Soil Mapping in Denmark

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Land Assessment History

In Western Europe land utilization was accepted as the normal basis for taxation for centuries. Those who benefited from the land were expected to pay towards the general welfare of society as well as to contribute to financing rearmament and warfare and other facets of life. It was also accepted that a land or property tax should be graduated according to the size of a property and the value of its land.

During the Middle Ages there were three different ways of assessing Danish land for taxation purposes (Mosbech, 1922; Pedersen and Steffensen, 1966): Number of "ploughs" (plough tax), amount of seed, and gold value. The first nationwide land assessment based on a systematic evaluation of the soil was King Christian V‘s Great Danish Land Register of 1688. This land assessment classified the soils according to their potential yields for various crops, e.g. good soil for barley and rye or good soil for oat production.

The taxation (valuation) unit was the Danish term: "tønde (td.) hartkorn" (one barrel of hard grain(barley and rye)), and at Zealand the farmer had to pay 1 td. hartkorn for every 2 td. land of good barley and rye soil he owned or 1 td. hartkorn for every 4 td. land of good oat soil. This land assessment was used for more than 150 years.

At the beginning of the 19th century the need for an improved basis for national taxation was urgent as the Danish Land Register of 1688 had not been updated regularly and tax rates varied too unjustly among properties. This led to The Great Danish Land Register of 1844 (Rothe, 1844) which involved a comprehensive, detailed national survey followed by production of cadastral maps at a scale of 1:4,000.

The land was evaluated according to the goodness of its soils and related characteristics.

The soils were valued according to a 24-point scale and the best soil was allotted the optimal quality value of 24. This soil was situated at Karlslunde between Roskilde and Køge on Zealand. The land assessment and the measured field sizes were the basis for determining the "hartkorn" values.

The principles of the national land assessment were outlined in 1802-05 but it took some time to complete due to several delays (Madsen *et al.*, 1992). Zealand, Lolland, Falster and Møn were assessed by 1813, Funen by 1820, and Jutland by 1826. Southern Jutland was, however, not assessed, except for the royal enclaves within Ribe county. Although most of the land register work and the definition of the "hartkorn" land values had been completed in 1826 it took almost 20 years before this new taxation system was fixed by law in 1844 (Jensen, 1944; Pedersen and Steffensen, 1966).

The Great Danish Land Register of 1844 was used as the basis for real property taxation for about 60 years. The new taxation legislation of 1903 terminated the use of "hartkorn" as the taxation unit, replacing it by the commercial, rateable value of real estate property as of today.

Although property evaluation following the 1903 Tax Reform Act was based on commercial value, there was still a desire to undertake a new national land assessment and renew the "hartkorn" values. This was partly because "hartkorn" was still used in connection with land parceling up to the 1960s, and because there was disagreement over the main principle on which to base real estate assessments.

Hence, from time to time, land surveyors and building societies called for a new national land assessment to be undertaken (Sørensen, 1930; Brink, 1926; Pedersen, 1932). Thus, in 1949 the Ministry of Agriculture appointed a Land Assessment Commission, whose task it was to lay down the guidelines for trial assessments to be carried out in every local authority. This commission had amongst its members agricultural scientists, farmers, land surveyors, chartered surveyors, and representatives from the National Land Register Office. It worked for about 20 years and based on approximately 25,000 test land assessments a report with recommendations for a new nationwide land assessment was sent to the Parliament in 1970 for approval (Jordboniteringskommissionen, 1970). Unfortunately, the proposal was never approved and soon to be forgotten.

In 1974 a land assessment of Bornholm was carried out based on texture, slope and drainage conditions and maps were constructed at scale 1:50,000 (Mathiesen, 1974). The best soil was allotted the value 39. This land assessment differed both from the principles laid down in 1844 land assessment and those of the 1949 Land Assessment Commission work, because the land assessment values were not directly related to the yield potential. Thus there is no direct link between assessment values and yield potential.

