

CROP MONITORING FOR AGRICULTURAL PROPOSITIONS

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Abstract:

The eighties are characterized by an increasing overproduction in agriculture within the Common Market. Restriction of production is under consideration now. This may be obtained by subsidies on more extensive production (lower yields) or by letting fields lie fallow (no yields). In all cases governmental agencies have to supervise such regulations.

A powerful monitoring system may be offered by remote sensing. Satellites are orbiting earth regularly. Optical measurements can be used either to classify an area or to estimate or predict yield. An important restriction to optical satellites are their weather-dependency. Microwave satellites can offer an important addition to optical measurements. Since radar is less weather-dependent, the frequency of observation can be increased. Research has to be focussed on the combined use of both kinds of information.

Finally, the fast growth in the field of geographic information systems (GIS) will offer the possibilities to incorporate foreknowledge into a monitoring system and to combine information from several sources.

1. INTRODUCTION

The last decade it is becoming more and more obvious that the ceiling of agricultural growth has been reached within the European Common Market. Intensifying, specialization and growth of production are being criticized seriously. Phenomenons like pollution of soil, water and air, decline of the variety of flora and fauna, levelling of the landscape and a decreasing quality of food are being related to the overproduction.

The primary cause of the increasing overproduction within the Common Market is the considerable growth of the productivity, i.e. the productivity of arable land, yielding higher crop yields. Production has increased more than the consumption of food within the Common Market. It may be expected that the discrepancy between the improvement of land productivity and the increase in food consumption will grow even more in the next years. The overproduction concerns primarily cereals and to a less extent sugarbeet. The Common Market will be forced to reform its agricultural policy severely.

Problems that have to be overcome with such a reform are primarily related to landbound agricultural production. The extent of this production has to be limited, which means that either yields per hectare must be decreased (extensive production) or the acreage must shrink (extensive rotation or change of land use).

2. ACREAGE CONTROL

Crop yield per hectare is only to some extent sensitive to the price ratios of the harvested product and the yield increasing means such as fertilizers and pesticides. The range in yield levels, for which an economic weighing of the optimal yield based on this price ratio is relevant, is small. The margin of price situations, in which the farming is non-paying or in which it is economical to aim at the highest yields, is very small. Recent developments in science and cultivation technique seem to concentrate on a complete control of growth conditions and extended application of biological disease and pests control with the ultimate goal to achieve the highest possible yield with lower costs of yield increasing means. As a result economic margins will even be smaller. This means that on short- and long-term little effect is to be expected of financial stimulus to decrease yields of agricultural crops. On the other hand, experiments with so-called integrated farming indicate that incomes can be maintained with less intensive production techniques for some crops. The latter is also advantageous from a point of disease control. Experiments have shown that yield of e.g. winterwheat may decrease with about 10% and of potatoes with about 25% by applying integrated farming.

In practice, acreage control (landretirement) will be the main tool for limiting agricultural production. Shrinking the acreage of arable land may be achieved by fallowing for short-term acreage control and by changing its use into forest, recreational or environmental facilities on a long-term.

The individual farmer may execute an order for acreage control in two ways. Firstly, he can fallow the same land each year and change its use. Secondly, he can incorporate acreage control in his rotational scheme. In the first situation, the acreage of all crops will decrease. In the second situation, the obligatory fallow may either compete with the crops with the lowest credit balance, which means that cereals will disappear first, or result into a less intensive rotation. The latter is particularly advantageous in relation to soil disease problems. An obligation to fallow could e.g. mean that at least 20% of the total acreage of a farm must be fallowed.

Fallowing does not mean that bare soil will be present because weeds would grow abundantly. In practice, fallowing often will mean that some green manure will be grown in stead of an economically profitable crop. Since chemical weed control should still be possible, the primary green manure for fallowing will be grasses. On the other hand, this green manure will have a yield increasing effect for the next crop, lowering the overall effect of fallowing to some extent.

