Land assessment maps of Denmark based on the Danish Soil Classification's data bases and former trial land assessments

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Abstract

During the last decade the establishment of a new Danish land assessment system has been debated. One of the strongest arguments in support of this idea was that such a mapping system at a farm level would make it possible to allot financial support to the farmers in a more correct way, e.g. farmers with good soils should be paid better than farmers on poor soils if land was ordered to lie fallow due to political reasons. A nationwide land assessment on a farm level is, however, very time consuming and expensive to carry out so until now it has been rejected. Meanwhile, existing maps from the Danish Soil Classification may be transformed to land assessment maps when combined with the nation-wide soil profile database or by using the test land assessments made by the 1949 Land Assessment Commission. By these approaches land assessment maps can be elaborated for use at national, county or municipal levels.

Keywords

Soil classification, land assessment, soil map.

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During the last decade a need for new land assessment maps has become more and more evident. Such maps could be an important planning tool, e.g. when allotting EU-funds to farmers as a compensation for land laid fallow or in case of other donations paid to the farmers due to governmental demands on agricultural land use. Furthermore, land assessment maps could be an important tool in environmental planning of the rural land, where a diminishing of the agricultural impact on the environment has great political interest. With these facts in mind a new land assessment was debated a few years ago, but not accepted by the farmers. So, today no up to date land assessment maps exist, and it will not be possible to generate such one on a farm level without huge economic inputs over many years. Meanwhile, it may be possible by means of pedotransfer functions to transform the existing soil maps into land assessment maps which can be of use in regional planning at national, county and municipal levels.

This paper describes a methodology for transformation of the Danish Soil Classification's maps to land assessment maps based on a calculation of the irrigation need on various soil types and based on the land values obtained by the work of the 1949 Land Assessment Commission. First a brief description of the land assessment history is outlined followed by a description of the methodology used for elaboration of new land assessment maps. Then a detailed description of the two soil investigations used for the construction of new land assessment maps is given, and as an example the transformation of the Danish Soil Classification's map to a land assessment map is demonstrated for the municipality of Tørring/Uldum in Eastern Jutland.

Land assessment history

In Western Europe land utilization was accepted as the normal basis for taxation for centuries. Those who benefited from the land had to pay to the general welfare of society and not least to finance rearmament and warfare. 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 the Danish Land for taxation purposes (Mosbech 1922; Pedersen & 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), 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 100 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 scale 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 & 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 when 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 all the "hartkorn" values. This was partly because "hartkorn" was still used in connection with land parcelling 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 members among 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 nation-wide 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, slopes and drainage conditions and maps were constructed at scale 1:50,000 (Mathiesen 1974). The best soil was alloted the value 39. This land assessment differed from the principles laid down in 1844-land assessment and in the 1949-land assessment commission work, because the land assessment values were not directly related to the yield potential. Thus a soil with half land assessment values does not necessarily have half the yield potential.

Methodology

The construction of new land assessment maps is based on soil data from two major soil investigations both carried out after the Second World War: the 1949-Land Assessment Commission work and the Danish Soil Classification 1975-79. Furthermore, data from a nationwide soil profile database have been used. The mapping units from the Danish Soil Classification are used for delineation of areas with identical land assessment values. The mapping units are ranked in three groups according to the irrigation need calculated based on the soil water retention values from the pedological database. These rankings are tested by the land assessment values obtained from the test plots from the 1949 Land Assessment Commission work.

Soil data used for elaboration of new land assessment maps

The land assessment of 1949

In 1949 the Ministry of Agriculture appointed a Land Assessment Commission, whose task it was to lay down the principles and guidelines for a new land assessment of Danish farmland (Jordboniteringskommissionen 1970). The commission concentrated on developing a land assessment system for arable land, meadows and grazing land, whilst woodlands were temporarily omitted. It was decided that the evaluation of assessments should be based on evaluations in the field rather than tests in the laboratory. In this way the outlined procedure in principle follows the Great Danish Land Register of 1844. The commission consisted of agricultural scientists, farmers, land surveyors, chartered surveyors, and representatives of the National Land Register Office, and they investigated about 25,000 test sites in order to build up a relationship between soil properties and land value.

The land assessment of areas with well-drained soils: On well-drained areas the soils were to be rated according to their natural characteristics and annual productivity in terms of crop yield per hectare given normal operational conditions. Trial rates on a 100-point scale (shown at intervals of 5 points) were then fixed. The scale was to resemble the German "Bodenzahl", so that the value increased linearly with productivity to a maximum of 100 points. When these rates were fixed the mineral soils were divided into seven classes: 1) heavy clay, 2) clay, 3) sandy clay, 4) clayey sand, 5) sand, 6) coarse sand and 7) gravel-rich sand. Under special circumstances the terms "rich in mull" or "poor in mull" were added. One of these seven classes was fixed for the topsoil, as well as one for the subsoil. Water retention capacity, soil colour, and the presence of plant roots were also included in the evaluation and rating.

The Land Assessment Commission then fixed the rates for areas on which the total yields of several years of experimental cultivation at national research centres and agricultural associations' field centres had been recorded. Based on these yield comparisons and the abovementioned soil evaluations, a classification scale for mineral soils was made, see Table 1.

Soil type	*Class*	*Topsoil*	*Subsoil*
Heavy clay	*1*	*50-90*	*50-80*
Light clay	*2*	*80-100*	*80-100*
Sandy clay	*3*	*70-90*	*70-90*
Clayey sand	*4*	*50-80*	*50-70*
Fine sand	*5*	*15-70*	*30-50*
Coarse sand	*6*	*0-50*	*15-30*
Gravelly sand	*7*	*0*	*0*

Table 1: *Mineral soil classification for land assessment. Rating range: 100-point scale (Jordboniteringskommisionen 1970).*

The next step was to consider the best way of combining the three rates for the topsoil, subsoil, and depth of topsoil to give the final rating value. A topsoil with a depth of 60 cm was to be termed as a "full depth topsoil", and soils with a topsoil deeper than 60 cm would be given their final rate based on their topsoil rate, only. For soils with a topsoil thinner than 60 cm the final rate was based on a weighting of the rates for the topsoil, the subsoil and the depth of the topsoil. From regression equations combining yield values and the abovementioned three soil characteristics, a soil assessment rate table was produced, Table 2.

