level of expence, uncertainty of investment, and problems concerning the responsibility for protecting the environment for future generations (9).

The specialization has also been distributed geographically according to the possibilities of the various territories. The most characteristic feature is that the specialized cattle-farms continuously have been spreading towards the west. This is connected with as well the many grazing areas in the western and northern Jylland as that it is far more difficult for landowners in these districts to get supplementary paid work than for farmers who live nearer the industrial towns of East Jylland and the Isles. On the contrary most of the farms without any husbandry are to be found towards the east where the soil is better fitted for plant growing and where city activities may secure employment to many hands.

RESUMÉ

En permanent landbrugsgeografisk inddeling?

Byg er i dag den vigtigste kornårt i landet og udgør 59% af det samlede landbrugsareal. Efter en årrækkes forbud er det fra 1979 igen tilladt at dyrke vinterbyg mod, at den behandles mod meldug, og denne afgrøde er atter i fremgang.

Hveden derimod bliver mere og mere østorienteret, og den landbrugsgeografiske forskel mellem Øst- og Vestdanmark har vist sig stabil gennem århundreder, idet den manifesterede sig f.eks. i 1600-årene i udbredelsen af de forskellige dyrkningssystemer (fig. 1); den synes endog at øges en smule (fig. 6). Isodenskortet fra 1980 (kort over hvede + byg i procent af det samlede omdriftsareal) viser påfaldende lighedspunkter med tilsvarende kort fra 1907, 1937-39, 1946, 1951, 1962 og 1971.

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Digital Analysis of Landsat Images for Land Use Mapping in Denmark

Vibeke Niels-Christiansen and Kjeld Rasmussen

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The applicability of Landsat-data for land use mapping in Denmark is analysed on the basis of a data set consisting of six superimposed images from the growing season 1982. The temporal variation in spectral signatures of crops and land use classes have been studied, and it is shown that classification accuracies of 80% can be obtained using Landsat against a 90% accuracy when data with 20-m resolution become available.

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The application of satellite images for the purpose of mapping land use has become a standard procedure in some countries, where conditions are favourable. In several European countries experiments have shown, however, that this methodology may not yet be well suited under the conditions encountered (see f.i. Wastenson et al. (1980), and Lichtenegger (1980)). The main limitations are: 1) the small size of the »typical« European field, 2) the high frequency of cloud cover, particularly in northern Europe, and 3) the complexity of the scene to be analysed, i.e. the great variety of crops and agricultural practices.

This paper intends to extract some important results from a study of the applicability of satellite images for land use mapping in Denmark. For full documentation of the study the reader is referred to the study reports (Rasmussen, 1982, Rasmussen & Niels-Christiansen, in press). The study has aimed at 1) identifying the optimal methodology to be applied and 2) the main limitations to the quality of the results.

The satellite images applied in this study have been 6 Landsat MSS scenes from the growing season 81/82 supplemented by 3 scenes from 80/81. It has been recognized from the beginning that attempts to base a semi- or fully operational land use mapping system on Landsat data are

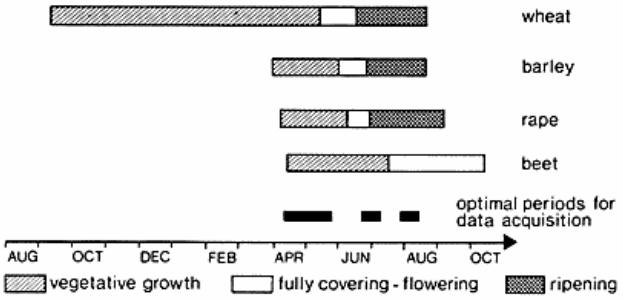

Fig. 1. Crop calendar for selected crops with emphasis on phenological stages important for crop identification. Optimal periods for data acquisition are indicated.

Fig. 1. Afgrødekalender for udvalgte afgrøder med angivelse af udviklingstrin af betydning for afgrødeidentifikation. Optimale optagelsestidspunkter for satellitbilleder er vist.

precluded because of the insufficient spatial resolution of the images. Thus, test areas characterized by rather large fields have been chosen in order to simulate the improved spatial resolution of sensors such as Landsat Thematic Mapper and the SPOT multispectral scanner. Utilization of the temporal development of crops and land use classes as a basis for identification has been emphasized.