Acreage control will become more attractive if it also serves the conservation of nature and environment. Since the last two decades serious environmental problems have arisen in relation to agricultural development. The question is whether and under which conditions landretirement can offer a solution for these problems. Acreage control or less intensive production techniques will have positive effects on the environment, because less fertilizers and less pesticides will be used. As such, acreage control has a clear merit, also financially, for the whole community.

3. ADMINISTRATIVE PROBLEMS OF ACREAGE CONTROL

Up to now, acreage control has not been accepted as a political tool, because the execution is expected to be very problematic. First of all, there are questions how to split the control measures over nations and regions. Secondly, there are considerable managerial and administrative problems involved.

A serious problem in case of temporary withdrawal by means of an obligation to fallow (or by growing green manure) or a more extensive use of arable land is control of the fulfillment of the obligation or conditions. The fulfillment has to be checked for each farm and sanctions have to be put if the conditions are not fulfilled. Offences that are committed can be that less hectares are fallowed or arable land of too poor quality. This means that the kind of crop for each field has to be checked. In practice, however, random samples will be taken because it is nearly impossible to check all fields. In case of more extensive production techniques, yields per hectare have to be checked or estimated.

If grasses are grown as a way of fallowing, this grass should be ploughed. If it is mown, it can be used as forage for cattle and it will compete with e.g. mais. Without inspection, however, it is quite well possible that the grass will be sold.

The feasibility of acreage control, particularly concerning the administrative control, is an important aspect. The administrative workload of acreage control programmes are partly dependent on technical facilities. With modern techniques of remote sensing, data processing and mapping, it should be possible to build a nearly automatic registration system of cultivated and non-cultivated lands. Subsequently, these techniques may assist in ascertaining an agricultural land use classification each year. This registration could be used as a "preventive" data base of basic material for a random control on a regional or national basis of the data provided by the farmers. So, either all farmers or a random sample of farmers are checked. In the latter situation, farmers do not know whether they will be checked or not.

4. ROLE OF REMOTE SENSING

As seen thus far, at national and regional level, one of the main requirements of an agricultural policy is knowledge of land cover and crop production. The two constituents of crop production are crop acreage and crop yield. Crop inventory involves the identification of crops and the measurement of their area. Conventional observations are very labour intensive and time-consuming. Moreover, they cannot provide the necessary degree of reliability.

Remote sensing techniques can provide information about agricultural crops over a large area, quantitatively and, above all, non-destructively. In particular, areal averaging is both easier and more accurate with remote sensing techniques. During the past decades knowledge about remote sensing techniques and their application to fields such as agriculture has improved considerably. Optical remote sensing, based on reflected solar radiation, has great possibilities for application in agriculture, particularly with regard to its relation with crop characteristics such as soil cover, LAI and dry matter weight. As such it may be used for estimating crop characteristics as well as for crop inventories based on these

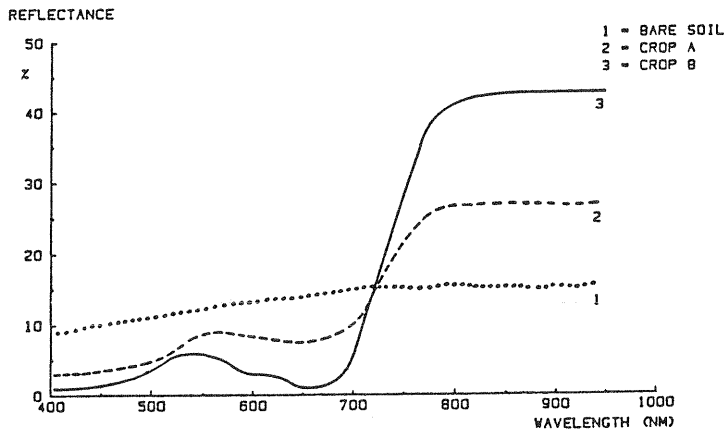


Figure 1: Spectral signature discrimination.