Heather investigation

In the thirties there was an increasing interest for information on suitability of heather for agriculture and afforestation. At that time heather covered more than 5% of the country. The investigation was carried out from 1938 to 1952 by the Danish Land Development Service and in total 160,020 ha were investigated. (Hove, 1962).

Systematic bog investigation

During the First World War the Danish peat resources were intensively utilised because the supply of foreign fuel failed. In early twenties it was decided to carry out a national bog and peat assessment to determine the amount and quality of Danish peat resources. This survey was carried out by Danish Land Development Service (Hedeselskabet) during a twenty year period and terminated in 1942. A total of 1625 bogs larger than 5 ha were investigated. (Thøgersen, 1942).

Danish Soil Classification 1975-90

From the end of the 1930s until the 1970s, more than 300,000 hectares of agricultural land were lost to other land uses. Some of this land was converted to new forest plantations. Urbanisation increased rapidly after the Second World War, and much agricultural land was lost to new housing and industrial estates, new recreational areas such as summer house areas and the space required for infrastructure. The Regional Planning Act of 1973, and the Local Planning Act of 1975, heralded the start of physical and environmental planning in Denmark. By this time, it had become apparent that agricultural land needed to be part of the overall planning process and that there was a need for a nationwide soil mapping programme. Thus, in 1974 the Danish Ministry of Agriculture appointed a commission consisting of 8 members, whose function it was to establish a soil classification procedure.

This commission consisted of experts from soil research centres, universities and agricultural organizations. Its members were called upon to determine the procedure for the practical development of a soil classification in accordance with five basic requirements:

1. The areas should be classified on the basis of permanent or stable characteristics.
2. There should be a national standard code of reference that would make it possible to classify soils as uniformly as possible.
3. The results should clearly illustrate the range of fertile and infertile soils.
4. The results should be mapped in such a way that they might be used in future planning at all levels.
5. The classification should be completed within a reasonable time limit (a maximum of three years).

The majority of experts believed that it was best to make a classification focussing upon a few important soil factors such as topsoil texture, slope and overall drainage conditions. Essentially, the work would make use of existing data, supported by textural analysis of the plough layer, but no link was made to the enormous work made by the 1949-commission. In order to benefit from local knowledge on soil conditions, local extension workers from agricultural organizations were to be consulted. These consultants would be able to advise on sites at which to carry out soil sampling and to delineate areas of identical soil types.

In December 1975, the Department of Soil Classification (Sekretariat for Jordbund-sklassificering, SfJ), was set up in the town of Vejle in East Jutland. Its task was to organise and undertake the work of the Danish Soil Classification.

Table 1 Definition of soil classes and soil types

Colour Code	Soil type	JB-nr.	Percentage by weight					
			Clay < 2 µm	Silt 2-20 µm	Fine Sand 20-200 µm	Total Sand 20-2000 µm	Org. Mat. 58.7 % C	Lime $CaCO_3$
1	Coarse Sandy Soil.	1	0-5	0-20	0-50	75-100	≤ 10	≤ 10
2	Fine Sandy Soil.	2			50-100			
3	Clayey Sandy Soil.	3	5-10	0-25	0-40	65-95		
		4			40-95			
4	Sandy Clayey Soil.	5	10-15	0-30	0-40	55-90		
		6			40-90			
5	Clayey Soil.	7	15-25	0-35		40-85		
6	Heavy Clayey Soil or Silty Soil.	8	25-45	0-45		10-75		
		9	45-100	0-50		0-55		
		10	0-50	20-100		0-80		
7	Organic Soil.	11					> 10	0-90
8	Calcareous Soil	12					≤ 10	> 10

Prior to this date, the county of North Jutland had already been classified (Mathiesen, 1975), and this county together with Bornholm was initially excluded from further classification. A databank was established at SfJ comprising two main departments:

1. Soil Map Department producing the basic data maps;
2. Geographical Database Department storing all the collected data, such as texture analyses.

