Remote Sensing – A Future Technology in Precision Farming

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Summary

The paper briefly reports the opportunities of remote sensing for precision farming, a coming main focus in agriculture. MW-remote sensig may play an important role because of its weather independence. In particular polarimetric information with SAR-systems will be a powerful tool to enhance the accuracy of the determination of biophysical parameters of agricultural crops. In the former SIR-C/X-SAR missions the cross-polarized C-band backscatter value Chv as well as the coefficient Lhh/Lvv could be shown to detect the amount of biomass of cereals very well. In another study conducted earlier in the vegetation period with the airborne E-SAR during the Pro Smart project „Vitalität“ the ratio Lhh/Xvv correlated well with the biomass of winter barley. From these data a map of the variability of the biomass within barley fields could be generated.

Foreseeable advantages in precision farming that can be achieved by remote sensing are:

- tracing target areas with abnormal appearance; early recording of hidden faults in field crops and on site identification of their causes
- improved partitioning of fields into zones of uniform crop management
- mapping of the spatial expansion of diseases and pests in field crops throughout the growing season; revision and enhancement of measures of pest control
- continuous or stage dependent mapping of the crop nutrient demand, e.g. nitrogen; revision and enhancement of measures of fertilizer application
- successive control of the effectiveness of crop management actions.

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Successful application of remote sensing in precision farming depends on the availability of ready to use products for the farmers. In order to transform remote sensing data in practicable site specific applications close cooperation between the operators of satellite systems and agro-consultants will be necessary.

Keywords: remote sensing, precision farming

Introduction

Precise actions in farming requires precise information on the crop status in terms of time and area. Remote sensing by aircraft in a few cases has already been used to contribute to precision farming with remote sensing information. In the near future also satellite remote sensing will play a major role in precision farming. Principles and potential of SAR-remote sensing, as applied in precision farming will be reported, and examples of applied SAR- and optical remote sensing in the field of precision farming will be shown. Both systems will have the potential to compete and to supplement each other.

Precision Farming

Physical status and appearance of the solid earth, even of ice and sea water, do not perform homogenous surfaces over area and time. This is especially true in agricultural fields. The normal status of an individual field plot is, under all criteria available to us, heterogeneity. Even arable land, new reclaimed with one single soil type, will never appear homogenous, but will consist of a number of sub units differing in soil moisture, soil roughness and biomass of growing crops etc. Meanwhile, also for small field plots, inhomogeneity is accepted to be normal, hence the purpose of precision farming (PF) will rather respect the differing field sub units, than to make them uniform. In addition, precision farming takes into consideration the change of crop layer in terms of area and time including ecological, as well as economic rules. Key technologies in PF are:

(1) geographical positioning systems on farm implement (like the GPS) while recording the crop status or any kind of agricultural actions from seeding to harvest,
(2) reliable recording of crop and soil status by sensors in the field,
(3) high resolution/precision techniques to perform agricultural actions,
(4) geographical information system (GIS) to register and document crop and soil status, as well as actions applied.

Remote Sensing and Precision Farming

Remote sensing (RS), a few years ago, was far away from being applicable in the field of PF. First of all, spatial and temporal resolution by RS have been inadequate. In the last few years , however, new satellites have been launched which demonstrate the potential of RS in PF. In the optical domain we are expecting improved full cover RS-systems with daily repetition rate which will reduce the weather risk. But still, in humid regions like western and central Europe, we will need to have at least some complementary weather independent RS-systems. Microwave-remote sensing would surely cover this particular requirement, and in addition, it will contribute complementary information about crop status because it reacts with other characters of the vegetation layer than the optical waves. The differing behaviour of optical and radar waves allows to record different characters of the plant canopy as shown in Figure 1.

The optical remote sensing uses the reflected sun light. In the VIS it will be absorbed at high rates by the vital vegetation layer, whereas in the NIR, cell structure and water pressure of the plant tissue is increasing the reflectance values. These relationships are well known and have been used for a long period of time. Much less we understand from the MW’s. But yet the potential to apply the MW’s in agriculture is there. The radar waves penetrate the crop canopy and react primarily with their volume and their structural elements, leaves and stems; long waves penetrate deeper than short waves. The orientation and size of the canopies structural elements, and the more horizontal or vertical distribution of water mass within, will have crucial influence on the intensity of backscatter. Because of the penetration, only at small incidence-angles and short waves (i.e. X-Band) with radar, an exclusive plant-layer-signal might be expected. On the other hand, long waves of radar (L-Band), combined with steep incidence angles on the other hand, even with full cover canopies, always create a mixed signal originating from the plant layer and the soil under it (Ulaby et al. 1982). These physically very complex relationships make it difficult to understand radar signals from crops.

Fig. 1: Remote Sensing with Optical Sensors and Radar; crop characters influencing spectral reflexion of optical waves (VIS und IR) and microwaves (Radar).

VIS und IR (λ, θ, Φ)	Radar $(\lambda, \theta, \rho, \Phi)$
- pigment composition 1) - pigment concentration 1)	- volume (stand height) 1) - vertical and horizontal distribution of plant organs 1)
- turgidity 2) - cell stucture 2)	- size, form and orientation of plant organs - distribution of fresh and dry biomass and phenology 1) - row direction
- senescence 1) 2) - phenology 1) 3) - leaf area index 3) - soil pigmentation 4) - soil moisture 4)	- soil roughness - soil moisture

λ =wavelength; θ =incidence angle; ρ =polarization; Φ = azimuth angle (look direction);
1)-4) related characters

But still, MW-RS benefits in PF because of its weather independence. However, the progress in the optical RS in this field of application deserves consideration. Inspite of the complementarity of both systems there will also be some competition between them.