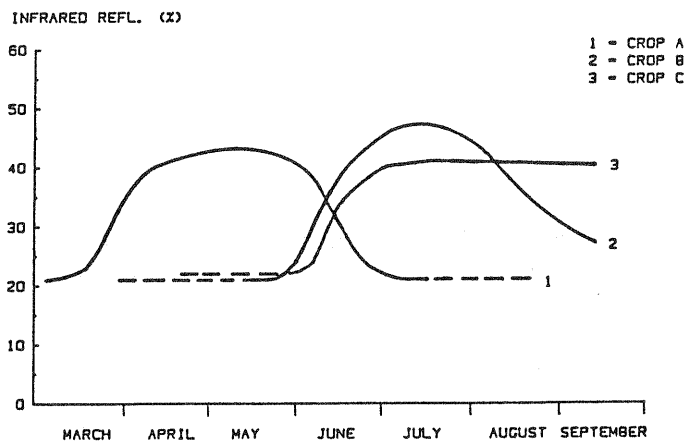


Figure 2: Temporal signature discrimination.

characteristics.

Crop identification is performed mostly by applying classification techniques using training areas. These classification techniques are based on the spectral information of each pixel within a scene. Conventionally, it is a pure multispectral classification technique on a pixel by pixel basis. Two approaches are possible when using this pure thematic information:

1. Monotemporal classification; only one acquisition date is used for the classification process, resulting in a spectral signature discrimination (figure 1).
2. Multitemporal classification; more acquisition dates are considered, improving the discrimination between crops (figure 2, temporal signature discrimination).

When working in a multitemporal way the following problems may be encountered:

1. Radiometric correction. When absolute comparisons between different dates have to be carried out, radiometric correction is needed for:
 - differences in sun elevation;
 - atmospheric effects;
 - different sensor characteristics.

In order to make data more comparable, they may be converted into spectral radiances. If possible, a conversion into spectral

reflectance factors is even better since reflectance factors are independent of the irradiance and fully comparable between dates and between sensors.

2. Geometric correction. A multirate analysis of imagery always requires an accurate geometric correction. A resampling has to be carried out, which is done either as image to image or as image to map.

Results of such multispectral techniques may be improved considerably if the relationships between pixels in the surrounding (neighbourhood) of a pixel are being considered. This means that besides thematic also spatial information is taken into account.

If repetitive coverage of the earth surface is required on a global scale, e.g. whole countries or the whole Common Market, satellites will be the main platform. Results of research, using satellites launched in the last decade, have shown to be very encouraging for agricultural applications. Especially data of Landsat-TM and SPOT are interesting with regard to the large amount of relatively small fields (in the order of 0.5 - 5.0 ha) within the Common Market.

The frequency of optical imaging will always be limited by the frequent heavy cloud cover in Europe. As a result, it is difficult to obtain a complete, cloudfree coverage of a whole nation during one growing season. Repetitive coverage during one growing season will be impossible by means of optical sensors only. For more regional areas remote sensing from airborne platforms might be used. These platforms may also be used to fill in small gaps in coverage of optical satellites.

The above means that for operational agricultural applications, radar sensors will provide the only source for repetitive coverage of the earth surface due to their all-weather sensing capability. This means that if reliably-timed, satellite data have to be obtained for the whole of e.g. the Common Market, optical and microwave (radar) sensors and data must be integrated (multisensor approach). The radar data can be used both as an addition to the optical data, and to fill in the gaps in optical coverage. An important aspect of developing future radar systems for satellites is that such systems should be optimised for specific applications, such as those in agriculture; they should not just be the products of technological development. Two important requirements to advanced remote sensing observation techniques are (ESA Land Applications Working Group, 1987):

1. they should have a high spatial and spectral resolution in order to cope with the small agricultural fields in large parts of Europe.
2. they should have an all-weather capability.