The classification work led to the collection of entirely new data stemming, in particular, from the texture analysis of soil samples from the plough layer or subsoil. Additionally, a slope classification map was compiled from old, detailed topographic maps. Drainage conditions were examined and recorded and, finally, existing surface geology maps created by the Danish Geological Survey - (today known as GEUS) were revised in order to meet the requirements of the Danish Soil Classification.

Samples for texture analysis were taken at about 36,000 sites (approximately 1 sample per km^2) from a depth of 0-20 cm and at selected sites also from a depth of 35-55 cm. No soils were sampled in urban and forest areas. The samples were taken by local agronomists in cooperation with the staff at the SfJ in Vejle. In the laboratory, texture, organic matter and calcium carbonate were determined on all samples and the results stored in databases (Mathiesen, 1980).

The agricultural land was classified into eight soil types according to the texture of 0-20 cm depth (Table 3). Each soil type was then assigned a map colour code (1-8). The remaining areas were divided into urban areas and forest areas. The soil types were further subdivided into 12 soil classes (JB 1-12) (see Table 1). The eight soil types were delineated on maps by local agronomists in cooperation with the staff at the SfJ. In this way the mapping benefited from local experience.

The agricultural land was classified according to slope:

1) 0-6°
2) 6-12°
3) more than 12°

Experiments had shown that in class 1 mechanized tillage was carried out without any problems, in class 2 minor difficulties might arise, whereas in class 3 mechanised tillage was almost impossible (Landbrugsministeriet, 1975).
By 1980 approximately 400 soil maps at a scale of 1:50,000 were available. The maps were published in colour with soil types printed in brown or yellow colours, the forests printed in green and the

urban areas in white (Nørr and Platou, 1984). The dominant geology was shown for every 25 ha as a notation in the upper right corner in a grid. The slope classes were indicated by hatching (shading).

Investigations to Enhance Soil Maps

A landscape map has been delineated on topographic maps at a scale of 1:100,000. The boundaries between different landscapes were drawn on basis of the contour lines, former landscape maps, and geological surveys published at a scale of 1:100,000. The country has been divided into 9 different landforms: 1: Salt marsh, 2: Raised seafloor, Littorina, and younger marine foreland, 3: Late glacial raised seafloor. 4: Dune landscape. 5: Saale glaciation landscape, 6: Outwash plain, 7: Weichsel moraine landscape, 8: Reclaimed area, 9: Rock.

Based on information from geological surveys (field determinations) the texture of the soil at 1 metre depth was classified as sandy or clayey. It has not been possible to set up an exact limit of clay content between the two types, but clayey subsoils normally contain more than 15% clay, sandy ones less than 10%.

The wetlands were delineated from old topographic maps (1:20,000) showing the extent of wetlands 60-80 years ago. The old topographic maps were preferred to later ones because of the recent decrease in wetlands due to drainage. The wetlands included bogs, river valleys, salt marsh areas, littorina deposits and younger marine forelands. They cover roughly 20% of the country.

In Jutland the water quality in some aquifers can be impaired by strong acidity and a high concentration of dissolved iron. This is due to the presence of iron sulphides in such an amount that acid sulphate soils develop when the land is drained. As iron sulphides are only stable under anaerobic conditions, acid sulphate soils will only be present in wetlands. Mapping of potentially acid sulphate soils was carried out in the years 1981-84 (Madsen *et al.*, 1985a and Madsen and Jensen, 1991). Approximately 8,000 soil profile descriptions have been made based on augering, and approximately 16,000 samples have been analysed. In the laboratory the lime-free samples were placed freely exposed to the air and pH was measured after 2, 8 and 16 weeks. If pH dropped below 3 the samples were considered to be acid sulphatic in nature. In the lime-containing samples the amount of pyrite and calcium carbonate was measured. Based on these results it was decided whether the samples were acid sulphatic or not. Soil maps were then elaborated dividing the wetlands into four classes based on the frequency of profiles containing acid sulphatic samples.

