urvey Papers, No. 15

QUALITY OF
SOIL MAPS.
A COMPARISON OF
SURVEY METHODS
IN A SANDY AREA.

B.A. Marsman and
J.J. de Gruijter

Survey Institute, Wageningen

SOIL SURVEY PAPERS, No. 15

QUALITY OF SOIL MAPS

A COMPARISON OF SOIL SURVEY METHODS IN A SANDY AREA

B.A. Marsman and J.J. de Gruijter

SOIL SURVEY INSTITUTE, WAGENINGEN, THE NETHERLANDS — 1986

ISBN 90 327 0217 3

CONTENTS

FOREWORD

The survey methods used by the Netherlands Soil Survey Institute (Stiboka) have not been altered since the foundation of the institute. Only groundwater has been added to the soil attributes surveyed by Stiboka. We have done many pedological investigations, but none on survey methods as such.

Our interest in this topic was stimulated because a group at Oxford University (P.H.T. BECKETT, S.W. BIE) made contact with Stiboka. The next step was for Stiboka to co-operate in the Oxfordshire project. In that project one area was subjected to survey by many survey methods and the quality of the results was tested. B.A. MARSMAN of Stiboka did the free survey there and this sparked off his interest in survey quality.

In the meantime Stiboka's J.J. DE GRUIJTER had completed his doctoral dissertation on numerical classification, and it was an obvious step for him to step over from soil classifications to soil maps.

This publication results from the follow-up of these activities. A large staff together with STEIN W. BIE, who was by then employed by Stiboka, designed the project. They developed stringent specifications for the methodology of the investigation. In addition to traditional measures of quality they also wanted to include measures of soil suitability. The project grew into a large research effort. Data processing and analyses also required much effort, but the perseverance of B.A. MARSMAN encouraged the group to complete the project. His work as a project co-ordinator involved consultations with other experts during the design phase of the project, the planning of the fieldwork, the input and processing of the data. In addition, he is the main author of this report. J.J. DE GRUIJTER was responsible for the statistical aspects of the design and analysis of the experiment. He also wrote Chapter 6 and Section 7.1.

With this study Stiboka has made an important first move. The aim of Stiboka is to produce usable soil maps. This can only be realized by critical evaluation of its own working methods and, if necessary, the introduction of improvements.

Stiboka's deputy director, J. SCHELLING (now retired), guided and enthusiastically supported this project.

F. SONNEVELD
Director

ACKNOWLEDGMENTS

Many employees of Stiboka contributed to this study. We are also very grateful for the discussions and advice given by many other colleagues. We acknowledge especially our colleagues from the Department of Soil Survey who made the maps and collected the field data: G. Ebbers, D.A. Eilander, D.J. Groot Obbink, C. Hamming, W. Heijink, H. Makken, R. Visschers, W.J.M. van der Voort and F. de Vries. Comments and advice on the terminology of Soil Taxonomy were given by H. de Bakker from the Department of Soil Classification.

J. Domhof (Land Use Department) gave much help in designing the suitability classification. Calculations of the mean highest and the mean lowest water-tables were made by H.C. van Heesen (Department of Soil Physics and Hydrology), based on the relations between the measured water-tables and the data on water-tables from the TNO Groundwater Survey in Delft.

Colleagues of the Department of Automation and Statistics programmed the preprocessing of the data and provided the delineations of the proximal soil maps: P.A. Burrough (now Department of Geography, University of Utrecht), B. Bunschoten (now Computervision, Alphen aan den Rijn), J. Denneboom, and J. van Kuilenburg (now Geological Survey of the Netherlands, Haarlem).

The calculations on the quality of the maps were programmed by J. de Jonge from CDC (Control Data Corporation) Rekencentrum, Rijswijk. We specifically wish to mention S.W. Bie (now Norwegian Computer Centre, Oslo), who prepared the original design of this study. His experience and insight in the subject were of great importance for this study. He also advised on terminology and translated the first chapters.

This project was guided by J. Schelling, deputy director of Stiboka (now retired). He gave valuable support by advice and discussions.

1. INTRODUCTION

In recent decades much research in pedology has centred on the construction of classification systems. We have seen a distinct development from descriptive, physiographic systems to systems based on morphometrically defined soil properties (SOIL SURVEY STAFF, 1975; FAO, 1974; AVERY, 1980; DE BAKKER & SCHELLING, 1966). A soil classification should not only name and order individual soils but also form the basis for the making of soil maps (DE BAKKER, 1970). Since the early seventies there has been increasing emphasis on the quality of soil maps based on these morphometric classifications. Considerable research effort has been directed towards the quality of soil maps, particularly in England, USA and Canada. At first, the studies were concerned with the purity of the map: the extent to which the content of the delineated areas corresponded to the specifications in the map legend. Later, the homogeneity of the mapping units attracted attention. The most important studies have been reviewed and the results evaluated by BECKETT & WEBSTER (1971) and WESTERN (1978).

The increased emphasis on the quality of soil maps is a logical consequence of the morphometry of the classification systems. Soil maps made on the basis of morphometrically defined criteria create a need for information on the quality of those criteria. Another argument for this is the increasing detail in the definition of the taxonomic units. Some workers (AMOS & WHITESIDE, 1975) believe that this increasing detail actually means that many delineated soil units are complex units. In addition, the development of morphometrically defined criteria makes it possible to quantify survey quality.

As stated above, soil maps were originally judged by the extent to which they corresponded to the specifications in the map legend. Later, the opinion developed that the value or quality of a soil map is not determined by map purity but rather by the possible applications of the map (e.g. suitability estimates) (BIE, 1972; SOIL SURVEY STAFF, 1975, pp. 407-410; WEBSTER, 1977). In this project many data were collected to investigate this latter type of quality.

In the early seventies the Netherlands Soil Survey Institute (Stiboka) began preliminary studies on the purity of some important mapping units (VAN DER VOORT, 1981). In 1975 the study was extended to include the quality of the most common types of soil maps. The aim of the study was to obtain information on the quality of soil maps made by traditional methods and soil maps compiled by alternative means. The expanding possibilities for automation both in map production and data handling by users may offer opportunities for changes in existing methods. But before new methods are introduced, it is necessary to evaluate the impact any changes would have on map quality. It was hoped that the results of the project would also indicate whether map quality can be improved.

This publication reports the results of the Stiboka project. In Chapter 2 the aims of the project are discussed in more detail.

The design of the project is described in Chapter 3. The basis of the project is formed by six soil maps at a scale of 1 : 50 000 based on the legend of the Soil Map of the Netherlands covering area A, and six soil maps at a scale of 1 : 10 000 of a smaller subarea of A, area B, based on the detailed map legend used for commissioned surveys. Four survey methods were applied to compile the soil maps, consisting of combinations of two alternative sampling procedures (purposive or random) and two alternatives for the delineation of soil boundaries (field or proximal). Randomly selected soil profile descriptions were used as test samples for quality checks. On the basis of these quality checks, estimates of 25 quality criteria were made.

Chapter 4 contains a general description of the project area, with geology, soil conditions, agricultural land use and suitability for agriculture of the project area. The reasons for choosing the area are outlined, and there is a discussion on the applicability of the results to other areas.

Chapter 5 presents data collecting methods and data processing. Data were collected for compiling the maps and, separately, also for testing these maps. The observations that were used for testing (test observations) were corrected to eliminate systematic errors of estimation made by the observers. From the test observations a number of variables on moisture supply capacity and related variables were derived. For the test observations we also estimated the soil's suitability for rye and for grass. The principles used for calculating the values are outlined in Chapter 5 together with a description of the suitability classifications used.

Chapter 6 describes the measures of quality used and the statistical estimation methods applied. For each soil map 25 quality measures were calculated. There were 7 measures of purity, 2 homogeneity indices for suitability for agriculture, and standard deviations for 16 soil variables. Map readability was evaluated on the basis of the number of mapping units, the number of areas delineated for each mapping unit, and the mean area of each delineated area.

Chapter 7 presents the results of the project after an analysis of their accuracy. There is an introductory review of the general levels of the quality measures. The conclusions on the various survey methods are based on paired comparisons of the various maps. From these, both the survey methods in general and individual aspects of the methods may be evaluated. A distinction was made between the estimates based only on measures of quality and those based on a combination of quality measures and criteria of map readability. The results are discussed in a separate Chapter (8).

Chapter 9 presents the conclusions of the project point by point. Finally, a glossary and a list of symbols are appended. The appendix contains seven of the investigated soil maps and their respective legends.

2. AIMS OF THE PROJECT

Producing soil maps is an important activity of many soil survey institutes. Much effort has been directed towards the development of classification systems and the designing of legends for soil maps. Much attention has also been paid to the use of maps, particularly for agricultural purposes, for instance by developing suitability classifications.

In contrast, in the Netherlands little research has been done on the quality of soil maps. Our knowledge of the quality of soil maps has been derived from a number of local investigations on the quality of soil maps especially made so that their quality could be tested. Most soil survey reports give no information on the quality of the maps, or at best, only very general indications.

It is necessary to know the quality of current soil maps in order to suggest possible improvements. It should be the object of future research to determine where improvements are needed most urgently and how they may be achieved.

In this project the primary aim was to reveal the effects of alternative survey methods on quality. In practice, various survey methods are used. The actual choice of method depends on tradition and on the experience with a particular method. Map scale, purpose of the survey, and the competence of the survey staff are a consideration too. Of course, costs and available time are also important.

The growing tendency towards automation, both in map production and map use, emphasizes the desire for research on survey methods. As long as we have little knowledge of the effects of survey method on map quality it is difficult to make proper choices.

This type of research may also point to map improvements through changes in the choice of criteria used in the classifications or in the subdivisions used. In addition, the results of this type of research may indicate the reliability of the maps. This may aid the map user to assess the utility of the map for a particular application.

The aims of this research project may be summarized as:

- estimating the quality of soil maps made by the existing survey method and three alternative survey methods;
- investigating the possibilities of improving the soil map by alterations in the survey method.

It was also thought that the results of this research might indicate the extent to which soil maps may be improved through changes in the classification system or map legends used.

3. PROJECT DESIGN

3.1 General

A number of soil maps were made for the project area, using different survey methods. For one area of 1600 ha, six soil maps at a scale of 1 : 50 000 were made with the legend of the Soil Map of the Netherlands, scale 1 : 50 000 (general map legend). In addition, for part of this area, 400 ha, six soil maps at a scale of 1 : 10 000 were made with the legend used by the Netherlands Soil Survey Institute for their commissioned surveys (detailed map legend; see Section 3.4).

The survey methods applied differed in the procedures used for choosing the observation points and the way in which the soil boundaries were delineated. Two sampling procedures and two boundary delineation methods were combined into four different survey methods (see Section 3.2).

The soil maps were tested on their quality. For this purpose profile descriptions were made for a large number of sites selected at random in the area. The sample was a stratified random one, based on a subdivision of both areas in 64 quadratic strata (Fig. 2). The observations used for testing the quality of the maps were corrected for systematic errors in estimation made by the surveyors (see Section 5.2).

In total, 25 quality measures were used, some obtained directly from the observations, others derived from these (see Section 5.3): The quality measures included 7 purity measures intended to convey information on the extent to which the delineated mapping units agreed with the definitions in the legend. There were a further 18 quality measures relating to the

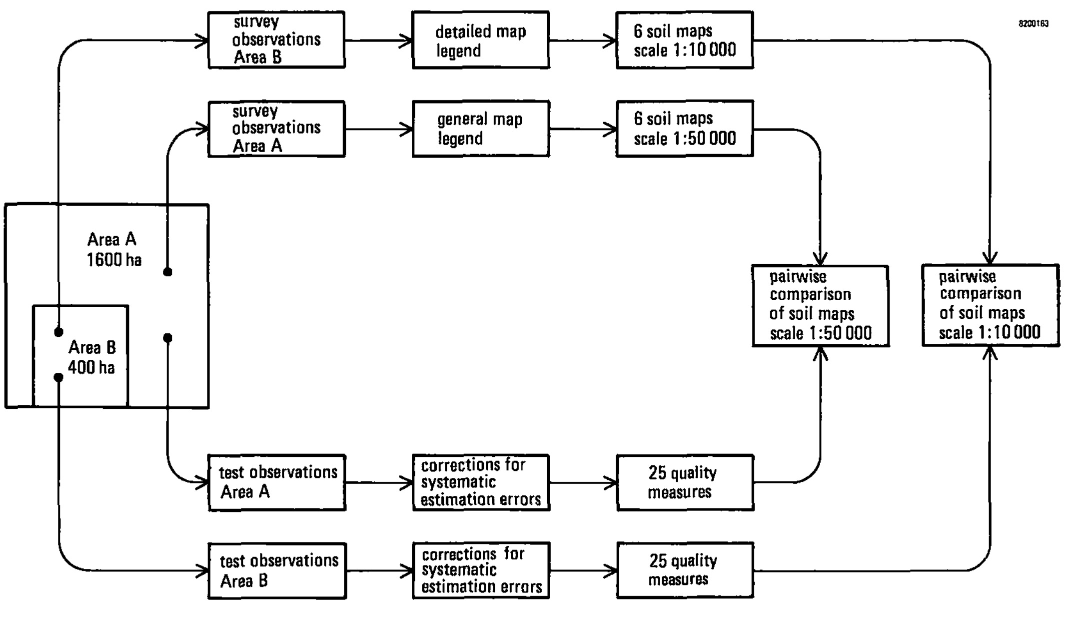


Fig. 1. Schematic representation of the design of the research.

homogeneity of the mapping units, of which 16 referred to the homogeneity of soil properties and 2 referred to the homogeneity of suitability for two agricultural land uses.

The evaluation of the survey methods used was based on comparisons of the values of the quality measures calculated for the soil maps (Section 7.3). Bij comparing pairs of soil maps it was also possible to estimate the effect of various aspects of the survey methods on the quality of the soil map.

Figure 1 gives a schematic overview of the design of the study.

3.2 Survey methods investigated

Soil maps may be made by various survey methods. In this investigation, methods that differed in the procedure for sampling observation points, and in the method of delineating boundaries were studied.

In general the ingredients of a survey method are:

a) defining classes of soil profiles (classification system, map legend);
b) observing the soil profiles in the survey area;
c) delineating and naming areas corresponding to the defined classes (a), based wholly or partly on the observations made (b).

For each of these steps several alternatives are open, leading to different soil maps.

In this study the Soil Classification Systems of the Netherlands (DE BAKKER & SCHELLING, 1966), developed by the Netherlands Soil Survey Institute, was used. Two map legends derived from this classification were applied: the map legend for the Soil Map of the Netherlands at a scale of 1 : 50 000, and the more detailed legend used in the surveys commissioned for maps at a scale of 1 : 10 000. For an explanation of these legends and the legend codes see Section 3.3. Our study focussed on procedures b and c mentioned above.

Two sampling procedures for observation points and two methods of delineating boundaries were combined to yield four survey methods. We investigated the effect that each procedure had on the end-product, i.e. the soil map.

The choice of survey methods is outlined below.

3.2.1 Sampling procedures for observation points: purposive versus random

In every survey pocedure a significant part of the effort is devoted to soil profile observations. In the Netherlands this normally entails a profile description to 1.20 m.

The number and locations of soil profiles to be described form two important elements of choice. The location may be the result of a purposive or a random choice.

The locations and number of purposive observations are decided upon by the surveyor during the survey. Random observations are selected by statistical procedures prior to the fieldwork (using e.g. simple random, systematic, or stratified random sampling procedures). The surveyor cannot influence this during the survey.

The two sampling procedures give rise to different sets of observation points. We may assume that this will lead to differences in the respective soil maps.

As an example of a random sampling procedure we chose a stratified random procedure that had an observation density similar to that of the purposive sampling. Study area A (1600 ha) was stratified into 64 square cells of 25 ha each (Fig. 2). Study area B (400 ha) was subdivided into 64 square cells of 6.25 ha each. For area A each cell had four simple random observation points. For area B each cell had nine simple random points.

The "free survey" technique (STEUR, 1961) was used to achieve a purposive choice of observation points. This free survey is the normal survey method used by Stiboka. The location of each observation point is a function of a number of ad hoc decisions taken during the field-

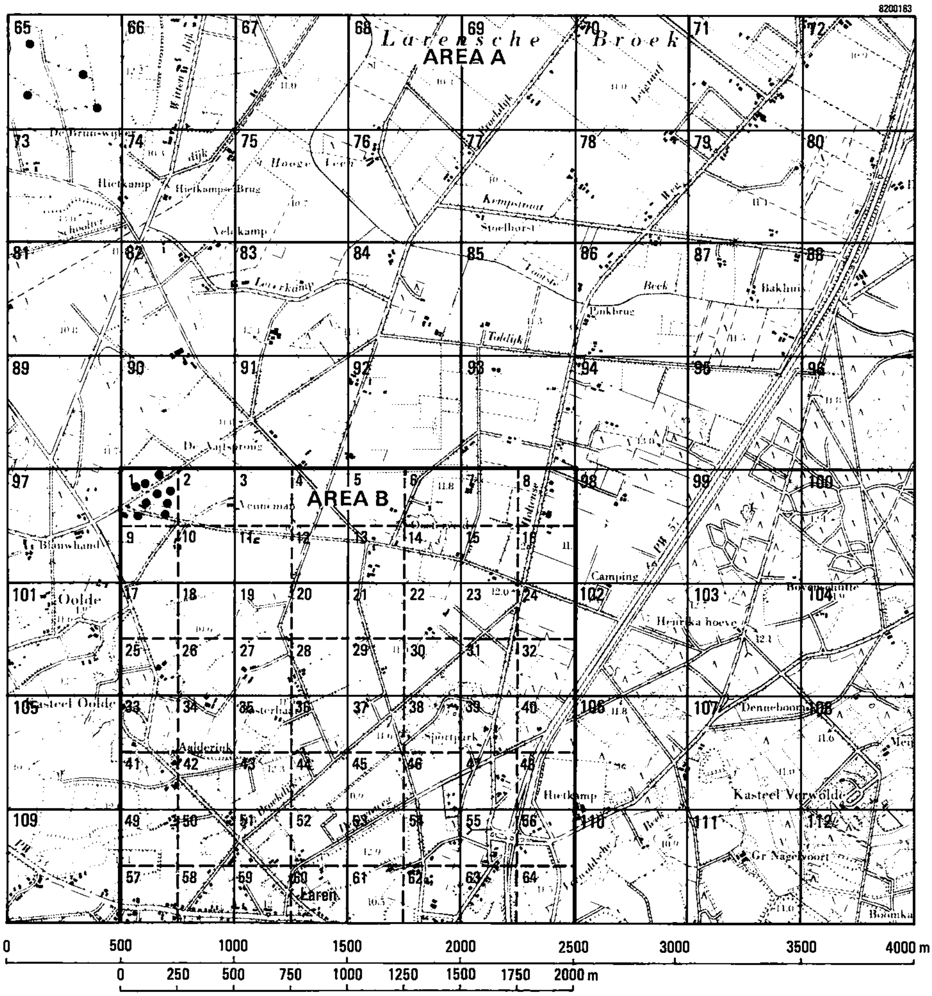


Fig. 2. Stratification of areas A and B used for sampling. (In area B 64 strata of 6.25 ha for survey and test observations; in area A 64 strata of 25 ha for survey, and 48 of 25 ha and 64 strata of 6.25 ha for test observations.)

work. The most important factors used in making the decisions are:
- the soil classification used,
- the map scale,
- the presence of recognizable terrain features,
- the surveyor's personal knowledge of the interrelations between soil and the landscape, topography, and vegetation,
- the intricacy of the soil pattern,
- the correspondence between the expected and the observed.

In addition to the procedure for sampling the observation points the actual number of observations (observation density) is also important for the mapping. Stiboka has instituted certain norms: for a mapping at a scale of 1 : 50 000 the guide figure is 1 observation per 6 to 10 hectares, corresponding to 2.5-4 observations per cm^2 of published soil map. For a mapping at a scale of 1 : 10 000 the guide figure is 3 observations per 2 ha, corresponding to 1.5 observations per cm^2 of published map.

The project was so designed to ensure that maps made by purposive and random sampling had the same observation density. For random sampling the observation density was the same over the whole project area. The effects of any local incidental variations were limited by the use of stratification. A certain amount of variation in observation density over the whole area was inevitable when the choice of observation points was purposive.

Above we have discussed factors influencing the location of observation points. The same factors also pertain to observation density. In free survey the surveyor may adjust observation density in a particular area, for the reasons given above. Small-scale maps (1 : 50 000 and smaller) show greater variation in observation density than large-scale maps (1 : 10 000).

After the free-survey maps with purposive sampling had been completed it became apparent that the mean observation density of the 1 : 50 000 soil map of the project area was higher than the norm. On the other hand, the 1 : 10 000 free-survey map had a lower mean observation density. To assure a fair comparison at both map scales we compiled an extra set of soil maps based on random sampling with observation densities corresponding to the actual densities arising from the free-survey maps (Fig. 4 and Table 4). Table 1 gives an overview of the observation series used for compiling the soil maps.

Table 1 The observation series for the compilation of the soil maps (survey series)

	Name of observation series	Sampling procedure	Number	Density per 10 ha	Name of soil map for which observations are used (Map code)
Area A (1600 ha) soil maps 1:50000 — Observation series A	A1	purposive	356	2.2	PuFi-50; PuPr-50
	A2	random	253	1.6	RaFi-50,d; RaPr-50,d
	A2+4/10 A3	random	349	2.2	RaPr-50; RaPr-50,g
Area B (400 ha) soil maps 1:10000 — Observation series B	B1	purposive	446	11.2	PuFi-10; PuPr-10
	B2	random	548	13.7	RaFi-10,d; RaPr-10,d
	8/10 B2	random	452	11.3	RaPr-10; RaPr-10,g

Table 4 outlines all observation sets used for compiling and testing the maps. The number of observations differ slightly from those given in Table 1 for some maps of area B. This is because there were 41 ha of built-up land for which no observations were used for making the soil map.

3.2.2 Delineating boundaries: in the field or proximally

A fundamental assumption for soil survey is that similar soil-forming factors lead to similar soil profiles: the closer two points are to each other, the greater the probability that the soil-forming factors have been the same. Soil variation in an area is not randomly distributed within the area. We can recognize a soil pattern in which a group of bordering and similar soil profiles is systematically adjacent to other groups of similar soil profiles.

On the soil map the surveyed area is subdivided into a number of delineated areas. The surveyor attempts to separate groups of similar soil profiles from others in order to reduce the range of soil properties present within each delineated area, compared with the range over the area as a whole. A significant factor in the quality of the soil map is the extent to which the surveyor has succeeded in this task.

We may delineate the soil boundaries by two distinctly different methods:

a) field methods, in which the information derived from the soil observation points, plus information on the landscape is used;
b) mathematical methods, in which a given algorithm computes the position of the soil boundaries solely on the basis of the data from the observation points.

In this study both methods were used, in order to assess their respective influence on the quality of the soil map.

Boundary delineation by field methods relies on a continuous use of terrain features (differences in vegetation, topography and field pattern) together with point observations. When delineating the boundaries, the understanding of relations between terrain features and soil conditions is used as much as possible. This understanding is derived from experience gained during survey of similar areas. The disadvantage of this method is that systematic errors may arise if the assumed relations are less valid or are invalid in the actual survey area. Furthermore, the terrain features frequently relate to only a subset of the criteria on which the classification units have been defined. The remaining criteria may have no or weak relations to the terrain features.

If the assumed relations are valid, the method has the advantage of requiring relatively few observation points to enable the soil boundaries to be delineated (STEUR, 1961).

Field delineation may also involve the use of additional aids: aerial photographs, old topographic maps, vegetation maps and geological maps. The procedure used in this study was based on old topographic maps (published circa 1880).

Field delineation is generally assumed to be more appropriate for small-scale maps than for large-scale ones. With increasing map scale the observation density also increases and reduces the contribution from terrain features and other aids to boundary delineation.

As an example of mathematical boundary delineation we chose the proximal method. The principle of this method is to allocate each point in the survey area to the class of the nearest observation point. To achieve this, each observation point is initially separated from neighbouring observation points by the construction of mid-normals (perpendicular bisectors) on the lines connecting the point with its neighbours. This gives rise to a so-called Thiessen polygon. This polygon surrounds all points that are closer to this observation point than to any other observation point (see Fig. 3). If the areas of two or more bordering polygons are allocated to the same class, the common mid-normal(s) are removed.

In this study the Thiessen polygons were constructed by a computer using the program written by GREEN & SIBSON (1978). Common lines were later removed manually. The above program was chosen as it became apparent that the costs of using SYMAP program normally used to construct Thiessen polygons would be prohibitive.

Proximal delineation is pure computation and ignores terrain features. The only way the surveyor can influence the result is by the choice of observation points. The class to which the polygon is allocated depends solely on the properties of the soil profile at the observation point.

In contrast to field delineation, proximal delineation requires that each observation point is allocated to the corresponding class. The observation point is subsequently circumscribed, either separately or in combination with neighbouring observation points of the same class.

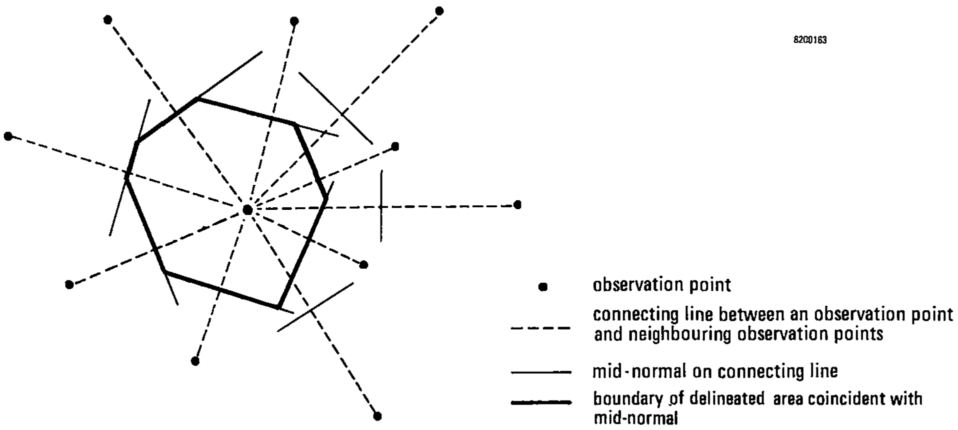


Fig. 3. Delineation of areas in proximal soil maps.

Field delineation gives the surveyor the opportunity of treating observation points that the thinks represent small areas as impurities in other classes. We may expect that proximal delineation will lead to many and small delineated areas. To allow a realistic comparison with field delineation we included generalized versions of the proximal maps (RaPr-10,g and RaPr-50,g) in this study. The generalization was achieved by aggregating delineated areas. This results in new, predominantly complex delineated areas. Technically, this is achieved by removing some lines and adding no new ones. Two main guidelines were followed for the aggregation:

a) the resulting delineated area had to constitute a reasonable area for the map scale concerned;
b) original delineated areas had to be aggregated in such a way that the differences for agricultural suitability within the aggregated areas were minimized.

The names of the new aggregated mapping units were based on combinations of the constituent class names and were often very long and cumbersome. Therefore, class names representing very small areas were deleted when the sum of these areas did not exceed 30% of the delineated area.

3.3 Classification system, map legends and map scales

In this study two map legends were applied: the legend of the Soil Map of the Netherlands, scale 1 : 50 000 (general legend), and the more detailed legend of the commissioned soil surveys, scale 1 : 10 000, undertaken by the Netherlands Soil Survey Institute on contract (detailed legend). We shall subsequently refer to these legends as classifications, more specifically as the general and detailed classifications, respectively; see Glossary. Both classifications are based on the System of Soil Classification for the Netherlands (DE BAKKER & SCHELLING, 1966). This system gives a classification that proceeds from the higher levels to subgroups.

The following processes and properties used in the System of Soil Classification are relevant to our project area: podzolization, formation of A1 horizon, hydromorphy, strong human influence, thickness of A1 horizon, peaty horizons, and textural criteria such as sandy soils, clay soils, sand cover, clay cover.

For both classifications the subgroups constitute the starting point for further subdivisions at lower levels. The subdivisions relevant to our project area relate to: texture of the topsoil (loam and clay content, coarseness of the sand), sand cover/clay cover; bog-iron ore; peaty layers in the subsoil; reworked soils – excavated soils – raised soils – levelled soils; groundwater classes.

The subgroup level is the basis for both classifications, but the subdivisions in the detailed classification are finer than those in the general classification. This finer detail relates to: the subdivisions for loam content and coarseness of the sand, thickness classes for the A1 horizons; colour and type of topsoil for some soils; bog-iron ore horizons.

Whilst the general classification is solely used for the Soil Map of the Netherlands, the detailed classification has been adopted for a wide range of commissioned surveys. The normal scale is 1 : 10 000, but 1 : 15 000 and 1 : 25 000 also occur.

The general classification is immutable. This is not the case with the detailed classification. Local soil conditions and specifications from the party commissioning the map may alter the level of detail for relevant aspects. The differences between both soil classifications may give rise to differences on the soil maps. On the 1 : 50 000 soil map complex mapping units often arise. These rarely occur on the commissioned maps.

In this study we chose two sets of soil maps: a mapping at a scale of 1 : 50 000 employing the general classification and a mapping at a scale of 1 : 10 000 using the detailed classification, thus ensuring that the two most common types of soil maps of the Netherlands were represented in our study. Both the differences in map scale and levels of classification are large enough to constitute separate objects for study.

All classification units distinguished on both groups of soil maps are indicated in the Appendix. Below we explain in full the classification codes used for the 1 : 50 000 and 1 : 10 000 soil mappings.

For the 1 : 50 000 maps, the classification code given in the legend consists of a group of alpha-numeric characters, each of which describes a separate discriminating criterion for classifying the soils. The classifications system is described in DE BAKKER & SCHELLING (1966) and the classification codes are explained fully in DE BAKKER et al., 1984. Here we will explain the classification codes for sandy soils, because on most maps in our study only these soils were distinguished. (Very small areas of clayey soils were distinguished on some of the proximal soil maps.) The description given here is sufficient to understand the way in which the classification was used in the tests of map quality described in this publication.

The legend code is centred about one or two capital letters that code the main classes of the legend:

W – shallow peaty soils
Y – moder podzol soils
H – humus podzol soils
EZ – thick earth soils
Z – acid sandy soils.

Depending on the main legend class, the capital letter may be immediately preceded and/or followed by a single lower case roman letter; these code the *subgroup* of the soil in the Dutch system of soil classification. The preceding lower case letter describes the properties of the topsoil of the soil profile (e.g. thickness, colour and nature). The second lower case letter after the capital letter mainly indicates the presence or absence of hydromorphic characteristics, depth of brown mottles, etc. This position of the legend code is also used to indicate a buried spodic horizon for legend class W, and a Bv horizon for legend class Z. Except for the shallow peaty soils (W), this letter is followed by two numbers. The first number describes the coarseness of the sand fraction (sand classes) of the topsoil; the second number describes the loam content of the topsoil (loam classes).

Besides these basic symbols, the soil code may contain additional symbols, printed on the map as italic lower case letters or as symbols. These so-called "Additions" are used to modify the basic soil code to take account of disturbed soil, thin deposits of clay or sand, etc. Sometimes, more than one modifier may be needed. In this study, the modifiers encountered preceding the main code are:

z – thin deposit of sand
k – thin deposit of clay
f – thin layers of bog iron ore.

Modifiers placed after the main code are:

w – thin peat or peaty horizon in the soil profile
v – peat or peaty subsoil
↧ – excavated soil
↥ – raised soil
↦ – reworked soil.

In this study we have termed these phenomena "additions".

As well as these codes, which are printed in black on the maps, each delineation is provided with a blue roman numeral from I to VII, indicating the groundwater class.

Examples of the composition of the legend code and the position of the discriminating criteria are shown below.

k p Z g 2 3 *v* III

position: 1 2 3 4 5 6 7 8

position 3	one or two capital letters indicating the main class of the legend
positions 2, 4	lower case roman letter, sometimes absent. With 3, these letters code the subgroup of the soil in the Dutch system of soil classification
position 5	number: code for the coarseness of the sand fraction (sand classes). Rarely absent
position 6	number: code for the loam content (loam classes). Rarely absent
positions 1, 7	one, occasionally two, italic lower case letters or symbols; additions for modifying the basic legend code. Often absent
position 8	roman numeral printed in blue and indicating the groundwater class.

The 1 : 10 000 legend codes for subgroup (positions 2, 3, 4) and for groundwater class (position 8) are similar to those for the 1 : 50 000 mapping. But, in the 1 : 10 000 mapping, more classes are distinguished for the coarseness of sand (position 5) and loam content (position 6). Also, for certain legend classes, two or three lower case letters may precede the main class of the legend; these indicate a further division of the thickness and colour of the A1 horizon. The 1 : 10 000 mapping also has narrower class limits for some of the phenomena listed under the additions *(z, k, f)* that are placed in position 1.

3.4 The soil maps analysed

In all, 12 soil maps were analysed: 6 of area A at a scale of 1 : 50 000 using the general classification and 6 of area B at a scale of 1 : 10 000 using the detailed classification. For each map scale, 4 survey methods were used to generate 4 different maps. In addition, for each map scale a generalized proximal map (see Section 3.2.2) and a proximal map with adjusted observation density (see Section 3.2.1) were produced.

We labelled the soil maps with self-descriptive codes relating to the survey methods. The first part of the code relates to the sampling procedure: purposive (= Pu) or random (= Ra). The second part of the code describes the method of delineating the soil boundaries: field delineation (= Fi) or proximal delineation (= Pr).

An additional numerical code was appended: 50 to indicate the map scale 1 : 50 000 and 10

Table 2 Coding of the soil maps

8200163

Soil map		Description		
scale 1:50000	scale 1:10000	sampling procedure	method of boundary delineation	additional comments
PuFi-50	PuFi-10	purposive	field	—
RaFi-50,d	RaFi-10,d	random	field	differing density
RaPr-50,d	RaPr-10,d	random	proximal	differing density
RaPr-50	RaPr-10	random	proximal	—
RaPr-50,g	RaPr-10,g	random	proximal	generalized
PuPr-50	PuPr-10	purposive	proximal	—

Pu = purposive sampling
Ra = random sampling
Fi = field delineation
Pr = proximal delineation

to indicate 1 : 10 000. To signify that the map has been generalized a "g" may appear in the code. The codes for maps with adjusted observation density contain the suffix "d" (density).
The map codes are explained in Table 2 and in Symbols and Abbreviations.

3.5 Testing the soil maps

The quality of the soil maps was tested using profile descriptions from randomly chosen observation points. These descriptions had not been used for the compilation of the map in question. In area B the stratification used (64 square cells of 6.25 ha each) applies both to the observation points used for compiling the map and those used for testing. In area A the same stratification was also used for both data sets (squares of 25 ha each), with the exception of the area within A occupied by area B. In the latter area the original 6.25 ha stratification was maintained for testing the 1 : 50 000 soil maps. Figure 2 outlines the stratifications.