S\D	*60*	*55*	*50*	*45*	*40*	*35*	*30*	*25*	*20*	*15*	*10*	*5*	*0*
100	50	55	59	62	65	66	67	68	68	68	68	67	67
95	50	55	58	61	63	64	65	65	65	65	65	64	64
90	50	54	57	60	61	62	63	63	63	62	62	61	61
85	50	54	56	58	59	60	60	60	60	59	59	58	57
80	50	53	55	57	58	58	58	58	57	56	55	54	54
75	50	53	54	55	56	56	56	55	55	54	52	51	50
70	50	52	53	54	54	54	54	53	52	51	49	48	47
65	50	51	52	53	53	52	51	50	49	48	46	45	44
60	50	51	51	51	51	50	49	48	46	45	43	42	40
55	50	50	50	50	49	48	47	45	44	42	40	38	37
50	50	50	49	49	47	46	45	43	41	39	37	35	34
45	50	49	48	47	46	44	42	40	38	36	34	32	30
40	50	49	47	46	44	42	40	38	36	33	31	29	27
35	50	48	46	44	42	40	38	35	33	30	28	26	24
30	50	48	45	43	41	38	35	33	30	28	25	22	20
25	50	47	44	42	39	36	33	30	27	25	22	19	17
20	50	47	43	40	37	34	31	28	25	22	19	16	13
15	50	46	42	39	35	32	29	25	22	19	16	13	10
10	50	45	41	38	34	30	26	23	19	16	13	10	7
5	50	45	40	36	32	28	24	20	17	13	10	6	3
0	50	44	39	35	30	26	22	18	14	10	7	3	0

Table 2: *Site sketch of the precise location of a soil sampling site (Jordboniteringskommisionen 1970).*

This shows the rate table for a topsoil (T) rated at 50, showing the possible combinations of topsoil depth (D) and subsoil rate (S). The topsoil depth (D), shown at intervals of 5 cm, ranges from a depth of 5 to 60 cm. The subsoil rate (S) is shown at intervals of 5 points. Similar tables were developed for other topsoil rating values.

The land assessment of wetlands: The Land Assessment Commission also attempted to outline rules for an evaluation of wetland soils. However, it was difficult to reach a clear and scientifically satisfying classification. The result was a division of wetland soils into 4 main groups:

- *Mineral soils:* wetland areas whose topsoil layers consist of mineral soils and at least 20 cm deep.
- *Muddy soils:* soils developed in either saltwater marsh or freshwater marsh areas.
- *Blanket bog soils:* soils in which the mineral soils are covered by an organic layer to a maximum depth of 30 cm, or by an organic layer topped by mineral soils to a maximum depth of 20 cm.
- *Bog soils:* soils having a peat layer to a minimum depth of 30 cm or a peat layer topped by a thin layer of mineral soils to a maximum depth of 20 cm.

The four wetland soil groups were described in further details and the mineral soil classification, based originally upon the seven previously presented soil texture classes, was extended to include wetland soils as well (texture classes 11-17), see Figure 1.

The degree of wetness was considered so important that the rates of the wetland soils were modified according to which of the 4 drainage categories they belonged. The categories were defined according to the drainage depth, as far as to the level of the water table below the surface, Figure 1. Modification was achieved by applying a rate reduction factor in the range 0.2-1.0.

The Land Assessment Commission had many difficulties in applying the rate table to the wetland areas, and in establishing the correct relationships between the best mineral soils and the best organic soils. Based on advices of horticulturalists specialized in grass cultivation the best peatlands were defined as being equal to 2/3 the quality of the best mineral soils (still based on a 100-point scale). The best peatlands were thereafter rated at 65 points.

Fixing the trial land assessment values for local districts and parishes: The Land Assessment Commission under-

Figure 1: The 1949 Land Assessment Commission. Comparison of soil classification and land assessment. (Jordboniteringskommissionen 1970).

SOIL DESCRIPTION				ASSESSMENT VALUES	
			Designation	Topsoil values with ± correction for the humus content	Subsoil values
MINERAL SOILS	CLAYEY SOILS	heavy	1	50 - 90	50 - 80
		light	2	80 - 100	80 - 100
		sandy	3	70 - 90	70 - 90
	SANDY SOILS	clayey	4	50 - 80	50 - 70
		fine	5	15 - 70	30 - 50
		coarse	6	0 - 50	15 - 30
		gravelly	7	0 - 30	0 - 20
				Values for topsoil deeper than 60 cm	
WETLAND SOILS	MARSH SOILS	light	11	80 - 90	Values corrected according to drainage conditions (drain. class, cf. x)
		heavy	12	50 - 80	
	MUDDY SOILS	salt water deposits	13	70 - 95	
		freshwater deposits	14	65 - 80	
	BOG SOILS	decomposed	15	45 - 65	
		partly or non-decomposed			
		blanket bog	16	30 - 50	
		raised bog	17	20 - 50	
	FRESHWATER MEADOWS:	described and assessed according to values 1-7 and 11-17. When stratified, the thickness of each topsoil layer is indicated.	With topsoil depths of below 60 cm for soil types 11 - 17, the above assessment scale is used, while the subsoil is described and assessed in the same way as mineral soils. Hence the assessment values related to the topsoil and subsoil are then corrected with respect to drainage conditions, cf x).		
	SALTWATER MEADOWS:	described and assessed according to the values 1-7 (mineral soils)			

x) drainage class	Estimated drainage depth, metres	Correction factor
1	fully drained (above 1 m depth)	1.0
2	0.6 - 1.0	0.6 - 1.0
xx) 3	0.2 - 0.6	0.2 - 0.6
4	morass, no assessment value given	–

xx) To this class belong the normally waterlogged, often inundated areas with their characteristic vegetation.

took an enormous amount of work in the field fixing the trial rates. The selection of sampling sites was based on ordnance survey maps and chartered surveyors' maps showing the local real estate properties. On average, test rates were fixed for every 250-300 hectares of land. The sample sites for the fixing of rates were marked on the ordnance survey maps. At the same time, site sketches were made showing the precise location accompanied by parameters for topsoil texture, subsoil texture, topsoil depth and land assessment values, Figure 2. The site sketch should make it possible to find the sampling sites at a later occasion. When finished, the various subcommittees had undertaken approximately 25,000 sample site ratings across the whole country with the exception of urban areas. All information is today stored at the Danish National Survey and Cadastre (Kort- og Matrikelstyrelsen).

In 1970, the Land Assessment Commission concluded its work and delivered its final report. However, the undertaking of a new national land assessment based on their recommendations was considered to be too expensive at that time. Furthermore, the accomplishment of such a highly comprehensive work was judged to be too time-consuming.