A second generation soil map

In the early 1990s, the county of Western Zealand decided to make a new plan for agriculture in the region. To support this, there was a need for more detailed soil information than that provided by The Danish Soil Classification, e.g. for calculation of the demand of water for irrigation and for delineation of sensitive areas according to drinking water quality (groundwater protection). Thus a project was initiated to develop the existing soil maps to provide more detailed information on texture.

The principle for construction of the second generation soil maps at a scale of 1:50,000 was to combine already existing topographical, geological and landscape maps to delineate specific geographical units having the same soil type. Based on analytical data from different sites within the county the map units were assigned a soil texture at three depths according to the JB-system shown in Table 1. The three depths were 0-30 cm, 30-60 cm and 60-120 cm (Fransen and Madsen, 1998).

Pedological investigations

Several soil profile investigations have been carried out during the last decades. Among these, two large investigations will be described briefly. In relation to the establishment of the main gas pipeline system from the North Sea across Denmark in 1981-84 (Figure 1), pedological investigations along the lines were carried out (Madsen and Jensen, 1985). About 800 detailed profile descriptions and about 8,000 soil profile classifications were made.

In order to improve the efficiency of nitrogen fertilizers used in Danish farming, the Danish Agricultural Advisory Centre established a nationwide 7 km grid. The grid was established in 1986 and contains approximately 850 intersections. At all the intersections pedological investigations were carried out from 1987-90 by Bureau of Land Data (ADK) in cooperation with the Geographical Institute at the University of Copenhagen. This led to the establishment of The Danish Soil Profile Database.

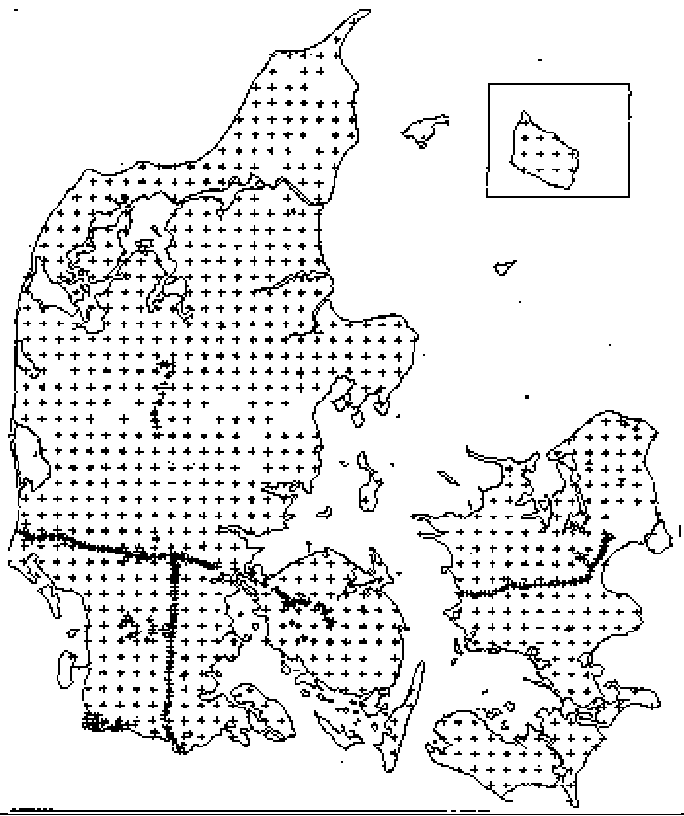

Figure 1: Location of Profile pits

Monitoring

At all intersects in the 7 km grid, 50m x 50m test plots were established, in which the content of inorganic nitrogen was determined twice a year at four depths. On the basis of these data the farmers are advised on their use of N-fertiliser (Østergaard, 1990) In the beginning of the nineties, 393 sites from the 7 km grid were selected to represent Danish soils in the Danish heavy metal monitoring program. For comparison twenty additional fields with sewage sludge application were selected.