Table 3 Observation series for the testing of the soil maps

8200163

Area	Name of observation series	Total no. of observations	No. of observations per stratum	Density per 10 ha
Area A (1600 ha) scale 1:50000	A3[c]	256	4	1.6
Area B (400 ha) scale 1:10000	B3[c]	576	9	14.4

Table 3 shows the series of observation points (test series) relating to the profile descriptions used for testing the soil maps. Observation sets not listed in Table 3 may also have been used for testing. In principle, all available random observations not used for compiling a particular soil map were available as test observations. The number of test observations therefore varied considerably between soil maps. For example, for testing the soil maps of area A not only were the observations from series A3 but also the random observations from series B2 and B3 (Table 4) were used. The latter arose from area B within area A. Conversely, for testing soil maps of area B, random observations from series A2 and A3 that originated from area B were used.

Table 4 The soil maps investigated, and the number of observations used for compilation and testing of the maps

Area, Scale, Classification	Type of soil map		Survey method		Survey series and number of observations 2)	Test series and number of observations 2)
	map code 1)	description	choice of borings	method of delineation		
Area A scale 1:50000 general classification 1600 ha	PuFi-50	field delineation and purposive choice ("1:50000 soil map of the Netherlands")	purposive	field	A1 (356)	A2^c + A3^c (509)
	RaFi-50,d	field delineation based on series of randomly chosen profile descriptions	random	field	A2 (253)	A3^c–1 (255)
	RaPr-50,d	proximal map based on the same observations as map RaFi-50,d	random	proximal	A2 (253)	A3^c (256) B2^c + B3^c (1100)
	RaPr-50	proximal map as RaPr-50,d but with higher observation density	random	proximal	A2 + 4/10 A3 (349)	6/10 A3^c (160) B2^c + B3^c (1100)
	RaPr-50,g	proximal map as map RaPr-50 but generalized	random	proximal	A2 + 4/10 A3 (349)	6/10 A3^c (160) B2^c + B3^c (1100)
	PuPr-50	proximal map based on the profile descriptions of the "1:50000 soil map of the Netherlands"	purposive	proximal	A1–1 (355)	A2^c + A3^c (509) B2^c + B3^c (1100)
Area B scale 1:10000 detailed classification 400 ha (mapped 359 ha, built-up area 41 ha)	PuFi-10	field delineation and purposive choice (commissioned survey)	purposive	field	B1 (446)	1/4 A2^c 1/4 A3^c–2 B2^c–18 B3^c–41 } 1191
	RaFi-10,d	field delineation based on series of randomly chosen profile descriptions	random	field	B2–18 (530)	1/4 A2^c 1/4 A3^c–2 B3^c–41 } 661
	RaPr-10,d	proximal map based on the same randomly chosen profile descriptions as map RaFi-10,d	random	proximal	B2–19 (529)	1/4 A2^c 1/4 A3^c–2 B3^c–41 } 661
	RaPr-10	proximal map as map RaPr-10,d but with lower observation density	random	proximal	8/10 B2–15 (437)	1/4 A2^c 1/4 A3^c–2 B3^c–41 2/10 B2^c–4 } 753
	RaPr-10,g	proximal map as RaPr-10 but generalized	random	proximal	8/10 B2–15 (437)	1/4 A3^c–2 1/4 A2^c B3^c–41 2/10 B2^c–4 } 753
	PuPr-10	proximal map based on the profile descriptions from the normal commissioned survey (PuFi-10)	purposive	proximal	B1–1 (445)	1/4 A2^c 1/4 A3^c–2 B2^c–18 B3^c–41 } 1191

1) For the definition of map codes, see Table 2 and Symbols and Abbreviations.

2) For the description of the survey and test series, see Tables 1 and 3 and Symbols and Abbreviations

8200163

Table 4 contains an overview of the subsets and numbers of observations used for testing and those for compiling the soil maps.

We wish to emphasize that there is one important difference between the descriptions of the randomly chosen profiles used for compiling a soil map and those used for testing it. The profile descriptions are all based on field estimates. Estimated values may differ from real values because of random and systematic estimation errors. The estimated values were corrected for systematic estimation errors for a number of soil properties. This was achieved by computing the relations between field estimates and laboratory analyses for 30 soil samples. In Section 5.2 this procedure is outlined. For the current purpose we draw attention to the fact that for each randomly chosen profile description (series A2, A3, B2 and B3) there are 2 versions: an uncorrected profile description and a profile description corrected for systematic estimation errors. The corrected descriptions have been designated by the letter "c". Only corrected profile descriptions were used to test the soil maps. Only uncorrected observations were used to compile the maps.

3.6 Design of the comparisons of survey methods

In principle, we may compare all soil maps listed in Table 4 with each other. But all comparisons are not equally interesting. Some pairs of soil maps differ in one aspect only, other pairs in two or more aspects. If we compare maps varying in one aspect only, any differences in quality may be attributed to that aspect. If two or more aspects vary, differences result from the combined influence of all aspects without allowing for a quantitative study of each aspect. In addition, there may be other differences between pairs of soil maps, e.g. generalization (see Section 3.2.2) and observation density (see Section 3.2.1). The soil maps were compiled by different surveyors, and each map bears the stamp of the individual surveyor. This applies not only to systematic estimation errors, but also to the location of the purposively chosen observations and to the delineation and naming of the mapped areas. In this study it is not possible to evaluate the influence of each individual surveyor.

For this research we specified that in order to be able to interpret the results, the soil maps should vary in only one or two aspects. Other aspects must – as far as possible – be equivalent. Therefore we did not compare soil maps of area A with soil maps of area B. In such a comparison differences may be caused by varying soil conditions, map scale, observation density, and the degree of detail in the classification used.

Figure 4 and Table 5 give overviews of the pairs of soil maps we compared and of the aspects in which the pairs differ.

Table 5 Pairs of soil maps in comparisons

8200163

Pairs of soil maps		Aspects of comparisons
Area A	Area B	
PuFi-50 and PuPr-50	PuFi-10 and PuPr-10	boundary delineation
RaFi-50,d and RaPr-50,d	RaFi-10,d and RaPr-10,d	boundary delineation
RaPr-50 and PuPr-50	RaPr-10 and PuPr-10	sampling procedure
PuFi-50 and RaFi-50,d	PuFi-10 and RaFi-10,d	sampling procedure observation density
PuFi-50 and RaPr-50	PuFi-10 and RaPr-10	sampling procedure boundary delineation
RaPr-50,g and PuPr-50	RaPr-10,g and PuPr-10	sampling procedure generalization
RaFi-50,d and PuPr-50	RaFi-10,d and PuPr-10	sampling procedure boundary delineation, observation density
RaPr-50,d and RaPr-50	RaPr-10,d and RaPr-10	observation density
RaPr-50 and RaPr-50,g	RaPr-10 and RaPr-10,g	generalization

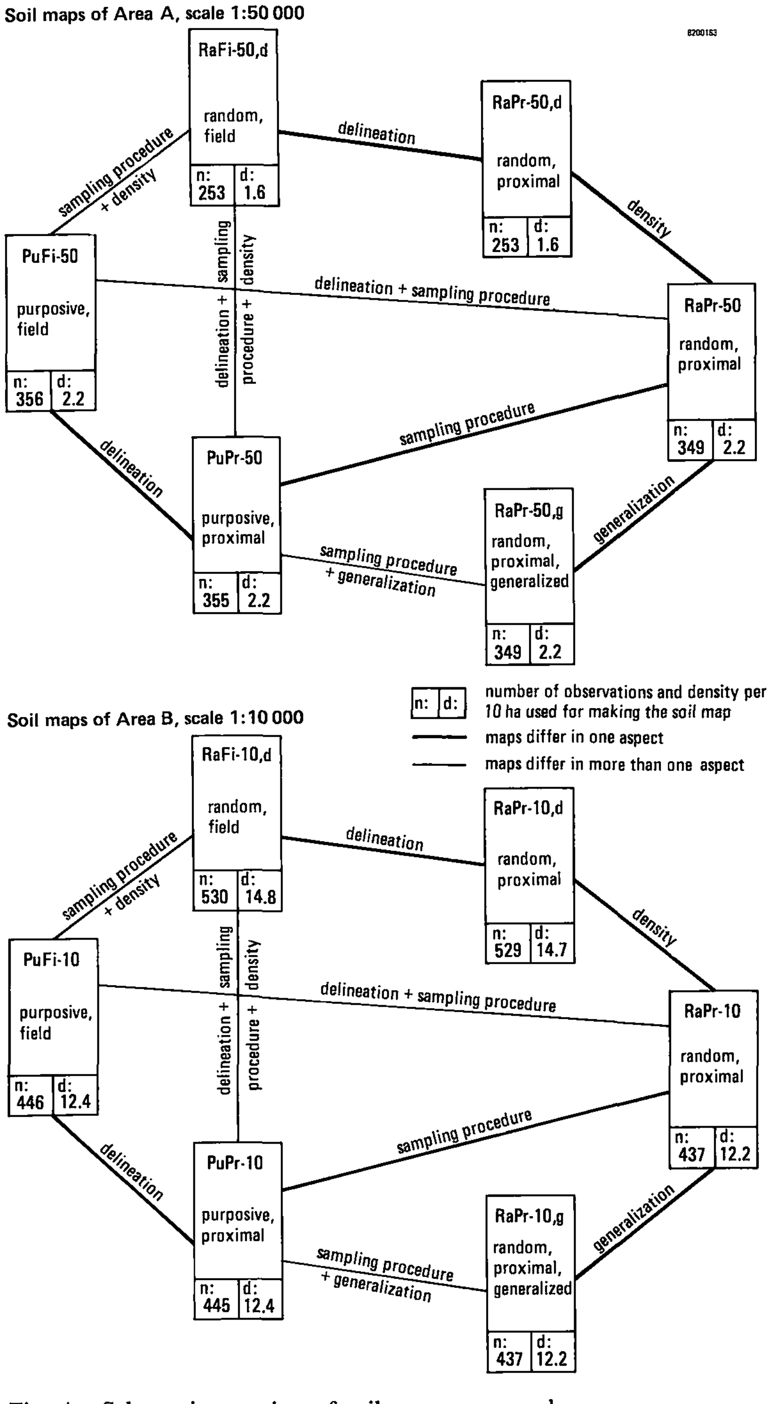


Fig. 4. Schematic overview of soil maps compared.

4. THE PROJECT AREA

4.1 Location of the area

The project area is located north of the village of Laren in the province of Gelderland, in a gently undulating cover-sand area sloping slightly from the east-southeast (approx. 12.5 m above sea level) towards the west-northwest (approx. 9.50 m above sea level). The area consists of area A of 1600 ha containing area B of 400 ha (Fig. 5). Soil maps at a scale of 1 : 50 000 were made of area A. To save time and effort soil maps at a scale of 1 : 10 000 were only made of the smaller area B.

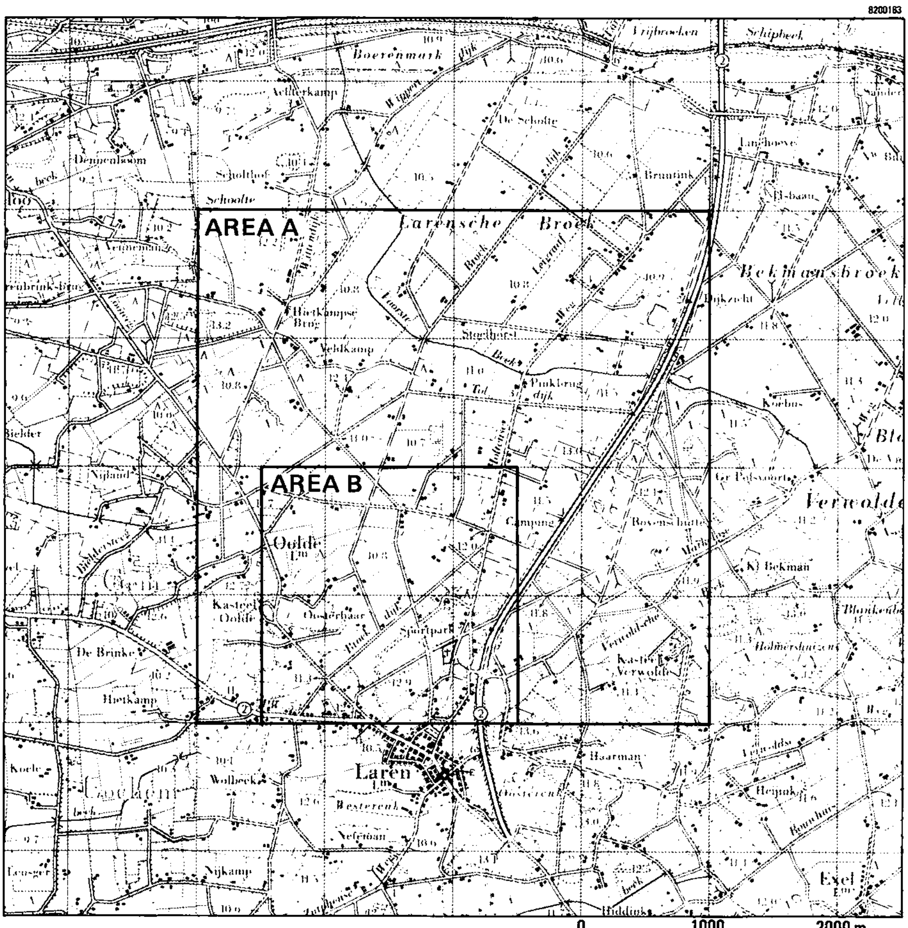


Fig. 5. Location of project areas.

4.2 Geology

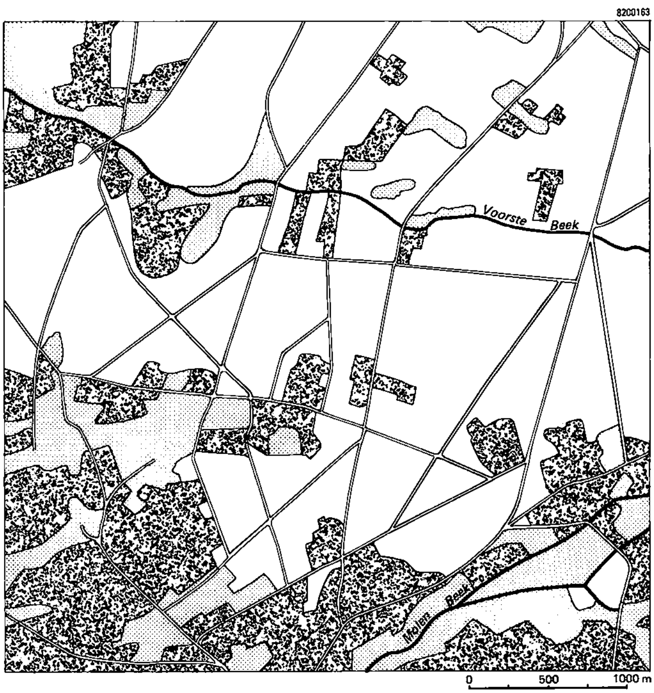
The cover sand at the surface is of aeolian, Pleistocene origin. The loam content is low to medium and the coarseness of the sand very fine to medium fine. The median of the sand fraction (M50) varies from 130 to 160 μm.

The thickness of the cover-sand layer ranges from just over 1 m to several metres. The thickest deposits are on ridges and plateaus. Here, the deposits normally comprise younger cover sand overlying older cover sand. In the lower areas the cover-sand layer is thinner. The younger deposit is usually absent, so that the older formation is exposed at the surface. Below the cover sand we find gravelly, coarse sandy layers deposited by the wandering system of the river Rhine (the Kreftenheye Formation). Holocene deposits occur only sporadically and only as clayey brook deposits a few decimetres thick (the Singraven Formation).

Peaty layers have formed in some low-lying areas. In some of the highest areas inland dunes are present (the Kootwijk Formation).

4.3 General soil conditions

The soil pattern of the project area is typical for cover sand areas. Higher land cultivated before 1880 has Plaggepts (enk earth soils), Plaggeptic Haplohumods (kamp podzol soils) and Plaggeptic Haplaquods (laar podzol soils) (see Fig. 6). These higher soils are normally con-



grassland | arable land | non-agricultural land (mainly heath and conifers)

Fig. 6. Land use in project area in 1880.

tiguous with lower areas that serve as natural drainage systems. The lower areas have richer soils that were already in use as grasslands before the introduction of artificial fertilizers (Fig. 6). Here we find Typic Humaquepts (beek earth soils) and Typic Psammaquents (vlak vague soils).

Prior to 1880, an important part of the sandy soils was covered with heather or - for a smaller part - with conifers (Fig. 6). These soils were then in common use for keeping sheep and cutting heather turves. The turves were used as bedding in stables and sheepfolds and later spread on arable land as fertilizer (DOMHOF, 1953). This method of manuring gave rise to the enk earth soils, kamp podzol soils and laar podzol soils. Following the introduction of artificial fertilizers, unused land was gradually brought into cultivation. Recently reclaimed areas have predominantly Typic Haplaquods (veld podzol soils). Depending on their position relative to the ground water we may subdivide them into wet veld podzol soils (groundwater classes III and V), moist veld podzol soils (classes V* and VI) and dry veld podzol soils (classes VII and VII*). The highest spots of the recently reclaimed land may have Typic Haplohumods (haar podzol soils) and locally Typic Udipsamments (duin vague soils).

4.4 Land use and suitability for agriculture

As in most of the sandy areas, mixed forms of land use originally occupied the project area. The lower and moderately high ground were used for grassland, and the higher ground for arable land. Today, grassland dominates, with scattered arable fields usually cropped with forage maize. In the southeastern part of the project area there are woods, mainly coniferous.

The soils in the project area are poor sands. In most years there is a precipitation deficit during the growing season (see Section 5.3.1). The agricultural capability of the soils is therefore strongly influenced by the amount of moisture available in the root zone and the depth to the water-table.

The depth to the water-table varies considerably. This is because of the short-range variability in evaluation. The lowest areas have summer water-tables at 0.70-1 m below surface, and the highest areas at circa 3.50 m. Spring water-tables are approximately 1 m above summer levels.

The depth to the water-table is denoted on the soil maps by the use of a groundwater classification (VAN HEESEN, 1970). This classification forms part of both soil classifications used (see Appendix 1). The divisions range from class (Gt) I to VII inclusive, indicating declining groundwater influence.

4.5 Choice of the project area

The data sets for a study of this kind encompass many aspects. The soil maps had to be made according to different survey methods. The compilation of one map had to be independent of that of others. Limited manpower and time did not allow large areas to be investigated. To alleviate this problem an area representative of soil conditions in other sandy areas had to be chosen.

Figure 7 shows the location of the project area and the distribution of Pleistocene sandy soils in the Netherlands. Most of these soils consist of fine cover sands. The soils of the project area are exclusively of this material. The project area may be considered to be representative of the Dutch cover-sand areas, not only geologically but also pedologically. Both the types of soils occurring and the areal proportions of the soil classification units correspond closely to what may be observed in other cover-sand areas.

Another reason for choosing this particular project area was that the Netherlands Soil Survey Institute was already engaged in the routine soil survey of the area, using its free-survey

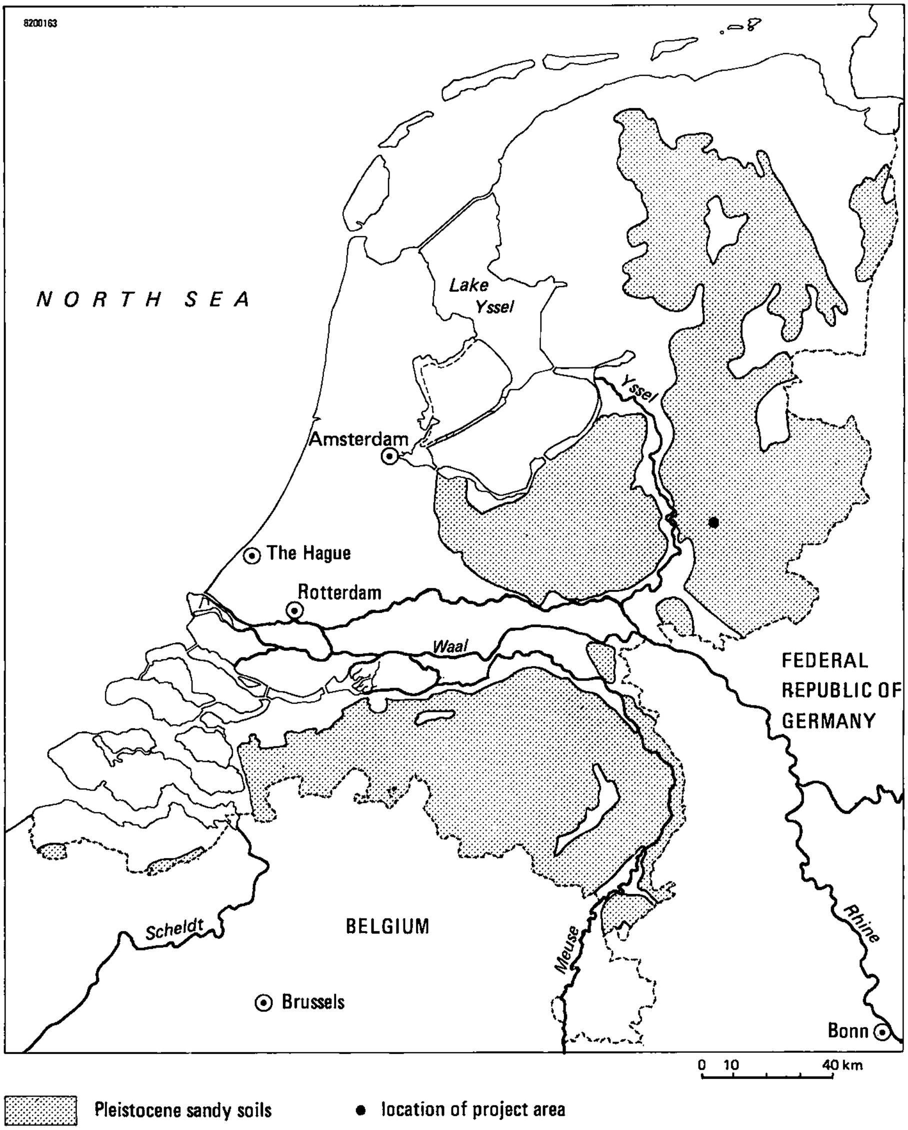


Fig. 7. Distribution of Pleistocene sandy soils in the Netherlands (after DE BAKKER, 1979).

method, at the time that the project was scheduled to start (summer 1975). The fieldwork for the 1 : 50 000 soil map was completed before the project began, but the 1 : 10 000 soil map was compiled in summer 1975.

The maps have subsequently been published. They are: the Soil Map of the Laren (Gelderland) Reallotment Area, scale 1 : 10 000 (GROOT OBBINK, 1976), and the Soil Map of the Netherlands, scale 1 : 50 000, Map Sheet 34 West and East (STICHTING VOOR BODEMKARTERING, 1979).

5. DATA COLLECTION AND DATA PROCESSING

5.1 Collecting the soil data

Collecting data for this study was extensive and complex. In addition to the data for compiling the soil maps, a second set of data for testing the map quality had to be collected. These test data were corrected for systematic estimation errors and used for deriving a number of quality measures.

5.1.1 Data for compiling the soil maps

Profile descriptions of borings down to 120 cm were made for all survey observations used for compiling the soil maps. The type, thickness and depth of the observed horizons were described. For each horizon, estimates were made of the content of humus, clay and loam, and the coarseness of the sand fraction.

Using these and other data (such as homogeneity, colour and mottles) the soil profiles described were compared with the definitions of the soil classification used (see Section 3.3), and were then classified. In the project area the definitive characteristics used in the soil classification were: mineral earthy layer, peaty topsoil, intermediate peaty layer, thick and moderately thick A1 horizon, prominent podzol B horizon, hydromorphic characteristics, human influence, sand cover, clay cover, sandy soils, clay soils and peaty soils.

In addition rooting depth and groundwater class were noted for each profile description. The groundwater class was derived from estimates of the mean highest and mean lowest water-tables (MHW and MLW respectively) (VAN HEESEN, 1970). The estimates of the MLW are primarily based on the depth and intensity of iron concretions and reduction, the presence or absence of mottles, and soil profile development.

The field estimates were supported by laboratory analyses for humus, clay and loam content, and the coarseness of the sand fraction, performed on a number of samples. There are some observation wells in the study area and their data were also used. The water-tables had been recorded every two weeks for a period of several years. The relation between the depth of the gley phenomena at the observation wells and the MHW and MLW values calculated from records from observation wells was used to support MHW and MLW estimates for the profile descriptions.

5.1.2 Data for testing the soil maps

Data for testing the soil maps were collected at a large number of randomly chosen observation points (test data; Section 3.5). The data were collected using the same procedures as for the observation points used to compile the maps (Section 5.1.1). As well, additional data were gathered in order to correct the test data for systematic errors of estimation (Section 5.2).

These additional data were obtained by:

- letting the surveyors estimate selected values for all horizons in a set of chosen profile pits;
- collecting duplicate samples from the relevant horizons so that estimated values could be verified by laboratory analyses;
- measuring water-tables periodically at 64 observation points chosen randomly from all observation points used for testing;
- collecting detailed elevation data for all observation points used for testing.

Additional data on water-tables were collected from test observation points with relatively deep water-tables. This was required in order to derive a number of important quality measures from the test data. The profile descriptions of the observation points were limited to the upper 120 cm. Relatively high-lying soils have their lowest water-tables (MLW) and sometimes their highest water-tables (MHW) below this depth. For mapping purposes these MHW's and MLW's were denoted by ">120" only. In order to calculate the moisture supply capacity (Section 5.3.1) and the frequency distribution of some soil properties (Section 6.2.5), it is necessary to know the absolute depth of the water-tables.

The periodic measurements of the water-tables at the 64 points showed that the groundwater regime of the project area is very uniform. When the actual MLW values in relation to sea-level were calculated, a smooth surface with an inclination of 20 cm per km, sloping from the east-southeast to the west-northwest was obtained. This enabled an isohypse map with an equividistance of 10 cm to be constructed. As a result we were able to estimate the actual MLW of each observation point fairly accurately.

This method was not applicable for deriving deeper MHW values (>120 cm). Measurements showed that the MHW level was much more irregular than the MLW level. Again, relating the data to sea-level gave a general inclination from the east-southeast to the west-northwest, but with considerable local variation. The depth of the MHW is influenced by local differences in elevation and drainage status.

To derive data for deeper MHW's we made use of the fluctuations (the difference between MLW and MHW) known at the 64 observation points. For each observation point the fluctuation was substracted from the derived value of the MLW. For observation points with a good drainage status or in relatively low-lying areas a smaller fluctuation was used than for other observation points. The fluctuation values applied were based on measurements taken at the 64 observation points. They varied between 65 cm and 100 cm.

5.2 Correcting the test observations

The profile descriptions used for testing the soil maps were based on field estimates. These estimates may differ from real values because of random and systematic errors of estimation, or because the profile descriptions of the A series and B series were made by different surveyors - which means that the random and systematic errors of estimation also differed between the two series. Any errors in estimating the test observations will obviously influence the results of the testing. Therefore, the estimated values of the most important soil properties were corrected to eliminate systematic errors in estimation made by the observers. This was achieved by computing the relations between field estimates and laboratory analyses for 30 soil samples. Correction formulae were established for humus content, clay content, loam content, the coarseness of sand (median in μm), mean highest water-table (MHW) and mean lowest water-table (MLW). Field estimates of the four soil properties concerning soil texture were made by each surveyor for 30 samples, that were taken from 10 representative profile pits. Afterwards, duplicate samples were taken from the profile pits, for laboratory analyses. All field estimates of the observations used for testing were corrected using the correction formulae shown in Table 6.

The field estimates of MHW and MLW were corrected using another procedure, for which the relations between measurements of water-tables at randomly selected sites and field estimates of MHW and MLW made at the same sites were computed. In area A, 16 observation points were randomly selected from all the observation points used for testing. In a similar way, 48 observation points were selected in area B. The dates on which the water-tables were measured were chosen on the basis of data from a few observation wells located within the project area. In these observation wells water-tables had been measured fortnightly for more than 10 years. Thus, the levels for MHW and MLW could be calculated exactly for these

Table 6 Correction formulae applied to field estimates

8200163

Variable	Observer	Observation series	Number	Residual standard deviation	Range	Correction formulae
Median (m)	B	B2, B3	28	8.77	$m < 110$	152
					$110 \leq m \leq 160$	$407.8 - 4.088m + 0.01605m^2$
					$160 < m$	$4 + m$
	A	A2, A3	28	8.57	$m < 90$	156
					$90 \leq m \leq 155$	$343.5 - 3.384m + 0.01445m^2$
					$155 < m$	$11 + m$
Loam (l)	B	B2, B3	30	8.00	$0 \leq l \leq 100$	l
	A	A2, A3	30	7.19	$0 \leq l \leq 100$	$1.627 + 0.7663\,l$
Clay (k)	B	B2, B3	30	1.89	$0 \leq k \leq 100$	$1.24 + 0.786k - 0.0157k^2$
	A	A2, A3	30	2.10	$0 \leq k \leq 100$	$1.43 + 0.418k$
Humus (h)	B	B2, B3	29	1.20	$0 \leq h \leq 100$	$0.752 + 1.1861h$
	A	A2, A3	29	1.62	$0 \leq h \leq 100$	$0.733 + 1.1165h$
Mean lowest water-table (L)	B	B2, B3	5	8.35	$0 \leq L \leq 120$	L
	A	A2, A3	13	12.74	$0 \leq L \leq 120$	$13 + L$
Mean highest water-table (H)	B	B2, B3	12	16.68	$0 \leq H \leq 120$	$0.38 + 1.270H - 0.0012H^2$
	A	A2, A3	47	27.75	$0 \leq H \leq 120$	$26.7 - 0.152H + 0.0134H^2$

sites. At the moment that the water-table in the observation wells had reached the MHW or MLW level, the water-tables at all the 64 observation points were measured. These measurements were also made for two levels between MHW and MLW.

Each of the levels was measured on the same day for all observation points. But the values of the water-tables did not exactly correspond with the MHW or MLW, because of a time-lag. In soils with relatively high water-tables, MHW and MLW are reached a few days earlier than in soils with relatively low water-tables. Therefore, the measured values were corrected for this discrepancy. These corrections were derived from the relation between the data on the water-tables of a particular observation point and the data from an observation well with a water-table at a comparable depth (VAN HEESEN, 1970). In most cases the corrections that needed to be made to the measured values because of the time-lag were small: they varied between 0 cm and 5 cm for both MHW and MLW.

Correction formulae were derived from the relations between field estimates for MHW and MLW and measurements of the water-tables made when the MHW or MLW level was reached at the 64 observation points (Table 6). The formulae were used to correct all field estimates of MHW and MLW.

A general study carried out in the project area showed that it was not feasible to correct systematic errors in some aspects of profile descriptions such as the number, the nature and thickness of soil horizons, and that it was also difficult to correct for differences in the identification of diagnostic horizons, the description of colours and the recognition of mottles. In this study, all surveyors made profile descriptions independently at 20 sites. Profile descriptions of soil profiles whose successive horizons differed strongly were found to be broadly similar. The same was true for profile descriptions of profiles with strongly developed and clearly visible soil characteristics in the different horizons. But when soil characteristics were weakly developed, or the soil profile differed sharply from the central concept of a particular profile class, there were great differences between profile descriptions. These differences concerned the number and thickness of the soil horizons distinguished, or the classification of these soil profiles. The corrections applied to the test data did not remove these kinds of systematic errors.

5.3 Calculating derived soil properties

The soil maps were tested with the corrected test data. In all, 25 measures of quality were used (Section 6.2). Thirteen of these related to directly observed soil properties. The other measures of quality related to properties derived from those that were directly observed. The test data had to be processed so that these measures of quality could be calculated. The calculations and descriptions are discussed below.

5.3.1 Moisture supply capacity and related properties

Moisture supply capacity for grass and winter rye was calculated for all test profiles. The moisture supply capacity is defined as the total amount of moisture (mm) supplied by the soil to a crop in a growing season with statistically defined climatic conditions. We used a "10% dry year". In such a year the cumulative evapotranspiration surplus (= precipitation deficit) has the statistical probability of being exceeded only once in every ten years (RIJTEMA, 1971).

The potential evapotranspirations of winter rye and grass are different. For grass, the growing season is 150 days. In a "10% dry year" the precipitation deficit is 233 mm and the potential evapotranspiration is 470 mm. Winter rye has a growing season of 90 days. Here, the precipitation deficit in a "10% dry year" is 163 mm and the potential evapotranspiration 288 mm.

The amount of moisture supplied by a soil to a crop can be visualized as being the amount of moisture available in the root zone, augmented by unsaturated flow from the groundwater to the root zone during the growing season. The additional supply of moisture from the

Table 7 Polynomials used for estimating the moisture supply capacity

8200163

i	x_i	winter rye b_i	grass a_i
1	I	1.87894×10^{2}	2.68869×10^{2}
2	D	6.02607×10^{-1}	1.06900
3	V	-3.50985×10^{-1}	-3.36679×10^{-1}
4	L	-2.21507×10^{-1}	-4.51455×10^{-1}
5	D^2	-5.29507×10^{-2}	-6.40779×10^{-2}
6	DV	3.56911×10^{-2}	4.20700×10^{-2}
7	DL	1.50782×10^{-2}	2.16622×10^{-2}
8	V^2	-1.15169×10^{-2}	-1.74990×10^{-2}
9	VL	2.41982×10^{-3}	7.28370×10^{-3}
10	L^2	-3.32730×10^{-3}	-7.80148×10^{-3}
11	D^3	-1.26445×10^{-4}	-1.66680×10^{-4}
12	D^2V	3.86430×10^{-4}	2.94928×10^{-4}
13	D^2L	8.15622×10^{-7}	1.95619×10^{-4}
14	DV^2	-1.26314×10^{-4}	-1.43832×10^{-4}
15	DVL	-1.58004×10^{-4}	-1.55946×10^{-4}
16	DL^2	2.73880×10^{-5}	-4.26824×10^{-5}
17	V^3	4.45194×10^{-5}	5.79857×10^{-5}
18	V^2L	-3.16669×10^{-6}	2.04878×10^{-6}
19	VL^2	1.51579×10^{-5}	4.80636×10^{-6}
20	L^3	2.38775×10^{-7}	1.65614×10^{-5}

Moisture supply capacity grass $= \sum_{i=1}^{20} a_i x_i$

Moisture supply capacity winter rye $= \sum_{i=1}^{20} b_i x_i$

D = rooting depth
V = mean spring water-table
L = mean lowest water-table

groundwater is caused by the crop taking up moisture from the root zone, thereby creating a potential gradient below the root zone. The root zone is defined as the surface layer in which 80% of the roots occur (RIJTEMA, 1971).

The moisture supply capacity can be calculated from a computer simulation model for unsaturated flow above a shallow water-table (DE LAAT, 1980). To avoid having to make calculations from the simulation model for the individual test profiles, the relations between the variables used in the model were estimated by polynomials, using the method of least squares. The simulation model indicates the relations between moisture supply capacity and rooting depth (D), mean spring water-table (V), and mean lowest water-table (L). The coefficients of the polynomials used for estimating the moisture supply capacity are listed in Table 7. The polynomials were used to calculate the moisture supply capacity for rye and grass for all test profiles. They were derived from the corrected values for MHW and MLW and the field estimates of rooting depth. To calculate the amount of available moisture in the root zone the corrected values of humus content and loam content were used.

