MONITORING SOIL EROSION USING LAND COVER AND TILLAGE DERIVED FROM SATELLITE IMAGERY

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Abstract

Under the North Sea Agreement, Norway was obliged to reduce the discharge of nutrient salts from agricultural fields by 50% within 1995. Remote sensing from satellites can be used to monitor soil tillage in the areas concerned. An experiment was carried out which shows that it is possible to classify the different agricultural classes with a high degree of accuracy using LANDSAT TM images. However, cloud conditions in late autumn makes it interesting to investigate the use of satellite SAR images to detect tillage. The results of classifying SAR images which have been speckle reduced, show that ploughed and stubble fields can be discriminated with a high degree of confidence when the soil moisture level is high. The best result is obtained using a field-by-field classification method. In an operational system, geocoded SAR images should be used as a supplement to the optical images.

1. Introduction

Under the North Sea agreement, Norway had undertaken to cut the discharge of nutrient salts to the North Sea by 50% within 1995. One of the main sources of pollution is nutrient salts from fields tilled in the autumn. The government wishes to reduce the tillage in the autumn in regions vulnerable to erosion. In order to follow up on the initiative, the Norwegian Pollution Authority (SFT) wants to monitor soil tillage in areas drained to the North Sea. In colaboration with the Norwegian Institute of Land Inventory (NIJOS), Center for Soil and Environmental Research (Jordforsk) and the Norwegian Defence Research Establishment (NDRE), NR has carried out an experimental project in order to determine whether this is possible, and how satellite monitoring can be implemented as an operational activity.

The objective for using remote sensing in this application is to monitor the land use and tillage that is present most of the winter season for all or most agricultural areas in Norway. This information is used as input to a soil erosion model that estimates the soil erosion for each agricultural unit.

The most common agricultural classes in Norway are ranked in the following way according to their erosion potential (in descending order): ploughed fields, autumn grain, harrowed fields, stubble fields, and meadow/pasture. Hence, these classes must be discriminated using remote sensing imagery.

2. Optical experiments

Experiments were carried out in the period 1990-1993 using optical images (Solberg and Strand, 1992). Image data from SPOT HRV (XS) and Landsat Thematic Mapper (TM) was tested. Thorough ground truthing was performed, and the resulting maps were compared to the classification results of the image data. The classifier used was Haslett's contextual classifier (Haslett 1985) taking into account the pixel neighbourhood.

It was found that the classes autumn grain and meadow/pasture could not be discriminated using SPOT data. The two classes were joined into one aggregate class: green vegetation. The results showed an overall accuracy of 80-90%.

The general experience with Landsat was that TM data gave better discrimination of the classes, and it was possible to discriminate autumn grain from meadow/ pasture. Landsat TM gave an overall accuracy of 85-95%.

It will always be a problem to detect the latest tillage when using image data from the autumn. The latest ploughing and harrowing is often limited by the first snow, and the imagery has to be taken before the snow covers the ground. Therefore, a strategy to acquire the imagery in the spring was tested. It showed that data obtained in the autumn discriminate much better between the classes than data obtained in the spring. The results directed attention to the problem of changing characteristics of each class as a function of time. Changes are present is almost all classes:

- Ploughed fields tend to get brighter with time due to surface dry-up and humus washed away uncovering brighter mineral material
- The spectral influence of the underlying soil in autumn grain is decreasing rapidly with time
- Stubble and harrowed fields change continuously due to the growth of weeds and decay of dead organic material
- The chlorophyll content in meadow/pasture varies due to natural seasonal changes in temperature and soil moisture.

The overall conclusion was that the best results would be achieved when at least two Landsat TM images, acquired in September/ October and November, are used. (See Figure 1 for an example of TM data from one of the test areas.)

3. Radar experiments

The optical experiments showed that the weather conditions in Norway in the late autumn make it difficult to obtain cloud-free images, and are thus a limiting factor. Therefore, an experiment was carried out during the autumn 1991 using ERS-1 Synthetic Aperture Radar (SAR) images (Solberg 1992, Weydahl 1992). The SAR is able to observe the Earth's surface regardless of the atmospheric conditions, cloud cover and daylight. The ERS-1 SAR instrument has only one band (one frequency at 5.3 GHz and VV-polarization). In general, multiband data (multi frequency and multi polarization) give the best results, but the available data from operational SAR

Figure 1. Landsat TM image band 4 (near infrared) acquired on October 20, 1991 over Kjeller, one of the soil erosion monitoring test sites.