The samples were analysed for arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc (Jensen *et al.*, 1996). It is recommended that this monitoring programme is repeated in 10 years time.

In 1998 funding was granted for the project: 'Monitoring the environmental impact of modern agriculture with respect to phosphorus, copper, zinc and pesticides in relation to management'. One of the components of this project is to resample and reanalyse the grid points in the 7 km grid to determine whether the content of these substances have changed during the past 12 years.

Use of Soil Information

The Nationwide Danish Soil databases have been widely used for planning of rural land at county and national level. Initially, the soil information was used in respect to the protection of valuable agricultural land around expanding urban settlements. Later it was also used in agricultural water planning (Madsen and Platou, 1983; Holst and Madsen, 1986; Holst and Madsen, 1988). It has also been used for mapping wind- and water erosion (Madsen *et al.*, 1985, Hasholt *et al.*, 1990), nitrate loss from farmland (Børgesen *et al.*, 1997), areas giving rise to ochre pollution (Madsen *et al.*, 1985a, Madsen and Jensen, 1991), and marginal land (Madsen and Holst, 1987; Svendsen and Pedini, 1987).

In the last 5 years there has been an increasing interest in soil data from European authorities, and the Danish soil databases have been used as the national input to various European projects. In 1998 The European Soil Bureau completed the compilation of the Soil Map of Europe at a scale of 1:1,000,000 and the European Soil Profile Analytical database. The part of the project concerned with Danish soils was compiled by GI and ADK.

In 1995 25 Danish profiles from the Danish 7km grid were selected as a part of the European monitoring for forest health programme (Madsen and Olsson, 1995).

In 1997 and 1998 data were supplied to a European research project IMPEL (Integrated Model for Predicting European Land Use). The Danish Institute of Agricultural and Fisheries Economics was the Danish participant in this project.

In 1998 the project 'Using existing soil data to derive hydraulic parameters for simulation models in environmental studies and in land use planning' was completed with the production of a joint European database known as HYPRES (Hydraulic Properties of European Soils). This project was financed by the European Commission (Wösten *et al.*, 1998). DIAS was the Danish party in this project.

Other Soil Mapping Activity

Mapping the surface geology

Mapping the surface geology of Denmark is the responsibility of the Danish Geological Survey (GEUS). This important activity started in 1888, and at present, about 90% of the country has been mapped. Figure 2 shows those parts of the country that have been mapped so far.

Mapping of the surface geology is based on augering using a one-metre auger. Samples are taken at a depth of approximately 1m and classified directly in the field. The classification is based on lithology, texture, organic content, colour and landscape characteristics. Any abrupt change in the genesis of the soil material taken from the top metre is registered. The density of the borings across the landscape is approximately one sample per 4 hectares

National Ordnance Survey maps (scale 1:20,000) were the main reference source for the field investigations. Fieldwork maps were formerly only 1/9 size of the Ordnance Survey maps and had to be redrawn to meet the Ordnance Survey format. These earlier manuscripts, along with field work records, represent GEUS's original mapping material. However, the 1:25,000-scale maps subsequently introduced during the 1970s were found to be ideal for fieldwork, and since then GEUS has used this scale.

The redrawn field maps provided the source material for the final "GEUS First Series" published in map sheets at a scale of 1:100,000. Half of the country has been published at this scale. Other parts of the country have been surveyed, but maps have not yet been published. The introduction of the 1:50,000 scale has meant that GEUS now produces coloured maps at this scale. These are published partly as "Series A" and partly as a different map series. For example, the mapsheet 1215 IV "Viborg" has been published as "Map Series No. 1, 1986". In 1989, on the basis of surface mapping and borehole data (geological basic data maps), GEUS issued a four-part, national surface geology map at a scale of 1:200,000.

Danish Forest Site Classification

In early 1990s, a system for forest site classification and mapping of afforestation areas was developed in a co-operation between The Danish Forest and Nature Agency and the Department of Earth Sciences, University of Aarhus. The system is inspired by the German site classification system used in Lower Saxony. In the field one auger boring is made per hectare and supplemented with one soil profile with matching analyses on all the soil types present in the area.

