26.0	155.0	3.0	3.0
32.0	45.0	10.0	105.0	45.0	85.0	45.0	20.0	35.0	3.0	15.0	155.0	5.0	10.0	2.0	150.0	0.0	0.0	24.0	150.0	3.0	2.0
33.0	45.0	20.0	115.0	60.0	70.0	60.0	55.0	25.0	3.0	15.0	155.0	6.0	35.0	2.0	145.0	0.0	1.0	55.0	-1.0	3.0	4.0
34.0	45.0	20.0	120.0	60.0	70.0	60.0	55.0	28.0	3.0	16.0	155.0	5.0	32.0	2.0	140.0	0.0	0.0	60.0	-1.0	2.0	0.0
35.0	45.0	20.0	120.0	45.0	85.0	45.0	55.0	25.0	4.0	16.0	145.0	6.0	20.0	2.0	150.0	0.0	0.0	60.0	-1.0	2.0	0.0
36.0	45.0	20.0	115.0	45.0	85.0	45.0	55.0	22.0	3.0	17.0	140.0	7.0	23.0	4.0	150.0	0.0	0.0	65.0	-1.0	2.0	0.0
37.0	30.0	10.0	115.0	95.0	35.0	95.0	47.0	22.0	4.0	17.0	145.0	8.0	40.0	2.0	155.0	0.0	2.0	55.0	-1.0	3.0	2.0
38.0	25.0	10.0	120.0	45.0	85.0	45.0	45.0	18.0	4.0	19.0	145.0	8.0	25.0	22.0	155.0	3.0	3.0	60.0	-1.0	3.0	2.0
39.0	20.0	10.0	120.0	38.0	92.0	38.0	32.0	18.0	5.0	18.0	145.0	9.0	47.0	65.0	-1.0	3.0	3.0	45.0	-1.0	3.0	2.0
40.0	20.0	10.0	120.0	75.0	55.0	75.0	40.0	16.0	5.0	20.0	145.0	8.0	30.0	3.0	155.0	0.0	2.0	40.0	-1.0	3.0	3.0
41.0	25.0	30.0	130.0	85.0	45.0	85.0	75.0	35.0	2.0	12.0	155.0	3.5	40.0	1.0	160.0	0.0	0.0	22.0	150.0	3.0	3.0
42.0	25.0	30.0	130.0	75.0	55.0	75.0	56.0	25.0	2.0	13.0	155.0	4.5	25.0	1.0	160.0	0.0	0.0	24.0	155.0	3.0	2.0
43.0	25.0	30.0	130.0	75.0	55.0	75.0	65.0	22.0	2.0	12.0	160.0	3.5	25.0	20.0	150.0	3.0	3.0	16.0	150.0	2.0	3.0
44.0	25.0	30.0	130.0	55.0	75.0	55.0	62.0	28.0	2.0	13.0	155.0	3.5	10.0	1.0	150.0	0.0	0.0	15.0	140.0	0.0	0.0
45.0	25.0	25.0	110.0	100.0	30.0	100.0	70.0	23.0	2.0	14.0	155.0	5.0	50.0	1.0	180.0	1.0	1.0	55.0	-1.0	2.0	1.0
46.0	25.0	25.0	100.0	100.0	30.0	100.0	75.0	25.0	3.0	15.0	150.0	5.0	45.0	1.0	165.0	1.0	1.0	65.0	-1.0	2.0	0.0
47.0	30.0	25.0	110.0	110.0	20.0	110.0	78.0	30.0	4.0	16.0	155.0	5.0	10.0	1.0	160.0	0.0	0.0	60.0	-1.0	3.0	0.0
48.0	35.0	25.0	110.0	110.0	20.0	110.0	73.0	55.0	5.0	19.0	145.0	6.0	20.0	2.0	160.0	0.0	2.0	60.0	-1.0	3.0	0.0
49.0	55.0	50.0	130.0	-1.0	0.0	130.0	97.0	35.0	2.0	13.0	155.0	5.5	35.0	1.0	175.0	0.0	1.0	1.0	185.0	0.0	2.0
50.0	45.0	50.0	130.0	-1.0	0.0	130.0	104.0	25.0	2.0	14.0	160.0	6.5	40.0	0.0	160.0	0.0	1.0	0.0	180.0	0.0	1.0
51.0	45.0	50.0	130.0	-1.0	0.0	130.0	95.0	24.0	2.0	11.0	155.0	5.0	30.0	1.0	165.0	0.0	1.0	1.0	180.0	0.0	1.0
52.0	40.0	50.0	130.0	-1.0	0.0	130.0	96.0	26.0	2.0	13.0	160.0	6.0	20.0	1.0	170.0	0.0	0.0	1.0	175.0	0.0	1.0
53.0	40.0	35.0	130.0	-1.0	0.0	130.0	64.0	35.0	2.0	14.0	155.0	6.0	45.0	1.0	165.0	0.0	1.0	1.0	165.0	0.0	1.0
54.0	30.0	35.0	130.0	-1.0	0.0	130.0	60.0	30.0	2.0	13.0	160.0	5.5	40.0	1.0	165.0	0.0	1.0	1.0	165.0	0.0	2.0
55.0	25.0	35.0	130.0	110.0	20.0	110.0	68.0	25.0	2.0	14.0	155.0	6.5	45.0	1.0	170.0	0.0	1.0	16.0	150.0	2.0	3.0
56.0	40.0	35.0	130.0	-1.0	0.0	130.0	68.0	35.0	2.0	15.0	160.0	6.0	55.0	0.0	180.0	0.0	1.0	1.0	165.0	0.0	2.0
57.0	50.0	50.0	130.0	-1.0	0.0	130.0	64.0	25.0	2.0	14.0	155.0	6.5	25.0	1.0	160.0	0.0	0.0	1.0	155.0	0.0	1.0
58.0	45.0	50.0	130.0	-1.0	0.0	130.0	62.0	45.0	2.0	13.0	160.0	6.0	10.0	1.0	165.0	0.0	0.0	1.0	165.0	0.0	1.0
59.0	40.0	45.0	130.0	-1.0	0.0	130.0	52.0	25.0	3.0	14.0	155.0	5.5	30.0	1.0	170.0	0.0	1.0	0.0	165.0	0.0	1.0
60.0	40.0	45.0	130.0	-1.0	0.0	130.0	64.0	24.0	2.0	14.0	160.0	6.0	25.0	1.0	160.0	0.0	1.0	1.0	165.0	0.0	2.0
61.0	30.0	30.0	130.0	80.0	50.0	80.0	34.0	24.0	2.0	13.0	160.0	7.0	47.0	1.0	170.0	0.0	2.0	18.0	155.0	2.0	4.0
62.0	30.0	30.0	130.0	75.0	55.0	75.0	33.0	28.0	2.0	14.0	155.0	6.5	35.0	1.0	145.0	0.0	2.0	18.0	155.0	2.0	4.0
63.0	30.0	30.0	130.0	95.0	35.0	95.0	48.0	24.0	2.0	12.0	155.0	6.0	30.0	1.0	160.0	0.0	1.0	18.0	150.0	2.0	4.0
64.0	25.0	30.0	130.0	100.0	30.0	100.0	50.0	22.0	2.0	14.0	155.0	6.0	30.0	1.0	165.0	0.0	1.0	16.0	150.0	2.0	4.0