The Danish Soil Classification

From the end of the 1930s until the 1970s, more than 300,000 hectares of agricultural land were lost to other land uses. A certain amount of this land was converted to new forest plantations. Urbanization was increasing 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 the expansion of the road and motorway network. The Regional Planning Act of 1973, and the Local Planning Act of 1975, heralded the start of physical and environmental planning in Denmark. By that time, it had become apparent that agricultural land had to be part of the overall planning process and that there was a need for a nation-wide soil mapping. 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 undertaking of the soil classification in accordance with 5 basic requirements:

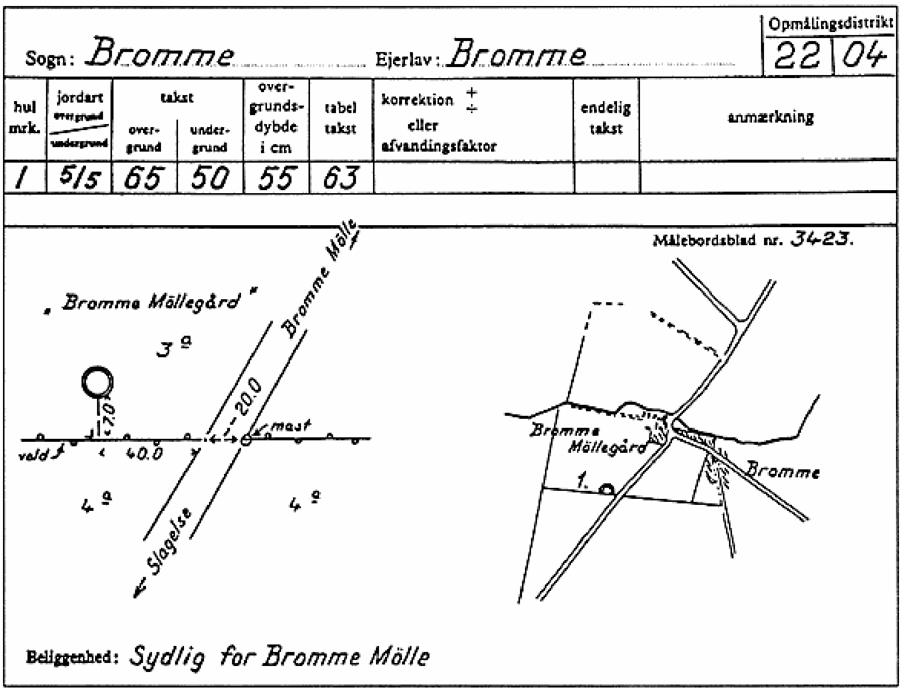

Figure 2: Skite sketch of the precise location of a soil sampling site (Jordboniteringskommissionen 1970).

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

The majority of experts believed that it was best to make a classification focusing 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 plant-breeders from agricultural organizations should be consulted. These consultants would be able to advise on the best sites to carry out soil sampling and to delineate areas of identical soil types.

In December 1975, the Department of Soil Classification (Sekretariat for Jordbundsklassificering, SfJ), was set up in the town of Vejle in East Jutland. Its task was to organize and undertake the work of the Danish Soil Classification. Prior to this date, the county North Jutland had already been classified (Mathiesen 1975), and this county together with Bornholm were initially excluded from further classification. A data bank was established at SfJ comprising two main departments:

- A Soil Map Department producing the basic data maps.
- A 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, the steepness of slopes was determined from 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 analyses were taken at about 36,000

<table>
<tr><th rowspan="2">Map colour code</th><th rowspan="2">Textural class</th><th rowspan="2">JB-no.</th><th colspan="5">% by weight</th></tr>
<tr><th>Clay < 2 μm</th><th>Silt 2-20 μm</th><th>Fine sand 20-200μm</th><th>Sand 20-2000μm</th><th>Humus 58.7% C</th></tr>
<tr><td>1</td><td>Coarse sand</td><td>1</td><td rowspan="2">0-5</td><td rowspan="2">0-20</td><td>0-50</td><td rowspan="2">75-100</td><td rowspan="2"></td></tr>
<tr><td>2</td><td>Fine sand</td><td>2</td><td>50-100</td></tr>
<tr><td rowspan="2">3</td><td>Coarse clayey sand</td><td>3</td><td rowspan="2">5-10</td><td rowspan="2">0-25</td><td>0-40</td><td rowspan="2">65-95</td><td rowspan="2"></td></tr>
<tr><td>Fine clayey sand</td><td>4</td><td>40-95</td></tr>
<tr><td rowspan="2">4</td><td>Coarse sandy clay</td><td>5</td><td rowspan="2">10-15</td><td rowspan="2">0-30</td><td>0-40</td><td rowspan="2">55-90</td><td rowspan="2">< 10</td></tr>
<tr><td>Fine sandy clay</td><td>6</td><td>40-90</td></tr>
<tr><td>5</td><td>Clay</td><td>7</td><td>15-25</td><td>0-35</td><td rowspan="4"></td><td>40-85</td><td></td></tr>
<tr><td rowspan="3">6</td><td>Heavy clay</td><td>8</td><td>25-45</td><td>0-45</td><td>10-75</td><td rowspan="3"></td></tr>
<tr><td>Very heavy clay</td><td>9</td><td>45-100</td><td>0-50</td><td>0-55</td></tr>
<tr><td>Silt</td><td>10</td><td>0-50</td><td>20-100</td><td>0-80</td></tr>
<tr><td>7</td><td>Organic</td><td>11</td><td></td><td></td><td></td><td></td><td>> 10</td></tr>
<tr><td>8</td><td>Atypic</td><td>12</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Table 3. The Danish Soil Classification's textural classes.

sites (by random stratified sampling and 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. Soils in urban areas and forests were not investigated. 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 in all samples and the results stored in databases (Mathiesen 1980).

The agricultural land was classified into 8 soil types according to the texture at 0-20 cm depth, Table 3. Each soil type was then assigned a map colour code MCC 1-8. The remaining areas were divided into urban areas and forest areas. Table 3 shows that the soil types were further subdivided into 12 soil classes (JB 1-12). The 8 soil types were drawn 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 also divided into three slope classes: 1) 0-6°, 2) 6-12° and 3) more than 12°. Experiments have shown that in class 1 mechanized tillage is carried out without any problems, in class 2 minor difficulties may arise, while in class 3 mechanized tillage is almost impossible.