THE DATA BASIS

Six Landsat scenes from the growing season 81/82, covering most of the island of Funen, have been applied. The acquisition dates were 17/10 81, 27/3 82, 14/4 82, 8/6 82, 14/7 82, and 31/7 82. Considerable cloud cover is present on the images from 17/10 81 and 14/4 82 which limits the use of these images. As a supplement, three Landsat scenes from the growing season 81/81, covering most of the island of Zealand, have been utilized. Acquisition dates of these scenes were 15/5 81, 9/7 81, and 1/9 81. The six 81/82-images as well as the three 80/81-images have been digitally superimposed with an accuracy of appr. 15 m (r.m.s.-value of misregistration in line- and sample directions). Documentation of the method applied and the accuracies obtained can be found in Hansen (1982) and Rasmussen & Niels-Christiansen (in press). Extensive land use mapping by conventional methods has been performed, particularly in the summer of 82 for the Funen test area.

SPECTRAL SIGNATURES OF LAND USE CLASSES

Based on the Landsat images and the ground truth available, a study of the temporal development of spectral signatures of Danish crops and land use classes has been made in order to 1) evaluate their separability and 2) identify the optimal timing of data acquisition. In fig. 1 is shown an approximate crop calendar for the most important crops in the test areas for the 81/82 growing season. The found optimal timing of satellite image acquisition is

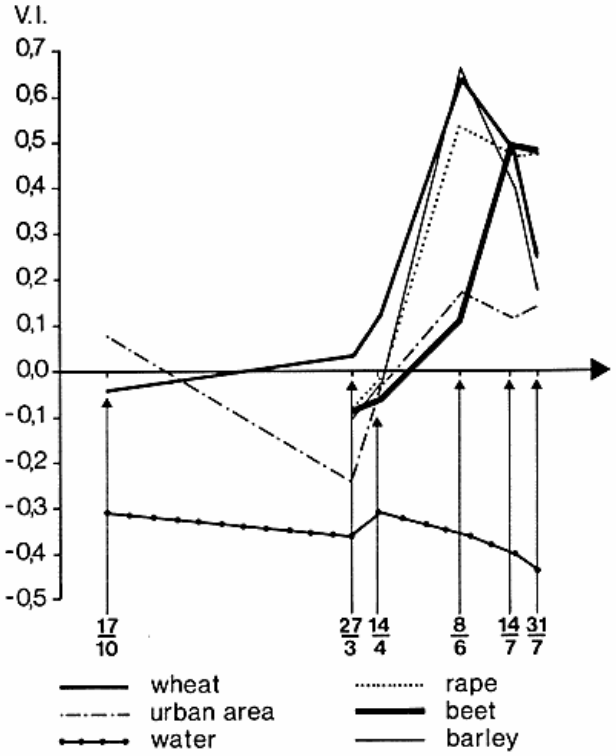

Fig. 2. Vegetation Index (VI) for selected crops and land-use classes as a function of time.

Fig. 2. Vegetations Index (VI) for udvalgte afgrøder og arealanvendelsesklasser vist som funktion af tiden.

marked. A spring acquisition will make separation between autumn- and spring-sown crops possible, whereas data from end of June/beg. of July and end of July/beg. of August will make discrimination of crops within these two categories possible. Since the phenological stage of a crop is a very important determinant of spectral signature, it is not surprising that the optimal timing of data acquisitions corresponds to periods where various crops are in different stages. The validity of the results, shown in fig. 1, is of course limited because cloudfree Landsat images are not available for substantial parts of the 81/82 growth season.

Green vegetation is characterized by high reflectance in the near-infrared region (Landsat bands 6 & 7) and low reflectance in the red region (Landsat band 5), when compared to bare ground. An index, called the vegetation index (VI), has thus been constructed (Rouse et al., 1973):

$VI = b7-b5/(b7 + b5)$

where b5 and b7 respectively denote the (uncorrected) grey level values of Landsat bands 5 and 7. VI has the following properties: 1) It varies between -1 and +1, with high values for picture elements with an extensive green vegetation (high values of leaf area index), and low (even negative) values for unvegetated surfaces. 2) Effects of terrain slope and aspect, sun angle and light haze have been partly removed.