Our understanding of the physics of solar energy reflected by the Earth's surface is better than that of the microwave energy that is backscattered (e.g. in plant physiology the absorptance and reflectance of solar radiation has been fully studied). The latter must be improved further in order to be able to extract quantitatively useful information from space radar data. Finally, the synergy of optical and microwave data needs to be fully investigated for agricultural applications. The various problems that are being expected from this combination have to be investigated thoroughly. These problems are related to:

1. physical interpretation of what is measured (models will play an essential role);
2. radiometric correction of the various data sources;
3. geometric correction from image to a common geometric base (e.g. a

- map) for both optical and radar data;
4. optimal choice of sensor parameters;
 5. integration with foreknowledge (ancillary data) in a geographic information system;
 6. technical possibilities.

Modelling the relation between remote sensing measurements and crop characteristics will play an important role in our understanding of the possible combined use of optical and microwave sensors. As a start, in the next section two rather simple models will be treated, one used in the optical region and one in the microwave region. It will be shown that they have more in common than it is generally assumed. In near future, they will have to be combined into one model.

5. MODELLING CANOPY REFLECTANCE AND BACKSCATTER

5.1 Optical region

In the optical region of the electromagnetic spectrum, complicated physical reflectance models are being used for obtaining a better understanding of the complex interaction between solar radiation and plant canopies. Such reflectance models describe the transfer of radiation within a canopy or within canopy layers and finally give the total reflectance of a certain vegetation. These models usually simulate reflectance factors for varying crop characteristics. They are difficult to invert and too complicated for practical applications.

For practical applications, in literature a whole range of different vegetation indices based on reflectances is being used for estimating crop characteristics such as LAI, biomass and yield. Based on such crop characteristics these indices can also be used for classification purposes. However, most of these indices lack a solid physical basis. The mathematical description of such an index to crop characteristics such as LAI differs from author to author, since the relations are mostly derived empirically.

An example of an approach, suitable for practical applications is the following simplified (semi-empirical) reflectance model for the estimation of LAI (Clevers, 1986). This approach is based on the SAIL-model, as introduced by Verhoef (1984). The SAIL-model includes scattering and extinction functions for canopy layers containing fractions of oblique leaves. In the model of Clevers it is assumed that in the multitemporal analysis the soil type is given, and soil moisture content is the only varying property of the soil. In optical remote sensing, often, not the conventional definition of soil cover (defined as the relative vertical projection of the canopy on the soil surface), but an "apparent soil cover" is being used by taking the sun-sensor geometry into account. This apparent soil cover can be described as the fractional horizontal area of soil obscured and shaded by vegetation at the particular combination of sun and view angles existing at the instant of the observation.

In this approach, the measured reflectance, r , is written as a linear combination of the apparent soil cover, B , and its complement, with the reflectances of the canopy, r_v , and of the soil, r_s , as coefficients, respectively:

$$r = r_v \cdot B + r_s \cdot (1-B) \quad (1)$$

For estimation of LAI, the measured reflectance should be corrected for fractional soil reflectance, because soil background will influence the measured reflectance independently of LAI. The difference r' between the composite reflectance, r , and the soil component of the scene will be called the corrected reflectance and it is (according to equation 1) defined as:

$$r' = r - r_s \cdot (1-B) = r_v \cdot B \quad (2)$$

The corrected reflectance is the reflectance one would have obtained with a black background.

For an infrared band the subscript ir will be used and equation (2) is then written as:

$$r'_{ir} = r_{ir} - r_{s,ir} \cdot (1-B) \quad (3)$$

It can be proven (Clevers, 1988) that this corrected infrared reflectance can be ascertained as a weighted difference of total measured infrared and red reflectances:

$$r'_{ir} = r_{ir} - C \cdot r_r \quad (4)$$

with $C = r_{s,ir}/r_{s,r}$, the ratio of infrared and red reflectances of bare soil. This ratio is essentially independent of the soil moisture content for a specific soil type. Once this ratio is known, one does not need to measure the reflectances of bare soil each time.