In addition to the moisture supply capacity, four other properties for both crops were calculated. These were derived from the data used to calculate the moisture supply capacity, viz.: available moisture in the root zone, capillary rise, percentage capillary rise and percentage available moisture. These properties are defined in Section 6.2.5.

5.3.2 The suitability for grass and rye

When investigating the quality of soil maps the choice of the measures of quality is of paramount importance. The purpose for which the soil map is used is an obvious guideline when making this choice. We therefore selected measures that related to the extent of homogeneity for two applications. For this purpose, suitability classifications were developed for grass and winter rye. Each soil profile used for testing the map was allocated to a class in each of the two classifications. Using a homogeneity index the homogeneity of the mapping units and of the map as a whole was calculated for suitability for each of the crops (see Section 6.2.6).

The suitability classifications for the two crops differed, because they have different requirements of moisture supply capacity and drainage status. We chose grass as one crop, as it is the most common crop on these sandy soils. Winter rye, however, is little grown these days and it would have been more natural to choose forage maize or potatoes. The model that used to estimate the moisture supply capacity (DE LAAT, 1980) makes assumptions about root penetration and mean spring water-table on 14 April. Maize and potatoes begin their growing seasons later, so that for these crops the assumptions of the model are not valid.

The design of this study had the following requirements for the suitability classifications:

a. each soil profile had to be allocable to one class only in each of the suitability classifications;
b. it has to be possible to perform the allocation automatically.

The two suitability classifications used were both derived from the system for soil map interpretation in use at the Netherlands Soil Survey Institute (HAANS, 1979; HAANS & VAN LYNDEN, 1978). The classification system relies on a number of assessment factors, each of which is subdivided into a number of levels. Some of the factors apply to various types of land use, others only to one. The soil properties observed are rated for each assessment factor. The degree of suitability for a particular type of land use is determined by a combination of levels of the relevant assessment factors.

The moisture supply capacity in a "10% dry year" and the drainage status were used as assessment factors for both crops (Tables 8 and 9). The bearing capacity (against poaching) only applies to grass, whilst the workability (structural stability) relates to winter rye only. In this area the latter two factors are influenced by the presence or absence of a poorly permeable

Table 8 Levels of assessment factors for winter rye

8200163

Moisture supply capacity in a 10% year

1	⩾ 163 mm	(E rel = 1.0)
2	⩾ 120 and < 163 mm	(E rel 0,87 – 1.0)
3	⩾ 80 and < 120 mm	(E rel 0,75 – 0.87)
4	< 80 mm	(E rel < 0.75)

Drainage status (mean highest water-table (MHW))

1	> 50 cm
2	> 30 and ⩽ 50 cm
3	⩽ 30 cm

Soil workability/structural stability

1	without poorly permeable layer for winter rye
2	with poorly permeable layer for winter rye

For winter rye a poorly permeable layer is defined as:
a layer at least 10 cm thick, with a humus content of ⩾ 15% and beginning ⩽ 20 cm below the surface, or with a clay content of ⩾ 15% and/or a loam content of ⩾ 35% and beginning ⩽ 30 cm below the surface, independent of the drainage status.

Table 9 Levels of assessment factors for grass

8200163

Moisture supply capacity in a 10% year

1	⩾ 233 mm	(E rel = 1.0)
2	⩾ 170 and < 233 mm	(E rel 0.87 – 1.0)
3	⩾ 115 and < 170 mm	(E rel 0.75 – 0.87)
4	⩾ 70 and < 115 mm	(E rel 0.65 – 0.75)
5	< 70 mm	(E rel < 0.65)

Drainage status (mean highest water-table (MHW))

1	> 30 cm
2	> 15 and ⩽ 30 cm
3	⩽ 15 cm

Bearing capacity (poaching sensitivity)

1	without poorly permeable layer for grass
2	with poorly permeable layer for grass

For grass a poorly permeable layer is defined as:
a layer at least 10 cm thick, with a humus content ⩾ 15% and beginning at the surface, or with a clay content ⩾ 15% and/or a loam content ⩾ 35%, beginning ⩽ 20 cm below the surface and with a drainage level ⩽ 30 cm below the surface

Table 10 Suitability classes for winter rye

8200163

	Class description		Assessment factors			Particular criteria
			moisture supply capacity (mm)	drainage status (cm)	workability/ structural stability	
1.1	Very well suited (without limitations)		≥ 163	> 50	good	–
1.2	Quite well suited (few limitations)		120 – 163	> 50	good	–
		or:	120 – ≥ 163	30 – 50	good	with moderately thick or thick improved topsoil
		or:	80 – 120	> 50	good	with thick improved topsoil
2	Moderately suited (limited potential)		120 – ≥ 163	> 50	poorly permeable layer	–
		or:	120 – ≥ 163	30 – 50	good	without moderately thick or thick improved topsoil
		or:	80 – 120	30 – 50	good	–
		or:	80 – 120	> 50	good	without thick improved topsoil
3	Poorly suited (few potential)		< 80	–	–	–
		or:	–	≤ 30	–	–
		or:	–	30 – 50	poorly permeable layer	–
		or:	80 – 120	> 50	poorly permeable layer	–

Table 11 Suitability classes for grass

8200163

	Class description		Assessment factors		
			moisture supply capacity (mm)	drainage status (cm)	bearing capacity/ poaching sensitivity
1.1	Very well suited (without limitations)		170 – ≥ 233	> 30	good
1.2	Quite well suited (few limitations)		115 – 170	> 30	good
2	Moderately suited (limited potential)		70 – 115	> 30	good
		or:	115 – ≥ 233	15 – 30	good
		or:	115 – ≥ 233	> 30	poorly permeable layer
		or:	≥ 233	15 – 30	poorly permeable layer
3	Poorly suited (few potential)		< 70	–	–
		or:	–	≤ 15	–
		or:	70 – < 233	15 – 30	poorly permeable layer
		or:	70 – 115	15 – 30	good
		or:	70 – 115	> 30	poorly permeable layer

layer. To facilitate automatic allocation to suitability classes we morphometrically defined two types of poorly permeable layers on the basis of depth, thickness, and clay, loam and humus content. The definitions were made in close co-operation with the Land Use Department of the Netherlands Soil Survey Institute, and are based on practical experience. The definitions were derived especially for this project and only apply to the cover-sand project area.

Both suitability classifications have four suitability classes (Tables 10 and 11). Each class is defined in terms of one or more combinations of levels of the three assessment factors. The general description of the suitability classes is:
Class 1.1: very well suited (without limitations)
Class 1.2: quite well suited (few limitations)
Class 2 : moderately suited (limited potential)
Class 3 : poorly suited (few potential).

Tables 12 and 13 present the combinations of levels of the assessment factors as keys for the suitability classification. Table 14 lists the suitability classes on the basis of the levels of the assessment factors.

Table 12 Key to the suitability classes for winter rye on the basis of levels of the assessment factors

8200163

Suitability class	Levels of: moisture supply capacity	drainage status	workability/ structural stability	
1.1	1	1	1	
1.2	2	1	1	
	1	2	1	only if a moderately thick or thick improved topsoil is absent
	2	2	1	only if a moderately thick or thick improved topsoil is absent
	3	1	1	only if a thick improved topsoil is present
2	1	1	2	
	2	1	2	
	3	2	1	
	1	2	1	only if a moderately thick or thick improved topsoil is absent
	2	2	1	only if a moderately thick or thick improved topsoil is absent
	3	1	1	only if a thick improved topsoil is absent
3	1	3	1	
	1	2	2	
	1	3	2	
	2	3	1	
	2	2	2	
	2	3	2	
	3	3	1	
	3	1	2	
	3	2	2	
	3	3	2	
	4	1	1	
	4	2	1	
	4	3	1	
	4	1	2	
	4	2	2	
	4	3	2	

Table 13 Key to the suitability classes for grass on the basis of levels of the assessment factors

8200163

Suitability class	Levels of: moisture supply capacity	Levels of: drainage status	Levels of: bearing capacity/ poaching sensitivity
1.1	1	1	1
	2	1	1
1.2	3	1	1
2	1	2	1
	1	1	2
	1	2	2
	2	2	1
	2	1	2
	3	2	1
	3	1	2
	4	1	1
3	1	3	1
	1	3	2
	2	3	1
	2	2	2
	2	3	2
	3	3	1
	3	2	2
	3	3	2
	4	2	1
	4	3	1
	4	1	2
	4	2	2
	4	3	2
	5	1	1
	5	2	1
	5	3	1
	5	1	2
	5	2	2
	5	3	2

Table 14 The suitability classes for winter rye and grass ordered on the levels of the assessment factors

Winter rye

Moisture supply capacity	Drainage status 1, workability/structural stability 1	Drainage status 1, workability/structural stability 2	Drainage status 2, workability/structural stability 1	Drainage status 2, workability/structural stability 2	Drainage status 3, workability/structural stability 1	Drainage status 3, workability/structural stability 2
1	1.1	2	2[1)]	3	3	3
2	1.2	2	2[1)]	3	3	3
3	2[2)]	3	2	3	3	3
4	3	3	3	3	3	3

Grass

Moisture supply capacity	Drainage status 1, bearing capacity/poaching sensitivity 1	Drainage status 1, bearing capacity/poaching sensitivity 2	Drainage status 2, bearing capacity/poaching sensitivity 1	Drainage status 2, bearing capacity/poaching sensitivity 2	Drainage status 3, bearing capacity/poaching sensitivity 1	Drainage status 3, bearing capacity/poaching sensitivity 2
1	1.1	2	2	2	3	3
2	1.1	2	2	3	3	3
3	1.2	2	2	3	3	3
4	2	3	3	3	3	3
5	3	3	3	3	3	3

8200163

1) Suitability class 1.2 applies if a moderately thick or thick improved topsoil is present

2) Suitability class 1.2 applies if a thick improved topsoil is present

6. MEASURES OF THE QUALITY OF SOIL MAPS

6.1 Introduction

Soil-survey quality control is still in its infancy, but it is already apparent that there are two alternative approaches to defining and quantifying survey quality: one is based on cartographic criteria and the other on pedological criteria. The cartographic quality of a soil map is assessed from the readability of the map; the pedological quality reflects the accuracy and precision of the information presented by the map. To describe the quality of soil maps we used the terminology shown in Fig. 8.

The present study deals mainly but not exclusively with pedological quality, and the measures of quality applied relate to this. To assess pedological quality required one or more measures of quality selected from a wide range of alternatives. We used several types of quality measures. Their definitions and interpretation are presented in Section 6.2. Section 6.3 specifies the statistical methods used on the available test data to estimate the quality of the final map.

Various aspects determine the cartographic quality of soil maps. In this study we only considered the parameters mentioned in Fig. 8. The parameters which are related to the readability of soil maps are discussed in Section 6.4.

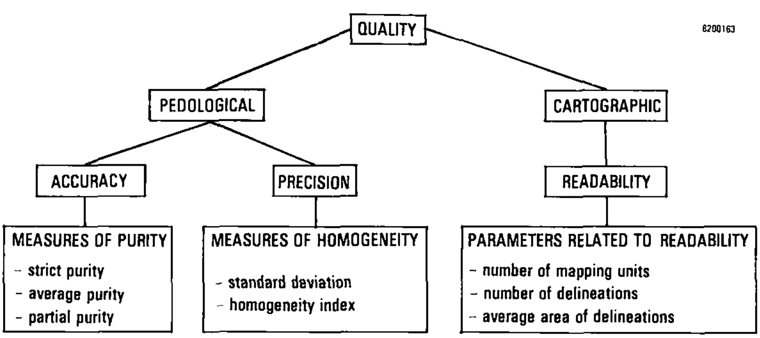


Fig. 8. Terminology to describe the quality of soil maps, used in this study.

6.2 Measures of quality: definitions and interpretations

6.2.1 General

The measures of quality adopted in this study may be divided into two types: measures of purity and measures of homogeneity. Measures of purity include strict purity, average purity and five partial purities. The measures of homogeneity relate to standard deviations for 16 different soil properties and the homogeneity indices for suitability for rye and for grass.

Measures of purity have a long tradition in soil survey. Both their definitions and interpretations are simple. These measures indicate the degree to which the classification criteria shown on the map are satisfied by the properties of the soil profiles in the field. They reflect the accuracy with which the occurrences of the taxonomic units in the field are indicated on the map. The disadvantages of purity measures are that all deviations from the class definitions are equally weighted, regardless of their type or extent. No allowance is made for variations within the class limits.

Measures of homogeneity indicate how homogeneous the mapping units are for selected soil properties. These properties may be measured or observed directly, or they may be derived, such as assessment factors or suitability classes. In contrast to the purity measures, the homogeneity measures are independent of the criteria of the classification. If for a given property a mean value of a mapping unit is used as the estimate for values at individual points in the area, the error of such estimates will decrease as the homogeneity of the mapping unit increases.

We adopted the standard deviation within the mapping units as a measure of the homogeneity of quantitative soil properties. This was not possible for the suitabilities for grass and rye, being qualitative properties in this case. For these two suitability classifications another measure was chosen: the homogeneity index.

A disadvantage of the measures of quality used is that they relate to the variation between individual soil profiles, including short-range lateral variability. However, for practical use, variations within a field are of minor importance, because the management of that field is adjusted to the "average" soil suitability of the field.

In the following sections true (i.e. population) values of parameters are denoted by capital letters, whilst their estimates and values of soil profiles are denoted by the corresponding lower-case letters.

6.2.2 *Partial purities*

A partial purity of a map or part thereof is defined as the proportion (expressed as a percentage) of its area in which a subset of the classification criteria shown is satisfied by the properties of the soil profiles in the field.

All criteria used for both classifications applied in this study were subdivided into the following five subsets, each yielding a partial purity:

1. subgroup: percentage purity with respect to all criteria defining the subgroup and higher levels in the Dutch system of soil classification;

2. sand classes: percentage purity with respect to the class subdivision of sand coarseness, expressed as the median of the sand fraction (M50) in μm;

3. loam classes: percentage purity related to the class subdivision of loam content (% < 50 μm), expressed as the percentage by weight of the inorganic fraction of the soil;

4. "additions":* percentage purity with respect to certain aspects associated with various mapping units, e.g. sand cover, clay cover, reworked soils.

5. groundwater class: percentage purity related to the groundwater class, which is defined in terms of the mean highest and mean lowest water-tables, expressed in cm below the surface.

For the statistical analysis, the values of the partial purities of individual soil profiles were used, defined as

p_{ijk} = 1 if the *i*th profile has the properties meeting the *j*th subset of classification criteria predicted by the *k*th soil map and its legend;

p_{ijk} = 0 otherwise.

This definition shows that the purity $\overline{P}_{jk}$ of the *k*th soil map, with regard to the *j*th subset of criteria, is the average of the purity values of all *N* profiles in the mapped area:

* The term 'additions' is defined in Section 3.3

$$\overline{P}_{jk} = \sum_{i=1}^{N} p_{ijk}/N \qquad (1)$$

6.2.3 *Strict purity*

The strict purity of a map or part thereof is defined as the proportion (or percentage) of the area in which the soil profiles fulfil exactly all the classification criteria given on the map.

Analogous to partial purity we may consider the values of strict purity of individual profiles as:

p_{isk} = 1 if the *i*th profile has the properties meeting all classification criteria predicted by the corresponding mapping unit on the *k*th soil map;

p_{isk} = 0 otherwise, where *s* indicates the strict purity.

Analogous to partial purity, the strict purity of the *k*th soil map is the mean of all values of strict purity for all *N* profiles within the mapped area:

$$\overline{P}_{sk} = \sum_{i=1}^{N} p_{isk}/N \qquad (2)$$

The strict-purity value of the *i*th profile is the lowest partial-purity value of that profile:

$$p_{isk} = \min\{p_{i1k}, \ldots, p_{i5k}\} \qquad (3)$$

but note that:

$$\overline{P}_{sk} \leqslant \min\{\overline{P}_{1k}, \ldots, \overline{P}_{5k}\} \qquad (4)$$

Equality is reached only if for every i $p_{imk} = 1$ implies that $p_{ijk} = 1$ for all j, where m denotes the subset of criteria with the lowest purity.

6.2.4 *Average purity*

The average purity is defined as the arithmetic mean of all (here 5) partial purities.

$$\overline{P}_{ak} = (\overline{P}_{1k} + \ldots + \overline{P}_{5k})/5 \qquad (5)$$

This is equivalent to:

$$\overline{P}_{ak} = \sum_{i=1}^{N} p_{iak}/N \qquad (6)$$

where $p_{iak} = (p_{i1k} + \ldots + p_{i5k})/5$ for $i = 1, \ldots, N$.

This measure is thus the purity value averaged over both the profiles and the subsets of classification criteria.

Partial, strict and average purities are measures of quality that may be also applied to parts of maps, such as mapping units or groups of mapping units and delineated areas. The purity values are then averaged over all the soil profiles that occur within the part of the area being considered. The purity of the map is equal to the average of the purities of the mapping units, weighted with their respective areas.

As in other studies, purities were reported as percentages. These percentages were obtained by multiplying the proportions by 100. The procedures for statistical inference (Section 6.3.2) are more easily presented in terms of proportions.

6.2.5 Standard deviations within mapping units

We used the standard deviation within mapping units as a measure of the variation of the following soil properties:

MHW: mean highest water-table (cm below surface);
MLW: mean lowest water-table (cm below surface);
rooting depth: the thickness of the layer containing 80% of the roots (cm) (= root zone);
humus content at depths of 10, 30 and 50 cm: the percentage of organic material by weight at depths of 10 cm, 30 cm and 50 cm;
moisture supply capacity: total moisture (in mm) supplied by the soil to a crop in a "10% dry year";
available moisture: total moisture available to the crop (in mm) in the root zone of the soil profile (moisture supply capacity minus capillary rise);
capillary rise: the amount of water (mm) available to the crop that rise from the groundwater to the base of the root zone by unsaturated flow (moisture supply capacity minus available moisture);
percentage capillary rise: the percentage reduction in actual moisture supply capacity if no capillary rise from the groundwater takes place

$$\left(\frac{\text{capillary rise} - 15}{\text{moisture supply capacity}}\right) \times 100;$$

percentage available moisture: the percentage of the moisture supply capacity contributed by available moisture

$$\left(\frac{\text{available moisture}}{\text{moisture supply capacity}}\right) \times 100.$$

The standard deviations of MHW, MLW, rooting depth and the humus contents were calculated directly from the test data. The other standard deviations relate to soil properties that were derived from the test data. For the latter, separate standard deviations were calculated for rye and grass.

For this study, the homogeneity of the uth mapping unit of a given map with regard to a quantitative soil property is defined as the standard deviation S_u within that unit. This is the square root of the variance S_u^2:

$$S_u^2 = \sum_{i=1}^{N_u} (x_{iu} - \overline{X}_u)^2 / N_u \qquad (7)$$

where x_{iu} denotes the value of the ith soil profile in the uth mapping unit, and $\overline{X}_u$ the average over all N_u profiles in that unit. For the complete map the square root of the pooled variance within all M mapping units applies:

$$S_w^2 = \sum_{u=1}^{M} A_u S_u^2 \qquad (8)$$

where $A_u = N_u/N$ denotes the relative area of the uth mapping unit.

We will also consider the standard deviation within classification units, which is defined analogously to the standard deviation within mapping units. In the hypothetical case of a soil map with a strict purity of 100% the two standard deviations are equal.

Because of the impurities, the standard deviation within mapping units is usually greater than the standard deviation within classification units, especially when the soil properties used are definitive for the classification units. For such properties the standard deviation within classification units constitutes in practice the lower limit for that within mapping units. The upper limit is the standard deviation S_t of the total area, defined as:

$$S_t^2 = \sum_{u=1}^{M} \sum_{i=1}^{N_u} (x_{iu} - \overline{X})^2/N \qquad (9)$$

where $\overline{X}$ denotes the mean over all N profiles in the area.

6.2.6 Homogeneity indices

To estimate the uniformity of a mapping unit with respect to the suitability of its soil for rye or grass, we devised the following homogeneity index. This index is defined as the sum of the squared differences between the actual proportions of the mapping unit occupied by the suitability classes and equal proportions for all classes; the latter corresponds with a theoretical, most heterogeneous situation. As there are four classes for each suitability classification, the homogeneity index for the *u*th mapping unit is:

$$H_u = \sum_{c=1}^{4} (F_{cu} - \frac{1}{4})^2 \qquad (10)$$

where F_{cu} gives the relative frequency of the *c*th class within the *u*th unit. The homogeneity index for the total map is defined as the mean over all mapping units weighted by their relative areas:

$$H_w = \sum_{u=1}^{M} A_u H_u \qquad (11)$$

H_u and H_w may vary between 0 (all classes present in equal proportions) and 0.75 (only one class present in each mapping unit).

As with the standard deviations, we also looked at the homogeneity of classification units: this too was defined the same way as in the case of mapping units. The homogeneity of the total area was also defined similarly:

$$H_t = \sum_{c=1}^{4} (F_c - \frac{1}{4})^2 \qquad (12)$$

where F_c denotes the relative frequency of the *c*th class in the area. Likewise, the difference between H_w for a map and H_t represents the actual gain achieved by making that map. The difference between H_w for the classification and H_t represents the potential gain achieved by mapping with 100% strict purity.

Analogous to the purities, numerical data on H_w and H_t are given as percentages of the maximum value 0.75. The statistical estimation procedure (Section 6.3.4), however, is more easily presented in terms of the original quantities.

The homogeneity index is a rather abstract measure. Although the index is calculated from the actual frequency distributions of the suitability classes, the correspondence between frequency distributions and the values of the homogeneity index cannot easily be understood. This is because a minor decrease in the homogeneity gives rise to a relatively large decrease in the value of the index. At first we tried to characterize the homogeneity with a simpler parameter, namely the percentage of the most frequently occurring suitability class. Sample estimates of this percentage would have been severely biased; therefore we decided to use the more abstract homogeneity index.

To give more information about the frequency distributions the percentage occupied by the

Table 15 Values of the homogeneity index for some typical areal distributions for four suitability classes

8200183

Areal distributions (in %) for the four suitability classes				Homogeneity index (in %)
1.1*)	1.2	2	3	
100	0	0	0	100.0
90	10	0	0	76.0
80	20	0	0	57.3
80	10	10	0	54.7
70	20	10	0	38.7
70	10	10	10	36.0
60	40	0	0	36.0
60	30	10	0	28.0
60	20	20	0	25.3
60	20	10	10	22.7
50	50	0	0	33.3
50	40	10	0	22.7
50	30	20	0	17.3
50	30	10	10	14.7
50	20	20	10	12.0
40	40	20	0	14.7
40	40	10	10	12.0
40	30	30	0	12.0
40	30	20	10	6.7
40	20	20	20	4.0
30	30	30	10	4.0
30	30	20	20	1.3
25	25	25	25	0.0

*)To improve the readability of this table the most frequently occurring suitability class is listed under 1.1.

(N.B. A change in the sequence of areal distributions has no influence on the value of the homogeneity index.)

most frequently occurring suitability class is in some instances presented in addition to the homogeneity index.

To our knowledge, the measure of homogeneity used here has not been applied in soil science and therefore most readers will be unfamiliar with it. To give some idea of its numerical behaviour we present the values for some typical areal distributions in Table 15. For convenience, the percentage of the most frequently occurring suitability class is listed under class 1.1. Note from Equation 10 that a change in the sequence of areal distributions has no influence on the value of the index.

6.3 Measures of quality; statistical estimation

6.3.1 General

All 7 purities, 16 standard deviations and 2 homogeneity indices were statistically estimated for each of the 12 maps. In addition, standard deviations and homogeneity indices were estimated for the two classifications and the two areas. Each of these estimates is based on a stratified random sample of test profiles. See Chapter 3 for the sampling procedure.

To make the maps, the original field estimates were used. For testing, however, the estimates were corrected to remove systematic errors of estimation as far as possible. The corrections are described in Section 5.2. For a detailed account of the statistical procedures followed see COCHRAN (1977).

6.3.2 Estimation of purities

From Equations 1, 2 and 6 it follows that the partial, strict and average purities of the maps are to be estimated as the mean of the corresponding purity values in the area concerned. Hence, the estimates $\bar{p}$ of the purities were calculated as a weighted average of the sample means within strata:

$$\bar{p} = \sum_{h=1}^{L} W_h \bar{p}_h \qquad (13)$$

where L denotes the number of strata, W_h denotes the weight of the hth stratum, and $\bar{p}_h$ denotes the sample mean of the purity values in the hth stratum, i.e.:

$$\bar{p}_h = \sum_{i=1}^{n_h} p_{hi}/n_h \qquad (14)$$

where n_h and p_{hi} denote the number of test observations and the ith purity value respectively in the hth stratum. The weight W_h is the size of the stratum, which is defined as the ratio N_h/N of the number of profiles in the stratum and in the total area, and measured as the ratio A_h of the corresponding areas. If systematic observation errors in the purity values are negligible $\bar{p}$ is a minimum variance unbiased estimator. Its variance was estimated according to:

$$s^2(\bar{p}) = \sum_{h=1}^{L} W_h^2 s_h^2/n_h \qquad (15)$$

where s_h^2 denotes the sample variance of the purity values in the hth stratum:

$$s_h^2 = \sum_{i=1}^{n_h} (p_{hi} - \bar{p}_h)^2/(n_h - 1) \qquad (16)$$

In the present case, the sampling fractions n_h/N_h are negligible for each stratum. Then, $s^2(\bar{p})$ is an unbiased estimate of the true variance. In some cases there was only one test profile in a stratum and in others there were none: in these cases s_h^2 could not be estimated. Such strata were then amalgamated with adjacent strata. This happened to about one-quarter of the small strata in testing map PuFi-50 and map RaFi-50,d.

For the paired comparisons of the maps we tested which differences in purity were statistically significant. This was done by the one-sample or the two-sample t-test, depending on the situation. Actual sampling in this study lies mostly between the one-sample and the two-sample case, i.e. the samples partly overlap. Except for the maps PuFi-50 and RaPr-50 the overlap was relatively large, so the one-sample test was applied to the purity values of the common test profiles. The two-sample test was used for the comparison of map PuFi-50 with map RaPr-50. Map PuFi-50 was tested with 509 test profiles and map RaPr-50 was tested with 1260 test profiles: the maps had 160 test profiles in common. The covariance introduced by this overlap was neglected when the variance of the estimated difference in purity was calculated.

The purity $\bar{p}_u$ of a given mapping unit u was estimated as follows. First, the test profiles for the map concerned were used to estimate the proportion of the total area covered by that mapping unit. For this, the same procedure was used as for estimating the purities of the total maps. But, instead of being applied to purity values the procedure was applied to a dummy variate that had a value of 1 if the test profile occurred in the delineated areas of that mapping unit, and a value of 0 if it did not. The same procedure was also used to estimate the proportion of the total area covered by the pure part of the mapping unit. Finally, the ratio of these proportions was used to provide an estimate of the purity of the mapping unit. The variance of this estimate $\bar{p}_u$ was calculated according to:

$$s^2(\bar{p}_u) = \frac{1}{a_u^2} \sum_{h=1}^{L} \frac{W_h^2}{n_h(n_h - 1)} \left\{ \sum_{i=1}^{n_{hu}} (p_{hiu} - \bar{p}_{hu})^2 + n_{hu}(1 - \frac{n_{hu}}{n_h})(\bar{p}_{hu} - \bar{p}_u)^2 \right\} \qquad (17)$$

where

a_u = estimate of the proportion (N_u/N) of the total area covered by the uth mapping unit;
n_{hu} = number of test profiles in the hth stratum and the uth mapping unit;
p_{hiu} = purity value of the ith test profile in the hth stratum and the uth mapping unit;
$\bar{p}_{hu}$ = sample mean of the purity values in the hth stratum and the uth mapping unit.

6.3.3 *Estimation of standard deviations*

The standard deviation of a given soil property within the uth mapping or classification unit, S_u, was estimated according to:

$$s_u^2 = \overline{x_u^2} - \bar{x}_u^2 + s^2(\bar{x}_u) \qquad (18)$$

where $\bar{x}_u$ and $\overline{x_u^2}$ denote the estimated mean of the original values and of the squared values of a property respectively, within the uth unit. Both $\bar{x}_u$ and $\overline{x_u^2}$ were obtained by the same procedure as used to estimate the purity of mapping units (Section 6.3.2), except that the values of the soil property were used instead of purity values. Similarly, $s^2(\bar{x}_u)$ was calculated as in Equation 17.

Estimates of S_w^2 for maps and classifications were obtained by pooling the variances within the units with at least 2 test profiles:

$$s_w^2 = \frac{\sum_{u=1}^{m} a_u s_u^2}{\sum_{u=1}^{m} a_u} \qquad (19)$$

where m denotes the number of units with $n_u \geqq 2$.

The variance within the areas, S_t^2, was estimated by a similar procedure, although the procedure was simpler because in this case units need not be distinguished:

$$s_t^2 = \overline{x^2} - \bar{x}^2 + s^2(\bar{x}) \qquad (20)$$

where $\bar{x}$ and $\overline{x^2}$ denote the estimated mean of the original values and of the squared values of a proberty respectively within the area. Both $\bar{x}$ and $\overline{x^2}$ were obtained by the same procedure as used to estimate the purity of maps (Section 6.3.2), except that the values of the soil property or its squares were used instead of purity values. Similarly, $s^2(\bar{x})$ was calculated as in Equation 15.

6.3.4 *Estimation of the homogeneity indices*

The homogeneity of the uth mapping or classification unit, defined as H_u in Equation 10, was estimated by:

$$h_u = \frac{n_u}{n_u - 1} \left\{ \sum_{c=1}^{4} f_{cu}^2 - \frac{1}{4} - \frac{3}{4n_u} \right\} \qquad (21)$$

where f_{cu} denotes the estimated relative frequency of the cth suitability class in the uth unit, calculated by the same procedure as used for the purity of mapping units (Section 6.3.2).

Estimates of H_w for maps and classifications were obtained by pooling the h_u's of the units with at least 2 test profiles:

$$h_w = \frac{\sum_{u=1}^{m} a_u h_u}{\sum_{u=1}^{m} a_u} \qquad (22)$$

The homogeneity indices of the areas, H_t, were estimated in a similar way:

$$h_t = \frac{n}{n-1} \left\{ \sum_{c=1}^{4} f_c^2 - \frac{1}{4} - \frac{3}{4n} \right\} \qquad (23)$$

where f_c denotes the estimated relative frequency of the cth suitability class in the area, calculated by the same procedure as used for the purity of maps (Section 6.3.2).

For a simple random sample of size n, with sample frequencies f_c (c = 1, ..., 4), it can be shown that Equation 23 provides an unbiased estimate of H_t. This follows from the expectation of the squared sample frequencies (see e.g. JOHNSON and KOTZ, 1969, p. 51):

$$E(f_c^2) = \frac{F_c}{n} + \frac{n-1}{n} \cdot F_c^2 \qquad (24)$$

A similar remark can be made with regard to h_u in Equation 21. Although sampling in this study was stratified instead of simple random, Equations 21 and 23 were used for simplicity.

6.4 Readability

As will appear in Chapter 7, the proximal maps show a much more fragmented pattern than the maps made by field delineation. For this reason, a generalized variant of the proximal soil maps was also tested. Furthermore, it seemed unrealistic to compare the maps only in terms of accuracy and precision, as their readability varied so strongly. It was therefore decided to take the aspect of readability into consideration too, as fas as feasible.

It seems difficult to find parameters by which the readability of maps can be quantified appropriately and still are measurable practically. In this study, we confined ourselves to a simple but coarse approach: the number of mapping units, the number of delineated areas and their average size were adopted as parameters related to readability. The data are presented in Section 7.3.3.

7. RESULTS

7.1 Accuracy of the results

A Two types of error have been propagated in the results presented in this chapter: sampling error and observation error. These kinds of error constitute largely independent sources; therefore they are discussed in separate sections.

7.1.1 Sampling error

This type of error stems from the fact that the quality measures have to be calculated from a limited sample of test observations only. Other samples would have led to different results: we can only approximate the true values of the quality measures. Because we used a form of random sampling, however, it is possible to quantify the sampling error. For simplicity this has been done for two maps only: RaFi-50,d and RaFi-10,d. The former was tested with 255 observations, which is the smallest of the samples used to test the 1 : 50 000 maps (see Table 4). The sampling errors calculated for RaFi-50,d can therefore safely be assigned to the other maps at that scale because their true sampling errors are likely to be smaller. (Although RaPr-50 and RaPr-50,g have only 160 test observations uniformly distributed over the whole area A, this will be more or less compensated for by the extra 1100 observations in one-quarter (B) of the area.) For the same reason map RaFi-10,d, tested with 661 observations, was chosen as a reference for the 1 : 10 000 maps.

7.1.1.1 Measures of purity

For ease of interpretation the sampling errors are expressed as half the width of 95% confidence intervals. This quantity was calculated as being 1.96 times the standard error, because the samples were relatively large and therefore the sampling variations must have followed an approximately normal distribution. The standard errors were calculated according to Equation 15 (Section 6.3.2).

The results are presented in Table 16. This table indicates that half the interval for the strict purity of map RaFi-50,d is 3.7%. The purity itself is estimated to be 9.4% (Table 17). Therefore, it can be stated with 95% confidence that the true value of the strict purity of this map lies between 9.4 - 3.7 = 5.7% and 9.4 + 3.7 = 13.1%.

As a check on the usefulness of the reference maps the standard errors of the purities of all maps were calculated and compared with those of RaFi-50,d and RaFi-10,d. This confirmed that most of them were slightly smaller than or about equal to those of the reference maps. Only in a few instances were the standard errors more than 10% larger than the corresponding values for the two reference maps. These exceptions have been footnoted in Table 16.

7.1.1.2 Indices of homogeneity

These quality measures were estimated by Equation 22 (Section 6.3.4), in which the denominator represents the sum of the relative areas of the mapping units that have at least 2 test borings. Because of the high sampling density this sum approaches unity to within 1%, so that in evaluating the sampling error the estimation formula may be reduced to

$$h_w \doteq \sum_{u=1}^{m} a_u h_u \qquad (25)$$

Table 16 Half width of approximate 95% confidence intervals for the quality measures of maps RaFi-50,d and RaFi-10,d, used as reference for the 1:50 000 and 1:10 000 maps, respectively

Quality measures	RaFi-50,d	RaFi-10,d
PERCENTAGE PURITY Strict purity (%)	3.7 [1)]	2.4 [2)]
Average purity (%)	2.1	1.7
Purity subgroups (%)	6.7	3.7
Purity sand classes (%)	0.0 [3)]	3.1
Purity loam classes (%)	2.3	3.4
Purity "additions" (%)	6.1	3.8
Purity groundwater classes (%)	6.1	3.7
HOMOGENEITY INDICES OF THE SUITABILITY Homogeneity index rye (%)	5.3	3.7
Homogeneity index grass (%)	7.2	5.1
VARIATION IN SOIL PROPERTIES (standard deviations) Mean highest water-table (MHW) (cm)	4.8	2.4
Mean lowest water-table (MLW) (cm)	4.7	2.4
Rooting depth (cm)	1.6	0.98
% humus at 10 cm depth	0.23	0.12
% humus at 30 cm depth	0.27	0.29
% humus at 50 cm depth	0.28	0.43
Moisture supply capacity for grass (mm)	4.8	2.2
Moisture supply capacity for rye (mm)	3.1	1.5
Available moisture for grass (mm)	2.5	1.7
Available moisture for rye (mm)	3.2	2.3
Capillary rise for grass (mm)	4.8	2.1
Capillary rise for rye (mm)	2.9	1.8
Percentage capillary rise for grass	2.1	0.93
Percentage capillary rise for rye	1.8	1.1
Percentage available moisture for grass	2.2	0.99
Percentage available moisture for rye	1.8	1.2

1) RaPr-50 and RaPr-50,g: 5.1%
2) RaPr-10,g: 2.8%
3) No variation in purity values of test observations

Ignoring the covariances between the terms $a_u h_u$ and using the statistical independence between a_u and h_u gives

$$V(h_w) \doteq V(\sum_{u=1}^{m} a_u h_u) \doteq \sum_{u=1}^{m} V(a_u h_u) = \sum_{u=1}^{m} \left\{ H_u^2 V(a_u) + A_u^2 V(h_u) + V(a_u)V(h_u) \right\} \quad (26)$$

where V denotes (true) sampling variance.