By 1980 approximately 400 soil maps at scale 1:50.000 were available. The maps have been published in colour with soil types printed in brown or yellow colours, the forests printed in green and the urban areas in white (Nørr & Platou 1984). The dominant geology is shown for every 25 ha as a notation in the upper right corner in a grid. The slope classes are indicated by hatching. Figure 3 shows

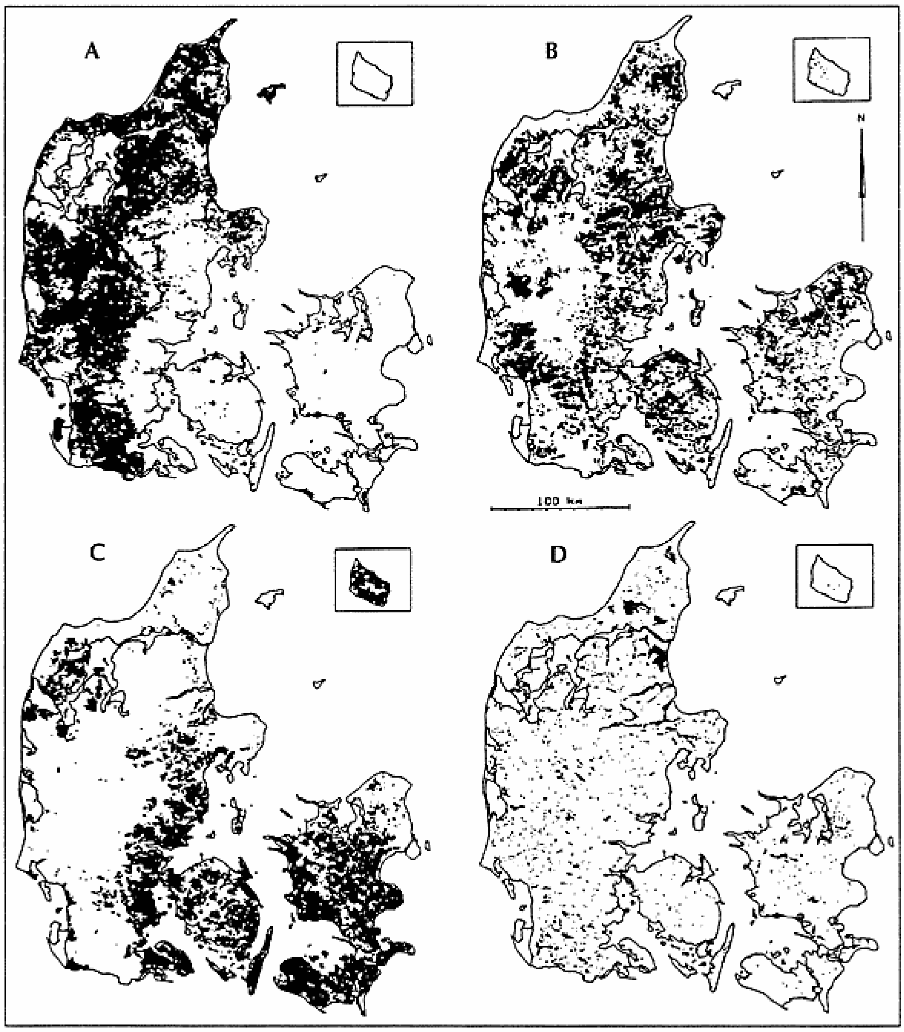

Figure 3: Computer-drawn simplified soil maps of Denmark: A) MCC 1 + 2, B) MCC3, B) MCC 4-6 and D) MCC 7. For further description of the MCC-codes see Table 3.

Landscape type	*Total area km²*	*MCC 1*	*MCC 2*	*MCC 3*	*MCC 4*	*MCC 5*	*MCC 6*	*MCC 7*	*MCC 8*
Saltmarsh	*358*	*11.8*	*6.1*	*8.7*	*3.7*	*11.1*	*45.3*	*13.4*	*0.0*
Littorina	*2495*	*18.8*	*28.2*	*18.0*	*4.9*	*2.0*	*0.9*	*27.0*	*0.4*
Yoldia	*906*	*2.5*	*55.3*	*27.9*	*3.4*	*1.1*	*0.3*	*9.4*	*0.0*
Dune	*1070*	*73.5*	*19.9*	*1.6*	*0.2*	*0.0*	*0.1*	*4.7*	*0.0*
Saale	*4331*	*52.5*	*4.9*	*34.4*	*2.2*	*0.0*	*0.1*	*5.8*	*0.0*
Outwash plain	*3996*	*68.7*	*2.6*	*12.6*	*1.3*	*0.2*	*0.1*	*14.6*	*0.0*
Weichsel	*20938*	*8.3*	*7.5*	*32.6*	*38.6*	*9.5*	*0.4*	*3.2*	*0.0*
Reclaimed land	*426*	*22.1*	*23.2*	*18.9*	*11.3*	*5.1*	*0.5*	*6.3*	*12.6*

Table 4: *An example of an areal calculation based on data from the Danish soil classification. Relationship between landscape type and soil type (map colour code, MCC). Topsoil type (MCC) as % of Landscape Type.*

computer-drawn simplified soil map of Denmark, and Table 4 gives an example of an areal calculation based on the soil and landscape data.

Additional maps were constructed for improving the use of the soil maps in regional planning. A landscape map was delineated from topographic maps at a scale of 1: 100,000. The boundaries between different landscape units were drawn on the basis of 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 marshes, 2) Raised sea-floors, Littorina, and younger marine forelands, 3) Late glacial-raised sea-floors, 4) Dune landscapes, 5) Saale glaciation landscapes, 6) Outwash plains, 7) Weichsel moraine landscapes, 8) Reclaimed areas and 9) Bedrocks. Based on information from geological surveys (field determinations) the texture of the soil at 1 metre depth has been 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 contain normally more than 15% clay and sandy ones less than 10%. The wetlands were outlined 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 are bogs, river valleys, salt marsh areas, littorina deposits and younger marine forelands. They cover roughly 20% of the country.