Finally, the corrected infrared reflectance can be used for estimating LAI:

$$LAI = -1/\alpha \cdot \ln(1 - r'_{ir}/r_{\infty,ir}) \quad (5)$$

with α and $r_{\infty,ir}$ being two parameters that have to be estimated empirically from a training set, but they have a physical nature (cf. figure 3).

Equation 5 is the inverse of a special case of a well-known growth curve, namely the "Mitscherlich curve" running through the origin. In this way, the problem of inversion of the SAIL-model is solved by making some assumptions for simplification. In order to apply the above approach a database should be built of spectral soil information (ratios of soil reflectances) and of spectral crop information (α and $r_{\infty,ir}$ in equation 5). In future, such a database may be consulted instead of analysing a training set.

The above model may be used directly for determining LAI. This LAI often is directly related to biomass and other crop characteristics.

5.2 Microwave region

In the microwave region, a similar approach could be used. For instance, the CLOUD-model (Attema & Ulaby, 1978) is a semi-empirical model in which the radarbackscatter is related to canopy and soil parameters. It is based on a first-order solution of the radiative transfer model (Hoekman et al., 1982). A canopy is modelled as a cloud of water droplets, that are held in place by the vegetative matter. The measured radarbackscatter is described as the summation of the

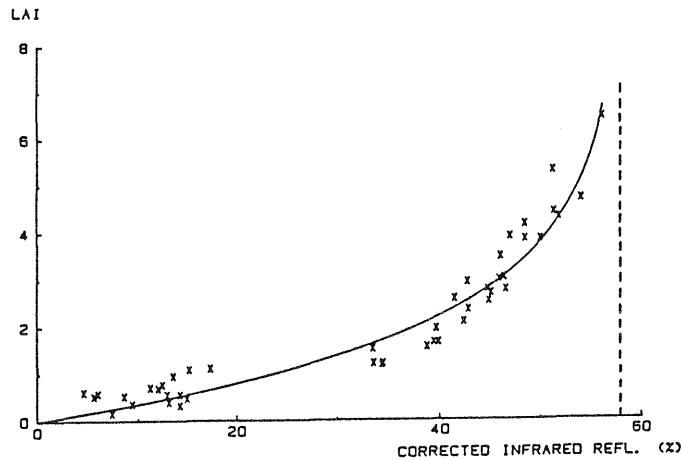


Figure 3: Regression of LAI on corrected infrared reflectance. $r_{\infty,ir}$ is the asymptotic value for the corrected infrared reflectance and α is a measure for the speed with which this curve runs to this asymptotic value (combination of extinction and scattering coefficients). In this example: $\hat{\alpha} = 0.53$ and $\hat{r}_{\infty,ir} = 57.9$.

contribution of the canopy and the contribution of the soil background. For instance, for a one-layer model we get for the radar backscattering coefficient γ :

$$\gamma = C \cdot (1 - \exp(-DWh/\sin\theta_g)) + \gamma_{soil} \cdot \exp(-DWh/\sin\theta_g) \quad (6)$$

C = backscattering coefficient of an opaque (dense) layer
 γ_{soil} = backscattering coefficient of soil (dependent on moisture content)
 W = water content of the canopy (in $\text{kg}\cdot\text{m}^{-3}$)
 h = canopy height (in m)
 DWh = transmittance of a radar wave in the vegetation
 θ_g = grazing angle.

Bouman (1987) introduced a "microwave soil cover", f , and used this as a weighting factor in the summation of canopy and soil contributions. This microwave soil cover is defined as:

$$f = 1 - \exp(-DWh/\sin\theta_g) \quad (7)$$

As a result equation 6 reduces to:

$$\gamma = C \cdot f + \gamma_{soil} \cdot (1-f) \quad (8)$$

For instance, in case of no vegetation, f equals 0 and the backscatter reduces to the unattenuated backscatter from the soil surface. In case of a dense vegetation cover, f equals 1. This definition may be regarded analogous to the apparent soil cover applied in the optical region. Equation 8 resembles equation 1 very much.