To estimate the quantities in Equation 26 we used estimators that are unbiased under simple random sampling. (Ignoring the stratification is assumed to introduce a negligible bias in this case.) Thus H_u^2 and A_u^2 were estimated by

$$\hat{H}_u^2 = h_u^2 - v(h_u) \quad (27)$$

and

$$\hat{A}_u^2 = a_u^2 - v(a_u) \quad (28)$$

where v denotes an unbiased estimators of the sampling variance. Substitution in Equation 26 results in

$$v(h_w) = \sum_{u=1}^{m} \left\{ h_u^2 v(a_u) + a_u^2 v(h_u) - v(h_u)v(a_u) \right\} \quad (29)$$

where for $v(a_u)$ we adopted the usual

$$v(a_u) = a_u(1 - a_u)/(n - 1) \quad (30)$$

To construct $v(h_u)$ we first derived the following expression for $V(h_u)$ from the definition of h_u in Equation 21 and the moments of binomial and multinomial distributions (JOHNSON and KOTZ, 1969, pp. 51 and 284):

$$V(h_u) = \frac{2}{n_u(n_u - 1)} \left\{ \sum_{c=1}^{4} F_{cu}^2 + (2n_u - 4) \sum_{c=1}^{4} F_{cu}^3 - (2n_u - 3) (\sum_{c=1}^{4} F_{cu}^2)^2 \right\} \quad (31)$$

(This expression is equivalent to that in Good's comment on PATIL and TAILLIE (1982).)

An unbiased estimator for $V(h_u)$ was then constructed by substituting unbiased estimators for the three terms in Equation 31, derived from the expectations:

$$E(h_u + \frac{1}{4}) = \sum_{c=1}^{4} F_{cu}^2 \quad (32)$$

$$E \left\{ \frac{n_u^2 \sum_{c=1}^{4} f_{cu}^3 - 3(n_u - 1)(h_u + \frac{1}{4}) - 1}{(n_u - 1)(n_u - 2)} \right\} = \sum_{c=1}^{4} F_{cu}^3 \quad (33)$$

$$E\left\{h_u^2 - v(h_u) + \frac{1}{2}h_u + \frac{1}{16}\right\} = \left(\sum_{c=1}^{4} F_{cu}^2\right)^2 \tag{34}$$

This resulted in

$$v(h_u) = \frac{1}{(n_u - 2)(n_u - 3)}\left\{\frac{4n_u^2}{n_u - 1}\sum_{c=1}^{4} f_{cu}^3 - (4n_u - 6)h_u^2 - (2n_u + 7)h_u - \frac{n_u}{4} - 2\frac{1}{8} - \frac{4}{n_u - 1}\right\} \tag{35}$$

Thus Equations 29, 30 and 35 were applied to the test data of the reference maps to produce estimates of the sampling variances. These estimates were used to calculate half the width of 95% confidence intervals, in the same way as for the purities. The results are presented in Table 16.

At this point it should be noted that apart from random sampling error as discussed above there is also systematic error. Unlike the case of the purities, the estimator used for the homogeneities is biased. Compare Equation 21 with the more general

$$h_u = \sum_{c=1}^{4}\left\{f_{cu}^2 - v(f_{cu})\right\} - \frac{1}{4} \tag{36}$$

which is unbiased if f_{cu} and $v(f_{cu})$ are unbiased under the sampling design used. As already stated in 6.3.4, the estimator for $V(f_{cu})$ which is implicitly used in Equation 21, is unbiased under simple random sampling instead of under stratified random sampling. The effect of using (21) instead of (36), will depend on how the sample sizes are distributed among the strata. We expect that where this distribution is proportional to the size of the strata, the effect will have been a slight overestimation of the variances of f_{cu}, hence underestimation of H_u. With the exception of the proximal maps at scale 1 : 50 000, all maps have this type of distribution (see Table 4).

The 1 : 50 000 proximal maps, however, have strongly disproportional distributions of sample sizes, so that for these maps we expect the variances of f_{cu} to be underestimated, and hence H_u to be overestimated.

We assume that within this subset of maps the biases are about equal and comparisons are still possible. Comparisons between 1 : 50 000 maps with proximal and field delineation, however, are difficult to interpret.

7.1.1.3 Standard deviations within mapping units

Analogous to Equation 29 the estimator used for the sampling variance of s_w^2 is

$$v(s_w^2) = \sum_{u=1}^{m}\left\{s_u^4\, v(a_u) + a_u^2\, v(s_u^2) - v(s_u^2)v(a_u)\right\} \tag{37}$$

with $v(a_u)$ given by Equation 30. For $v(s_u^2)$ we used an estimator that would be unbiased under simple random sampling and normal distribution within mapping units:

$$v(s_u^2) = 2s_u^4/(n_u + 1) \tag{38}$$

Confidence intervals for the variances within mapping units were calculated in the same way as for the purities and homogeneities. Square root transformation of the limits of these intervals resulted in 95% confidence intervals for the standard deviations. The estimated standard deviations are not in the middle of these intervals. For simplicity, only the largest difference, i.e. between the estimate and the lower limit of the interval, is presented in Table 16. It is worth mentioning that the ratios of these differences to the estimates are fairly constant. With map RaFi-50,d they range from 11 to 14%, and with map RaFi-10,d from 7 to 9%, except for the humus contents at depths of 30 and 50 cm, where they are 12%.

7.1.2 Observation error

There are two possible causes of observation error. First, by error in locating the soil profiles with given random coordinates, other than the assigned profiles may in fact have been observed and included in the sample. Second, field estimates of soil properties are subject to error.

We tried to avoid systematic error in the test data by taking three steps:

- the test profiles were located as accurately as possible (up to about 5 m on 1 : 10 000 maps and 10 m on 1 : 50 000 maps);
- the surveyor who collected the test data was given no information from the soil maps;
- the field estimates were calibrated against laboratory data.

We assume that by doing this we reduced possible systematic errors to a negligible level, but random errors certainly persisted in our test data. Below we shall discuss globally how this type of error may have been propagated in the estimates of purities, homogeneities and standard deviations.

Some of the observation errors will have led to misclassification of a test profile and this may have resulted in a wrong purity value for that profile. However, such deviations may go in both directions and because of the random nature of the observation errors we expect that most of them cancelled each other out. Therefore we consider it unlikely that misclassification of test profiles has caused absolute errors of more than a few per cent in the estimated purities.

Furthermore, we assume that observation error in the differences between purity values is negligible compared with sampling error, because the maps were tested with partly the same sets of test profiles and because the errors were generated in a similar way.

Observation errors may also have caused test profiles to be incorrectly assigned to suitability classes, which in turn may have led to errors in the estimated homogeneities. With very homogeneous mapping units this would take the form of underestimating the homogeneity, because more test observations belonging to the common class would be assigned to rare or even absent classes than vice versa. Most of the present mapping units, however, are heterogeneous. Therefore we assume that observation error has introduced only little negative bias in the estimated homogeneities; presumably a few per cent in the absolute sense.

For the same reasons as with the purities we assume that the observation error in the differences between homogeneities is negligible compared with the sampling error.

In contrast to the estimates of purities and homogeneity indices, the estimates of standard deviations may be seriously biased by random observation error. This effect proved to be much more important than we expected.

If within each mapping unit the observation error does not correlate with the soil property concerned, the calculated variance will overestimate the variance of the property by an amount equal to the variance of the observation error. If there is a positive correlation between the observation error and the soil property the bias will be larger, and if there is a negative correlation it will be smaller.

By regressing field estimates on the measurements used for calibration, we were able to

calculate the standard error of observation for three properties:
humus content: 1.2% (series A) and 0.9% (series B);
mean highest water-table: 16.3 cm (series A) and 12.7 cm (series B);
mean lowest water-table: 9.4 cm (series A) and 7.5 cm (series B).
This makes it clear that the bias of the estimated standard deviations of these properties might be appreciable. As we have no information about the mentioned correlations within mapping units, we are uncertain about the actual degree of this bias. The same is true for the other soil properties.

Because the correlations will generally differ between maps, the bias extends to an unknown degree into the differences between maps. For this reason we decided to base our conclusions only on the purities and homogeneity indices; the standard deviations are only presented as tentative background information.

7.1.3 *Testing the differences between maps*

For the pairwise comparisons of maps as discussed later in this report, approximate tests of significance were applied to differences between purities and between homogeneity indices. The test procedure used for differences between purities has already been described in Section 6.3.2.

The approximate test on differences between homogeneity indices is based on the assumptions that the estimated homogeneities are (1) normally distributed, with (2) standard errors equal to those calculated for the reference maps according to Equation 29, and (3) are mutually uncorrelated. Thus by this test a difference was judged to be significant at the 5% level if in absolute value it exceeded $1.96\sqrt{2}$ times the standard error of the reference map. (Assumptions 2 and 3 tend to make this test conservative in the sense that the actual significance level will be higher than the nominal one.) A similar test at the 10% level (with a factor $1.64\sqrt{2}$) was used to spot weakly significant differences in homogeneity.

Significant differences in purities and in homogeneity indices are indicated in Tables 21, 22, 24, 25 and 26 by closed circles around the highest of the two values compared; the weakly significant differences are indicated by dashed circles. In these tables relatively large differences between standard deviations have been marked by superscript primes on the lower values.

The latter type of differences were selected by formally applying a test at the 10% level, similar to the one used for the homogeneity indices. It is stressed that this is only meant as a rough screening procedure; the usual guarantees in terms of probabilities do not apply here, because of the bias of the estimated standard deviations.

7.2 The quality of the soil maps in general

The quality of the soil maps was calculated, using 3 groups of measures of quality:
- measures of purity for 7 types of purity;
- standard deviation for 16 different soil properties;
- homogeneity indices for the suitability for winter rye and for grass.

Purity measures refer to the accuracy of the mapping, whereas standard deviations and homogeneity indices indicate the precision of the mapping. See also Figure 8.

7.2.1 *Purity measures*

In addition to strict purity and average purity, 5 partial purities were defined. Partial purities were distinguished for the following attributes: subgroup, sand classes, loam classes, "additions"* and groundwater classes. All criteria used for both classifications applied were subdivided into five subsets, each defining a partial purity. The definition and interpretations of the purity measures are described in Section 6.2.

For many years the term "purity" has been used in Stiboka's publications and soil maps without being explicitly defined: it has merely been stated that the aim is to achieve a purity of at least 70%. The results of the present study suggest that the old concept of "purity" corresponds with what we defined as the average purity in this study (Section 6.2).

The scores for the measures of purity of all the soil maps investigated are shown in Table 17. Strict purity appears to be very low for all soil maps. For soil maps with general classification it ranges from 7% to 13%. For those with detailed classification it ranges from 8% to 11%. Map PuFi-50 (purposive observations, field delineation) achieves the highest score. The lowest score for strict purity is achieved by map PuPr-50 (purposive observations, proximal delineation). When comparing the scores of purity measures, maps RaPr-50,g and RaPr-10,g had to be excluded, because they had been generalized from maps RaPr-50 and RaPr-10, respectively. These generalized maps mainly consist of complex mapping units. Because the profile classes have been enlarged, the generalized maps achieve higher scores for purities.

The average purities are very similar for all soil maps. For soil maps with general classification the average purity ranges from 64% to 70%, while for maps with a detailed classification it ranges from 59% to 62%.

Differences between soil maps with respect to partial purities are also small, in most cases. But for a particular map a relatively high purity for one attribute is often accompanied by a relatively low purity for another attribute.

The classes for subgroups and groundwater are identical for both classifications used. In spite of the larger map scale used for maps with detailed classification, the purity for subgroups is not higher. The relatively low scores result from the soil pattern in area B being more complex than that in area A. In general, the purity of groundwater classes is higher for soil maps with detailed classification.

The partial purity of groundwater classes is lower than for any of the attributes of the other four partial purities.

In the detailed classification, the class ranges for sand classes, loam classes and additions are smaller than in the general classification. As a result, purities for sand classes and loam classes are lower on the 1 : 10 000 maps (detailed classification). In spite of the more detailed classification, the purities for "additions" are similar for both classifications and map scales used.

In general, differences in purities between all maps are small. Strict purity is very low, with scores of about 10%. This means that soil profiles that exactly meet all the criteria of the classification used cover only 10% of the maps. Although strict purities are low, average purities calculated as the arithmetical mean of 5 partial purities range from 60% to 70%.

The strict purity of the generalized proximal maps (RaPr-50,g; RaPr-10,g) is markedly higher. These maps predominantly consist of complex mapping units. The strict purities are higher because the profile classes have been enlarged. Also, average purities increase by about 10% as a result of generalization.

Soil maps with detailed classification have higher observation densities, owing to the larger map scale used (1 : 10 000). Despite this, the purities for sand classes and loam classes are distinctly lower than those on soil maps with general classification. Obviously, the positive influence of map scale and observation density is outweighed by the negative influence of more detailed classes for sand and loam.

* The term "additions" is defined in Section 3.3.

Table 17 Variation (expressed as standard deviation) in soil properties, homogeneity indices of the suitability and the percentage purity

	Area A (general classification)									Area B (detailed classification)								
	Variation in area	Variation in general classification used	Code soil maps: PuFi-50	RaFi-50,d	RaPr-50,d	RaPr-50	RaPr-50,g	PuPr-50	Limits of variation	Variation in area	Variation in detailed classification used	Code soil maps: PuFi-10	RaFi-10,d	RaPr-10,d	RaPr-10	RaPr-10,g	PuPr-10	Limits of variation
VARIATION IN SOIL PROPERTIES (standard deviations)																		
Mean highest water-table (MHW) (cm)	44.9	11.7	33.5	34.4	34.3	31.9	32.4	36.7	31.9 – 36.7	46.9	13.3	27.1	26.5	31.3	33.5	29.6	28.7	26.5 – 33.5
Mean lowest water-table (MLW) (cm)	47.4	14.6	34.7	35.1	35.9	34.0	33.5	38.0	33.5 – 38.0	50.5	13.7	28.5	27.6	32.6	35.5	31.8	30.5	27.6 – 35.5
Rooting depth (cm)	17.8	10.0	16.1	14.4	14.6	14.0	12.8	15.8	12.8 – 16.1	17.9	9.4	14.2	14.4	14.6	14.8	14.3	14.5	14.2 – 14.8
% humus at 10 cm depth	2.5	1.3	1.6	1.6	1.6	1.5	1.4	2.4	1.4 – 2.4	1.8	1.8	1.6	1.5	1.5	1.5	1.6	1.6	1.5 – 1.6
% humus at 30 cm depth	2.4	1.3	1.9	2.0	2.2	2.1	2.1	2.2	1.9 – 2.2	3.0	2.6	2.5	2.4	2.2	2.4	2.5	2.6	2.2 – 2.6
% humus at 50 cm depth	2.7	1.3	2.0	2.0	2.5	2.4	2.2	2.5	2.0 – 2.5	4.0	2.6	3.3	3.5	3.4	3.2	3.1	3.2	3.1 – 3.5
Moisture supply capacity for grass (mm)	45	18	40	40	39	38	37	40	37 – 40	40	17	31	29	30	31	30	32	29 – 32
Moisture supply capacity for rye (mm)	24	12	24	23	22	22	20	22	20 – 24	19	10	17	16	16	16	16	17	16 – 17
Available moisture for grass (mm)	29	13	23	22	23	22	20	25	20 – 25	32	14	22	23	23	23	22	23	22 – 23
Available moisture for rye (mm)	38	17	30	28	29	28	25	32	25 – 32	43	19	29	31	30	31	29	30	29 – 31
Capillary rise for grass (mm)	51	15	39	39	39	36	35	41	35 – 41	50	16	29	29	33	35	32	31	29 – 35
Capillary rise for rye (mm)	34	14	27	26	26	25	22	29	22 – 29	34	15	22	24	24	25	23	24	22 – 25
Percentage capillary rise for grass	22	7	17	17	16	16	15	18	15 – 18	21	8	12	12	14	15	13	13	12 – 15
Percentage capillary rise for rye	20	9	16	16	16	15	13	17	13 – 17	19	9	13	14	14	15	13	14	13 – 15
Percentage available moisture for grass	22	7	16	16	16	15	14	17	14 – 17	22	7	12	13	15	15	14	13	12 – 15
Percentage available moisture for rye	21	9	17	16	16	16	14	18	14 – 18	22	10	15	15	16	16	15	15	15 – 16
HOMOGENEITY INDICES OF THE SUITABILITY																		
Suitability for rye	4.1	52.0	11.7	14.0	14.4	17.5	13.3	14.7	11.7 – 17.5	1.1	44.7	19.5	20.5	16.8	15.9	18.8	20.4	15.9 – 20.5
Suitability for grass	18.9	61.2	25.7	24.0	25.6	29.6	24.9	28.3	24.0 – 29.6	16.3	54.9	32.1	35.6	35.1	32.9	32.4	32.5	32.1 – 35.6
PERCENTAGE PURITY							1)		1)							1)		1)
Strict purity (%)	–	–	12.5	9.4	9.7	10.5	17.4	7.4	7.4 – 12.5	–	–	9.3	10.7	9.4	8.0	17.1	8.2	8.0 – 10.7
Average purity (%)	–	–	67.2	70.0	63.8	66.4	74.2	65.1	63.8 – 70.0	–	–	61.0	61.8	58.9	58.9	68.2	58.8	58.8 – 61.8
Purity subgroups (%)	–	–	50.8	56.0	48.1	53.3	57.4	41.0	41.0 – 56.0	–	–	51.1	52.4	47.4	44.0	55.7	49.8	44.0 – 52.4
Purity sand classes (%)	–	–	100	100	100	100	100	100	100	–	–	84.2	79.2	79.3	81.6	82.8	83.9	79.2 – 84.2
Purity loam classes (%)	–	–	92.6	96.6	90.8	90.7	93.5	89.4	89.4 – 96.6	–	–	68.4	72.4	73.2	73.6	82.4	60.7	60.7 – 73.6
Purity "additions" (%)	–	–	47.4	58.5	46.7	51.5	71.5	59.0	46.7 – 59.0	–	–	58.7	59.5	50.0	51.7	66.8	57.0	50.0 – 59.5
Purity groundwater classes (%)	–	–	45.4	39.0	33.5	36.3	48.5	36.1	33.5 – 45.4	–	–	42.7	45.7	44.5	43.6	53.0	42.6	42.6 – 45.7

8200163

(20.0) Soil map with smallest standard deviation or the highest percentage purity or the highest homogeneity index

20.0 Soil map with the largest standard deviation or the lowest percentage purity or the lowest homogeneity index

1) When referring to the highest and the lowest percentages of purity and in the column "Limits of variation" for percentage purity, the generalized soil maps (....., g) have been omitted from the comparisons

Of the partial purities, those for groundwater classes have the lowest purity. For soil maps with general classification the values vary between 33% and 46%: in maps with detailed classification the values vary between 42% and 46%. Although the purity for sand classes and loam classes is low in the soil maps with detailed classification, in these maps the purities for groundwater classes are higher. Since maps of both classifications have identical classes, the higher score of the detailed soil maps must be caused by the larger map scale and the higher observation density.

7.2.2 Standard deviations of the soil properties

The relative success of the two soil classifications and the six maps at each scale was compared in terms of the pooled within-class standard deviations of 16 soil properties measured at the test observations. For the classifications we calculated the standard deviations within classification units. For the soil maps the standard deviations within mapping units were calculated. The variation within the surveyed area as a whole is given by the total standard deviation, estimated from the same sets of test observations, but ignoring the classifications (Table 17). The relative variation, defined as the pooled within-class standard deviation divided by the total standard deviation and multiplied by 100, can be used to compare the results (Table 18). These results indicate the relative successes of the maps and the soil classifications in reducing within-class standard deviations. In the hypothetical case of a soil map having a strict purity of 100%, the relative variation of soil map and classification would be equal. It must be reiterated that the estimates of the standard deviations are positively biased and that much uncertainty surrounds their true values (Section 7.1). Therefore the statements based on these results, as made in the following sections, are only tentative.

Both classifications considerably reduce the variation of most soil properties. The classifications are more successful for some properties than for others. On the other hand, in almost all cases the reduction in total variation for a given soil property is similar for both the general and detailed classifications (Table 18).

Three levels of relative variations can be distinguished for both classifications used:

a. *Relative variation ca. 30%:* MHW; MLW; capillary rise for grass; percentage capillary rise for grass; percentage available moisture for grass.
b. *Relative variation ca. 40%:* moisture supply capacity for grass; available moisture for grass and rye; capillary rise for rye; percentage available moisture for rye.
c. *Relative variation ca. 50%:* rooting depth; % humus at various depths; moisture supply capacity for rye; percentage capillary rise for rye.

As mentioned earlier, the relative variation in soil properties for the classification indicates how much the variation existing within the total area has been reduced. This is the maximum reduction that can be achieved by using that classification. But by mapping, this maximum reduction will never fully be realized, because of the impurities of soil maps. The reduction of variation that has actually been realized is revealed by comparing the relative variations of the individual soil maps with those of the classifications (Table 18). In general, relative variations for the soil maps vary between 65% and 80% for most soil properties. But for some soil properties on soil maps with the detailed classification, relative variations range between 55% and 70%.

The relative variations of all soil maps and for all soil properties are considerably higher than those of the relevant classifications. Differences in variations between individual soil maps often appear to be systematic. But they are relatively small for all soil properties.

The greatest reduction in relative variation was achieved for available moisture, capillary rise, percentage capillary rise and percentage available moisture. Soil maps with detailed classification (map scale 1 : 10 000) also show relatively small variations for MHW and MLW.

Table 18 Relative variation in soil properties (as percentage of the variation in the total area) and relative homogeneity indices for suitability (as percentage of the index for the classification)

	Area A (general classification)									Area B (detailed classification)								
	Variation in area	Variation in general classifica-tion used	PuFi-50	RaFi-50,d	RaPr-50,d	RaPr-50	RaPr-50,g	PuPr-50	Limits of variation	Variation in area	Variation in detailed classifica-tion used	PuFi-10	RaFi-10,d	RaPr-10,d	RaPr-10	RaPr,10,g	PuPr-10	Limits of variation
VARIATION IN SOIL PROPERTIES (standard deviations)	absolute	%	%	%	%	%	%	%	%	absolute	%	%	%	%	%	%	%	%
Mean highest water-table (MHW) (cm)	44.9	26	75	77	76	71	72	82	71 – 82	46.9	28	58	56	67	71	63	61	56 – 71
Mean lowest water-table (MLW) (cm)	47.4	31	73	74	75	71	70	80	70 – 80	50.5	27	56	54	65	70	63	60	54 – 70
Rooting depth (cm)	17.8	56	90	81	82	79	72	89	72 – 90	17.9	53	79	80	82	83	80	81	79 – 83
% humus at 10 cm depth	2.5	52	64	64	64	60	56	96	56 – 96	1.8	100	89	83	83	83	89	89	83 – 89
% humus at 30 cm depth	2.4	54	79	83	92	88	88	92	79 – 92	3.0	87	83	80	73	80	83	87	73 – 87
% humus at 50 cm depth	2.7	48	74	74	93	89	81	96	74 – 96	4.0	65	83	88	85	80	78	80	78 – 88
Moisture supply capacity for grass (mm)	45	40	89	89	87	84	82	89	82 – 89	40	43	78	73	75	78	75	80	73 – 80
Moisture supply capacity for rye (mm)	24	50	100	96	92	92	83	92	83 – 100	19	53	89	84	84	84	84	89	84 – 89
Available moisture for grass (mm)	29	45	79	76	79	76	69	86	69 – 86	32	44	69	72	72	72	69	72	69 – 72
Available moisture for rye (mm)	38	45	79	74	76	74	66	84	66 – 84	43	44	67	72	70	72	67	70	67 – 72
Capillary rise for grass (mm)	51	29	76	76	76	71	69	80	69 – 80	50	32	58	58	66	70	64	62	58 – 70
Capillary rise for rye (mm)	34	41	79	76	76	74	65	85	65 – 85	34	44	65	71	71	73	68	71	65 – 73
Percentage capillary rise for grass	22	32	77	77	73	73	68	82	68 – 82	21	38	57	57	67	71	62	62	57 – 71
Percentage capillary rise for rye	20	45	80	80	80	75	65	85	65 – 85	19	47	68	74	74	79	68	74	68 – 79
Percentage available moisture for grass	22	32	73	73	73	68	64	77	64 – 77	22	32	55	59	68	68	64	59	55 – 68
Percentage available moisture for rye	21	43	81	78	78	78	67	86	67 – 86	22	45	68	68	73	73	68	68	68 – 73
RELATIVE HOMOGENEITY INDICES (as percentage of the index for the classification)	%	absolute	%	%	%	%	%	%	%	%	absolute	%	%	%	%	%	%	%
Suitability for rye	8	52.0	23	27	28	34	26	28	23 – 34	2	44.7	44	46	38	36	42	46	36 – 46
Suitability for grass	31	61.2	42	39	42	48	41	46	39 – 48	30	54.9	58	65	64	60	59	59	58 – 65

8200183

(71) Soil map with smallest standard deviation or with highest homogeneity index

82 Soil map with largest standard deviation or with lowest homogeneity index

In some cases the relative variations of these properties account for nearly 50% of the variation within the total area.

7.2.3 *Homogeneity indices*

The homogeneity index quantifies the homogeneity of soil maps and classifications with respect to the suitability classes for rye and grass (Section 6.2.6). This index ranges between 0% and 100%. A soil map achieves the maximum value if only one suitability class is allocated to the entire area of each individual mapping unit, indicated on that map. This means that the same suitability class is allocated to all test observations occurring within the delineations of an individual mapping unit. The lowest homogeneity index (0) is achieved if all four suitability classes are equally distributed over the test observations that occur within the delineations of each of the mapping units.

Homogeneity indices for rye and grass were also calculated for both classifications, using the same procedure as described for the calculation of standard deviations (Section 7.2.2).

Although the soil maps were produced by different survey methods, the differences in homogeneity indices are small (Table 17). For soil maps with a general classification the homogeneity index for rye ranges between 11 and 18 and that for grass ranges between 24 and 30. Over the total area the homogeneity index is 4.1 for rye and 18.9 for grass. Mapping results in improving the homogeneity of an area with respect to its suitability for rye and grass, but the values of the homogeneity indices are far below the maximum score. It must be remembered that there is a non-linear relation between the value of the homogeneity index and the areal distribution of the suitability classes. Table 15 shows some examples of how values of the homogeneity index relate to the areal distribution of the suitability classes.

Although the classification used in area B is more detailed, the homogeneity indices are lower than those of the general classification (Table 17). This is because the soil varies more in this area. Homogeneity indices for soil maps with detailed classification range from 16 to 21 for rye and from 32 to 36 for grass. The soil maps of area B appear to be more homogeneous for the suitability classes than the soil maps with general classification in area A. Furthermore,in area B differences in homogeneity indices between individual soil maps are smaller.

The homogeneity indices were calculated for the entire map by averaging the values of all mapping units distinguished and by weighting with their areas. As will be described in Section 7.3 it is not possible to compare the soil maps by using the values of the quality measures of individual mapping units. But to give some idea of the homogeneity of individual mapping units with respect to suitability classes, examples of the areal distribution of suitability classes are given in Table 19 for certain important mapping units. Sets of areal distributions cannot easily be compared. Therefore, in this section we only use the percentage of a mapping unit occupied by the most frequently occurring suitability class.

Table 19 gives the areal distributions of suitability classes for some important mapping units produced by different survey methods. The percentage of a mapping unit occupied by the most frequently occurring suitability class has been marked. In the case of soil maps with general classification and suitability for rye this percentage varies between 40 and 75, whereas suitability for grass achieves percentages between 55 and 80. The remaining areas of the mapping units are occupied by 2 or 3 other suitability classes. For soil maps with detailed classification the range of percentages is approximately the same as that of the soil maps with general classification. Variation in the percentage of a mapping unit occupied by the most frequently occurring suitability class depends both on the survey method used and on the taxonomic classes of individual mapping units.

The homogeneity indices for both classifications are considerably higher than those for the soil maps. Indices for the general classification score 52 and 61 for rye and grass respectively (Table 17). From these scores it is evident that the classification units are not completely homogeneous regarding the suitability classes. From Table 15, however, it appears that indices of about 50 or 60 are reasonably homogeneous. On average, one suitability class will be allocated to 80% of the test observations belonging to an individual classification unit.

The maximum score of the homogeneity for a soil map is equal to the homogeneity index for the classification used. Relative indices were calculated by expressing the indices of soil maps as a percentage of the index of the classification (Table 18). They indicate how much of the maximum homogeneity index was realized by making that map.

Relative homogeneity indices for soil maps with general classification vary between 23% and 34% for rye and between 39% and 48% for grass. The scores of the relative homogeneity indices for soil maps with detailed classification are approximately 15% higher: they vary between 36% and 46% for rye and between 58% and 65% for grass.

Differences in homogeneity indices between soil maps are small. For soil maps with general classification, map RaPr-50 scores highest for both suitabilities. This map was made by ran-

Table 19 Areal distribution of the suitability classes for rye and grass for some mapping units distinguished on soil maps produced with different survey methods

8200163

Mapping unit code	Map code	No. of test soil profiles	Area in % of total map area	Strict purity	Suitability classes for rye 1.1	rye 1.2	rye 2	rye 3	Suitability classes for grass 1.1	grass 1.2	grass 2	grass 3
Soil maps scale 1:50000												
Hn21-V*	PuFi-50	57	10.9	9.2	23	28	**44**	6	**78**	14	5	3
(1)	RaFi-50,d	31	12.0	3.6	7	34	**43**	16	**66**	18	11	5
(R: 0-0-100-0) (G: 95-5-0-0)	RaPr-50,d	9	3.5	11.1	11	22	**56**	11	**56**	11	33	0
	RaPr-50	3	2.1	37.5	0	25	**75**	0	**75**	25	0	0
	PuPr-50	328	14.2	8.4	13	30	**40**	17	**70**	11	16	2
zEZ21/23-VII	PuFi-50	58	11.2	62.6	24	**64**	10	2	19	**65**	16	0
(1)	RaFi-50,d	13	5.2	16.4	8	**75**	16	0	25	**49**	26	0
(R: 87-13-0-0) (G: 47-53-0-0)	RaPr-50,d	83	5.7	8.3	14	**75**	9	1	17	**55**	27	0
	RaPr-50	89	6.5	10.2	16	**71**	12	0	21	**66**	14	0
	PuPr-50	79	4.2	4.6	22	**70**	6	2	11	**73**	15	1
Soil maps scale 1:10000												
Hn33-V*	PuFi-10	142	12.0	5.7	8	30	**43**	19	**66**	14	20	0
(1)	RaFi-10,d	109	16.3	5.8	14	27	**39**	20	**70**	10	18	2
(R: 0-0-54-46) (G: 54-0-46-0)	RaPr-10,d	22	3.7	9.0	0	34	**53**	13	**73**	14	13	0
	RaPr-10	22	3.2	4.2	0	30	**49**	21	**70**	5	26	0
	PuPr-10	61	5.2	3.6	8	35	**35**	22	**58**	17	25	0
Hn33-VI	PuFi-10	254	21.7	12.4	14	**42**	39	5	**62**	29	9	0
(1)	RaFi-10,d	127	19.0	17.4	15	**49**	31	5	**63**	28	9	0
(R: 0-52-48-0) (G: 78-22-0-0)	RaPr-10,d	43	6.3	14.0	15	**52**	26	7	**59**	34	7	0
	RaPr-10	58	7.3	14.1	12	**42**	32	13	**53**	32	12	3
	PuPr-10	176	15.2	15.7	12	**42**	40	5	**67**	24	8	0
EZ35-VII	PuFi-10	57	4.9	23.9	**67**	33	0	0	30	**68**	2	0
(1)	RaFi-10,d	76	11.4	18.1	**57**	39	4	0	19	**77**	4	0
(R: 100-0-0-0) (G: 49-51-0-0)	RaPr-10,d	45	6.5	17.5	**63**	35	2	0	34	**66**	0	0
	RaPr-10	56	7.4	16.4	**59**	30	7	4	40	**57**	3	0
	PuPr-10	49	4.1	24.7	**60**	31	5	4	22	**72**	6	0

44 (circled) *% of a mapping unit occupied by the most frequently occurring suitability class*

(1) Areal distribution of the suitability classes for rye (R) and grass (G) in the classification classes corresponding to the selected mapping units

dom choice of observations and proximal delineation. But as explained in Section 7.1.1.2 the values of the homogeneity indices of the 1 : 50 000 maps with proximal delineation are overestimated, whereas these values are slightly underestimated for the 1 : 50 000 maps with field delineation. Of the soil maps with detailed classification, the highest scores were achieved by map RaFi-10,d. The survey method used for this map also involved the random choice of observations, but here field delineation was used.

7.3 Evaluation of survey methods

The survey methods were evaluated by comparing the values of the quality measures of pairs of soil maps made by different survey methods. For these comparisons, only values for the entire map were used. They were calculated by averaging the values of all individual mapping units and by weighting with their areas.

Although values of the quality measures were calculated for all individual mapping units they could not be used for comparisons because:

a. Most mapping units have very small areas on the map. Therefore, there are too few test observations for reliable estimates to be made.