The area is then subdivided into site types. An ecological code is assigned to each site type. This code gives to the forester information on water supply, nutrient supply, parent material and site specific factors such as layers restricting root growth, etc. Based on these maps a sensible selection of tree species can be made.

The system is in operation at the Danish Forest and Nature Agency and a few thousand hectares are mapped each year (Sørensen and Dalsgaard, 1993).

Future Tasks

During the seventies and eighties much effort and money was put into small scale soil mapping in Denmark. Very little progress was made in detailed soil mapping, except for the work done in connection with the Danish Forest Site classification. In the beginning of the nineties large farms and private companies started to use the concept of precision farming. The interest in this has grown since then. In 1998 a research programme on precision farming was launched and this has led to an increase in interest in detailed soil mapping.

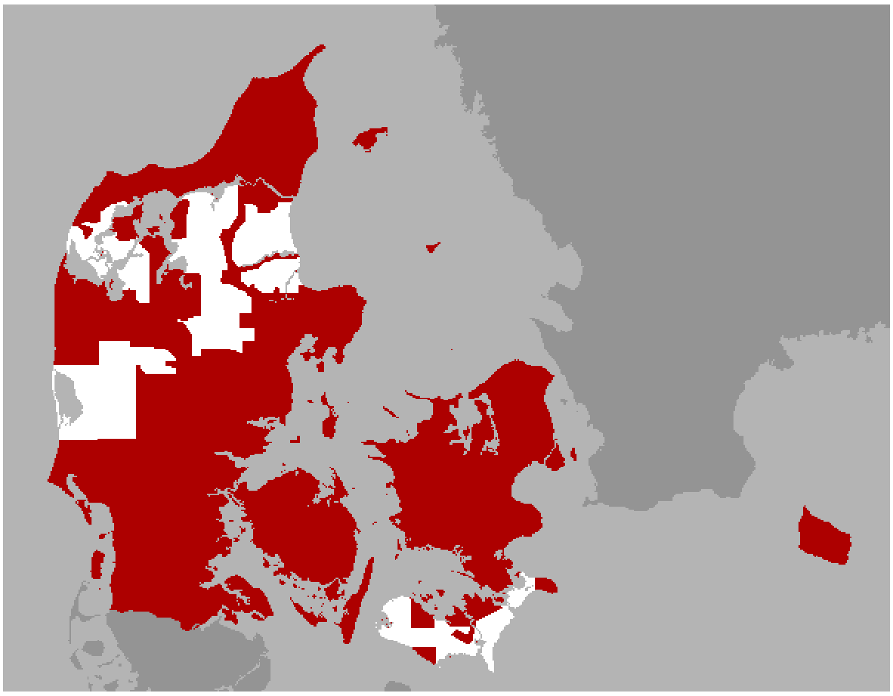

Figure 2 Surface geology maps of Denmark
[published areas shown in red]

In 1998 DIAS and GI together with other research institutes received funding for a land assessment project, the aim of which is to develop a new concept for land assessment taking into account both continuous and abrupt changes in the soilscape. The practical goals for the project are:

1. Establishment of the framework for a Danish soil series system on the basis of the DIAS database and the Danish Pedological Soil Classification System
2. Development of a new paradigm for a detailed survey (1:10,000 scale).
3. Quantification of soil variability in relation to mapping units, landform, topography and parent material.

The key to sustainable land management is detailed resource information, and in recent years there has been a marked increase in the demand for such information. This is in response to the necessity of implementing the environmental policies of Danish government authorities, on, for example, set-aside, nitrogen application and afforestation, which have been effective for some years.

However efficient implementation of present policies requires more detailed soil information than available, but this is not recognized by the authorities. It is the hope that the necessity for adequate, detailed soil information is appreciated by government authorities in the near future.

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