Pedological investigations: In order to use the soil maps from the Danish Soil Classification in regional modelling it was necessary to create a soil profile analytical database with information on soil physical and chemical properties. Several soil profile investigations have been carried out during the last decade. Among these, two large investigations will be described briefly. In relation to the establishment of the main gas pipeline system from the North Sea gasfields across Denmark in 1981-84, Figure 4, pedological investigations along the lines were carried out (Madsen et al. 1992). About 800 detailed profile descriptions and about 8,000 soil profile classifications were made. In order to improve the use of nitrogen fertilizers in Danish farming, the Danish Agricultural Advisory Centre established a nation-wide 7-km grid, in which the inorganic nitrogen content should be determined periodically (Østergård 1990). The grid was established in 1986 and contains approximately 850 intersections, Figure 4. In these, 50m x 50m testplots were established, in which the content of inorganic nitrogen was determined twice a year at four depths. Based on these data the farmers are advised according to their use of N-fertilizer. In all the intersections pedological investigations have been carried out by The

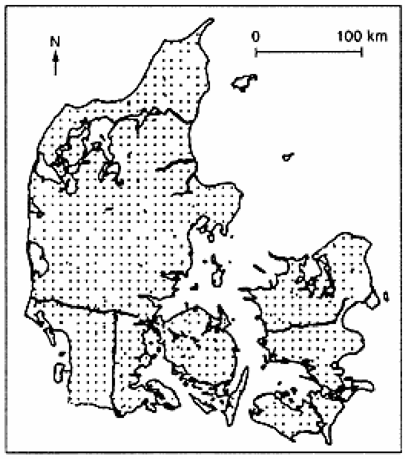

Figure 4: *Location of Danish soil profiles along the gas pipeline and within the 7x7 km grid investigations.*

Bureau of Land Data, the former SfJ, in cooperation with the Institute of Geography, University of Copenhagen, during the years 1987-90. Hereby a nation-wide pedological database has been established.

All the profiles were described in detail according to a system very similar to FAO's Guidelines for Soil Profile Description (Madsen & Jensen 1988). All descriptions are stored in numerical form in the computer system at the Bureau of Land Data. From each profile, samples were taken (according to the horizon sequence) and textural composition, organic matter, pH and calcium carbonate contents were determined. From selected profiles dithionite-citrate and pyrophosphate soluble iron and aluminium, CEC, exchangeable bases, total N and P, clay mineralogy, soil water retention and root densities were also measured. All analytical data and the location of the profiles are stored digitally which makes it possible to combine the results from the profile investigations with the soil maps. Hereby, soil physical and chemical properties can be transferred to mapping units.

The integration and uses of the different soil information in the database system: The soil database system has been widely used for planning of rural land at county- and national levels. First, the soil information was used for protection of valuable agricultural land around expanding urban settlements, but it was soon used in agricultural water planning (Madsen & Platou 1983; Holst & Madsen 1986; Holst & Madsen 1988). Furthermore, it has been used for mapping wind- and water erosion (Madsen et al. 1985; Hasholt et al. 1990), nitrate loss from farmland (Jensen et al. 1993), and marginal land (Madsen & Holst 1987; Svendsen & Pedini 1987). In a pilot project on the development of a new land assessment procedure, Hansen et al. (1992) modelled the potential yield of barley and winter wheat on different soil types defined in the Danish Soil Classification.

Results

The transformation of the Danish Soil Classification's soil map to land assessment maps was carried out in a pilot area, the municipal Tørring/Uldum in the county of Vejle, Fig. 5. The area is situated in the Weichsel glaciation landscape not far from the main stationary line. The morainic landscape dominates but outwash plains are common, too. This area was selected as it contains a wide range of soil types according to the Danish Soil Classification.

The study is exclusively restricted to farmland without permanent shallow groundwaters. Hereby wetlands were omitted as well as forest areas. The land assessment map should only include few classes, and it was decided to group the land into three classes: land of low, medium and

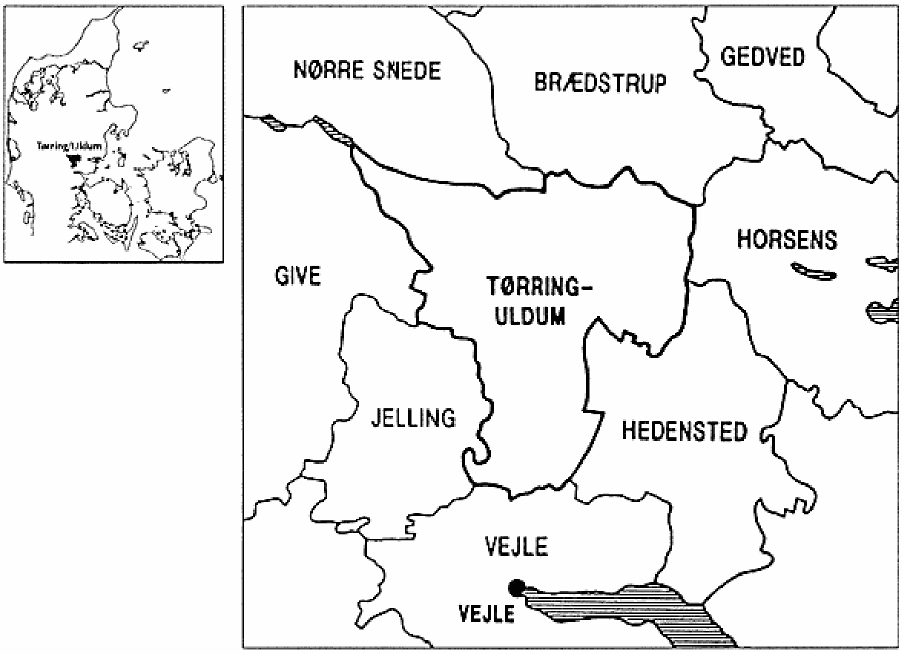

Figure 5: The municipal Tørring/Uldum in the county of Vejle.

high rank. Two different methods are used for the transformation of the soil types to land assessment maps:

- Irrigation need for barley production on the various soil types.
- An allocation of 1949-land assessment values to the various soil types.

First, the mapping units from the Danish Soil Classification defined by a MCC-number (1-8) and a subsoil texture class (sandy or loamy). The irrigation need for the different soil types is alloted the soil types based on the results obtained from the nation wide mapping of irrigation need (Madsen & Holst 1987). Based on these values the soil types are ranked in three groups, a low, medium and high irrigation need. These three groups are then validated by means of the land assessment values obtained by the 1949 Land Assessment Commission.