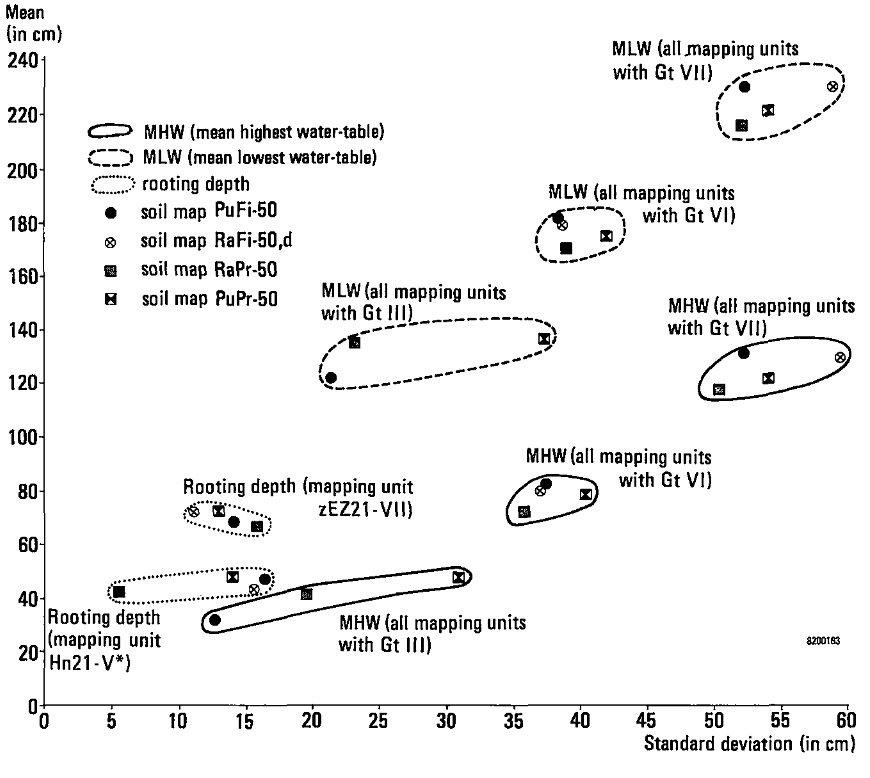


Fig. 9. Values for mean and standard deviation of mean highest water-table (MHW), mean lowest water-table (MLW) and rooting depth for a number of mapping units and groups of mapping units, distinguished on 4 soil maps.

Table 20 Mean and standard deviation for a number of soil properties for some mapping units used on four soil maps

Map code	Mapping unit	No. of test soil profiles	Area as % of total map area	Mean: MHW (cm)	Mean: MLW (cm)	Mean: Rooting depth (cm)	Mean: Moisture supply capacity grass (mm)	Mean: Moisture supply capacity rye (mm)	Mean: Capillary rise grass (mm)	Mean: % capillary rise grass	Mean: % available moisture grass	SD: MHW (cm)	SD: MLW (cm)	SD: Rooting depth (cm)	SD: Moisture supply capacity grass (mm)	SD: Moisture supply capacity rye (mm)	SD: Capillary rise grass (mm)	SD: % capillary rise grass	SD: % available moisture grass
PuFi-50	Hn21-V*	57	10.9	56.1	150.6	47.5	198	153	129	56	36	25.7	29.5	16.4	34	18	35	15	13
RaFi-50,d	Hn21-V*	31	12.0	49.0	139.6	43.5	203	153	138	61	32	19.7	20.1	15.8	31	16	21	10	11
RaPr-50	Hn21-V*	3	2.1	53.8	150.0	41.3	199	155	137	61	31	17.9	19.6	5.6	22	10	23	7	6
PuPr-50	Hn21-V	153	11.0	51.0	146.3	46.6	204	155	131	56	36	22.1	23.7	14.0	32	17	20	10	10
PuFi-50	Hn21-VI	131	26.2	78.4	176.5	48.2	166	138	97	45	45	35.1	35.8	17.3	50	32	45	20	17
RaFi-50,d	Hn21-VI	71	27.3	76.6	172.6	45.0	170	138	101	47	43	31.8	33.4	13.8	48	30	42	18	16
RaPr-50	Hn21-VI	60	5.1	61.0	157.1	41.8	189	150	121	56	36	20.5	22.5	13.1	31	18	28	10	11
PuPr-50	Hn21-VI	249	19.3	76.7	172.6	45.1	168	139	101	47	43	37.3	38.0	15.8	48	29	44	19	17
PuFi-50	zEZ23-VII	58	11.2	136.6	255.3	69.6	146	150	38	16	79	54.2	54.3	14.1	37	15	49	22	24
RaFi-50,d	zEZ21-VII	13	5.2	140.0	239.8	73.0	144	151	35	15	82	57.6	57.6	11.2	42	9.8	55	23	26
RaPr-50	zEZ21-VII	89	6.5	137.3	236.3	66.4	142	147	35	15	79	48.1	48.5	15.8	35	19	49	22	25
PuPr-50	zEZ23-VII	79	4.2	159.0	259.6	73.0	136	148	19	8	88	49.0	49.8	13.0	31	18	33	15	19
PuFi-50	all mapping units with Gt III	31	6.4	32.9	121.9	44.6	224	163	149	60	34	12.7	21.7	12.4	13	1	19	8	8
RaFi-50,d		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
RaPr-50		144	16.4	43.6	136.0	41.3	209	156	142	60	32	19.4	23.2	11.6	30	15	29	10	10
PuPr-50		184	12.0	48.9	138.8	48.4	211	160	133	55	38	31.0	37.7	16.6	27	8	41	17	17
PuFi-50	all mapping units with Gt VI	192	37.7	83.1	181.5	50.5	165	140	91	42	48	37.7	38.4	17.6	48	30	46	20	19
RaFi-50,d		124	47.9	82.7	180.7	49.3	167	140	92	43	48	37.2	38.6	16.2	47	28	46	21	20
RaPr-50		550	45.6	72.9	170.5	49.6	179	145	102	46	46	35.9	39.0	18.0	46	28	45	20	19
PuPr-50		572	38.5	79.1	175.7	50.1	173	144	96	44	47	41.6	41.9	17.7	46	26	47	21	21
PuFi-50	all mapping units with Gt VII	74	14.4	131.5	230.5	64.3	142	143	42	19	75	52.3	52.2	17.9	42	27	49	22	25
RaFi-50,d		28	11.1	130.6	230.7	66.5	145	144	45	20	74	59.0	58.9	18.1	47	28	54	24	28
RaPr-50		288	17.5	119.4	217.0	57.4	148	141	56	27	66	51.3	52.1	18.5	39	24	53	25	27
PuPr-50		252	12.1	122.7	223.5	62.0	147	143	48	22	71	53.9	54.1	20.2	44	29	48	23	25

8200183

b. Some mapping units occupy relatively large areas of the maps, but on individual maps their total areas delineated differ considerably.
c. The number of mapping units distinguished on maps with proximal delineation is more than twice the number on maps with field delineation.
d. Identical delineated areas on different maps are sometimes named after different mapping units. Here, individual surveyors have made a different choice out of the most closely related mapping units.

For these reasons, comparisons were not made between the same mapping units mapped with different survey methods. Still, values of quality measures show considerable differences between individual mapping units. These differences between mapping units on the same map are usually much greater than differences between identical mapping units mapped by different survey methods.

To give some impression of these differences, the means and standard deviations for a number of soil properties are given in Table 20. The data concern 3 mapping units and 3 groups of mapping units, surveyed by four different survey methods. Some of these data are depicted in Figures 9, 10 and 11, which enable the mean values of soil properties to be compared with the standard deviations of soil properties in two ways:
a. differences between individual mapping units on the same soil map;
b. differences between identical mapping units mapped by 4 different survey methods.
In general, the former differences are markedly greater than the latter. For some soil properties, differences are mainly in the mean values (Fig. 11). Other soil properties show differences both in the mean values and in the standard deviations (Figs. 9, 10).

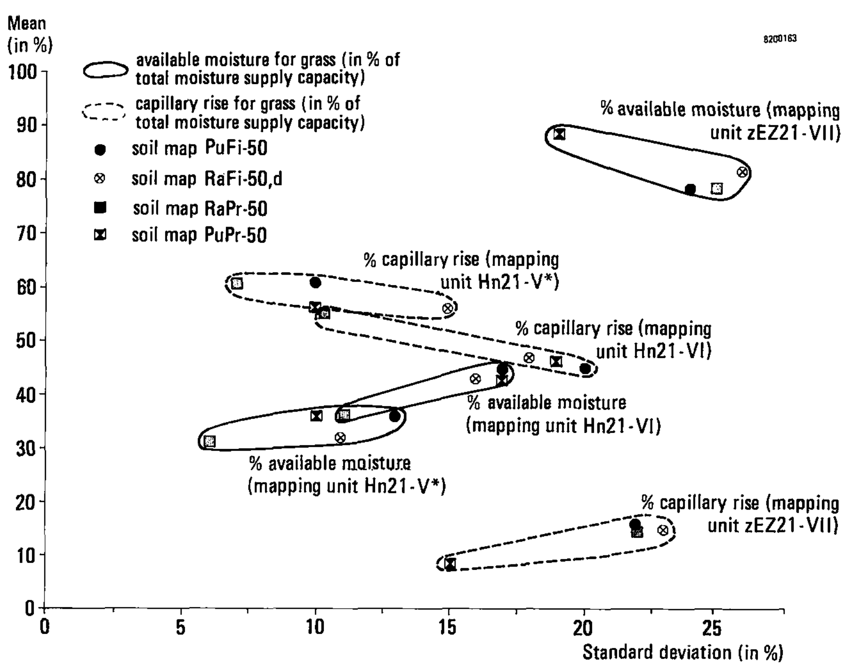


Fig. 10. Values for mean and standard deviation of percentage of available moisture and percentage of capillary rise for grass for 3 mapping units, distinguished on 4 soil maps.

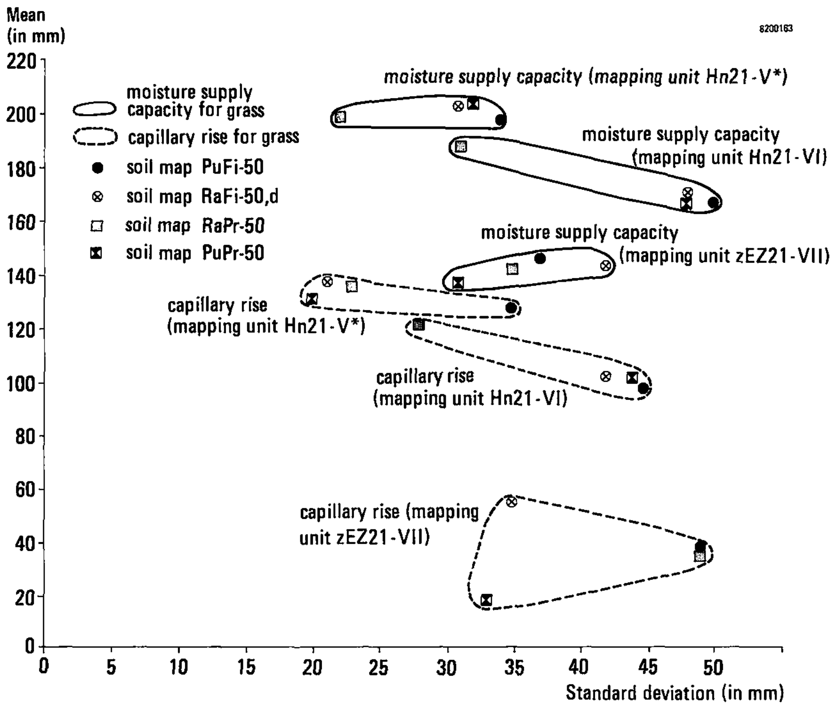


Fig. 11. Values for mean and standard deviation of moisture supply capacity and capillary rise for grass for 3 mapping units, distinguished on 4 soil maps.

In the next sections we will only compare the values of quality measures of the entire maps. This is done by pairwise testing of the differences between purities and homogeneities; see Section 7.1.3 for the procedure followed.

7.3.1 Comparisons of soil maps that differ in one aspect of the survey method

In this project, four survey methods were investigated. Two sampling procedures for observation points and two methods of delineating boundaries were combined to give four survey methods (Section 3.2). Soil maps with variation in only one aspect of the survey method are compared in Section 7.3.1. Those that differ in both aspects are described in Section 7.3.2. This distinction has been made to explain the influence of the individual aspect of a particular survey method on map quality (Section 3.6).

Soil maps made with different methods of delineating boundaries are compared in Section 7.3.1.1. Those that only differ in sampling procedure are described in Section 7.3.1.2.

Survey methods were evaluated by comparing only those soil maps with similar classification and map scale. The soil maps with general classification were at a scale of 1 : 50 000. Those with detailed classification were at a scale of 1 : 10 000. To avoid lengthy descriptions, maps will henceforth only be referred to by their map scale.

7.3.1.1 Influence of the method of delineation on map quality

Two methods of delineating boundaries are compared: a field method (Fi) and a proximal method (Pr). First the maps based on purposive sampling (Pu) are compared, next the maps based on random sampling (Ra).

(i) The influence of the method of delineation for soil maps with purposive sampling procedure

This influence can be measured by comparing the data of the 1 : 50 000 soil maps of PuFi-50 and PuPr-50 (Table 21, left-hand side). For the 1 : 10 000 soil maps the maps PuFi-10 and PuPr-10 must be compared (Table 22, left-hand side).

For 1 : 50 000 soil maps with purposive sampling procedure field delineation is superior to proximal delineation in terms of the following purities: strict purity, average purity, partial purities for subgroups, loam classes and groundwater. Proximal delineation scores a significantly higher value for the purity of 'additions' only. The better quality of the soil map with field delineation (PuFi-50) is also indicated by the lower standard deviations for humus at depth of 10, 30 and 50 cm.

Field delineation is also the superior method for 1 : 10 000 maps (Table 22; PuFi-10 and PuPr-10). But here only average purity and purity loam classes have a significantly better score. Strict purity and purity 'additions' also score higher but the differences are only weakly significant.

(ii) The influence of the method of delineation for soil maps with a random sampling procedure

The influence of the method of delineation can be measured by comparing the data of the 1 : 50 000 soil maps RaFi-50,d and RaPr-50,d (Table 21, right-hand side). For the 1 : 10 000 soil maps the maps RaFi-10, d and RaPr-10,d must be compared (Table 22, right-hand side).

Field delineation has an advantage over proximal delineation for soil maps at both map scales. For 1 : 50 000 soil maps the following purities achieve a significantly better score: average purity and the purities for subgroup, loam classes and "additions". The better quality of the soil map with field delineation (RaFi-50,d) is also indicated by the higher score for purity of groundwater classes (weakly significant) and a lower standard deviation for percentage humus at 50 cm depth. The quality of the 1 : 10 000 soil map is also higher when boundaries are delineated in the field (RaFi-10,d). For this map the average purity and the purities for subgroups and "additions" are significantly higher. The better quality of the soil map with field delineation is supported by lower standard deviations for MHW, MLW, capillary rise for grass, percentage capillary rise for grass and percentage available moisture for grass.

The influences of the method of delineation on the quality of soil maps are summarized in Table 23 (right-hand side) for both sampling procedures and both map scales. The following pairs of soil maps were compared:
PuFi-50 and PuPr-50; PuFi-10 and PuPr-10;
RaFi-50,d and RaPr-50,d; RaFi-10,d and RaPr-10d.

The quality of soil maps with field delineation appears to be better than that of maps with proximal delineation. But the number of quality measures with better score varies, depending on map scale and sampling procedure used.

From the comparisons it may be concluded that soil maps with field delineation achieved better quality for a number of purities than soil maps with proximal delineation. The superior quality of the soil maps with field delineation is also suggested by the lower standard deviations calculated for some soil properties.

Table 21 Comparison of the results from field and proximal boundary delineation on soil maps, scale 1:50 000, using the general map classification, applied to Area A and including both purposive and random sampling

8200163

Sampling procedure	Purposive observations		Random observations		General classification	Area A
Method of boundary delineation	Field delineation	Proximal delineation	Field delineation	Proximal delineation		
Map code	PuFi-50	PuPr-50	RaFi-50,d	RaPr-50,d		
PERCENTAGE PURITY Strict purity (%)	12.5	7.4	9.4	9.7		
Average purity (%)	67.2	65.1	70.0	63.8		
Purity subgroups (%)	50.8	41.0	56.0	48.1		
Purity sand classes (%)	100	100	100	100		
Purity loam classes (%)	92.6	89.4	96.6	90.8		
Purity "additions" (%)	47.4	59.0	58.5	46.7		
Purity groundwater classes (%)	45.4	36.1	39.0	33.5		
HOMOGENEITY INDICES OF THE SUITABILITY Homogeneity index rye (%)	11.7	14.7	14.0	14.4	52.0	4.1
Homogeneity index grass (%)	25.7	28.3	24.0	25.6	61.2	18.9
VARIATION IN SOIL PROPERTIES (standard deviations) *Mean highest water-table (MHW) (cm)*	33.5	36.7	34.4	34.3	11.7	44.9
Mean lowest water-table (MLW) (cm)	34.7	38.0	35.1	35.9	14.6	47.4
Rooting depth (cm)	16.1	15.8	14.4	14.6	10.0	17.8
% humus at 10 cm depth	1.6 '	2.4	1.6	1.6	1.3	2.5
% humus at 30 cm depth	1.9 '	2.2	2.0	2.2	1.3	2.4
% humus at 50 cm depth	2.0 '	2.5	2.0 '	2.5	1.3	2.7
Moisture supply capacity for grass (mm)	39.7	39.5	39.6	39.4	17.6	45.0
Moisture supply capacity for rye (mm)	23.6	21.9	22.6	22.1	11.8	23.6
Available moisture for grass (mm)	23.0	24.7	22.1	22.5	13.7	28.8
Available moisture for rye (mm)	30.1	32.0	28.3	29.3	17.1	37.5
Capillary rise for grass (mm)	39.0	41.4	39.0	39.0	15.4	51.1
Capillary rise for rye (mm)	26.8	28.8	25.6	25.9	14.3	33.9
Percentage capillary rise for grass	16.8	17.7	16.7	16.4	6.9	21.6
Percentage capillary rise for rye	16.4	17.3	15.6	15.6	8.9	20.1
Percentage available moisture for grass	16.5	17.5	16.5	16.0	6.5	21.8
Percentage available moisture for rye	16.9	18.1	16.2	16.2	9.2	21.4

(12.5) Significant difference ($\alpha = 5\%$)

' Relatively large difference (see Section 7.1.3)

(39.0) Weakly significant difference ($\alpha = 10\%$)

Table 22 Comparison of the results from field and proximal boundary delineation on soil maps, scale 1:10 000, using the detailed classification, applied to Area B and including both purposive and random sampling

8200183

Sampling procedure	Purposive observations		Random observations		Detailed classifications	Area B
Method of boundary delineation	Field delineation	Proximal delineation	Field delineation	Proximal delineation		
Map code	PuFi-10	PuPr-10	RaFi-10,d	RaPr-10,d		
PERCENTAGE PURITY Strict purity (%)	9.3	8.2	10.7	9.4		
Average purity (%)	61.0	58.8	61.8	58.9		
Purity subgroups (%)	51.1	49.8	52.4	47.4		
Purity sand classes (%)	84.2	83.9	79.2	79.3		
Purity loam classes (%)	68.4	60.7	72.4	73.2		
Purity "additions" (%)	58.7	57.0	59.5	50.0		
Purity groundwater classes (%)	42.7	42.6	45.7	44.5		
HOMOGENEITY INDICES OF THE SUITABILITY Homogeneity index rye (%)	19.5	20.4	20.5	16.8	44.7	1.1
Homogeneity index grass (%)	32.1	32.5	35.6	35.1	54.9	16.3
VARIATION IN SOIL PROPERTIES (standard deviations) Mean highest water-table (MHW) (cm)	27.1	28.7	26.5'	31.3	13.3	46.9
Mean lowest water-table (MLW) (cm)	28.5	30.5	27.6'	32.6	13.7	50.5
Rooting depth (cm)	14.2	14.5	14.4	14.6	9.4	17.9
% humus at 10 cm depth	1.6	1.6	1.5	1.5	1.8	1.8
% humus at 30 cm depth	2.5	2.6	2.4	2.2	2.6	3.0
% humus at 50 cm depth	3.3	3.2	3.5	3.4	2.6	4.0
Moisture supply capacity for grass (mm)	30.8	31.8	28.8	30.2	17.5	40.4
Moisture supply capacity for rye (mm)	16.6	17.2	16.2	16.2	10.3	18.6
Available moisture for grass (mm)	22.5	23.3	23.0	22.5	14.2	32.4
Available moisture for rye (mm)	29.0	30.3	30.5	30.5	18.7	42.7
Capillary rise for grass (mm)	29.5	31.4	28.6'	32.5	16.3	49.6
Capillary rise for rye (mm)	22.6	23.7	23.9	24.4	14.7	33.6
Percentage capillary rise for grass	12.3	13.0	12.5'	14.3	7.9	21.0
Percentage capillary rise for rye	13.4	13.9	14.0	14.4	9.0	19.4
Percentage available moisture for grass	12.4	13.1	12.8'	14.5	7.1	21.7
Percentage available moisture for rye	14.6	15.2	15.4	15.7	9.5	21.8

(61.0) Significant difference ($\alpha = 5\%$)

' Relatively large difference (see Section 7.1.3)

(9.3) Weakly significant difference ($\alpha = 10\%$)

Table 23 Significant differences between pairs of soil maps with only one aspect of the survey method differing

8200163

Method of boundary delineation/ Sampling procedure	Field delineation		Proximal delineation				Purposive observations		Random observations	
Area	A	B	A		B		A	B	A	B
Map scale	1:50 000	1:10 000	1:50 000		1:10 000		1:50 000	1:10 000	1:50 000	1:10 000
Map code	PuFi-50 RaFi-50,d	PuFi-10 RaFi-10,d	RaPr-50 PuPr-50	RaPr-50,g PuPr-50	RaPr-10 PuPr-10	RaPr-10,g PuPr-10	PuFi-50 PuPr-50	PuFi-10 PuPr-10	RaFi-50,d RaPr-50,d	RaFi-10,d RaPr-10,d
PERCENTAGE PURITY Strict purity (%)				◧		◧	●	○		
Average purity (%)	◧			◧		◧	●	●	●	●
Purity subgroups (%)			◧	◧	●	◧	●		●	●
Purity sand classes (%)		●			●	●				
Purity loam classes (%)	◧	⊡		◧	◧	◧	●	●	●	
Purity "additions" (%)	◧		○	◧	●	◧	◧	○	●	●
Purity groundwater classes (%)	○			◧		◧	●		○	
HOMOGENEITY INDICES OF THE SUITABILITY Homogeneity index rye (%)					○					
Homogeneity index grass (%)										

◧ Random observation best ($\alpha = 5\%$)
⊡ Random observation best ($\alpha = 10\%$)
● Purposive observation best ($\alpha = 5\%$)
○ Purposive observation best ($\alpha = 10\%$)

◧ Proximal delineation best ($\alpha = 5\%$)
● Field delineation best ($\alpha = 5\%$)
○ Field delineation best ($\alpha = 10\%$)

7.3.1.2 Influence of sampling procedure on map quality

Two sampling procedures were used to choose the observation points. In addition to observation points chosen by the surveyor during mapping (purposive observations – Pu) a stratified random strategy (random observation – Ra) was also introduced (Section 3.2.1).

Maps with purposive observations and those with random observations but whose soil boundaries were delineated in the field (Fi) will be compared first. Afterwards, both sampling procedures will be compared for maps with proximal delineation of the soil boundaries (Pr).

(i) Influence of sampling procedure for soil maps with field delineation

This influence on map quality can be measured by comparing the quality measures of 1 : 50 000 soil maps (PuFi-50 and RaFi-50,d) and those of 1 : 10 000 maps (PuFi-10 and RaFi-10,d). The values of the quality measures are recorded on the left-hand side of Tables 24 and 25. At a scale of 1 : 50 000, soil maps with random sampling procedure are significantly better than soil maps with purposive observations for 3 purities, viz: average purity; partial purities for loam classes and "additions". Except for purity for groundwater classes (weakly significant), none of the purity measures show the purposive sampling procedure to be advantageous (Table 24) when field delineation is used.

There are very few differences in quality measures between 1 : 10 000 soil maps with random observations and those with purposive observations. The comparison of soil maps PuFi-10 and RaFi-10,d indicates that only the purity of sand classes is significantly better when pur-

Table 24 Comparison of the results from purposive and randomly chosen observations on soil maps, scale 1:50 000, using the general classification and including both field and proximal delineation

8200163

Method of boundary delineation	Field delineation		Proximal delineation		Proximal delineation		General classification	Area A
Sampling procedure	Purposive	Random	Random	Purposive	Random	Purposive		
Map code	PuFi-50	RaFi-50,d	RaPr-50	PuPr-50	RaPr-50,g	PuPr-50		
PERCENTAGE PURITY								
Strict purity (%)	12.5	9.4	10.5	7.4	17.4	7.4		
Average purity (%)	67.2	70.0	66.4	65.1	74.2	65.1		
Purity subgroups (%)	50.8	56.0	53.3	41.0	57.4	41.0		
Purity sand classes (%)	100	100	100	100	100	100		
Purity loam classes (%)	92.6	96.6	90.7	89.4	93.5	89.4		
Purity "additions" (%)	47.4	58.5	51.5	59.0	71.5	59.0		
Purity groundwater classes (%)	45.4	39.0	36.3	36.1	48.5	36.1		
HOMOGENEITY INDICES OF THE SUITABILITY								
Homogeneity index rye (%)	11.7	14.0	17.5	14.7	13.3	14.7	52.0	4.1
Homogeneity index grass (%)	25.7	24.0	29.6	28.3	24.9	28.3	61.2	18.9
VARIATION IN SOIL PROPERTIES (standard deviations)								
Mean highest water-table (MHW) (cm)	33.5	34.4	31.9	36.7	32.4	36.7	11.7	44.9
Mean lowest water-table (MLW) (cm)	34.7	35.1	34.0	38.0	33.5	38.0	14.6	47.4
Rooting depth (cm)	16.1	14.4'	14.0'	15.8	12.8'	15.8	10.0	17.8
% humus at 10 cm depth	1.6	1.6	1.5'	2.4	1.4'	2.4	1.3	2.5
% humus at 30 cm depth	1.9	2.0	2.1	2.2	2.1	2.2	1.3	2.4
% humus at 50 cm depth	2.0	2.0	2.4	2.5	2.2'	2.5	1.3	2.7
Moisture supply capacity for grass (mm)	39.7	39.6	38.5	39.5	36.9	39.5	17.6	45.0
Moisture supply capacity for rye (mm)	23.6	22.6	21.7	21.9	20.1	21.9	11.8	23.6
Available moisture for grass (mm)	23.0	22.1	22.0'	24.7	20.1'	24.7	12.7	28.8
Available moisture for rye (mm)	30.1	28.3	28.5'	32.0	25.4'	32.0	17.1	37.5
Capillary rise for grass (mm)	39.0	39.0	36.5	41.4	35.1'	41.4	15.4	51.1
Capillary rise for rye (mm)	26.8	25.6	24.9'	28.8	21.9'	28.8	14.3	33.9
Percentage capillary rise for grass	16.8	16.7	15.5	17.7	14.7'	17.7	6.9	21.6
Percentage capillary rise for rye	16.4	15.6	15.2'	17.3	13.4'	17.3	8.9	20.1
Percentage available moisture for grass	16.5	16.5	15.1	17.5	14.4'	17.5	6.5	21.8
Percentage available moisture for rye	16.9	16.2	15.7'	18.1	13.9'	18.1	9.2	21.4

(70.0) Significant difference ($\alpha = 5\%$)

' Relatively large difference (see Section 7.1.3)

(45.4) Weakly significant difference ($\alpha = 10\%$)

Table 25 Comparison of the results from purposive and randomly chosen observations on soil maps, scale 1:10 000, using the detailed classification and including both field and proximal delineation

Method of boundary delineation	Field delineation		Proximal delineation		Proximal delineation		Detailed classification	Area B
Sampling procedure	Purposive	Random	Random	Purposive	Random	Purposive		
Map code	PuFi-10	RaFi-10,d	RaPr-10	PuPr-10	RaPr-10,g	PuPr-10		
PERCENTAGE PURITY Strict purity (%)	9.3	10.7	8.0	8.2	17.1	8.2		
Average purity (%)	61.0	61.8	58.9	58.8	68.2	58.8		
Purity subgroups (%)	51.1	52.4	44.0	49.8	55.7	49.8		
Purity sand classes (%)	84.2	79.2	81.6	83.9	82.8	83.9		
Purity loam classes (%)	68.4	72.4	73.6	60.7	82.4	60.7		
Purity "additions" (%)	58.7	59.5	51.7	57.0	66.8	57.0		
Purity groundwater classes (%)	42.7	45.7	43.6	42.6	53.0	42.6		
HOMOGENEITY INDICES OF THE SUITABILITY Homogeneity index rye (%)	19.5	20.5	15.9	20.4	18.8	20.4	44.7	1.1
Homogeneity index grass (%)	32.1	35.6	32.9	32.5	32.4	32.5	54.9	16.3
VARIATION IN SOIL PROPERTIES (standard deviations) Mean highest water-table (MHW) (cm)	27.1	26.5	33.5	28.7'	29.6	28.7	13.3	46.9
Mean lowest water-table (MLW) (cm)	28.5	27.6	35.5	30.5'	31.8	30.5	13.7	50.5
Rooting depth (cm)	14.2	14.4	14.8	14.5	14.3	14.5	9.4	17.9
% humus at 10 cm depth	1.6	1.5	1.5	1.6	1.6	1.6	1.8	1.8
% humus at 30 cm depth	2.5	2.4	2.4	2.6	2.5	2.6	2.6	3.0
% humus at 50 cm depth	3.3	3.5	3.2	3.2	3.1	3.2	2.6	4.0
Moisture supply capacity for grass (mm)	30.8	28.8	31.3	31.8	29.8	31.8	17.5	40.4
Moisture supply capacity for rye (mm)	16.6	16.2	16.3	17.2	15.9	17.2	10.3	18.6
Available moisture for grass (mm)	22.5	23.0	23.2	23.3	21.8	23.3	14.2	32.4
Available moisture for rye (mm)	29.0	30.5	31.1	30.3	29.0	30.3	18.7	42.7
Capillary rise for grass (mm)	29.5	28.6	35.1	31.4'	31.6	31.4	16.3	49.6
Capillary rise for rye (mm)	22.6	23.9	25.0	23.7	22.9	23.7	14.7	33.6
Percentage capillary rise for grass	12.3	12.5	15.1	13.0'	13.3	13.0	7.9	21.0
Percentage capillary rise for rye	13.4	14.0	14.6	13.9	13.4	13.9	9.0	19.4
Percentage available moisture for grass	12.4	12.8	15.5	13.1'	13.5	13.1	7.1	21.7
Percentage available moisture for rye	14.6	15.4	16.0	15.2	14.7	15.2	9.5	21.8

(84.2) Significant difference ($\alpha = 5\%$)

(72.4) Weakly significant difference ($\alpha = 10\%$)

' Relatively large difference (see Section 7.1.3) posive sampling is used. Random observations result in a weakly significantly higher purity for loam classes.

(ii) The influence of sampling procedure for soil maps with proximal delineation

For the 1 : 50 000 soil maps this influence will be examined by comparing maps RaPr-50 with PuPr-50, and RaPr-50,g with PuPr-50. For 1 : 10 000 soil maps the following maps have to be compared: RaPr-10 with PuPr-10; RaPr-10,g with PuPr-10.

The values of the quality measures for these maps are recorded in Tables 24 and 25, right-hand side.

Soil maps at a scale of 1 : 50 000: When boundaries had been delineated by proximal mapping, the results were slightly better when based on the set of random observations than when based on the observations that had been collected purposively. The map with random observations scores significantly higher for purity subgroups. The preference for random observations is also supported by the lower within-mapping-unit standard deviations for seven soil properties (Table 24).

For the generalized proximal soil map (RaPr-50,g) random observations were also found to be preferable to purposive observations. The standard deviations of most soil properties are reduced by generalizing soil map RaPr-50. Purities of generalized soil maps (.....,g) are significantly higher. This is a consequence of the enlarging of profile classes. Therefore, the purities of generalized soil maps cannot be compared with those of non-generalized soil maps.

Soil maps at a scale of 1 : 10 000: In contrast to the 1 : 50 000 maps, purposive observations produce better results than random observations when proximal delineation is used (Table 25; RaPr-10 and PuPr-10). The purities for subgroups, sand classes and "additions" are significantly higher. The homogeneity index for rye is weakly significantly higher. Preference for purposive observations is also indicated by the lower standard deviation for five soil properties. Only in the case of the purity of loam classes is a higher score achieved when random observations are used.

As in the case of the generalized 1 : 50 000 proximal map, generalizing the 1 : 10 000 proximal map results in slightly lower standard deviations for most soil properties (RaPr-10 and RaPr-10,g; Table 25). Therefore, the advantage of the purposive sampling procedure over random sampling procedure is lost when the proximal map is generalized.

The influences of the sampling procedure on the quality of soil maps are summarized in Table 23 (left-hand side). The following pairs of soil maps were compared: PuFi-50 and RaFi-50,d; PuFi-10 and RaFi-10,d; PaPr-50 and PuPr-50; RaPr-50,g and PuPr-50; RaPr-10 and PuPr-10; RaPr-10,g and PuPr-10. The influence of the sampling procedure on map quality differs, depending on the method of delineating boundaries and the map scale used.

From the paired comparisons it can be concluded that for 1 : 50 000 maps a random sampling procedure achieves higher quality than a purposive sampling procedure when field delineation is used. When soil boundaries are delineated proximally then both sampling procedures are equally successful.

The purposive sampling procedure scores higher quality when proximal delineation is used and soils are mapped at a scale of 1 : 10 000. Both sampling procedures are equally successful for 1 : 10 000 soil maps whose soil boundaries have been delineated in the field.