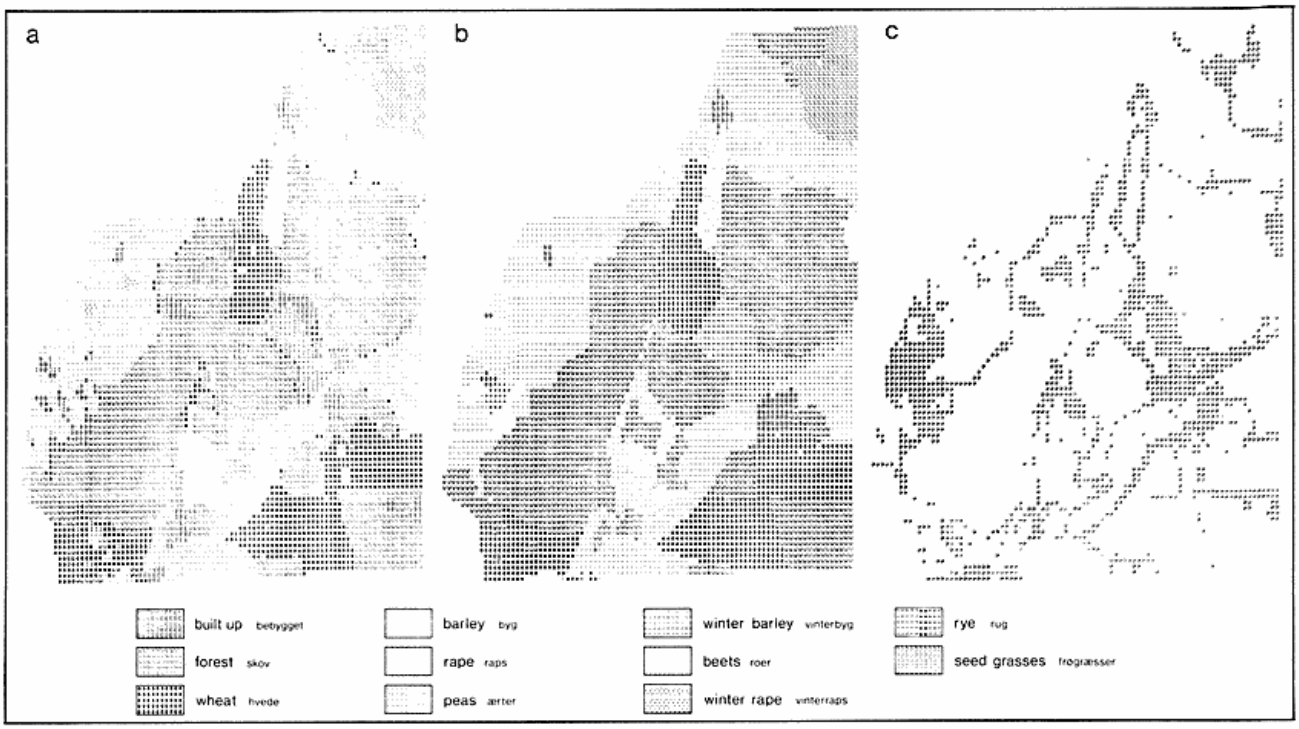

Fig. 3. The result of a crop classification, based on a multitemporal Landsat data set, for a small test area (a), compared to ground truth (b). The misclassified pixels are outlined in (c). The test area covered is approx 5×5 km, thus the scale differs considerably between the X- and Y-directions.

Fig. 3. Resultatet af en afgrødeklassifikation, baseret på et multitemporalt Lnadsat datasæt, for et lille testområde (a), sammenlignet med et afgrødekort fremstillet ud fra feltobservationer (b). De fejlklassificerede billedelementer er vist i (c). Testområdet er ca. 5×5 km, dvs. at den horisontale og vertikale skala er væsentligt afvigenden.

VI does not, of course, express all of the information contained in the four Landsat bands, and separability of crops and land use classes can therefore not be evaluated on the basis of their temporal variations in VI alone. By expressing the degree of vegetation cover of the surface, it does, however, contain important information, and a replacement of the four bands by a single index eases the graphical representation of temporal variations in spectral signatures of crops. Fig. 2 shows the variation of VI through the growth season 81/82 for some important crops and land use classes. Some of the ambiguities apparent from Fig. 2 can be resolved, when applying data from mid-May, such as available for the 80/81 growth season.

Thus, as more fully discussed in Rasmussen & Niels-Christiansen (in press), if data from a few critical periods are available, almost all Danish crops and land use classes can be separated with reasonable accuracy. It is also obvious from Figs. 1 & 2 that discrimination of a reasonable number of classes on the basis of one image alone is precluded. Analysis of a time-series of images, so-called multitemporal analysis, will therefore be a necessity.