Land assessment based on irrigation need: Due to liming, heavy manuring and fertilizing and extensive drainage of the land, water depletion during the growth season has become one of the most limiting factors for the plant production. Thus land assessment map based on irrigation need will be a useful tool in regional planning. By combining the Danish Soil Classifications soil and landscape maps and the nation-wide soil profile analytical database containing information on soil water retention, Madsen & Holst (1987) and Madsen et al (1992) calculated the root zone capacity for various combinations of soil types, landforms and the geological origin of the subsoil according to the Danish Geological Survey's maps at scale 1:25,000. By means of climatic data for a 30 year period the mean irrigation need for barley production was calculated for various root zone capacities within four precipitation zones, and Table 5 shows the root zone capacity and irrigation need for spring sown barley in the municipality Tørring-Uldum.

Table 5 shows that a soil of map colour code 1 with or without a clayey subsoil has a very high irrigation need. This is due to a low waterholding capacity, normally between 50 and 80mm. Opposite, the clayey soil types and hereby map colour codes 4, 5 and 6 have rather high root zone capacities even if they have a sandy subsoil. Thus, these soil types have a low irrigation need. Soils of map colour codes 2 and 3 are in the same category if they have a clayey subsoil. If not they are in an intermediate position between the two other categories. Based on the irrigation need it is hereafter possible to group the soil types into 3 land assessment categories:

Group 1: Soil types with an irrigation need for barley production between 60 mm and 80 mm.

Group 2: Soil types with an irrigation need between 40 mm and 60 mm.

Group 3: Soil types with an irrigation need less than 40 mm.

Topsoil/subsoil		*Root zone capacity*	*Irrigation need*
MCC1	*loamy*	*75 mm*	*68 mm*
	sandy	*72 mm*	*70 mm*
MCC2	*loamy*	*150 mm*	*35 mm*
	sandy	*122 mm*	*46 mm*
MCC3	*loamy*	*162 mm*	*31 mm*
	sandy	*112 mm*	*51 mm*
MCC4	*loamy*	*165 mm*	*30 mm*
	sandy	*147 mm*	*36 mm*
MCC5	*loamy*	*171 mm*	*28 mm*
	sandy	*157 mm*	*33 mm*
MCC6	*loamy*	*194 mm*	*23 mm*
	sandy	*174 mm*	*28 mm*

Table 5: *Root zone capacity and irrigation need in mm for spring sown barley in relation to soil type (MCC) and texture of the subsoil.*

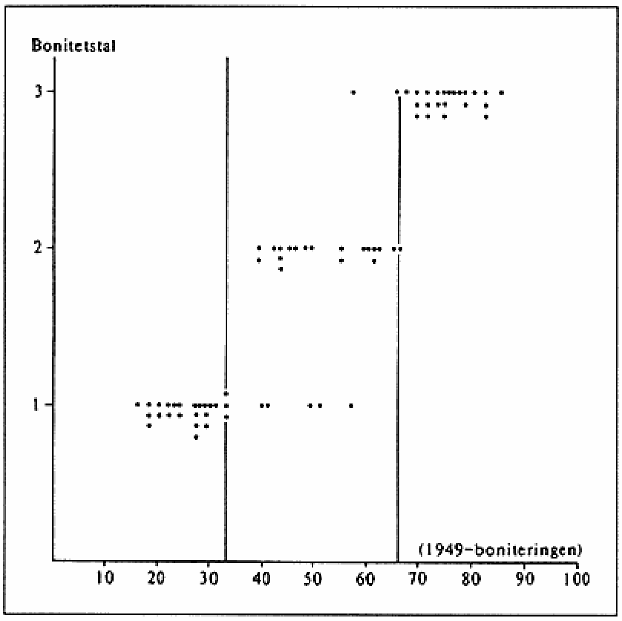

Figure 6: *Land assessment values based on irrigation need versus the values given by the 1949 Land Assessment Commision.*

The differences among the various soil types are due to differences in the soil water retention and the root development. The coarse sandy soils contain significantly less plant available water on a volumetric basis than the loamy ones and sandy subsoils impede root growth compared to the loamy ones. Thus, the good clayey soils contain in some cases more than 3 times as much plant available water than the coarse sandy soils.

Land assessment based on the 1949-Commission's work: The three land assessment classes can be evaluated by correlating these with land assessment values from the 1949 land assessment (Jordboniteringskommissionen 1970). In the test area of Tørring/Uldum 80 test trails from the 1949 Land Assessment Commission work exist. Of these it was not possible to locate two plots because the site description was insufficient. Seven of the test trials were located in wetlands (MCC 7) according to the Danish Soil Classification, and these seven trials were omitted. The remaining 71 trials with land assessment values were superimposed upon the Danish Soil Classification maps and links between the land assessment values (0-100) and the three groups based on map colour code values and subsoil texture were established, figure 6. In this figure the 1949 land assessments were grouped into three classes, as the soil types from the Danish Soil Classification. The following grouping was used (due to the proportionality suggested by the 1949-Commission):

Group 1: land assessment values 0-33
Group 2: land assessment values 34-66
Group 3: land assessment values 67-100

There is clear correlation between the grouping of the Danish Soil Classifications soil types and assessment values obtained from the 1949-land assessment work. At 64 of the 71 locations the classification is identical. Only in group 1 some discrepancies exist, where the 1949 land assessment gives higher ranks than the grouping based on