Table 26 Comparison of pairs of soil maps with both aspects of the survey methods differing

8200163

Area	A		B		A		B	
Map scale	1:50 000		1:10 000		1:50 000		1:10 000	
Method of boundary delineation	Field	Proximal	Field	Proximal	Field	Proximal	Field	Proximal
Sampling procedure	Purposive	Random	Purposive	Random	Random	Purposive	Random	Purposive
Map code	PuFi-50	RaPr-50	PuFi-10	RaPr-10	RaFi-50,d	PuPr-50	RaFi-10,d	PuPr-10
PERCENTAGE PURITY Strict purity (%)	12.5	10.5	9.3	8.0	9.4	7.4	*10.7*	8.2
Average purity (%)	67.2	66.4	**61.0**	58.9	**70.0**	65.1	**61.8**	58.8
Purity subgroups (%)	50.8	53.3	**51.1**	44.0	**56.0**	41.0	52.4	49.8
Purity sand classes (%)	100	100	**84.2**	81.6	100	100	79.2	**83.9**
Purity loam classes (%)	92.6	90.7	68.4	**73.6**	**96.6**	89.4	**72.4**	60.7
Purity "additions" (%)	47.4	51.5	**58.7**	51.7	58.5	59.0	59.5	57.0
Purity groundwater classes (%)	**45.4**	36.3	42.7	43.6	39.0	36.1	45.7	42.6
HOMOGENEITY INDICES OF THE SUITABILITY Homogeneity index rye (%)	11.7	17.5	19.5	15.9	14.0	14.7	20.5	20.4
Homogeneity index grass (%)	25.7	29.6	32.1	32.9	24.0	28.3	35.6	32.5
VARIATION IN SOIL PROPERTIES (standard deviations) Mean highest water-table (MHW) (cm)	33.5	31.9	27.1′	33.5	34.4	36.7	26.5	28.7
Mean lowest water-table (MLW) (cm)	34.7	34.0	28.5′	35.5	35.1	38.0	27.6′	30.5
Rooting depth (cm)	16.1	14.0′	14.2	14.8	14.4	15.8	14.4	14.5
% humus at 10 cm depth	1.6	1.5	1.6	1.5	1.6′	2.4	1.5	1.6
% humus at 30 cm depth	1.9	2.1	2.5	2.4	2.0	2.2	2.4	2.6
% humus at 50 cm depth	2.0′	2.4	3.3	3.2	2.0′	2.5	3.5	3.2
Moisture supply capacity for grass (mm)	39.7	38.5	30.8	31.3	39.6	39.5	28.8′	31.8
Moisture supply capacity for rye (mm)	23.6	21.7	16.6	16.3	22.6	21.9	16.2	17.2
Available moisture for grass (mm)	23.0	22.0	22.5	23.2	22.1′	24.7	23.0	23.3
Available moisture for rye (mm)	30.1	28.5	29.0	31.1	28.3′	32.0	30.5	30.3
Capillary rise for grass (mm)	39.0	36.5	29.5′	35.1	39.0	41.4	28.6	31.4
Capillary rise for rye (mm)	26.8	24.9	22.6′	25.0	25.6′	28.8	23.9	23.7
Percentage capillary rise for grass	16.8	15.5	12.3′	15.1	16.7	17.7	12.5	13.0
Percentage capillary rise for rye	16.4	15.2	13.4′	14.6	15.6	17.3	14.0	13.9
Percentage available moisture for grass	16.5	15.1	12.4′	15.5	16.5	17.5	12.8	13.1
Percentage available moisture for rye	16.9	15.7	14.6	16.0	16.2′	18.1	15.4	15.2

61.0 (circled) Significant difference ($\alpha = 5\%$)

′ Relatively large difference (see Section 7.1.3)

10.7 (dashed circle) Weakly significant difference ($\alpha = 10\%$)

7.3.2 Comparisons of soil maps that differ in both method of boundary delineation and sampling procedure

When maps that differ both in sampling procedure and method of boundary delineation are compared, the differences in quality result from the combined influence of both aspects. These differences can be explained by the influence of the individual aspect of the survey method on map quality, as described in Section 7.3.1.

Soil maps with purposive sampling procedure and field delineation were compared with soil maps with random sampling procedure and proximal delineation (Tables 26 and 27, left-hand side; PuFi-50 and RaPr-50; PuFi-10 and RaPr-10).

At a scale of 1 : 50 000 both survey methods produce soil maps of nearly equal quality. No significant differences were measured for purities and homogeneity indices, except for the purity of groundwater classes: here, the soil map with purposive observations and field delineation scores significantly higher.

If the same survey methods are compared for 1 : 10 000 maps, purposive sampling combined with field delineation achieves higher values for four of the seven purities. The superiority of this survey method is also supported by lower standard deviations for seven soil properties.

Table 27 Significant differences between pairs of soil maps with both aspects of the survey methods differing

Survey methods compared	Purposive, field/ random, proximal		Random, field/ purposive, proximal	
Area	A	B	A	B
Map scale	1:50 000	1:10 000	1:50 000	1:10 000
Map code	PuFi-50 RaPr-50	PuFi-10 RaPr-10	RaFi-50,d PuPr-50	RaFi-10,d PuPr-10
PERCENTAGE PURITY Strict purity (%)				○
Average purity (%)		●	●	●
Purity subgroups (%)		●	●	
Purity sand classes (%)		●		◧
Purity loam classes (%)		◧	●	●
Purity "additions" (%)		●		
Purity groundwater classes (%)	●			
HOMOGENEITY INDICES OF THE SUITABILITY Homogeneity index rye (%)				
Homogeneity index grass (%)				

● Purposive observations and field delineation best ($\alpha = 5\%$)

◧ Random observations and proximal delineation best ($\alpha = 5\%$)

● Random observations and field delineation best ($\alpha = 5\%$)

○ Random observations and field delineation best ($\alpha = 10\%$)

◧ Purposive observations and proximal delineation best ($\alpha = 5\%$)

Soil maps with random sampling procedure and field delineation were compared with soil maps with purposive sampling procedure and proximal delineation (Tables 26 and 27; right-hand side; RaFi-50,d and PuPr-50; RaFi-10,d and PuPr-10). Random sampling combined with field delineation achieves better results for soil maps at both scales. The 1 : 50 000 soil map scores better for three purities. The 1 : 10 000 soil map also achieves better results for three purities. Only purity for sand classes scores higher for the survey method with purposive observations combined with proximal delineation.

The advantage of the survey method with random sampling and field delineation over purposive sampling combined with proximal delineation is also indicated by lower standard deviations for some of the soil properties. In general, the differences between the values of the standard deviations are very small. But obviously there is a tendency for standard deviations to be lower for the survey method with random observations combined with field delineation.

Either aspect of the survey method may influence map quality positively or negatively. But the comparisons in Section 7.3.1 show that the aspects often have opposite influences. As a consequence, the influence of the individual aspect on the values of the quality measures will be partly or completely neutralized.

7.3.3 Differences in the readability of the soil maps

7.3.3.1 Readability in general

In previous sections the survey methods have been evaluated on the basis of the values of the quality measures only: these measures determine the pedological quality of soil maps. But in addition to the pedological quality, the usefulness of soil maps is also influenced by cartographic aspects that determine the readability of a soil map.

There is no objective method of measuring readability. It can be assessed by:

a. making inquiries of map users;
b. using parameters that affect readability, such as the number of mapping units, number of delineated areas, average size of delineated areas and frequency distribution of mapping units.

For practical reasons we applied these parameters.

Table 28 shows that there are approximately three times as many mapping units and delineated areas on soil maps with proximal delineation (.....Pr) as on soil maps with field delineation. If proximal delineation is combined with a random sampling procedure, there are more mapping units and delineated areas than when the purposive sampling procedure has been used. Consequently, soil maps with proximal delineation are characterized by a multitude of mapping units and a large number of very small delineated areas. The average size of delineated areas for these maps varies from 0.85 ha to 1.4 ha for 1 : 10 000 soil maps and from 6 ha to 9 ha for 1 : 50 000 soil maps. For soil maps with field delineation the corresponding values range from 2-3 ha and from 25-45 ha, respectively.

Both the large number of mapping units and the large number of delineated areas cause a very fragmented map pattern. Often, delineated areas on the map are too small to contain the codes of the mapping units.

In general, map users prefer soil maps with a limited number of mapping units. They also dislike maps whose delineated areas are very small. Because poor readability is systematically connected with proximal delineation, the survey methods cannot be evaluated solely on the basis of the values of the quality measures. In Section 7.3.4 both the quality measures and the readability of the maps will be used to evaluate the survey methods. The evaluation of a particular survey method based on quality measures can be positively or negatively changed

Table 28 Number of mapping units and delineated areas and their areal distributions on the various soil maps

Map code	No. of survey observa-tions	No. of mapping units	No. of delineated areas	Average no. of delineated areas per mapping unit	Average area of delineated areas in ha	Frequency distribution of mapping units by their areas (in % of total map area)		
						< 1%	1-5%	> 5%
Soil maps scale 1:50000 (Area A)								
PuFi-50	356	22	66	3	25	23	45	32
RaFi-50,d	253	19	36	2	44	26	37	37
RaPr-50,d	253	81	183	2.2	9	63	32	5
RaPr-50	349	100	251	2.5	6.4	69	26	5
RaPr-50,g	349	64	66	1	25	41	56	3
PuPr-50	355	48	226	4.5	7	54	38	8
Soil maps scale 1:10000 (Area B)								
PuFi-10	446	52	145	3	2.5	58	38	4
RaFi-10,d	530	36	131	3.5	2.7	39	50	11
RaPr-10,d	529	163	426	2.6	0.85	85	14	1
RaPr-10	437	148	356	2.4	1.0	84	14	1
RaPr-10,g	437	99	110	1.1	3.3	67	33	0
PuPr-10	445	85	262	3.1	1.4	68	28	4

8200163

by assessing the readability of the map made by this survey method. In this investigation, the readability only influences the evaluation of a survey method if a survey method with proximal delineation is compared with a survey method with field delineation. Three cases can be distinguished:

a. The values of the quality measures are better in the survey method with field delineation. The better readability of the soil map with field delineation enhances the preference for this survey method.
b. The values of the quality measures are approximately equal for both survey methods. Preference is given to the survey method with field delineation because the soil map is more readable.
c. The values of the quality measures are better in the survey method with proximal delineation. Here, higher values of the quality measures are combined with poor readability of the soil map. The magnitude of the differences between the quality measures of both maps decides which survey method will be preferred.

7.3.3.2 Influence of the number of observations on the readability of proximal soil maps

The readability of soil maps with proximal delineation does not increase if the number of observations is increased, as the comparisons between maps RaPr-50,d and RaPr-50, and maps RaPr-10 and RaPr-10,d show. For both pairs of soil maps only the observation density differs (Table 28). There are 38% more observations in map RaPr-50 than in RaPr-50,d, and 21% more in map RaPr-10,d than in RaPr-10. These maps have more mapping units and notably more delineated areas. This increase is proportional to the increase in the observation density. Thus, readability decreases as observation density increases.

The values of quality measures are slightly better if higher observation densities are used (Table 16).

7.3.3.3 Influence of generalization on the readability of proximal soil maps

Readability increases considerably if proximal soil maps are generalized (Table 28; map RaPr-50,g and map RaPr-10,g) because the number of delineated areas is drastically reduced and they become larger. Also, the number of mapping units decreases but is still considerably higher than in maps with field delineation. Map quality does not decrease if the map is generalized.

The generalized soil maps mainly consist of complex mapping units. The method of generalization used results in many of the mapping units being similar (Section 3.2.2), each represented by only one delineated area on the map.

The improved readability of the generalized soil maps mainly results from the number and size of the delineated areas. The number of mapping units does not decrease sufficiently and their complexity reduces the usefulness of the map.

7.3.4 Comparisons of the survey methods

The results of paired comparisons of soil maps based on the values of the quality measures are recorded in Tables 23 and 27. These comparisons also enable the survey methods to be ranked. Only the purity measures have contributed to this ranking; no significant differences were found between the homogeneity indices. The differences between the standard deviations of soil properties were not used for the ranking, given the great uncertainty about their true values, because of the relatively high proportion of observation errors (Section 7.1).

All possible combinations of the four survey methods were compared and the best survey method was indicated for all paired comparisons: see Table 29. Also, the number of purity measures that are better in the best survey method is indicated. If only one purity is significantly better, the survey methods are considered to be equally good.

Aspects of the survey method that have a positive influence on map quality are recorded in Table 30. (By implication, if one aspect had a positive influence then the other aspect had a negative influence.) Comparisons of survey methods that differ in both aspects merely indicate the combined effect of both aspects on map quality.

Influences of individual aspects of the survey method on map quality are described in Sections 7.3.1.1 and 7.3.1.2. These influences do not always clearly explain differences in the quality of soil maps made by different survey methods. The quality of a soil map made by a particular survey method results from the combined effects of both aspects. As mentioned before, these effects can be opposite and thus the influence of the individual aspect on the quality of that map will be partly or completely nullified.

In Table 31 all soil maps are mutually compared and ranked according to the number of purity measures with significantly higher values. The generalized soil maps were omitted from the comparisons because their purity values are not comparable with the purities of non-generalized soil maps.

From Table 31 it appears that the order in which the survey methods are ranked is slightly different between the two map scales.

Table 29 Paired comparisons of survey methods using the number of purities with significantly higher score (95% confidence intervals)

6200163

Map code	Survey methods compared	Best method and number of purities with higher score: map scale 1:50000		map scale 1:10000	
PuFi-50 en RaFi-50,d PuFi-10 en RaFi-10,d	purposive/field and random/field	random/field	3	=	1
PuFi-50 en RaPr-50 PuFi-10 en RaPr-10	purposive/field and random/proximal	=	1	purposive/field	4
PuFi-50 en PuPr-50 PuFi-10 en PuPr-10	purposive/field and purposive/proximal	purposive/field	5	purposive/field	2
RaFi-50,d en RaPr-50,d RaFi-10,d en RaPr-10,d	random/field and random/proximal	random/field	4	random/field	3
RaFi-50,d en PuPr-50 RaFi-10,d en PuPr-10	random/field and purposive/proximal	random/field	3	random/field	2
RaPr-50 en PuPr-50 RaPr-10 en PuPr-10	random/proximal and purposive/proximal	=	1	purposive/proximal	3

—— Best survey method, with higher score for 4 or more purities

– – Best survey method, with higher score for 2 or 3 purities

= Equally good survey methods (all purities are equal, or only 1 purity scores higher)

Table 30 Aspects with positive influence on quality

Aspect	Map scale 1:50000 General classification	Map scale 1:10000 Detailed classification
Comparisons with variation in one aspect		
Field delineation (with purposive observations)	+	(+)
Field delineation (with random observations)	+	(+)
Random observations (with field delineation)	(+)	=
Random observations (with proximal delineation)	=	
Purposive observations (with proximal delineation)		(+)
Comparisons with variation in two aspects		
Random observations with field delineation (versus purposive observations with proximal delineation)	(+)	(+)
Purposive observations with field delineation (versus random observations with proximal delineation)	=	+

\+ Definitely better for 4 or more purities

(+) Definitely better for 2 or 3 purities

= Approximately equal (all purities are equal, or only 1 purity is definitely better)

Ranking of survey methods for 1 : 50 000 maps

Best quality is achieved by the survey method with random observations and field delineation (RaFi-50,d), followed by the method with purposive observations and field delineation (PuFi). The survey method with random observations and proximal delineation (RaPr-50) is ranked equal third with purposive observations and proximal delineation (PuPr-50). The lowest score is achieved by the survey method with random observations and proximal delineation at lower observation density (RaPr-50,d).

Table 31 Paired comparisons of soil maps, ranked according to number of purity measures with higher score

Soil maps of Area A (map scale 1:50 000; general classification)

	RaFi-50,d	PuFi-50	RaPr-50	PuPr-50	RaPr-50,d
RaFi-50,d		(+)	(+)	(+)	+
PuFi-50	(-)		=	+	(+)
RaPr-50	(-)	=		=	(+)
PuPr-50	(-)	-	=		=
RaPr-50,d	-	(-)	(-)	=	

The suffix ....,d indicates that the soil map concerned was compiled with a lower observation density

Soil maps of Area B (map scale 1:10 000; detailed classification)

	PuFi-10	RaFi-10,d	PuPr-10	RaPr-10,d	RaPr-10
PuFi-10		=	(+)	(+)	+
RaFi-10,d	=		(+)	(+)	(+)
PuPr-10	(-)	(-)		=	(+)
RaPr-10,d	(-)	(-)	=		(+)
RaPr-10	-	(-)	(-)	(-)	

The suffix ....,d indicates that the soil map concerned was compiled with a higher observation density

\+ Definitely better score (in 4 or more purity measures)

(+) Moderately better score (in 2 or 3 purity measures)

= Approximately equal score (higher value for maximum 1 purity measure)

(-) Moderately worse score (in 2 or 3 purity measures)

\- Definitely worse score (in 4 or more purity measures)

Ranking of survey methods for 1 : 10 000 maps

Best quality is achieved by both survey methods with field delineation (PuFi-10 and RaFi-10,d; Table 31). Soil maps made with these survey methods are of approximately equal quality, followed by the map made by purposive observations and proximal delineation (PuPr). The survey method with random observations and proximal delineation (soil maps RaPr-10,d and RaPr-10) has the poorest quality.

The ranking of survey methods in order of decreasing quality of maps is similar for both map scales, except for the survey methods with proximal delineation. For 1 : 50 000 soil maps proximal delineation scores higher when a random sampling procedure is used (RaPr-50). But a purposive sampling procedure scores higher quality for 1 : 10 000 soil maps (PuPr-10). The difference between both rankings will be explained in Section 8.3.

In this section the evaluation of survey methods and the comparisons of soil maps has been based on purity measures only. If both purity measures and readability criteria are used, some of the results will change. As described in Section 7.3.3.1, the readability of a soil map only affects the ranking of the survey method when that method involves proximal delineation.

Evaluating the survey methods in terms of purity measures and readability of resulting maps

The order in which survey methods were ranked is presented in Table 33. Applying the three cases distinguished in Section 7.3.3.1 certain evaluations changed (Table 32) as follows:

Soil maps at a scale of 1 : 50 000:

a. The superiority of the RaFi method over the RaPr method and the PuFi method over the PuPr method is more marked.

Table 32 Paired comparisons of survey methods using purity measures and readability criteria

8200163

Map code	Survey methods compared	Best method based on quality measures and readability criteria	
		map scale 1:50000	map scale 1:10000
PuFi-50 en RaFi-50,d PuFi-10 en RaFi-10,d	purposive/field and random/field	random/field (– –)	=
PuFi-50 en RaPr-50 PuFi-10 en RaPr-10	purposive/field and random/proximal	purposive/field 1) (– –)	purposive/field (—)
PuFi-50 en PuPr-50 PuFi-10 en PuPr-10	purposive/field and purposive/proximal	purposive/field (—)	purposive/field 1) (—)
RaFi-50,d en RaPr-50,d RaFi-10,d en RaPr-10,d	random/field and random/ proximal	random/field (—)	random/field 1) (—)
RaFi-50,d en PuPr-50 RaFi-10,d en PuPr-10	random/field and purposive/proximal	random/field 1) (—)	random/field 1) (—)
RaPr-50 en PuPr-50 RaPr-10 en PuPr-10	random/proximal and purposive/proximal	=	purposive/proximal (– –)

—— Obviously best survey method

– – Best survey method in some respects

= Equally good survey methods

1) Outcome of comparison changed from Table 29 because of difference in readability

Table 33 Paired comparisons of soil maps, ranked according to number of purity measures with higher score and readability criteria

Soil maps of Area A (map scale 1:50 000; general classification)

	RaFi-50,d	PuFi-50	RaPr-50	PuPr-50	RaPr-50,d
RaFi-50,d		(+)	+	+	+
PuFi-50	(−)		(+)	+	+
RaPr-50	−	(−)		=	(+)
PuPr-50	−	−	=		=
RaPr-50,d	−	−	(−)	=	

The suffix ....d indicates that the soil map concerned was compiled with a lower observation density

Soil maps of Area B (map scale 1:10 000; detailed classification)

	PuFi-10	RaFi-10,d	PuPr-10	RaPr-10,d	RaPr-10
PuFi-10		=	+	+	+
RaFi-10,d	=		+	+	+
PuPr-10	−	−		=	(+)
RaPr-10,d	−	−	=		(+)
RaPr-10	−	−	(−)	(−)	

The suffix ....d indicates that the soil map concerned was compiled with a higher observation density

\+ Obviously better score
(+) Somewhat better score
= Equal score
(−) Somewhat worse score
− Obviously worse score

b. The slightly better quality of the RaFi method over the PuPr method also is more marked.
c. The parity of the PuFi and RaPr methods has changed in favour of the PuFi survey method.

Soil maps at a scale of 1 : 10 000:
a. The superiority of the PuFi method over the RaPr method is more marked.
b. The slightly better quality of the PuFi method over the PuPr method and the slightly better quality of the RaFi method over both proximal methods (PuPr and RaPr) is more marked.

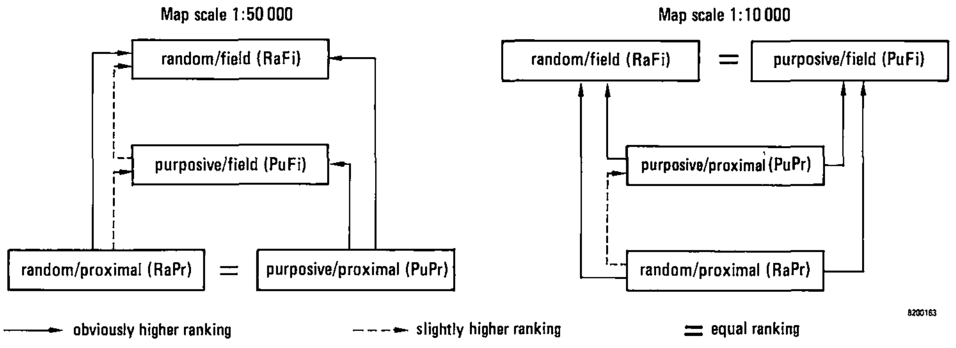


Fig. 12. Ranking of survey methods in descending order.

Fig. 12 shows the evaluation of the survey methods in terms of purity measures and readability criteria. The differences between the survey methods are indicated in terms of "obviously higher ranking", "slightly higher ranking" and "equal ranking".

Random and purposive sampling with field delineation (RaFi and PuFi) are equal first at scale 1 : 10 000, whereas at scale 1 : 50 000 they rank first and second, respectively. Purposive and random sampling with proximal delineation (PuPr and RaPr) rank third and fourth, respectively, at scale 1 : 10 000, whereas at scale 1 : 50 000 they rank equally third.

7.4 The effects of using a more general classification and of decreasing map scale on the quality of a soil map with field delineation

From the soil map with random observations and field delineation (RaFi-10,d) two extra maps were derived. Map A results from changing the detailed classification used for map RaFi-10,d into the general classification. Afterwards, the scale of map A was changed from 1 : 10 000 to 1 : 50 000 and delineated areas were enlarged to a size acceptable for maps at a scale of 1 : 50 000 (map B). The effects of using the general classification and decreasing the map scale were examined by comparing the values of the quality measures of both derived maps with those of the original soil map RaFi-10,d (Table 34). The effects on the number of mapping units and the number of delineated areas can be seen from Table 35.

Transferring the classification of map RaFi-10,d into the general classification hardly affects the appearance of the map (Table 35; map A). The number of delineated areas does not change. Obviously, neighbouring delineated areas differ considerably on the original map. Therefore, translation into the general classification does not result in delineated areas being amalgamated anywhere. But the number of mapping units is reduced from 36 to 34 (the two mapping units that were dropped were represented by very small areas on the original map).

Because the profile classes of the general classification are larger, higher purities are achieved (Table 34). Purities for subgroups and groundwater classes do not change, because the profile classes are the same for both classifications. Also, values for homogeneity indices and standard deviations of soil properties are very similar. Evidently, these cannot change if the number of mapping units and the delineated areas on the map remain the same.

In practice, the general classification is used for 1 : 50 000 soil maps. Therefore, the scale of soil map A with general classification should also be translated into scale 1 : 50 000 and the delineated areas should be enlarged to an acceptable size. The effects on the map quality

Table 34 The effects of using a more general classification (A) and decreasing map scale (B) on the quality of soil map RaFi-10,d

	RaFi-10,d	A [1]	B [2]
PERCENTAGE PURITY			
Strict purity (%)	10.7	(15.6)	(12.4)
Average purity (%)	61.8	(71.2)	(70.1)
Purity subgroups (%)	52.4	52.8	51.0
Purity sand classes (%)	79.2	(100)	(100)
Purity loam classes (%)	72.4	(92.5)	(90.6)
Purity "additions" (%)	59.5	(65.1)	(63.2)
Purity groundwater classes (%)	45.7	45.7	45.5
HOMOGENEITY INDICES OF THE SUITABILITY			
Homogeneity index rye (%)	20.5	20.2	(15.0)
Homogeneity index grass (%)	35.6	34.9	29.6
VARIATION IN SOIL PROPERTIES (standard deviations)			
Mean highest water-table (MHW) (cm)	26.5	26.3	29.0 '
Mean lowest water-table (MLW) (cm)	27.6	27.5	30.4 '
Rooting depth (cm)	14.4	14.4	15.0
% humus at 10 cm depth	1.5	1.6	1.6
% humus at 30 cm depth	2.4	2.5	2.6
% humus at 50 cm depth	3.5	3.5	3.7
Moisture supply capacity for grass (mm)	28.8	28.7	32.1 '
Moisture supply capacity for rye (mm)	16.2	16.2	18.2 '
Available moisture for grass (mm)	23.0	23.1	25.1 '
Available moisture for rye (mm)	30.5	30.6	33.1 '
Capillary rise for grass (mm)	28.6	28.5	31.7 '
Capillary rise for rye (mm)	23.9	23.8	25.2
Percentage capillary rise for grass	12.5	12.5	13.9 '
Percentage capillary rise for rye	14.0	14.0	14.7
Percentage available moisture for grass	12.8	12.7	14.0 '
Percentage available moisture for rye	15.4	15.4	16.3

[1] A Translation of the detailed classification into the general classification

[2] B Translation of the classification and decreasing the map scale from 1:10000 to 1:50000

(15.6) Difference significant ($\alpha = 5\%$) from the original map (RaFi-10,d)

' Difference from the original map (RaFi-10,d) relatively large (see Section 7.1.3)

Table 35 The effects of using a more general classification (A) and decreasing map scale (B) on the number of mapping units, delineated areas and the size of the delineated areas

Map code	No. of mapping units	No. of delineated areas	Average no. of delineated areas per mapping unit	Average size of delineated areas in ha	Frequency distribution of mapping units by their areas (in % of total map area)		
					< 1 %	1 – 5 %	> 5 %
RaFi-10,d	36	131	3.5	2.7	39	50	11
A 1)	34	131	4	2.7	38	47	15
B 2)	14	24	1.7	16.6	0	50	50

8200163

1) A Translation of the detailed classification into the general classification

2) B Translation of the classification and decreasing the map scale from 1:10000 to 1:50000

of decreasing the map scale can be seen in Table 34. The effects on the number of mapping units and on the number and size of the delineated areas are recorded in Table 35 (map B).

The transformation into map scale 1 : 50 000 results in the number of mapping units decreasing by 60% while the number of delineated areas decreases by 80%. As a consequence, the average size of the delineated areas increases from 2.7 ha to 16.6 ha. Many of the delineated areas on map A have been combined but few new soil boundaries have been drawn. Only two complex mapping units have been distinguished and many small delineated areas of map A have disappeared. They are considered to be impurities within the larger delineated areas of map B.

Decreasing the map scale combined with enlarging the delineated areas worsens the map quality. The values for purity are slightly lower than in map A. Compared with the original map, purities score higher because the profile classes of the general classification are larger. Soil map B achieves distinctly lower values for the homogeneity indices. Also, the standard deviations of most soil properties are higher.

The comparisons between original and derived maps show that transformation into the general classification hardly affects the quality of this map. But map quality decreases distinctly when map scale is decreased.

8. DISCUSSION

The results of this investigation will be discussed in terms of 8 topics. First, attention will be paid to the choice of the quality measures and their importance for various map users. Next, some results will be discussed in relation to the results of research done in other countries. Before the survey methods are evaluated, the influences of sampling procedure and method of delineation on the quality of soil maps will be discussed.

There were distinct differences between the appearance of the soil maps investigated. For this reason, the survey methods could not be assessed solely in terms of the quality measures. Differences in the readability of soil maps produced by different survey methods will be discussed and then the survey methods will be reassessed in terms of quality measures and readability criteria.

The consequences of spatial variability over short distances on the results of this investigation will be discussed. Finally, possibilities of improving the quality of soil maps are reviewed.

8.1 The choice of the quality measures

We quantified and characterized the quality of soil maps by various quality measures that were chosen from a large number of alternatives. Obviously, quality measures related to the purpose of the map are preferred. But the purpose of a map is not always known, or the map may be used for different purposes.

Judgments on quality of a soil map are only valid for those soil properties that are actually measured. High accuracy or precision for one soil property does not imply high quality for other soil properties. For this reason, general judgment on the quality of soil maps has to be based on a number of quality measures of various kinds.

In our study, 25 quality measures were used. They consist of purities, standard deviations of soil properties, and homogeneity indices for suitability classes. In addition, some parameters to quantify the readability of soil maps were adopted. Quality measures and readability criteria were used to estimate the quality of soil maps and to evaluate the survey methods.

Purity is commonly used to quantify the accuracy of soil maps (WILDING et al., 1965; BECKETT and WEBSTER, 1971; BIE and BECKETT, 1971). It is an objective measure with limited significance for map users. Purity only indicates the extent to which the content of the delineated areas corresponds to the specifications in the classification system used. Purity percentages indicate the accuracy but are not necessarily related to particular applications of soil maps. Also, purity does not differentiate between important and less important classification criteria. Another shortcoming of purity percentages is that they do not express the degree by which class limits are exceeded.

The limitations of purities apply especially to the strict purity, which is a complex and unweighted measure. Strict purity indicates the percentage of a soil map for which soil profiles meet all classification criteria, as predicted by the map legend. The percentage is influenced equally whether the value of only one property or the values of all the properties of a soil profile exceeds the class limits.

The low values of strict purity in this study mainly result from soil profiles that are impure with respect to one or two classification criteria. The correlations between soil properties – so-called correlative complex – seem to be lower than previously found.

Partial purities are less abstract measures than strict purity. Partial purities of single soil properties may be particularly important for certain applications of soil maps. In practice, information on the variation of important soil properties is the most preferable.

The average purity is a complex and unweighted parameter. It is defined as the arithmetic mean of all partial purities, in which each partial purity refers to a specified subset of the classification criteria.

Information about average purities has restricted significance for certain applications of the soil map. Some of the disadvantages of strict purity are absent, whereas information on all the classification criteria is nevertheless obtained from one figure. The old concept of purity used in earlier Stiboka publications was very similar to the average purity as defined in this study.

A second group of quality measures is related to the homogeneity of soil maps. Standard deviations were calculated for a number of soil properties. They are a measure of the precision of the soil map and may be used for specific applications, e.g. land reallotment and reclamation. Standard deviations have the disadvantage that their values for individual soil properties cannot easily be compared and summarized.

Homogeneity indices record the homogeneity of a soil map in relation to the areal distributions of classes. In this study, homogeneity indices were calculated for the suitability classes for rye and grass. Actually, homogeneity indices may be calculated for applications of any kind. They are useful for agriculture and planning. The value of the homogeneity index for a particular application strongly depends on the homogeneity of soil properties related to that application.

To sum up, strict purity and average purity have limited usefulness for map users. Partial purities are favoured for particular applications, especially when they refer to one soil property or a few closely related properties. But some of the objections to purity percentage still remain.

Standard deviations of soil properties and homogeneity indices are preferable to purities. They directly indicate the usefulness of the map for particular applications. Each of the standard deviations and homogeneity indices only defines the precision of the map with respect to the properties or suitabilities concerned. The quality of a soil map in general can be ascertained by applying a set of quality measures. The choice of individual quality measures should be primarily based on the applications of that particular map.

8.2 The results of this study compared with studies in other countries

Information on the accuracy of soil maps in other countries mainly concerns the strict purity. Occasionally, partial purities have been recorded for drainage class and parent material. They can hardly be compared with the level of the partial purities in this study, because of differing definitions and circumstances.

Low values for strict purity have been recorded, especially in recent studies (RAGG and HENDERSON, 1980). In general, in other countries the values of strict purity are higher than the value of approximately 10% found in this study. The comparison of purity percentages from different studies has some restrictions. The level of purities achieved strongly depends on the level of classification for which purity is calculated and on the degree of detail of the individual classification systems.

WILDING et al. (1965) investigated purities for different levels of classification for some mapping units in the United States. The following values were achieved: great soil group, 96%; subgroup, 85%; series, 42%; type, 39%. For some other mapping units scores were: order, 74%; great soil group, 44%; subgroup, 22%; series, 17% (MCCORMACK and WILDING, 1969).

Neither study records values for soil phases. Furthermore, no purities at type level are given in MCCORMACK and WILDING (1969). Obviously, these lowest levels of classification will achieve still lower values for purity. The strict purities in our study concern the lowest level of the classification system. The lowest levels of the classification system for the Netherlands are not systematically and hierarchically divided. For this reason, comparisons with the lowest levels of other classification systems are unsatisfactory. For some aspects, the lowest level of the classification system used in this study resembles the type-level, for other aspects it is comparable with the phase-level of the systems in English-speaking countries.

The lower values for strict purity found in this study might be partly caused by a lower level of classification being used. We believe that these lower values are mainly caused by the more morphometric and narrowly defined criteria of the classification system. This is shown when the criteria for groundwater classes are compared with those for drainage classes. Also, texture classes for sandy soils are defined more narrowly in the Netherlands than in other countries. In other countries the higher values for strict purity might also result from the distinction of intergrades and overlapping classes. These are used less often in the Netherlands.

Many investigators in other countries have collected data on variation of soil properties. Many of these properties are only interesting from a pedological point of view and hardly indicate usefulness of the soil map for particular application. This is especially true of colour criteria such as hue, value, and chroma of spots and horizons. The discussion on variation of soil properties will be restricted to those that are obviously related to the usefulness of maps.

Investigations on variations of soil properties have been summarized by WESTERN (1978) and by BECKETT and WEBSTER (1971). To enable data from different sources to be compared, BECKETT and WEBSTER have used the coefficient of variation (CV)

$$(CV = \frac{\text{standard deviation}}{\text{mean}} \times 100).$$

BECKETT and WEBSTER (1971), distinguished three groups of soil properties on the basis of their CVs:

group I, CV c. 20%: sand content, clay content, total phosphorus;
group II, CV c. 35%: organic-matter content, CEC, total nitrogen;
group III, CV c. 60%: available P, Mg, Ca, K.

They concluded that on series level, CVs within mapping units are only slightly higher than CVs within comparable profile classes (classification units).

In this study, relative variations of soil properties were calculated by expressing the standard deviation within mapping units as a percentage of the standard deviation in the total area (Table 18). So that our results could be compared with those of BECKETT and WEBSTER the coeffecients of variation were calculated for all standard deviations in Table 17. Half of the soil properties in this study appear to have CVs of approximately 20% (group I). The other soil properties achieve CVs ranging from 30% to 40% (group II). Only organic-matter content at 50 cm depth achieves high CVs, with mean values of 70% and 94% for the two groups of soil maps. It should be noted that values of the mean for this property are very low.

BECKETT and BURROUGH (1971) investigated soil variability in Berkshire. They used the relative variance (RV) as a parameter for measuring the extent to which the variability of soil properties within mapping units is less than their variability in the total mapped area

$$(RV = \frac{\text{pooled variance within mapping units}}{\text{total variance}}).$$

Relative variances were calculated for a number of soil properties. To compare our results with those of BECKETT and BURROUGH (1971) RVs of those soil properties that are comparable with the soil properties used in this study were converted into relative variations (relative standard deviations). The following soil properties were involved: clay content, sand content, organic-matter content, depth to carbonate, depth to gravel, depth to mottling and depth to bedrock.

In our study, relative variations of soil properties for soil maps vary between 55% and 80%. In the Berkshire study, relative variations were higher, ranging from 70% to 100%, with most properties achieving values of 90% or more. The relative variations within classification units were equal or only slightly lower than those of the corresponding mapping units. This agrees with BECKETT and WEBSTER (1971). However, for some of the definitive properties, relative variations in classification units at series level were distinctly lower than those of the corresponding mapping units. BECKETT and WEBSTER found relative variations of c. 50% for depth to carbonate, gravel, mottling and bedrock. These values are comparable with the relative variations for rooting depth and moisture supply capacity within classification units in our study. Most of the soil properties used in our study are non-definitive properties. Their relative variations in classification units mainly range between 25% and 50% for both classification systems.