LAND USE CLASSIFICATION TEST

For small areas, for which totally covering ground-truth has been collected, tests of four classification approaches have been made: Two supervised classification methods, the minimum (euclidian) distance and the maximum likelihood (with equal a priori probabilities of all classes) methods, have been applied. Two methods of generating

Classification algorithm	Source of statistics on spectral signatures: Direct utilization of ground truth information	Source of statistics on spectral signatures: Unsupervised classification followed by selection of representative classes
Test area: Ravnholt		
Maximum likelihood algorithm	69.5	83.3
Minimum distance algorithm	71.7	82.9
Test area: Gislev		
Maximum likelihood algorithm	67.5	78.5
Minimum distance algorithm	77.3	78.5

Table 1. The percentage of correctly classified picture elements in two test areas. Combination of two classification algorithms and two methods of generating statistics on spectral signatures have been tested.

Tabel 1. Procentdelen af alle billedelementer i to testområder som er korrekt klassificeret. Kombinationer af to klassifikationsalgoritmer og to måder at generere statistik, beskrivende arealanvendelsesklassers spektrale karakteristika, er blevet testet.

statistics on land use classes for use by the classification algorithm have been applied as well, of which the first one is based on direct utilization of ground truth, while the second one utilizes unsupervised classification followed by selection of the classes, which are judged as representative of true land use classes.

In table 1 are shown the overall classification accuracies obtained by using the above-mentioned methods on a 16-banded multitemporal image, which includes data from 27/3, 8/6, 14/7, and 31/7 82. An approximate overall accuracy of about 80% is obtained for two test areas which, as mentioned, have relatively large fields. Figs 3a and 3b show line-printer maps of ground truth data and classification results (minimum distance classification), and in Fig. 3c the misclassified areas are outlined.

The causes of misclassification have been analysed: As shown by Fig. 3c most misclassifications are of »geometrical« nature, situated along boundaries between land use classes. This indicates that the spatial resolution of the data and the digital overlay of several images are the dominating sources of errors. However, misclassifications of »non-geometrical« nature can also be observed. Some of these are caused by non-optimal image analysis procedures, while only a few are believed to be caused by non-separability of classes.

Concludingly, the classification tests indicate that accuracies of perhaps 90% will be obtainable, when images with 20-m resolution become available, provided images can be acquired with near-optimal timing.

IMPROVED IMAGE ANALYSIS METHODS

The image analysis procedures utilized above are quite commonplace and were originally developed for monotemporal analysis. Methods based on hierarchical or decision-tree concepts, particularly suited for multitemporal analysis, are being developed and will be applied to the data set. Further developments are being considered towards so-called »expert systems« (Metzler et al., 1983), involving utilization of information from other sources in the classification process in order to simulate an »intelligent« decision process.

OUTLOOK

The developments in the space- and computer technologies are extremely fast and ensure continued improvements of the satellite images and of the computers necessary to handle them. It can be foreseen that within a few years data from the French SPOT satellite will enable a semioperational land use mapping system to be established. Not only will SPOT provide images with the necessary spatial resolution, it will also improve chances of getting data at the optimal acquisition times, because of its off-nadir viewing capabilities. Whether the value of such a system may justify its costs is not known, however. Inclusion of a crop monitoring aspect – rather than just identification – in the system may increase its value considerable.

Combination of such a system with data from the microwave part of the spectrum will also increase its potential value, in particular because of the cloud penetration of synthetic aperture radar.

Both the application of off-nadir data from SPOT and synthetic aperture radar (from the European ERS-1 satellite planned for 1988) will, however, demand further studies of the interaction between electromagnetic radiation and vegetation canopies.

Resumé

Der gøres rede for en analyse af anvendeligheden af Landsat MSS digitale billeder til kortlægning af arealanvendelsen i Danmark. Seks billeder fra vækstsæsonen 1982 er blevet overlagt digitalt, og den temporale variation i de spektrale reflektionsegenskaber af arealanvendelsesklasser og afgrøder udnyttes som basis for klassifikation. For et testområde på Fyn opnås en klassifikationsnøjagtighed på 80%, og det påvises, at en nøjagtighed på 90% vil kunne forventes, når fremtidige data med 20m's rumlig opløsning samt forbedrede procedurer for billedbehandling bliver bragt i anvendelse.

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