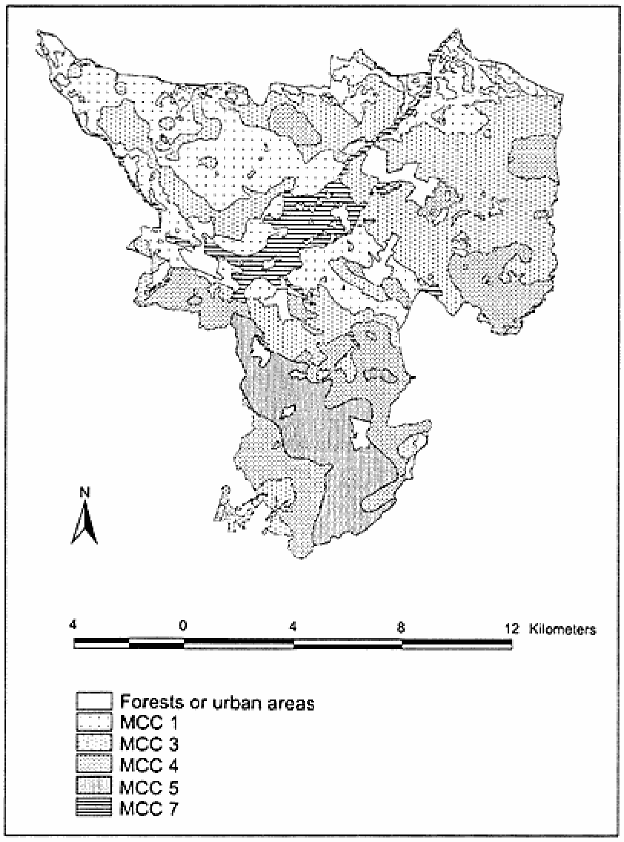

***Figure 7a:** Soil map, Tørring/Uldum.*

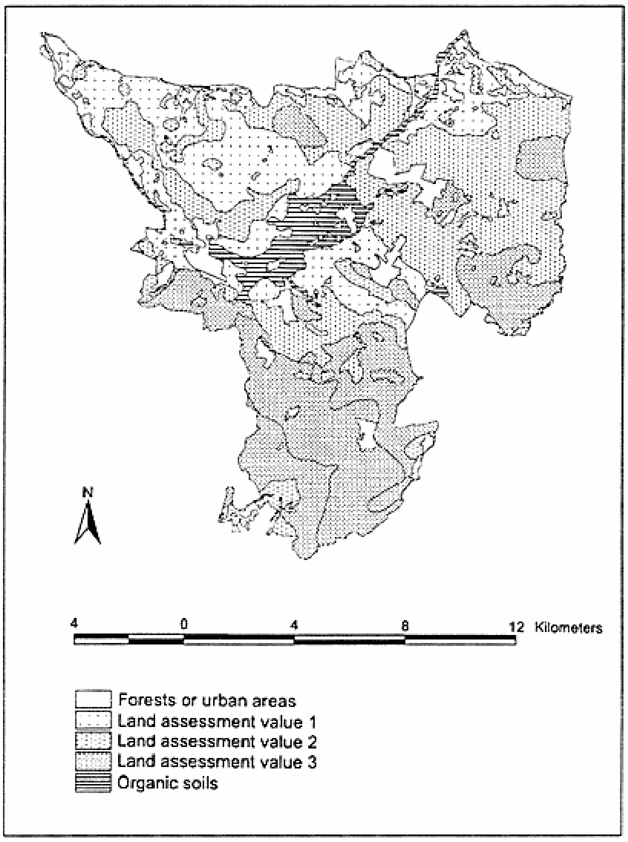

***Figure 7b:** Land assessment map, Tørring/Uldum.*

irrigation need. Some of these discrepancies might be due to failures or misinterpretations of the soil map and due to the fact that some coarse sandy soils have fine loamy sand in the subsoil which do not qualify the subsoil to be clayey, but raise the land assessment value considerably. Furthermore, deep A-horizons might raise the 1949 land assessment values significantly to a value greater than 33. It should be noted that the above-mentioned analysis was based on a small subset of the nation-wide investigation (71 samples out of approx. 25,000). It has not been investigated that the correlation for the Tørring-Uldum data set is valid for the whole country. However, similar investigations carried out for an area in Western Jutland on sandy soils and for an area dominated by clayey soils on Zealand show the same tendency between the grouping of soil types and assessment values (Hedegaard, 1996).

Figure 7 shows the soil map of the municipality Tørring-Uldum and the land assessment map.

Conclusion

It is possible to divide the Danish Soil Classification maps into three well-defined land assessment classes based on irrigation need for barley production. These classes correspond very well to a similar grouping of the soil types based on the test assessment trials investigated by the 1949 Land Assessment Commission.

References

Brink, A. (1926): En ny Hartkornsansættelse af Danmarks Landbrugsjord. *Tidsskrift for Opmålings- og Matrikulsvæsen,* 12, 7: 274-283.

Hansen G.K., N.H. Jensen, C. Jensen, B. Stougaard & S.W. Platou (1992): Jordbundsvariation og jordbonitet i Danmark. *Tidsskrift for Planteavl special serie.* Beretning S2224, Landbrugsministeriet.

Hasholt B., Madsen, H.B., Kuhlman H., Hansen A. & Platou S.W. (1990): Erosion and transport of phosphorous to rivers and lakes. *NPO-Forskning C12,* Miljøstyrelsen, København.

Hedegaard, M.K.B. (1996): Bonitering af landbrugsjord belyst ved Helle, Egtved og Slagelse kommuner som casestudies. *Unpubl. MSc-thesis.* Inst. of Geography, Univ. of Copenhagen. 96 p.

Heering, H.T. (1926): Bonitering af Skove. *Tidsskrift for Opmålings- og Matrikulsvæsen,* 11, 6: 173-177.

Holst K.Å. & Madsen H.B. (1986): The elaboration of drainage class maps covering Denmark. *Landscape and Urban Planning* 13: 199-218.

Holst K.Å. & Madsen H.B. (1988): Modelling the irrigation need. *Acta Agriculturæ Scandinavica* 38,3: 261-269.

Jensen, H. (1944): Matrikulen af 1844. *Tidsskrift for Opmålings- og Matrikulsvæsen,* 17: 5-23.

Jensen H.E., Hansen S., Stougaard B., Jensen C., Holst K.Aa. & Madsen H.B. (1993): Using GIS-Information to translate soil type patterns to agro-ecosystem management - the DAISY model: pp. 401-428. In: *H.J.P. Eijsackers & T. Hamers (ed.): Integrated soil and sediment research: A basis for proper protection.* Kluwer Academic Publisher. 763 p.

Jordboniteringskommissionen (1970): 1. del: om udarbejdelsen af vejledende regler for udførelsen af jordboniteringer. xx del: om kommissionens arbejde med ansættelse af prøvetakster i de enkelte kommuner. *Betænkning nr. 581/1970.*

Landbrugsministeriet (1975): Teknisk redegørelse. Landbrugsministeriet, København

Madsen H.B., Hasholt B. & Platou S.W. (1985): The development of a computerized erodibility map covering Denmark: 143-154. In *G. Chisci & R. P. C. Morgan (ed): Soil erosion in the European community - Impact of changing Agriculture.* Balkema, Rotterdam.

Madsen H.B. & Holst K.Å. (1987): Potential marginal land (In Danish). Marginaljorder og miljøinteresser, *Teknikerrapport nr. 1. Skov- & Naturstyrelsen.* København, Danmark.

Madsen H.B. & Jensen N.H. (1988): Vejledning til beskrivelse af jordbundsprofiler. Landbrugsministeriet Arealdatakontoret.