In general, in our study the variability of soil properties within mapping units agrees with BECKETT and WEBSTER (1971) but is less than in Berkshire (BECKETT and BURROUGH, 1971). In our study, the variations of soil properties within classification units (profile classes) are distinctly smaller for both classification systems. We believe this is caused by the more morphometrically and narrowly defined criteria of the classification system for the Netherlands, which results in soil maps with low strict purity, but rather homogeneous classification units.

We quantified the homogeneity of soil maps with respect to the suitability classes of two types of agricultural use with the homogeneity indices. In the literature we found no data on homogeneity with regard to suitability classes. Therefore, the values of the homogeneity indices cannot be compared with studies from elsewhere. But many investigators have emphasized the importance of homogeneity of mapping units with respect to potential land use. In their opinion, an appreciable proportion of impurities in a delineated area can be tolerated if these impurities respond similarly to crop management and to engineering manipulations (WILDING et al., 1965; SOIL SURVEY STAFF, 1975).

High purity of a soil map may result in a high score of the homogeneity index. But this score also depends on the variability of particular soil properties within the taxonomic classes of the classification system. The taxonomic classes of the classification systems applied in this study are not completely homogeneous with respect to the suitability classes for rye and grass. Besides, for the detailed classification the scores for the taxonomic classes are lower. This because the soil pattern is more complex and intricate in area B.

We found little difference between the values of the homogeneity indices for individual soil maps. These indices are considerably lower than the homogeneity indices of the classification system used, which indicate the maximum value for completely pure soil maps. The homogeneity indices of 1 : 10 000 soil maps are higher than those of 1 : 50 000 soil maps. Higher observation density combined with smaller delineated areas results in higher homogeneity indices.

The homogeneity index was calculated from the areal distribution of four suitability classes occurring within mapping units. In addition we used a parameter with a more straightforward interpretation, viz. the percentage of the mapping or classification unit occupied by the most frequently occurring suitability class. This was, on average, roughly 80% for both classification systems, but less for mapping units. For the most important mapping units the following percentages were achieved. For rye the percentage varied between 40% and 75%, depending on map scale and survey method used. For grass the percentage varied between 55% and 80%. The remaining areas of these mapping units are occupied by soil profiles allocated to 2 or 3 other suitability classes. Large parts of proximal soil maps and smaller parts of other soil maps have mapping units that occupy very small areas. Here, areal distributions of the suitability classes cannot be estimated properly. The areas of the mapping units allocated to the most frequently occurring suitability class for the total map can be derived from the homogeneity indices of that map (Tables 15 and 17). On average, 50% of the area of individual mapping units can be allocated to one suitability class with respect to the suitability for rye. The corresponding figure for suitability for grass is higher: 60%. These values for the whole map are lower than those of the important mapping units. Because most delineations of the unimportant mapping units are small, it may be concluded that small delineations are more heterogeneous than large ones.

The soil maps investigated are not very homogeneous in terms of suitability classes. Nevertheless, the areas of 50% and 60% allocated to one suitability class are higher than could be expected from the low values for strict purity. Apart from this, the taxonomic classes of the classification system are not completely homogeneous for suitability classes. From these facts it may be concluded that an important part of the impurities within delineated areas have suitabilities similar to the suitability of the dominant soil profile.

The finding that low purity can be accompanied by reasonable homogeneity regarding suitability is not new. It had already been established in 1965 by WILDING et al., who stated that the presence of a high percentage of mapping-unit inclusions does not necessarily reflect on the quality or reliability of the mapping. Most of the inclusions in their study could be interpreted as having similar suitability to the unit enclosing them. Only a small percentage of the inclusions represented soils that would behave strikingly differently from the dominant soil of the unit. They proposed that the definition of the mapping unit should be modified in such a way that it specifies the dominant member(s) of the mapping unit but does not attempt to specify the percentage either of the dominant member or of soil inclusions (WILDING et al., 1965). Also, the American Soil Taxonomy emphasizes the importance of homogeneity within delineated areas with respect to the responses to management for growing plants. The permitted amount of inclusions in a delineated area depends on how these inclusions respond to crop management and engineering manipulations (SOIL SURVEY STAFF, 1975, pp. 408-409).

8.3 The influence of the individual aspects of the survey method on the quality of the map

Random sampling and purposive sampling achieved approximately equal results for 1 : 50 000 soil maps with proximal delineation, but for 1 : 10 000 soil maps the quality achieved by purposive sampling was superior.

The values of the quality measures of the 1 : 50 000 soil map RaPr are no higher than those of the comparable 1 : 10 000 map (RaPr-10). The advantage of random sampling at scale 1 : 50 000 over scale 1 : 10 000 is relative, because of the poor results achieved by the purposive sampling procedure for maps at scale 1 : 50 000, yet purposive sampling produced relatively high scores at scale 1 : 10 000. The advantage of purposive sampling procedure for 1 : 10 000 proximal soil maps can be explained as follows. Most delineated areas on proximal maps contain only one observation. The delineated areas are classified and named solely after the soil properties of that observation. The average size of the delineated areas at scale of 1 : 10 000 is approximately 1 ha, whereas at scale 1 : 50 000 it is 7 ha. In our study area, the purposive sampling procedure enabled observations to be chosen satisfactorily for areas of about 1 ha. But in our area, areas of 7 ha are large enough to have some important internal variation, so it is not possible to characterize them fully by a single sampling point. As a consequence, it appears that the purposive sampling procedure achieved better results for 1 : 10 000 soil maps.

The superiority of purposive sampling on 1 : 10 000 proximal maps is also enhanced by the difference in the distribution of observation points between both map scales. The purposive sampling procedure generally results in a uniform distribution of observation points over a 1 : 10 000 map. But on a 1 : 50 000 map these points are more clustered, for reasons of efficiency and convenience (costs involved in travelling longer distances; terrain accessibility, etc.).

Whereas the placing of soil boundaries on proximal maps depends on the location of neighbouring observation points (Section 3.2.2), the size and shape of the delineations on 1 : 50 000 proximal maps will show more variation than at a scale of 1 : 10 000. As a result, soil boundaries on the map may deviate considerably from the actual soil boundaries in the field; this reduces map quality.

Random and purposive sampling achieved approximately equal results for 1 : 10 000 maps when soil boundaries had been delineated in the field. But for 1 : 50 000 soil maps random sampling achieves better results. In contrast with proximal soil maps, on maps with field delineation fewer mapping units are distinguished. Also, the delineated areas are larger and are based on more observations. As a consequence, the advantages and disadvantages of both sampling procedures, as mentioned above, become irrelevant if soil boundaries are delineated in the field.

When the sampling procedure is purposive, delineation of soil boundaries in the field is preferable to proximal delineation. This appears from the purities of the 1 : 50 000 soil map, most of which are significantly higher in the map whose boundaries were delineated in the field. For the 1 : 10 000 soil map whose boundaries are delineated in the field, however, only a few purities have a higher score.

Delineation of soil boundaries in the field is also preferable to proximal delineation for both map scales when the random sampling procedure is used.

8.4 The evaluation of the survey methods

8.4.1 Evaluating the survey methods using the quality measures only

The survey methods were judged by pairwise comparison of the quality values of the soil maps made by these methods. The methods were ranked according to the number of significantly better quality values they produced. Often, the differences between the values of the quality measures were relatively small.

The survey method with purposive sampling and proximal delineation (PuPr) ranks last when soils are mapped at a scale of 1 : 50 000. The differences between the other three survey methods are relatively small. The survey method with random sampling and field delineation (RaFi-50,d) was the best, closely followed by the method with purposive observations and field delineation (PuFi-50), which in turn was significantly better than the survey method with purposive sampling and proximal delineation (PuPr-50).

The order in which the survey methods are ranked is different when soils are mapped at scale 1 : 10 000. Now, both survey methods with delineation of soil boundaries in the field (PuFi-10 and RaFi-10,d) rank equal first. The survey method with purposive sampling and proximal delineation (PuPr) produces a soil map with lower quality. However, this survey method is slightly better than the random sampling procedure combined with proximal delineation (RaPr-10).

Although the low score of the latter survey method (RaPr) when soils are mapped at a scale of 1 : 10 000 seems to be remarkable, given the high rank of this survey method when soils are mapped at a scale of 1 : 50 000, it must be remembered that soil maps at different scales but produced by the same survey method are not comparable. As mentioned earlier (Sections 7.3.4 and 8.4), observation density, size of the delineated areas, and clustering of observation points are different for both map scales and have different effects on the quality of soil maps produced by some of the survey methods investigated.

8.4.2 *Evaluating the survey methods using quality measures and readability criteria*

When readability criteria are also used for evaluating the survey methods, the order in which survey methods are ranked does not change but the disadvantages of survey methods with proximal delineation increase. The proximal delineation is a mathematical method for which the position of the soil boundaries is computed solely on the basis of the data from the observation points. This results in a soil map with a large number of mapping units and a large number of very small delineated areas. The small size of the delineations is a problem at that map scale, and space for codes is often inadequate.

The readability of soil maps is important for traditional map users. For computerized data-processing, map readability itself is not important. But large numbers of mapping units and delineated areas can give rise to excessive computer costs, or they can make generalization of the original map inevitable.

The order in which the survey methods are ranked does not change when readability is taken into account. If only the quality measures are considered, survey methods with field delineation (RaFi, PuFi) score highest for both map scales. When readability is also taken into account, this preference is enhanced.

The RaFi method and the PuFi method are ranked equally for mapping at scale 1 : 10 000. For mapping at scale 1 : 50 000 the RaFi method is slightly superior. But the survey costs of random sampling (Ra) and purposive sampling (Pu) differ. Purposive sampling implies that the location of the observation points is also decided by travel time, accessibility of terrain, ease of location on the map, etc. As a consequence, much more time is spent on random sampling than on purposive sampling. In this study, we did not make exact time calculations, but our rough estimates of the time needed for random sampling are 30% additional time for mapping at scale 1 : 10 000 and 40% for mapping at scale 1 : 50 000. This implies that when survey costs are taken into account and observations are used solely for mapping, the purposive sampling procedure (PuFi) should be preferred for both map scales. However, when survey observations are also used for calculating statistical estimates of soil properties, the random sampling procedure has to be preferred, in spite of higher survey costs.

A stratified random sampling procedure was used in this study. Other procedures are feasible, e.g. observations at fixed distances (fixed grid) or random transects. These too are time-consuming, but not as much as the random sampling procedure used. When judging the effect of a particular sampling procedure on map quality, any increase in survey costs must be incorporated.

8.5 Some effects of spatial variability on the quality of the soil map

The survey methods investigated in this study differ considerably. But these differences are weakly expressed in the quality values of the soil maps made by these methods. Also, the variations of the soil properties within the mapping units of the 1 : 10 000 soil maps are not much less than those of the 1 : 50 000 soil maps, in spite of the more detailed mapping and the higher observation density. The purities of 1 : 10 000 soil maps are probably little higher than those of the 1 : 50 000 maps. This may be concluded from comparing the purities for groundwater classes, which have equal class limits for both classification systems used. These results suggest that large proportions of the total variation in the project area consist of short-range variations.

It may be questioned whether short-range spatial variations have much importance for the daily practice of land use. For most soil properties, the average soil condition within fields determines particular land use. The variation of soil properties within fields often has less impact on actual land use. It could be argued that these variations should be excluded from the calculations to quantify the quality of soil maps. The quality measure used in this and other studies applies to all variations of individual soil profiles, irrespective of the distances between them. Most of the short-range variations will be ignored if calculations are based on average values of soil properties within fields. Had this been done in our study, soil maps would have achieved a higher quality and the results of the comparisons between the survey methods would probably change. Future studies should be aimed at developing more realistic quality measures.

Research on spatial variability was also one of the aims of this study, but unforeseen circumstances prevented it. Recently, however, data on moisture supply capacity from this study were used to compare the accuracy of different methods of spatial interpolation (VAN KUILENBURG et al., 1982) and it was concluded that well over 50% of the total variation of moisture supply capacity consists of very short-range variations. KNEIB (1979) and BURROUGH (1981) have also shown that short-range variations may be very important. For some soil properties they found that most of the total variation occurs within a few metres.

As stated already an important part of the total variation within the project area probably consists of short-range variation. This restricts the possibilities of increasing the precision and accuracy of soil maps at scales 1 : 10 000 and 1 : 50 000 in cover-sand areas. Also, increasing the observation density or map scale will have little effect on the quality of the map.

Results on spatial variability must be judged carefully if derived from data with substantial level of random observation error, because in that case, the total variation and the ratio between short-range variation and total variation will be greatly overestimated.

Some authors (NORTCLIFF, 1978; BURROUGH, 1983) emphasize that soil surveys should be preceded by investigations on spatial variability of soil properties. More rational decisions could then be made on map scale, observation density, and map legend.

Usually, the choices of map scale, observation density, and map legend follow the common survey practice. Decisions on these aspects are rarely based on the soil conditions within the area to be surveyed. Previous knowledge of spatial variability within a particular area might support the decisions. But further research is needed to indicate how the decisions on map scale, observation density, and profile classes can be supported reliably by data on the spatial variability.

Studies on spatial variability of soil properties seem to be useful, but so far their application to soil survey has been prevented by the fact that these studies are relatively time-consuming. Probably, data on spatial variability are most useful for large-scale maps and maps with very specific purposes. For systematic surveys with a fixed map legend, such as the 1 : 50 000 Soil Map of the Netherlands their usefulness is restricted. Data on spatial variability may give rise to differentiation in survey procedure and map legend for different areas. However, this would greatly reduce the comparability of the soil information conveyed by such maps.

8.6 Ways of improving the quality of soil maps

The survey method does have an effect on the quality of the resulting soil map, but this effect is much smaller than could be expected from the large differences between the methods. Also, the accuracy and precision of 1 : 10 000 soil maps are not much higher than those achieved for 1 : 50 000 soil maps. This indicates that the possibilities of improving the quality of the soil maps are limited. Higher purities will be achieved by broadening the profile classes of the classification system. But, as a consequence, the variation of soil properties will increase and the homogeneity with respect to suitability classes may decrease. Also, higher observation density and larger map scale contribute little to the quality of a soil map if many soil properties vary greatly over short distances. Certainly, the quality of soil maps will improve if better procedures for estimating and measuring important soil properties are introduced. In particular, the groundwater classes could be mapped more accurately if the measuring of watertables in characteristic periods were more widespread and more frequent.

More attention should be paid to the accuracy of field estimates. This could be combined with automatic correction of the estimated values for systematic observation errors. Many soil surveys could be improved in this way.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Primary conclusions

Purities

1. The average purity ranged from 64-70% for 1 : 50 000 soil maps and between 59-62% for 1 : 10 000 soil maps. Values for strict purities were calculated for the lowest level of the Dutch classification system. They are very low, ranging from 7-12%.

   Five partial purities were applied. All criteria of the Dutch classification system were subdivided into five subsets, each yielding a partial purity. Purity for sand classes achieved the highest score with 100% for 1 : 50 000 soil maps and about 80% for 1 : 10 000 soil maps. The lowest values (34%-46%) were achieved for the purity of groundwater classes. Soil maps at a scale of 1 : 10 000 achieved slightly higher values than those of comparable 1 : 50 000 maps.
2. Neither the accuracy nor the usefulness of soil maps is satisfactorily characterized by the traditional strict purity. Deviations from the class definitions are weighted equally, regardless of their type or extent. Also, soil profiles that deviate in one criterion only have the same effect on the value of purity as those that deviate in all criteria.
3. Average purity takes into account both the deviations and all the good scores with respect to the classification criteria. Therefore, average purity is more useful than strict purity for indicating the accuracy of soil maps. The concept of purity, traditionally used in the reports published by the Netherlands Soil Survey Institute generally resembles the average purity as defined in this study.

Variations of soil properties

4. In this study, standard deviations of soil properties were calculated from calibrated field data. This calibration will have largely removed systematic observation error. Random observation error remained, however, and is included in the standard deviations presented here. The calibration data showed that this extra source of variation is substantial, but the available data were not sufficient to enable this effect to be properly quantified.
5. Obviously, the variation within mapping units for any soil property (expressed as standard deviation) will be smaller than the total variation in the area surveyed, but it will usually be larger than the variation within classification units.

   In the project area, for nearly all soil properties the variation within classification units ranges between 25% and 50% of the variation in the area. As a consequence of impurities, the variation within mapping units is considerably higher: for most properties it ranges between 65% and 80% of the total variation in the area.
6. The variations within mapping units found in this study are similar to the variations found in studies in other countries. In some cases we achieved lower variations within mapping units. In general, the variations within classification units in our study are considerably lower. Contrary to studies in other countries, the variations found within classification units in this study are considerably lower than the variations within the corresponding mapping units.
7. In this study, the variations within classification units are low, as are the strict purities of soil maps; this is because the classes in the classification system for the Netherlands are narrower than those of other classification systems. The criteria used for the Dutch classification system are often more morphometrically defined, and overlapping classes are less frequent.

8. We found considerable differences with respect to variations and mean values of certain soil properties (both definitive and non-definitive) between individual mapping units. When individual mapping units were compared, distinct differences were found for some soil properties, whereas others were very similar. Paired comparisons of mapping units resulted in different sets of strongly differentiating properties, depending on what kind of mapping units were compared.

Homogeneity with respect to potential land use

9. Neither classification used in this study is completely homogeneous with respect to the suitability classes for rye and grass. For the general classification the homogeneity index for rye was calculated to be 52% and that for grass 61%. The corresponding values for the detailed classification are 45% and 55%. About 80% of the soil profiles within the classification units will be allocated to the same suitability class when homogeneity indices score about 50%.

   The project area has very low homogeneity for rye. The index scores 4% for area A and 1% for area B. The corresponding indices for grass are 19% and 16%.

   The value of the homogeneity index for the classification is, in practice, an upper limit to the homogeneity index of a soil map, made with this classification. But the homogeneity indices for the soil maps investigated were actually far below this maximum. Expressed as a percentage of the value of the index for the classification system used, the homogeneity indices of the 1 : 50 000 soil maps range between 23% and 34% for rye and between 39% and 48% for grass. The indices for 1 : 10 000 soil maps were between 36% and 46% for rye and between 58% and 65% for grass.

10. The homogeneity indices were calculated from the areal distribution of four suitability classes. The homogeneity of soil maps can also be expressed by the areal percentage of the most frequently occurring suitability class within a mapping unit.

    Values for the total map may be calculated as a weighted average of these percentages over the mapping units on that map. For 1 : 50 000 soil maps this gives a figure of about 45% for rye and 60% for grass.

    For 1 : 10 000 soil maps the corresponding values are about 55% and 65%. The remaining areas were allocated to two or three other suitability classes.

11. Impurities negatively affect the homogeneity with respect to suitability classes. But about 50% of the impurities in this study have potential land use similar to that of the soil profiles after which the delineated area is named, and therefore these soil profiles could be allocated to the same suitability class.

Survey methods

12. *Evaluation of the survey methods based solely on the values of the quality measures*
    The 1 : 50 000 soil maps made by the random/field (RaFi) and purposive/field (PuFi) methods are very similar in quality, and rank above maps made by the random/proximal (RaPr) and purposive/proximal methods (PuPr). The soil map made by the random/field method (RaFi-50,d) is definitely superior to soil map RaPr-50,d. The poorest quality soil maps are those made by the purposive/proximal method or the random/proximal method at lower observation density.

    When soils are mapped at a scale of 1 : 10 000, the quality of the maps with field delineation (PuFi-10 and RaFi-10,d) is again the best. But for this map scale the soil map made by the random/proximal method (RaPr) has the lowest quality.

13. *Evaluation of survey methods based both on quality measures and readability criteria*
    When readability criteria are incorporated into the evaluation of the survey method, the order in which the survey methods are ranked does not change, but the value of survey

methods with proximal delineation decreases, because of the poor readability of the proximal maps. As a consequence, the differences in evaluation increase in favour of the survey methods with field delineation.

14. Soil maps with proximal delineation of soil boundaries, as used in this study, have poor readability. They are not suitable for the purposes of the traditional map-user, because of the large number of mapping units and very small size of many of the delineated areas.
15. The results of this study do not support the contention that the free survey method (purposive/field method) should be replaced by one of the other survey methods investigated. This conclusion applies only to cover-sand areas and the map scales investigated, and no considerations other than map quality and survey costs are taken into account.

    Field delineation is preferable to proximal delineation because of the better quality and readability of the resulting map.

    Changing the sampling procedure from purposive to random will improve the quality of the soil map when soils are mapped at a scale of 1 : 50 000. But this advantage does not outweigh the higher survey costs of the random sampling procedure and therefore the purposive sampling procedure is preferable in spite of the slightly poorer quality of the final map. The superiority of the purposive sampling procedure is evident when soils are mapped at a scale of 1 : 10 000, because both sampling procedures (RaFi and PuFi) produce soil maps of equal quality.

    The attractiveness of the random sampling procedure lies in the opportunities it gives for statistical analysis of soil data.

9.2 Secondary conclusions

1. At both map scales, the quality of proximal soil maps improves slightly when the number of random observations is increased. But the number of delineated areas increases proportionally and the readability of the soil maps decreases, because the size of the delineated areas decreases.
2. The readability of proximal soil maps strongly increases when these maps are generalized, because the size of the delineated areas increases. But the generalized map mainly consists of complex mapping units, whereas their number hardly decreases. This reduces the readability.
3. Purities increase when the detailed classification used for soil map RaFi-10,d is translated into the general classification. But in this case the translation has no effect on the boundaries of the delineated areas. The number of delineated areas remains the same, whereas the number of mapping units hardly decreases. As a consequence, similar values are achieved for the standard deviations of the soil properties and the homogeneity indices.
4. The map pattern and map quality change when the map scale of soil map RaFi-10,d is decreased from 1 : 10 000 to 1 : 50 000 and the delineated areas are adapted to the smaller map scale. Both the number of mapping units and the number of delineated areas decrease strongly, whereas the average size of the delineated areas strongly increases. The precision of the map distinctly worsens compared with the original map. This is indicated by the lower values of the homogeneity indices and the higher values for the standard deviations of soil properties. Decreasing the map scale combined with changes of the delineated areas has less effect on the accuracy of the map: this appears from the slightly lower values for purity.

9.3 Recommendations

1. For the present, the free survey method has to be maintained for mapping cover-sand areas at scales of 1 : 10 000 and 1 : 50 000.
2. Our knowledge about possibilities and restrictions of the current survey method needs to be extended by:
   – collecting data on the accuracy and precision of soil maps for regions with other parent materials. Particular attention should be paid to soil maps at scales of 1 : 25 000 and larger;
   – collecting data on the sources of errors of the free survey method, including suitability maps derived from these maps.
3. The following measures should be taken to improve the procedure of the free survey method:
   – the measuring of water-tables in characteristic periods has to be intensified and executed more frequently to achieve higher precision for the groundwater classes mapped;
   – field estimates should be systematically calibrated with laboratory analyses, to increase the accuracy of estimated values. The systematic errors of estimation made by individual surveyors should be identified and used for the automatic correction of the field estimates.
4. Further investigations for improving survey methods are needed and should be focussed on the following aspects:
   – developing techniques of interpolating point data (VAN KUILENBURG et al., 1982), using more advanced techniques than the proximal method used in this study. Investigations on interpolation techniques should also involve information on relevant landscape features;
   – ascertaining the relation between observation density and accuracy for different types of soil surveys, so that rational decisions on observation density can be made;
   – studying spatial variability of important soil properties in different areas to analyse how survey procedures could be made more efficient for specific commissioned surveys;
   – designing quality measures that are closely related to particular map uses;
   – developing operational procedures that can be embodied in everyday survey practice to measure the accuracy and precision of soil maps. Special attention should then be paid to the observation error in the test data.

SUMMARY

The conclusions of this study are valid for the project area. No research was done to ascertain the applicability of the results to comparable cover-sand areas.

In this summary only general information on the study and its results can be given. For complete information the reader is referred to the discussion in Chapter 8 and the conclusions and recommendations in Chapter 9.

The accuracy and precision of soil maps made by different survey methods were established and compared. Four survey methods were used. They differed in the sampling procedure for obtaining observation points and the method of delineating soil boundaries. Random sampling and purposive sampling were combined with proximal and field delineation, resulting in four survey methods.

Soil maps at a scale of 1 : 50 000 with a general classification were made for a cover-sand area of 1600 ha. In the same project area soil maps at a scale of 1 : 10 000 with a detailed classification were made for an area of 400 ha.

The quality of the soil maps was tested with the profile descriptions of a stratified random sample of observation points. After these test observations had been corrected for systematic estimation errors made by the surveyor, they were used to calculate 25 quality measures. A distinction had to be made between two main aspects of the quality of the maps: the accuracy and the precision. The accuracy of the soil maps was assessed using seven purity measures. The precision was established by the standard deviations for 16 quantitative soil properties and the homogeneity indices for suitability classes for rye and for grass.

The evaluation of the survey methods was not solely based on the values of the quality measures. Soil maps made with the proximal method of delineating boundaries appear to have a very complex map pattern, which causes the readability of the map to be poor. Where the readability of the soil maps differed strongly, some readability criteria were also used to evaluate the survey methods.

From the results of this study it may be assumed that large proportions of the total variation of some of the soil properties in the project area consist of short-range variations. This may be one of the reasons why the differences in quality between the soil maps made by different survey methods are relatively small.

This study does not support the proposition that the free survey method should be replaced by one of the other survey methods investigated in this study. The random sampling procedure produced soil maps of equal quality to that produced by purposive sampling, when mapping at a scale of 1 : 10 000. The quality of the 1 : 50 000 soil map was slightly superior when a random sampling procedure is used. But even then purposive sampling is preferable because the slightly better quality does not make up for the higher survey costs of the random sampling procedure.

Field delineation of soil boundaries produces soil maps with better quality for both map scales. These maps are also preferred because of the better readability as compared with soil maps with proximal delineation.

Average purities range between 64% and 70% for soil maps on a scale of 1 : 50 000. Soil maps at a scale of 1 : 10 000 have average purities between 59% and 62%.

Five partial purities were distinguished, each defining a subset of all criteria of the classification system used. Their values depend on the individual subset of criteria and the survey method applied. The extreme values are 34% and 100% for soil maps at a scale of 1 : 50 000. For soil maps at a scale of 1 : 10 000 these values are 43% and 84%.

Values for strict purity are all very low, varying between 7% and 12%.

The relative standard deviations within the classification units for soil properties predominantly vary between 25% and 50% of the total variation in the area. The relative standard deviations within mapping units vary between 65% and 80% for most soil properties. Soil maps at a scale of 1 : 10 000 have lower relative standard deviations for some soil properties. (Between 55% and 70%.)

The classifications applied appear not to be completely homo geneous with respect to suitability classes. On average, 80% of the soil profiles of individual classification units could be allocated to one suitability class. Homogeneity of the soil maps with respect to suitability classes is considerably lower. On average, the percentage of the area of individual mapping units of the 1 : 50 000 soil maps occupied by the most frequently occurring suitability class is 45% for rye and 60% for grass. For 1 : 10 000 soil maps the corresponding figures are 55% and 65%. The remaining area was usually allocated to two or three other suitability classes.

The values for strict purity in this study are lower than those obtained in studies done in other countries. But a large proportion of the impurities of mapping units had potential land use similar to those soil profiles after which the delineated area had been named and could be allocated to the same suitability class. This is one of the reasons why the traditional purity measures are considered to be inefficient criteria for characterizing the quality of soil maps.

Some of the relative variations within mapping units agree with those mentioned in studies from other countries, but others are lower. But generally, the variation within classification units of our study are considerably lower. Relatively low strict purities of soil maps combined with relatively small variations within classification units in this study are a consequence of the classes in the classification system of the Netherlands being more narrowly defined than in other classification systems.

Some of our conclusions only relate to a specific map or aspect of a survey method, viz. effects of generalization, higher density of random observations and readability of proximal maps. The effects on quality and readability of translating a detailed classification into a general classification and decreasing the map scale from 1 : 10 000 to 1 : 50 000 are established for one of the soil maps with field delineation.

Recommendations are made for further investigations on the possibilities and restrictions of the free survey method. Some measures to improve this survey method are suggested.

REFERENCES

AMOS, D.F. & E.P. WHITESIDE, 1975. Mapping accuracy of a contemporary soil survey in an urbanizing area. Soil Sci. Soc. Am. 39, 5: 937-942.

AVERY, B.W., 1980. Soil Classification for England and Wales. Higher categories. Technical Monograph No. 14, Harpenden. Bartholomew Press, Dorking.

BAKKER, H. DE, 1970. Purposes of soil classification. Geoderma 4, 3: 195-208.

BAKKER, H. DE, 1979. Major soils and soil regions in the Netherlands. Junk, The Hague/Pudoc, Wageningen. 203 pp.

BAKKER, H. DE & J. SCHELLING, 1966. Systeem van bodemclassificatie voor Nederland; de hogere niveaus. Pudoc, Wageningen. 217 pp.

BAKKER, H. DE, W. HEIJINK & G.G.L. STEUR (eds.), 1984. Sample areas from the Soil Map of the Netherlands 1 : 50 000. Netherlands Soil Survey Institute, Wageningen.

BECKETT, P.H.T., 1971. The cost-effectiveness of soil survey. Outlook on Agric. 6, 5: 191-198.

BECKETT, P.H.T. & P.A. BURROUGH, 1971. The relation between cost and utility in soil survey. IV: Comparison of the utilities of soil maps produced by different survey procedures, and to different scales. J. Soil Sci. 22, 4: 466-480.

BECKETT, P.H.T. & R. WEBSTER, 1971. Soil variability: A review. Soils and Fertiliz. 34, 1: 1-15.

BIE, S.W., 1972. The relative efficacy of different procedures for soil survey in developing countries and elsewhere. Oxford University.

BIE, S.W. & P.H.T. BECKETT, 1970. The costs of soil survey. Soils and Fertiliz. 33, 3: 203-217.

BIE, S.W. & P.H.T. BECKETT, 1971. Quality control in soil survey. I: The choice of mapping unit. J. Soil Sci. 22, 1: 32-49.

BUROUGH, P.A., 1981. The spatial variability of the soil of the trialfield PAGV1. Rapport nr. 1607. Stiboka, Wageningen. 31 pp.

BUROUGH, P.A., 1983. Multiscale sources of spatial variation in soil. II: A non-Brownian fractal model and its application in soil survey. J. Soil Sci. 34, 3: 599-620.

COCHRAN, W.G., 1977. Sampling techniques. Wiley, New York.

DOMHOF, J., 1953. Strooiselwinning voor potstallen in verband met de profielbouw van heide- en oude bouwlandgronden. (With summary: Procurement of litter for built-up heath-sod litter manure in connection with the profile of heath-soils and old arable land.) Boor en Spade 6: 192-203.

FAO, 1974. FAO-Unesco Soil Map of the World, 1 : 5 000 000, Volume I, Legend. Unesco, Paris.

GREEN, P.J. & R. SIBSON, 1978. Computing Dirichlet tessellations in the plane. Computer J. 21, 2: 168-173.

GROOT OBBINK, D.J. et al., 1976. Ruilverkaveling Laren (Gld.); de bodemgesteldheid. Rapport nr. 1208. Stiboka, Wageningen.

HAANS, J.C.F.M. (ed.), 1979. De interpretatie van bodemkaarten; rapport van de Werkgroep Interpretatie Bodemkaarten, Stadium C. Rapport nr. 1463. Stiboka, Wageningen. 221 pp.

HAANS, J.C.F.M. & K.R. VAN LYNDEN, 1978. Assessment factors as an aid for interpreting soil surveys. In: Abstracts for papers presented at Commission Sessions. 11th Intern. Congr. of Soil Sci., Edmonton.

HEESEN, H.C. VAN, 1970. Presentation of the seasonal fluctuation of the watertable on soil maps. Geoderma 4, 3: 257-278.

JOHNSON, N.L. & S. KOTZ, 1969. Discrete distributions. Houghton Mifflin, Boston.

KNEIB, W., 1979. Untersuchungen zur Gruppierung von Böden als Grundlage für die Bodenkartierung. Christian-Albrechts-Universität, Kiel.

KUILENBURG, J.J. VAN et al., 1982. Accuracy of spatial interpolation between point data on soil moisture supply capacity, compared with estimates from mapping units. Geoderma 27, 4: 311-325.

LAAT, P.J.M. DE, 1980. Model for unsaturated flow above a shallow water-table, applied to a regional sub-surface flow problem. Pudoc, Wageningen.

MCCORMACK, D.E. & L.P. WILDING, 1969. Variation of soil properties within mapping units of soils with contrasting substrata in N.W. Ohio. Proc. Soil Sci. Soc. Am. 33, 4: 587-593.

NORTCLIFF, S., 1978. Soil variability and reconnaissance soil mapping: A statistical study in Norfolk. J. Soil Sci. 29, 3: 401-418.

PATIL, G.P. & C. TAILLIE, 1982. Diversity as a concept and its measurement. Journal of the American Statistical Association 77: 548-567.

RAGG, J.M. & R. HENDERSON, 1980. A reappraisal of soil mapping in an area of southern Scotland. I: The reliability of four soil mapping units and the morphological variability of their taxa. II: The usefulness of some morphological properties and of a discriminant analysis in distinguishing between the dominant taxa of four mapping units. J. Soil Sci. 31, 3: 559-580.

RIJTEMA, P.E., 1971. Een berekeningsmethode voor de benadering van de landbouwschade ten gevolge van grondwateronttrekking. Nota no. 587. ICW, Wageningen.

SIBSON, R. & P.J. GREEN, 1976. User's guide Fortran Tile 003. School of Mathematics, University of Bath.

SOIL SURVEY STAFF, 1975. Soil taxonomy; a basic system of soil classification for making and interpreting soil surveys. Agriculture Handbook No. 436. Dept. Agriculture, Washington, D.C.

STEUR, G.G.L. et al., 1961. Methods of soil surveying in use at the Netherlands Soil Survey Institute. Boor en Spade 11: 59-77.

STICHTING VOOR BODEMKARTERING, 1979. Bodemkaart van Nederland, schaal 1 : 50 000. Toelichting bij de kaartbladen 34 West Enschede en 34 Oost Enschede - 35 Glanerbrug. Wageningen, 166 pp.

VOORT, W.J.M. VAN DER, 1981. De bodemkundige variatie binnen twee enkelvoudige legenda-eenheden (Rn44C en Rd90A) op de bodemkaart van Nederland, schaal 1 : 50 000. Boor en Spade 20: 206-224.

WEBSTER, R., 1977. Soil survey: its quality and effectiveness. In: Soil Resource inventories. Proceedings of a workshop held at Cornell University; Agronomy Mimeo No. 77-23, Ithaca, New York.

WEBSTER, R. & H.E. CUANALO DE LA C., 1975. Soil transect correlograms of North Oxfordshire and their interpretation. J. Soil Sci. 26, 2: 176-194.

WESTERN, S., 1978. Soil survey contracts and quality control. Monographs on soil survey. Clarendon, Oxford.

WILDING, L.P., R.B. JONES & G.M. SCHAFER, 1965. Variation of soil morphological properties within Miami, Celina and Crosby mapping units in West-Central Ohio. Proc. Soil Sci. Soc. Am. 29, 6: 711-717.

GLOSSARY

1 Average purity
Arithmetic mean of all partial purities (7) considered in a given context (Section 6.2.4).

2 Classification system
System of classes of soil profiles (profile classes) to which each soil profile of the population of soil profiles might be allocated. In this study in particular: system used for making soil maps.