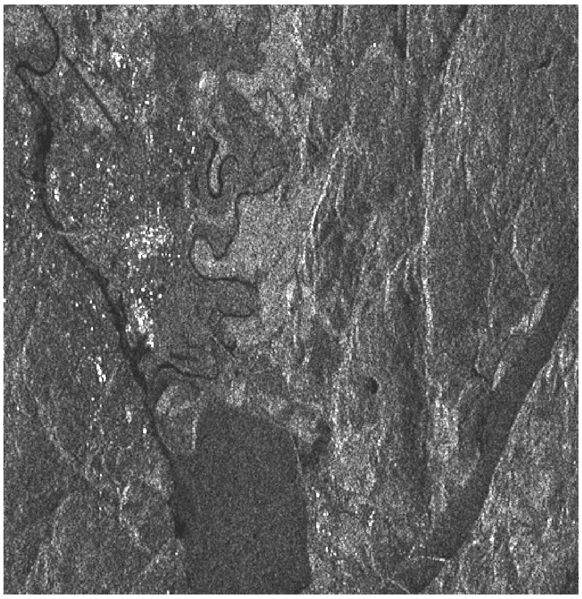

Figure 2. ERS-1 SAR image of the same area acquired on October 17, 1991. The ploughed areas are the bright areas along the mid vertical axis of the image. Copyright original data: ESA/Eurimage/TSS/Spacetec.

systems will be limited to a single band for several years. The idea was therefore not to replace optical remote sensing, but to supplement the latest possible optical acquisition with SAR imagery when necessary.

Comparing pixel mean values and variance in the SAR images for some test fields showed that the classes stubble, meadow/ pasture, and autumn grain could not be discriminated. It is also possible that some harrowing will give a backscatter similar to ploughed fields, and some meadow/pasture will give a backscatter similar to stubble fields. The conclusion drawn was that the classes should be joined into two aggregate classes: "ploughed" and "stubble". (See Figure 2.)

Classifying SAR images based on their pixel grey level values only, will in many cases require speckle noise reduction. The noise reduction algorithm should remove the noise without reducing the resolution of the image too much. Four noise reduction filters were tested: Mean, Median, Lee (Lee 1980 and 1981) and Crimmins (Crimmins 1985). All filters gave significantly improvements over the unfiltered image in classification of ploughed (bright) areas (5-10% improvement).

The ERS-1 SAR images acquired during the autumn of 1991 showed large temporal changes in agricultural areas. This was due to harvest, tillage and natural variations in soil moisture and temperature. Increased soil moisture in ploughed fields gave a 3-6 dB increase in the backscatter value compared to stubble or frozen soil. Therefore, the best SAR acquisition time will be in late autumn after heavy rainfall when the ground is not frozen, or when the the surface is melting after a period of frost. In an operational system, geocoding and radiometric correction of SAR images will be necessary to correct for topographical effects in hilly areas.

Computing statistics for each field suggested the idea of classifying each field as an entity, as a single homogeneous object. For this kind of classification, a priori information about the field boundaries must be available. A field boundary can e.g. be a property border, a road or a river. An operational system for soil erosion has to include a GIS data base with information defining the agricultural areas. A natural extension of the GIS data can be a map of field boundaries. A classification of each field could then be performed automatically. An assumption for this idea to be valid is that each field contains only one class.

The results from a field-by-field classification gave a rate of correct classification of 89% for ploughed and 100% for stubble fields for relatively flat areas in a November SAR image. The corresponding classification rates for the contextual classifier (pixel-by-pixel classification) were 66% for ploughed and 73% for stubble. This method is obviously superior to normal pixel-by-pixel classification.

4. Discussion and conclusions

The classification experiments have shown that a reliable operational system for monitoring soil erosion can be based on satellite imagery as the main data source. When designing an operational system, the following factors require special attention:

- The optical spectral characteristics of the relevant classes will change continuously. In order to get reliable classification results it is necessary to select the right time for optical image acquisition and use at least two acquisitions.
- The Landsat TM image covers a scene almost ten times larger than SPOT HRV (185 × 185 km compared to 60 × 60 km) for only twice the cost of one SPOT image. TM has also got the best spectral resolution and sufficient spatial resolution for this particular task.
- Due to weather conditions in the late autumn, SAR images should be used as a supplement to the optical images. ERS-1 SAR images acquired during the autumn of 1991 showed large temporal changes in agricultural areas. This was due to harvest and tillage. Increased soil moisture at ploughed fields gave a 3-6 dB increase in the backscatter value compared to stubble or frozen soil. Therefore, the best SAR acquisition time will be in late autumn after heavy rainfall and when the ground is not frozen, or when the the surface is melting after a period of frost.
- Speckle reduction filters should be used to increase the overall classification result of SAR images. By using a field-by-field classification, accuracy of 89% for ploughed and 100% for stubble were obtained for areas with some slope (slope angle < 10%), compared to 84% and 93%, respectively, for completely flat areas using a pixel-by-pixel classifier.
- In an operational system, geocoding and radiometric correction of SAR images will be necessary to correct for topographical effects in hilly areas.

A prototype system for soil-erosion monitoring has been developed. The system employs Landsat TM data from two acquisitions. SAR data is not yet applied due to the necessity of further research on radiometric correction for terrain effects. The prototype system involves the three institutes NR, NIJOS and Jordforsk who are responsible for, respectively, the satellite image analysis, soil erosion modelling and statistical erosion analysis. It is expected that the system will be run by a single or two institutes in the future when more experience is gained and fine-tuning of the system is completed.

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