Madsen H.B., Nørr A.H. & Holst K.Aa. (1992). The Danish Soil Classification. *Atlas of Denmark* I,3. Reitzel, Copenhagen.

Madsen H.B. & Platou S.W. 1983. Land use planning in Denmark. *Nordic Hydrology* 14, 267-276.

Mathiesen, F.D. (1974): Bonitetsanalyse af landbrugsjord - Bornholm. *Landboorganisationernes kontaktudvalg for landskabsplanlægning,* Rønne.

Mathiesen, F.D. (1975): Klassificering af landbrugsjord - Nordjyllands Amt. *Landboorganisationernes kontaktudvalg for landskabsplanlægning,* Ålborg.

Mathiesen F.D. 1980: Soil classification in Denmark. Its results and applicability. *EEC-report on land resource evaluation EUR 6875.*

Mosbech, J.L. (1922): Nogle Meddelelser om det ældre sønderjyske Matrikulsvæsen. *Tidsskrift for Opmålings- og Matrikulsvæsen,* 9, 10-11: 229-262.

Nørr, A.H. & S.W. Platou (1984): Edb-baseret kortproduktion ved Landbrugsministeriets Arealdatakontor. *Landinspektøren* 32,3: 101-118.

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Hansen G.K., N.H. Jensen, C. Jensen, B. Stougaard & S.W. Platou (1992): Jordbundsvariation og jordbonitet i Danmark. *Tidsskrift for Planteavl special serie.* Beretning S2224, Landbrugsministeriet.

Hasholt B., Madsen, H.B., Kuhlman H., Hansen A. & Platou S.W. (1990): Erosion and transport of phosphorous to rivers and lakes. *NPO-Forskning C12,* Miljøstyrelsen, København.

Hedegaard, M.K.B. (1996): Bonitering af landbrugsjord belyst ved Helle, Egtved og Slagelse kommuner som casestudies. *Unpubl. MSc-thesis.* Inst. of Geography, Univ. of Copenhagen. 96 p.

Heering, H.T. (1926): Bonitering af Skove. *Tidsskrift for Opmålings- og Matrikulsvæsen,* 11, 6: 173-177.

Holst K.Å. & Madsen H.B. (1986): The elaboration of drainage class maps covering Denmark. *Landscape and Urban Planning* 13: 199-218.

Holst K.Å. & Madsen H.B. (1988): Modelling the irrigation need. *Acta Agriculturæ Scandinavica* 38,3: 261-269.

Jensen, H. (1944): Matrikulen af 1844. *Tidsskrift for Opmålings- og Matrikulsvæsen,* 17: 5-23.

Jensen H.E., Hansen S., Stougaard B., Jensen C., Holst K.Aa. & Madsen H.B. (1993): Using GIS-Information to translate soil type patterns to agro-ecosystem management - the DAISY model: pp. 401-428. In: *H.J.P. Eijsackers & T. Hamers (ed.): Integrated soil and sediment research: A basis for proper protection.* Kluwer Academic Publisher. 763 p.

Jordboniteringskommissionen (1970): 1. del: om udarbejdelsen af vejledende regler for udførelsen af jordboniteringer. xx del: om kommissionens arbejde med ansættelse af prøvetakster i de enkelte kommuner. *Betænkning nr. 581/1970.*

Landbrugsministeriet (1975): Teknisk redegørelse. Landbrugsministeriet, København

Madsen H.B., Hasholt B. & Platou S.W. (1985): The development of a computerized erodibility map covering Denmark: 143-154. In *G. Chisci & R. P. C. Morgan (ed): Soil erosion in the European community - Impact of changing Agriculture.* Balkema, Rotterdam.

Madsen H.B. & Holst K.Å. (1987): Potential marginal land (In Danish). Marginaljorder og miljøinteresser, *Teknikerrapport nr. 1. Skov- & Naturstyrelsen.* København, Danmark.

Madsen H.B. & Jensen N.H. (1988): Vejledning til beskrivelse af jordbundsprofiler. Landbrugsministeriet Arealdatakontoret.

Madsen H.B., Nørr A.H. & Holst K.Aa. (1992). The Danish Soil Classification. *Atlas of Denmark* I,3. Reitzel, Copenhagen.

Madsen H.B. & Platou S.W. 1983. Land use planning in Denmark. *Nordic Hydrology* 14, 267-276.

Mathiesen, F.D. (1974): Bonitetsanalyse af landbrugsjord - Bornholm. *Landboorganisationernes kontaktudvalg for landskabsplanlægning,* Rønne.

Mathiesen, F.D. (1975): Klassificering af landbrugsjord - Nordjyllands Amt. *Landboorganisationernes kontaktudvalg for landskabsplanlægning,* Ålborg.

Mathiesen F.D. 1980: Soil classification in Denmark. Its results and applicability. *EEC-report on land resource evaluation EUR 6875.*

Mosbech, J.L. (1922): Nogle Meddelelser om det ældre sønderjyske Matrikulsvæsen. *Tidsskrift for Opmålings- og Matrikulsvæsen,* 9, 10-11: 229-262.

Nørr, A.H. & S.W. Platou (1984): Edb-baseret kortproduktion ved Landbrugsministeriets Arealdatakontor. *Landinspektøren* 32,3: 101-118.

Pedersen, V.E. (1932): Jordbonitering og Jordbeskatning. *Tidsskrift for Opmålings- og Matrikulsvæsen*, 13, 3: 57-69.

Pedersen, V.E. & J. Steffensen (1966): Lærebog i matrikelvæsen, 1. del: matrikelvæsenets historie og administration. DSR - Forlag, København 1966.

Rothe, C. (1844): Beretning om den i Aaret 1844, for Kongeriget indførte nye Skyldsætnings Væsen og Historie. Kjøbenhavn 1844.

Svendsen T.B. & Pedini M. (1987): Relationship between soil types and forest production. Marginaljorder og Miljøinteresser, *Teknikerrapport nr. 4. Skov- og Naturstyrelsen*, København, Danmark.

Sørensen, O.S. (1930): Landinspektørernes Stilling i Forhold til Vurderingsarbejderne, særlig med Henblik paa en eventuel ny Bonitering. *Tidsskrift for Opmålings- og Matrikulsvæsen*, 12, 9: 331-346.

Østergård H.S. (1990): Kvadratnettet for nitratundersøgelser i Danmark 1986-89. Landbrugets Rådgivningscenter, Landskontoret for Planteavl, Skejby, Århus.