3 Classification unit
A class of soil profiles defined in terms of soil properties. In this study in particular: a profile class whose geographic distribution a soil map intends to indicate (Section 3.3).

4 Delineation

a. Coherent part of a map, which has only one cartographic signature (i.e. combination of colour, shading and/or code), and which adjoins no other part of that map with the same signature.

b. Set of all soil profiles in a part of the terrain that corresponds geographically with a delineation (4a) on a map.

5 Homogeneity index

a. For area, mapping unit or classification unit:
A measure indicating the homogeneity of an area, mapping unit (6) or classification unit (3) with respect to a given system of classes. In this study it is defined as the sum of the squared differences between the actual relative frequencies of the four suitability classes and the frequencies they would have under equal distribution. Numerical values are expressed as percentages of the maximum value 0.75 (Section 6.2.6).

b. For maps:
Mean value of the homogeneity index of all mapping units (6) of a soil map weighted by their relative areas (Section 6.2.6).

c. For the classification system:
Average value of the homogeneity index for all the classification units (3) of a classification system weighted by their relative frequencies.

6 Mapping unit
The union of all delineations (4a and b) of a map that have been given the same cartographic signature. The legend of a map relates each mapping unit to one or more classification units (3), so that the properties of all soil profiles in a mapping unit are predicted to satisfy the definition criteria of the related classification unit(s).

7 Partial purity
Proportion (expressed as a percentage) of the area of a map or part thereof in which a subset of the classification criteria shown is satisfied by the properties of the soil profiles in the field.

8 Proximal delineation
A method of constructing delineations (4) in such a way that each point in a survey area is allocated to the same mapping unit (6) as its nearest survey observation point (Section 3.2.2). In this study also: the result of a proximal delineation.

9 Purposive sample
Sample drawn by a procedure with the purpose of obtaining a certain type of information, but with unknown probabilities of selecting the samples which could be drawn by the procedure (Section 3.2.1).

10 Simple random sample
Sample drawn in such a way that all sample of the same size have equal probability of selection (Section 3.2.1).

11 Standard deviation

a. For area, mapping unit or classification unit:
Square root of the variance (14) of a soil property in an area, mapping unit (6) or classification unit (3) respectively (Section 6.2.5).

b. For a map:
Square root from the mean of the variances (14) of all mapping units (6) of a map, weighted with their relative areas.

c. For the classification system:
Square root from the mean of the variances (14) of those classification units (3) of a classification system (1) used on the map, weighted with their relative frequencies (Section 6.2.5).

12 Stratified random sample
Union of simple random samples (10) each drawn from one of the strata into which a population (here: area) is subdivided (Section 3.2.1).

13 Strict purity
Proportion or percentage of the area of a map or part thereof where the soil profiles exactly meet all classification criteria of the classification system (2) as defined in the map legend. In this study the strict purity may also be interpreted as the proportion of soil profiles that meet all the relevant criteria (Section 6.2.3).

14 Variance
Mean squared difference between the individual values of a property and their mean.

SYMBOLS AND ABBREVIATIONS

Statistical symbols

Symbol	*Section*	*Description*
A	6.2.5	True value of the relative area of a mapping unit or relative frequency of a classification unit
a	6.3.2	Estimated value of the relative area of a mapping unit or relative frequency of a classification unit
a	6.2.4	Subscript for purities indicating the average purity
c	6.2.6	Subscript for suitability classes
E	6.3.4	Statistical expectation value
F	6.2.6	True value of the relative frequency of a suitability class
f	6.3.4	Estimated value of the relative frequency of a suitability class
H	6.2.6	True value of a homogeneity index
h	6.3.4	Estimated value of a homogeneity index
h	6.3.2	Subscript for strata of a stratified random sample
i	6.2.2	Subscript for soil profiles
j	6.2.2	Subscript for subsets of classification criteria
k	6.2.2	Subscript for soil maps
L	6.3.2	Number of strata of a stratified random sample
M	6.2.5	Number of mapping units of a soil map or number of classification units of a classification system
m	6.3.3	Number of mapping units or number of classification units with two or more test observations
N	6.2.2	Number of profiles in an area, or mapping unit or classification unit
n	6.3.2	Number of test observations in an area, or mapping unit or classification
p	6.2.2	Purity value of a soil profile
$\bar{P}$	6.2.2	True value of a purity of a map or mapping unit
$\bar{p}$	6.3.2	Estimated value of a purity of a map or mapping unit
S	6.2.5	True value of a standard deviation
s	6.3.2	Estimated value of a standard deviation
s	6.2.3	Subscript for purities indicating the strict purity
t	6.2.5	Subscript of standard deviations and homogeneity indices for the total area
u	6.2.5	Subscript of mapping units
W	6.3.2	Weight of a stratum
w	6.2.5	Subscript of standard deviations or homogeneity indices for the mapping units of a soil map or the classification units of a classification system
x	6.2.5	Value of a property of a soil profile
$\bar{X}$	6.2.5	True mean value of a soil property for an area, or mapping unit or classification unit
$\bar{x}$	6.3.3	Estimated mean value of a soil property
$\overline{x^2}$	6.3.3	Estimated mean squared value of a soil property

Observation series for the compilation of the soil maps (survey observations)

A1 Series of 356 observations obtained from a purposive sampling procedure and used for compilation of the soil maps PuFi-50 and PuPr-50

A2 Series of 253 observations resulting from a stratified random sampling procedure and used for compilation of the soil maps RaFi-50,d, RaPr-50,d, RaPr-50 and RaPr-50,g

A3 Series of 256 observations resulting from a stratified random sampling procedure. From this series 96 observations were used for the compilations of soil maps RaPr-50 and RaPr-50,g, to achieve higher observation density

B1 Series of 446 observations obtained from a purposive sampling procedure and used for the compilation of soil maps PuFi-10 and PuPr-10

B2 Series of 548 observations resulting from a stratified random sampling procedure. From this series 530 observations were used for the compilation of the soil map RaFi-10,d and RaPr-10,d. For the compilation of the soil maps RaPr-10 and RaPr-10,g 437 observations were used

Observation series for the testing of the soil maps (test series)

$A2^c$ Series of 253 observations resulting from a stratified random sample. Profile descriptions were corrected for systematic estimation errors of the surveyor. The complete series was used for the testing of the soil maps PuFi-50 and PuPr-50 and partly used for the testing of soil maps PuFi-10, RaFi-10,d, RaPr-10,d, RaPr-10, RaPr-10,g and PuPr-10

$A3^c$ Series of 256 observations resulting from a stratified random sample. Profile descriptions were corrected for systematic estimation errors of the surveyor. The complete series was used for the testing of soil maps PuFi-50, RaFi-50,d, RaPr-50,d and PuPr-50. The series was partly used for the testing of soil maps RaPr-50, RaPr-50,g, PuFi-10, RaFi-10,d, RaPr-10,d, RaPr-10, RaPr-10,g and PuPr-10

$B2^c$ Series of 542 observations resulting from a stratified random sample. Profile descriptions were corrected for systematic estimation errors of the surveyor. The complete series was used for the testing of the soil maps PuFi-10 and PuPr-10 and for testing the central part of the soil maps RaPr-50,d, RaPr-50, RaPr-50,g and PuPr-50. The series was partly used for testing soil maps RaPr-10 and RaPr-10,g

$B3^c$ Series of 552 observations resulting from a stratified random sample. Profile descriptions were corrected for systematic estimation errors of the surveyor. The complete series was used for testing of the soil maps PuFi-10, RaFi-10,d, RaPr-10,d, RaPr-10, RaPr-10,g and PuPr-10, and for testing the central part of the soil maps RaPr-50,d, RaPr-50, RaPr-50,g and PuPr-50

Coding of the soil maps

PuFi- Soil map produced by a purposive sampling procedure of the observation points and delineation of soil boundaries in the field

RaFi- Soil map produced by a stratified random sampling procedure of the observation points and delineation of soil boundaries in the field

RaPr- Soil map produced by a stratified random sampling procedure of the observation points and proximal delineation of the soil boundaries

PuPr- Soil map produced by a purposive sampling procedure of the observation points and proximal delineation of the soil boundaries

Pu.- Purposive sampling procedure

Ra.- Stratified random sampling procedure

.Fi- Delineation of soil boundaries in the field

.Pr- Proximal delineation of soil boundaries

.. – 10 Soil maps of area B at a scale of 1 : 10 000 with a detailed classification

.. – 50	Soil maps of area A at a scale of 1 : 50 000 with a general classification
.. – .,g	Generalized soil map
.. – .,d	Soil maps with deviating observation density. For 1 : 50 000 soil maps the density was lower, whereas for 1 : 10 000 soil maps it was higher

Surveyed areas

A	Area of 1600 ha mapped at a scale of 1 : 50 000 with a general classification
B	Area of 400 ha situated within area A and mapped at a scale of 1 : 10 000 with a detailed classification

Abbreviations

MHW	Mean highest water-table
MLW	Mean lowest water-table
V	Mean spring water-table

SERIES SOIL SURVEY PAPERS

No. 1. *Jongerius, A* and *G. Heintzberger:* The preparation of mammoth-sized thin sections. 1963 — out of print

No. 2. *Jager, A.* and *W.J.M. van der Voort:* Collection and preservation of soil monoliths from sandy soils and ripened clay soils above and below the water table. 1966 — out of print

No. 3. *Broek, J.M.M. van den* and *L. van der Waals:* The Late Tertiary Peneplain of South Limburg (The Netherlands). Silifications and fossil soils; a geological and pedological investigation. 1967 — Nfl. 2.—

No. 4. *Brinkman, R.* and *L.J. Pons:* A pedo-geomorphological classification and map of the Holocene sediments in the coastal plain of the three Guianas. 1968 — Nfl. 9.50

No. 5. *Sombroek, W.G.* and *I.S. Zonneveld:* Ancient dune fields and fluviatile deposits in the Rima-Sokoto river basin (N.W. Nigeria). 1971 — Nfl. 14.50

No. 6. *Bal, L.:* Micromorphological analysis of soils. Lower levels in the organization of organic materials. 1973 — Nfl. 17.50

No. 7. *Crommelin, R.D.* and *J.J. de Gruijter:* Cluster analysis applied to mineralogical data from the coversand formation in the Netherlands. 1973 — Nfl. 7.—

No. 8. *Vink, A.P.A.* and *E.J. van Zuilen:* The suitability of the soils of The Netherlands for arable land and grassland. 1974 — Nfl. 18.50

No. 9. *Ismail, S.N.A.:* Micromorphometric soil-porosity characterization by means of electro-optical image analysis (Quantimet 720). 1975 — Nfl. 19.50

No. 10. *Jongerius, A.* and *G. Heintzberger:* Methods in soil micromorphology. A technique for the preparation of large thin sections. 1975 — Nfl. 10.—

No. 11. *Gibbons, F.R.* and *J.C.F.M. Haans:* Dutch and Victorian approaches to land appraisal. 1976 — Nfl. 12.50

No. 12. *Gruijter, J.J. de:* Numerical classification of soils and its application in survey. 1977 — out of print

No. 13. *Bouma, J.:* Soil survey and the study of water in unsaturated soil. Simplified theory and some case studies. 1977 — Nfl. 20.—

No. 14. *Kooistra, M.J.:* Soil development in recent marine sediments of the intertidal zone in the Oosterschelde - The Netherlands. A soil micromorphological approach. 1978 — Nfl. 35.—

No. 15. *Marsman, B.A.* and *J.J. de Gruijter:* Quality of soil maps. A comparison of survey methods in a sandy area. 1986 — Nfl. 35.—

ISBN 90 327

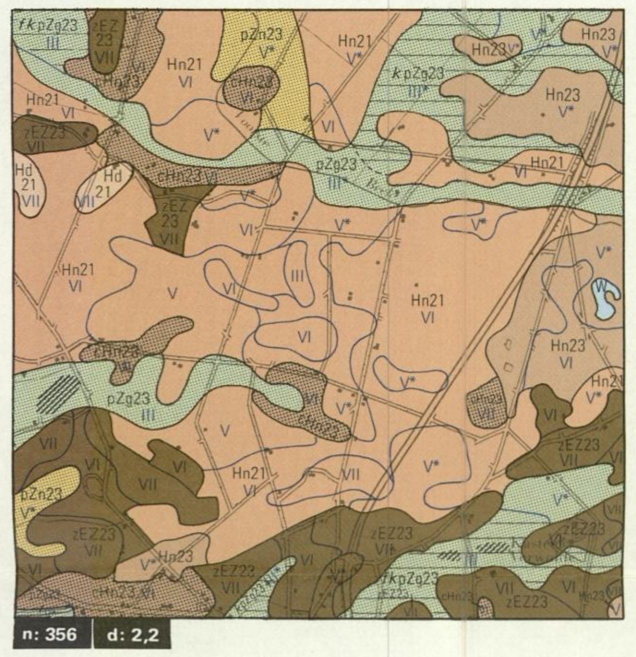
SOIL MAPS BASED ON DIFFERENT SURVEY METHODS

APPENDIX 1

B.A. Marsman and J.J. de Gruijter:
Quality of soil maps; a comparison of
survey methods in a sandy area,
Soil Survey Papers, No. 15 (1982)

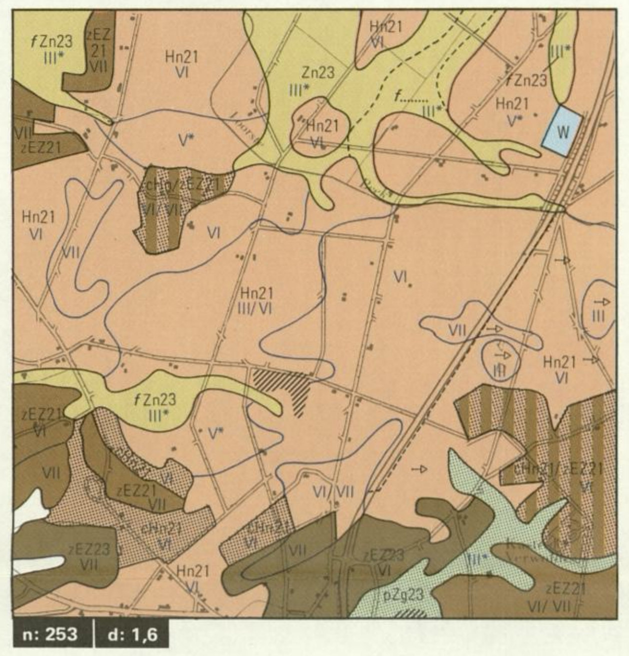
SOIL MAPS SCALE 1 : 50 000 BASED ON A GENERAL CLASSIFICATION

PuFi - 50 Free observation points; field delineation



n: 356 | d: 2,2

RaFi - 50 d Random observation points; field delineation

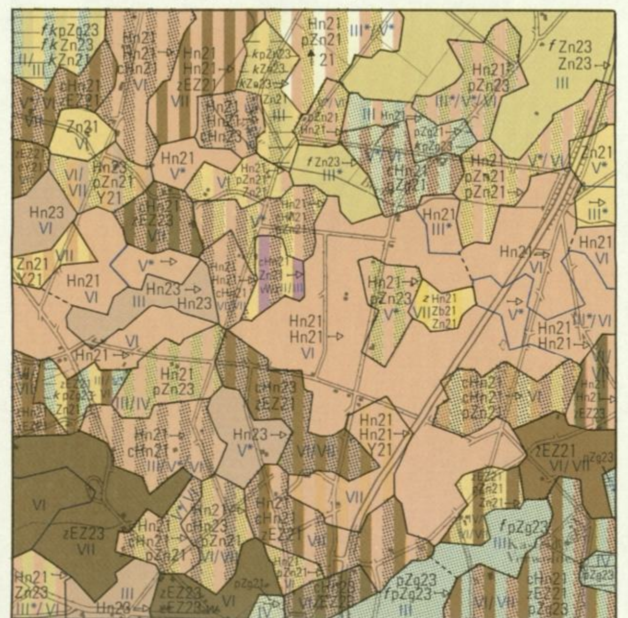


n: 253 | d: 1,6

RaPr - 50 Random observation points; proximal delineation

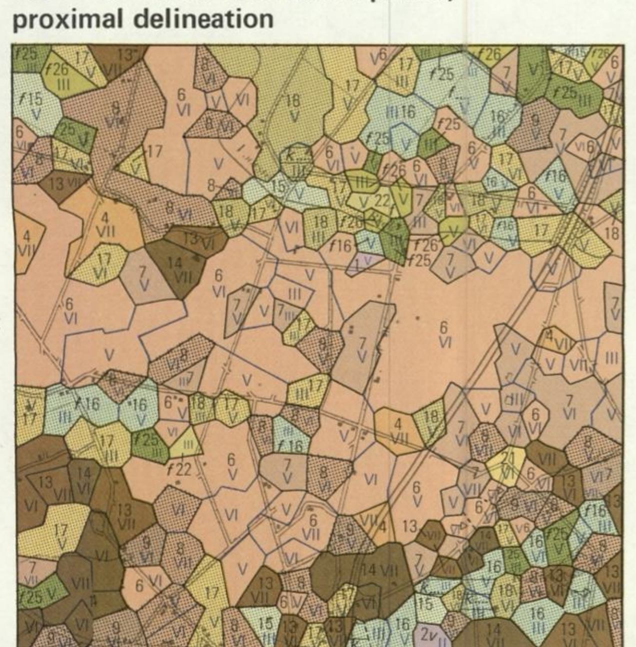
n: 349 | d: 2,2

RaPr - 50g Random observation points (as RaPr - 50); generalized proximal delineation



n: 349 | d: 2,2

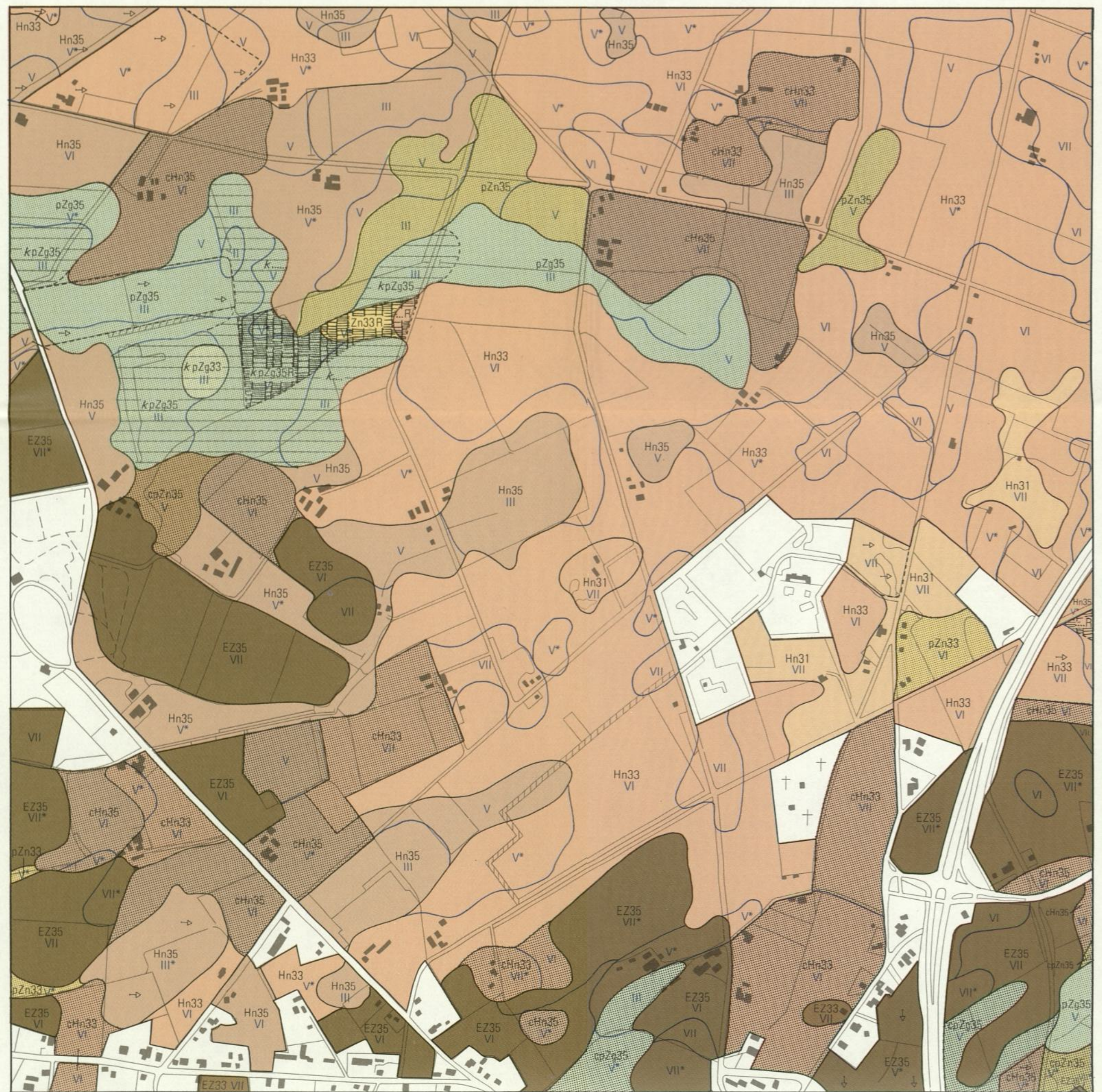
PuPr - 50 Free observation points; proximal delineation



n: 355 | d: 2,2

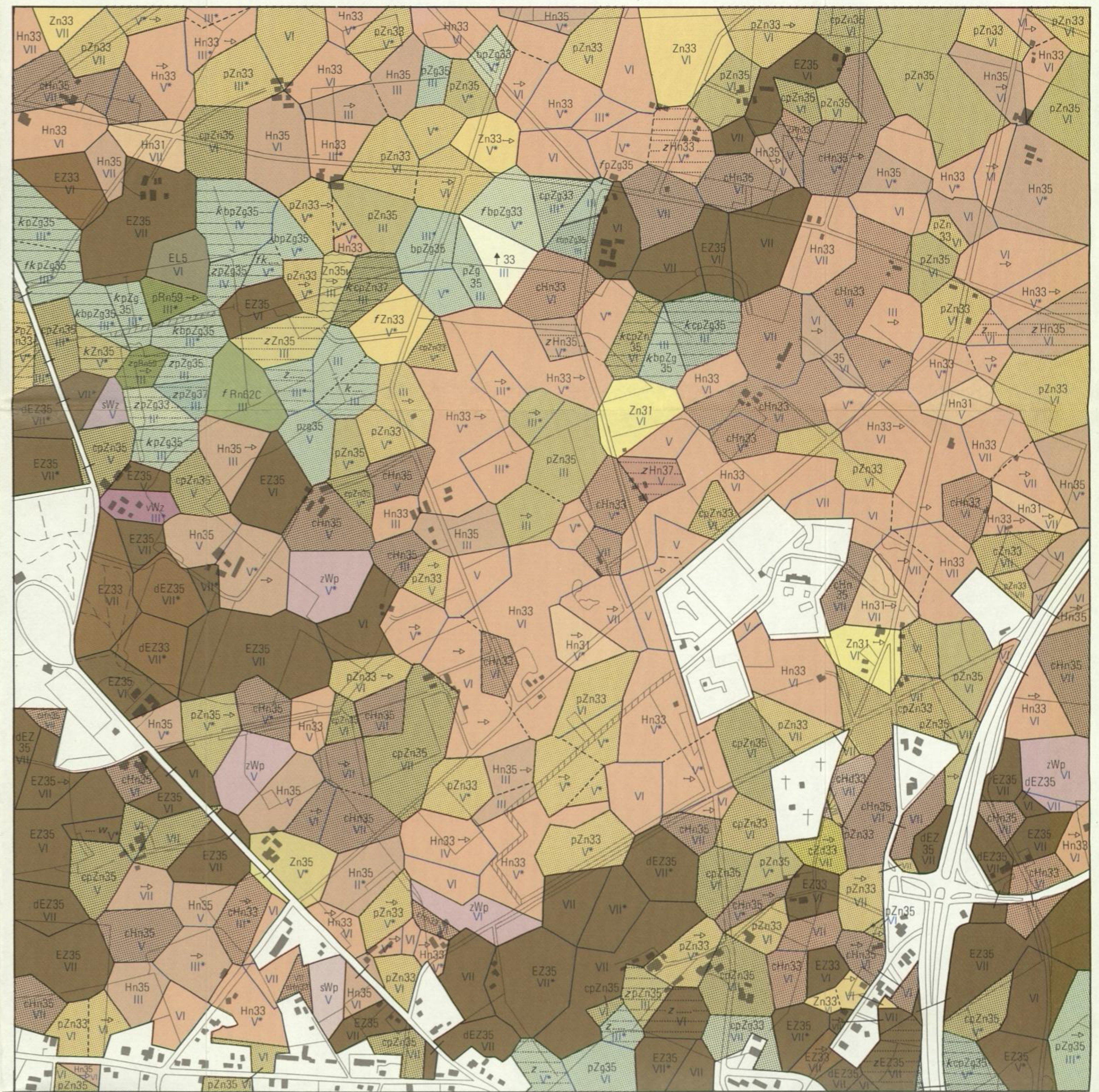
SOIL MAPS SCALE 1 : 10 000 BASED ON A DETAILED CLASSIFICATION

PuFi - 10 Free observation points; field delineation



n: 446 | d: 12,4

RaPr - 10 Random observation points; proximal delineation



n: 437 | d: 12,2

MAPPING UNITS 1)

(Soil units, including both groundwater classes and additional signs)

SOIL UNITS: General classification; maps scale 1:50 000 — SOIL UNITS: Detailed classification; maps scale 1 : 10 000

SANDY SOILS

	Legend code	Legend no.	General classification (1:50 000)	Legend code	Legend no.	Detailed classification (1:10 000)
HISTIC SOILS						
HISTIC SOILS				sWp	30	histic epipedon overlain by a non-humose sand-cover and with a spodic horizon
	zWp	1	histic epipedon overlain by a humose sand-cover and with a spodic horizon	zWp	31	histic epipedon overlain by a humose sand-cover and with a spodic horizon
	zWz	2	histic epipedon overlain by a sand-cover	sWz	32	histic epipedon overlain by a non-humose sand-cover
	vWz	3	histic epipedon at the surface	vWz	33	histic epipedon at the surface
TYPIC HAPLORTHODS						
ORTHODS	Y21	4	fine sand and slightly loamy fine sand			
PLAGGEPTIC HAPLORTHODS						
	cY21	5	sand and slightly loamy fine sand			
TYPIC HAPLAQUODS						
AQUODS	Hn21	6	fine sand and slightly loamy fine sand	Hn31	34	very fine sand
	Hn23	7	slightly loamy and loamy fine sand	Hn33	35	slightly loamy very fine sand
				*Hn53	36	slightly loamy medium fine sand
				Hn35	37	very loamy very fine sand
				Hn37	38	extremely loamy very fine sand
PLAGGEPTIC HAPLAQUODS						
	cHn21	8	fine sand and slightly loamy fine sand	cHn33	39	slightly loamy very fine sand
	cHn23	9	slightly loamy and loamy fine sand	cHn35	40	very loamy very fine sand
				*cHn55	41	very loamy medium fine sand
TYPIC HAPLOHUMODS						
HUMODS	Hd21	10	fine sand and slightly loamy fine sand	Hd33	42	slightly loamy very fine sand
PLAGGEPTIC HAPLOHUMODS						
	cHd21	11	fine sand and slightly loamy fine sand	cHd33	43	slightly loamy very fine sand
AQUIC PLAGGEPTS						
PLAGGEPTS	EZg23	12	slightly loamy and loamy fine sand	*EZg35	44	very loamy very fine sand
TYPIC PLAGGEPTS						
	zEZ21	13	fine sand and slightly loamy fine sand	EZ33	45	slightly loamy very fine sand
	zEZ23	14	slightly loamy and loamy fine sand	EZ35	46	very loamy very fine sand
				EL5	49	extremely loamy very fine sand
CUMULIC PLAGGEPTS						
				dEZ33	47	slightly loamy very fine sand
				dEZ35	48	very loamy very fine sand

SOIL UNITS: General classification; maps scale 1:50 000 — SOIL UNITS: Detailed classification; maps scale 1 : 10 000

	Legend code	Legend no.	General classification (1:50 000)	Legend code	Legend no.	Detailed classification (1:10 000)
TYPIC HUMAQUEPTS						
AQUEPTS				With black A1 - horizon		
	pZg21	15	fine sand and slightly loamy fine sand	pZg33	50	slightly loamy very fine sand
	pZg23	16	slightly loamy and loamy fine sand	*pZg53	51	slightly loamy medium fine sand
				pZg35	52	very loamy very fine sand
				pZg37	53	extremely loamy very fine sand
				With brown A1 - horizon		
				bpZg33	56	slightly loamy very fine sand
				bpZg35	57	very loamy very fine sand
				*bpZg55	58	very loamy medium fine sand
				*bpZg37	59	extremely loamy very fine sand
PLAGGEPTIC HUMAQUEPTS						
				With black A1 - horizon		
				cpZg33	54	slightly loamy very fine sand
				cpZg35	55	very loamy very fine sand
				With brown A1 - horizon		
				cbpZg35	60	very loamy very fine sand
SPODIC HUMAQUEPTS						
				With 15 - 30 cm thick A1 - horizon		
	pZn21	17	fine sand and slightly loamy fine sand	pZn31	61	very fine sand
	pZn23	18	slightly loamy and loamy fine sand	pZn33	62	slightly loamy very fine sand
				pZn35	63	very loamy very fine sand
				pZn37	64	extremely loamy very fine sand
				With 30 - 50 cm thick A1 - horizon		
				cpZn33	65	slightly loamy very fine sand
				cpZn35	66	very loamy very fine sand
				cpZn37	67	extremely loamy very fine sand
UDIPSAMMENTIC HAPLUMBREPTS						
UMBREPTS	*tZd21	19	fine sand and slightly loamy fine sand	*tZd33	68	slightly loamy very fine sand
PLAGGEPTIC HAPLUMBREPTS						
	cZd21	20	fine sand and slightly loamy fine sand	cZd33	69	slightly loamy very fine sand

SOIL UNITS: General classification; maps scale 1:50 000 — SOIL UNITS: Detailed classification; maps scale 1 : 10 000

	Legend code	Legend no.	General classification (1:50 000)	Legend code	Legend no.	Detailed classification (1:10 000)
TYPIC PSAMMAQUENTS						
AQUENTS	Zn21	21	fine sand and slightly loamy fine sand	Zn31	70	very fine sand
	Zn23	22	slightly loamy and loamy fine sand	Zn33	71	slightly loamy very fine sand
				Zn35	72	very loamy very fine sand
				Zn55	73	very loamy medium fine sand
HAPLAQUENTIC PSAMMAQUENTS						
				*Zn37	74	extremely loamy very fine sand
PLAGGEPTIC PSAMMAQUENTS						
				cZn33	75	slightly loamy very fine sand
TYPIC UDIPSAMMENTS						
PSAMMENTS	Zd21	23	fine sand			
DYSTROCHREPTIC UDIPSAMMENTS						
	Zb21	24	fine sand and slightly loamy fine sand			

CLAYEY SOILS

	Legend code	Legend no.	General classification (1:50 000)	Legend code	Legend no.	Detailed classification (1:10 000)
TYPIC HUMAQUEPTS						
AQUEPTS	pRn59	25	sandy loam	pRn59	76	sandy loam
TYPIC HAPLAQUEPTS						
	Rn62C	26	sandy loam	Rn62C	77	sandy loam

MISCELLANEOUS (non-classified soils)

Legend code	Legend no.	General classification (1:50 000)	Legend code	Legend no.	Detailed classification (1:10 000)
↑21	27	slightly loamy fine sand	↑33	78	slightly loamy very fine sand

Scheme of groundwater classes (cm below surface)

Groundwater class	Mean highest watertable (GHG)	Mean lowest watertable (GLG)
II	< 40	50 - 80
III	< 40	80 - 120
III*	25 - 40	80 - 120
IV	> 40	80 - 120
V	< 40	> 120
V*	25 - 40	> 120
VI	40 - 80	> 120
VII	80 - 140	> 160
VII*	> 140	> 160

Additional signs for mapping units on the lowest level of classification

- z ...... sand cover; thickness 15 - 40 cm
- k ...... alluvial deposit (> 8 % clay), overlying Pleistocene sand
- f ...... bog iron ore; thickness at least 10 cm and starting within 50 cm depth (for maps scale 1 : 50 000: locally bog iron ore)
- ...... w peat or peaty horizon; thickness 15 - 40 cm and starting between 40 and 80 cm depth
- ...... v peat or peaty subsoil; starting below 80 cm depth
- ...... R ridge - and - furrowed
- excavated, raised, reworked — used only if soils are classified
- small hummocks with deviating soils, being mainly Plaggepts or plaggeptic soils (used only for soil maps scale 1 : 50 000 with general classification)

Other signs

- built - up area (not surveyed rural areas)
- W water and marsh

EXPLANATION OF SOIL TAXONOMY TERMINOLOGY, USED IN THIS LEGEND

For the classification, Soil Taxonomy terminology (Soil Survey Staff, 1975) is used, with only the following exceptions:

1. A group of histic soils is distinguished for soils with a histic epipedon (both Humaquepts and Haplaquods)
2. The meaning of the following adjectives deviates from Soil Taxonomy:
   a. "plaggeptic" is used for soils with a plaggen horizon, 30 - 50 cm thick,
   b. "cumulic" is used for Plaggepts with a plaggen epipedon thicker than 80 cm,
   c. "spodic" is used for Humaquepts with no mottles, usually accompanied by a weak accumulation of amorphous material,
   d. "dystrochreptic" is used for Udipsamments with a " colour B horizon", whereas soil texture is too sandy for a cambic horizon
3. The textural classes for sandy soils according to the Dutch system (De Bakker and Schelling, 1966) are based on the median of the sand fraction (50 - 2000 μm) and the loam content (% < 50 μm) All soils having less than 8 % clay over a depth of at least 40 cm are considered sandy soils.
   a. Textural classes for maps scale 1 : 50 000 (general classification):
      median 105 - 210 μm = fine sand
      loam content 0 - 17.5 % = sand and slightly loamy sand
      loam content 10 - 32.5 % = slightly loamy and loamy sand
   b. Textural classes for maps scale 1 : 10 000 (detailed classification):
      median 105 - 150 μm = very fine sand
      median 150 - 210 μm = medium fine sand
      loam content 0 - 10 % = sand
      loam content 10 - 17.5 % = slightly loamy sand
      loam content 17.5 - 32.5 % = very loamy sand
      loam content 32.5 - 50 % = extremely loamy sand

1) The mapping units are indicated on the map with the legend code (or legend no.) of the soil unit, an additional sign if relevant and a Roman numeral for the groundwater class

* Mapping units not existent on the soil maps shown in this Appendix

n: | d:
n: number of observations
d: density/10 ha

STI BO KA SOIL SURVEY INSTITUTE, WAGENINGEN THE NETHERLANDS 1982

Printed by Europees Cartografisch Instituut, Rijswijk (ZH), The Netherlands