By inversion, the CLOUD-model may be used directly for determining characteristics such as soil moisture content, plant water content and plant height. The latter crop characteristics are directly related to e.g. biomass. This estimation of object parameters with e.g. the CLOUD-model has to be studied further.

5.3 Combined use

As stated before optical and microwave models should be combined in near future. In general, existing models describe the reflectance or backscatter as a function of object parameters (such as soil and crop characteristics). Since several unknown object parameters are involved in these models, a combination of e.g. several spectral bands or polarizations will be needed in order to get a set of independent equations. If the number of independent equations equals the number of unknown object parameters, the inversion problem may be solved. Either measurements in the optical region or measurements in the microwave region may yield such a set of equations. Due to the amount of object parameters (vegetation and soil) that are involved in models and the high correlation between many spectral bands and between polarizations, it is more likely that for many applications a combination of optical and microwave measurements will be needed for solving the inversion problem (enough independent equations). At least, the accuracy of parameter estimation may be increased by combining optical and microwave data. Research should be focussed on this combination. As stated at the end of sections 5.1 and 5.2, both optical and microwave models can be applied in determining crop characteristics such as biomass. As a next step crop growth models should be directly linked to the inverted remote sensing models. Crop growth models describe the relation between physiological processes in plants and environmental factors such as solar radiation, temperature and water and nutrient availability. Estimates of crop growth often are inaccurate for sub-optimal growing conditions. Remote sensing may yield information about the actual status of a crop, resulting in an improvement of crop growth models. In this way crop growth may be estimated in time, finally resulting into a prediction of crop yield at harvest time.

This paper is intended to show the necessity for combining optical and microwave remote sensing for a particular application. It is not intended to discuss the practical consequences in detail. For that purpose a feasibility study should be performed.

6. GEOGRAPHIC INFORMATION SYSTEMS

Geographic information systems (GIS) can enable decision-makers to deal more effectively with the various kinds of information they receive. The main purpose of a GIS is to process spatial information. Spatial analysis involves tremendous volumes of data. Data stored in a GIS can be rapidly manipulated, reconfigured, updated, compared and displayed in a format and at a scale designed to meet a specific need. GIS are powerful tools for integrating and analysing data derived from various sources.

As an input in an agricultural information system the combination of optical and radar data, as described in the previous section, can be used. A part of such an information system should be contained by digital terrain models, in order to be able to correct the remote sensing data for illumination and sensor geometry as well as for terrain altitude. Into such an agricultural information system data of various types will have to be incorporated, including ancillary data. The latter may include e.g. climatic data, soil type, field history, field boundaries and other topographical features. It may include also

spectral soil and crop information needed as an input for the model inversion (cf. the end of section 5.1). Besides as a primary input, remote sensing data may also be used for checking, reconfiguring and updating the information that is present in a GIS.

The integration of remote sensing and geographic information systems is essential for effective agricultural application. The amount of remote sensing data often is such that one must use digital image analysis systems. By combining remote sensing image analysis and geographic information systems, one can have timely and accurate knowledge of an agricultural region. Finally, expert systems may be designed for such specific applications as crop inventories. They should allow for more efficient data processing and analysis, as well as help users with little experience in computerized spatial data processing and modeling.

7. CONCLUSIONS

- The Common Market will be forced to reform its agricultural policy in order to stop the increasing overproduction. Acreage control will be the main tool.
- Control of the fulfillment of the conditions for acreage control as a political tool is very problematic. Remote sensing may provide basic material for such a control.
- For operational agricultural applications, optical and microwave systems must be integrated and used as an input to an agricultural information system. In near future, optical and microwave models must be combined and linked to crop growth models.

8. LITERATURE

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