As mentioned above, the advantage of optical RS is the much better understanding of the received signals. With optical sensors we can already get from satellites very high ground resolution with one single scene. In the following figure we established wheat fields and treated them differently with nitrogen fertilizers and fungicides in order to create differences in biomass and vitality of this crop.

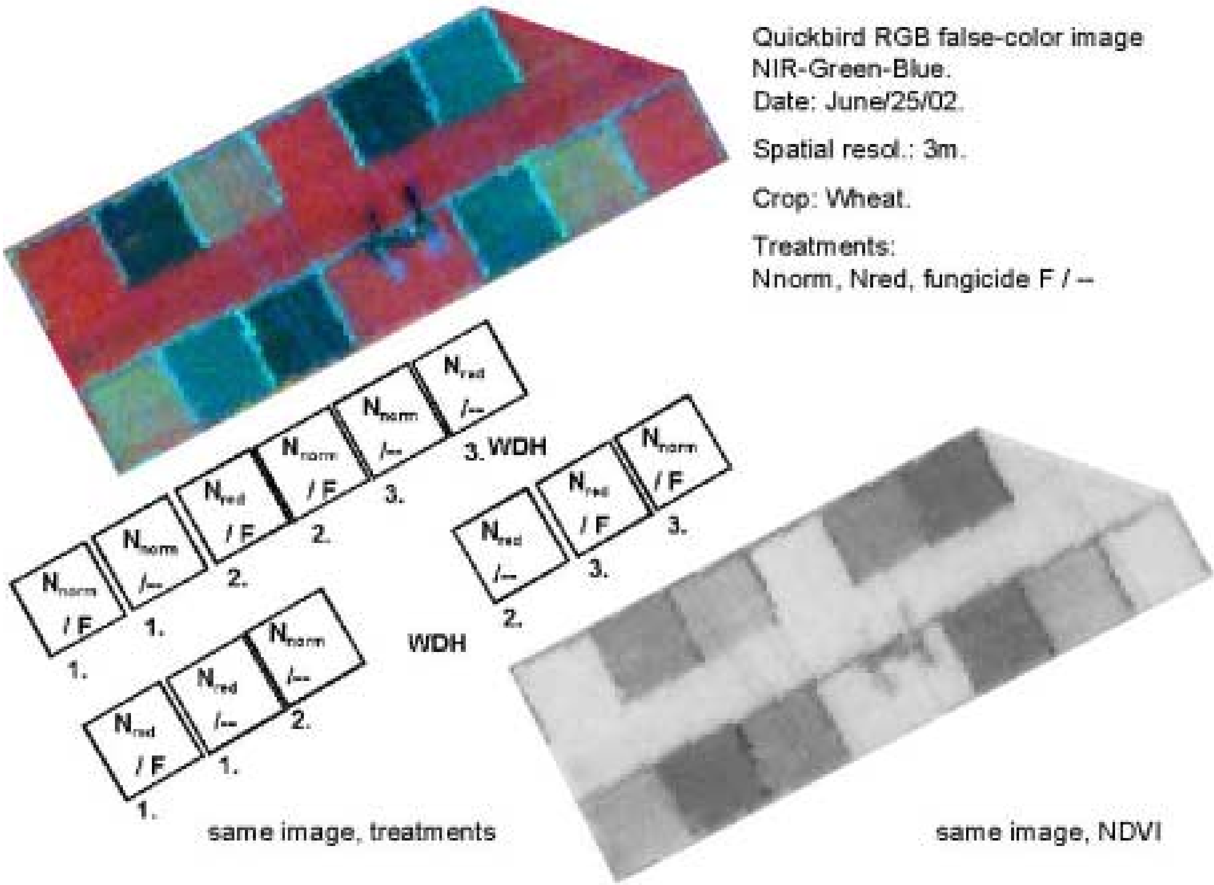

Fig. 2: Quickbird RGB false-color image NIR-Green-Blue. Date: June/25/02. Spatial resol: 3m. Crop: Wheat. Treatments: fertilizer N_{norm}, N_{red}, fungicide F/--.

In the Quickbird image shown, the field blocks, damaged by fungal diseases and nitrogen deficits, appeared clearly. One can imagine how precise this information will be.

So, this image gives some idea how the field of competition looks like between optical and MW-RS, and it is an argument for multiband and multipolarisation MW-systems. MW's have a good potential to register biomass. Biomass distribution in a crop field gives valuable information over time, where and when a crop is affected by nutrient and/or water deficits and diseases. In the X-SAR/SIR-C-mission we found very good correlation between radar backscatter and fresh biomass of winter barley and maize. This was found in ratios of the backscatter intensities of L-band hh-polarisation versus vv-polarisation.

Figure 3 shows the relation of fresh winter barley biomass and the ratio Lhh/Lvv. The respective plant samples have been taken in the same type of barley during a 10 day shuttle mission in April 1994 along a seasonal gradient from the south of Italy to the south of Germany (Steingiesser and Kühbauch 1998).

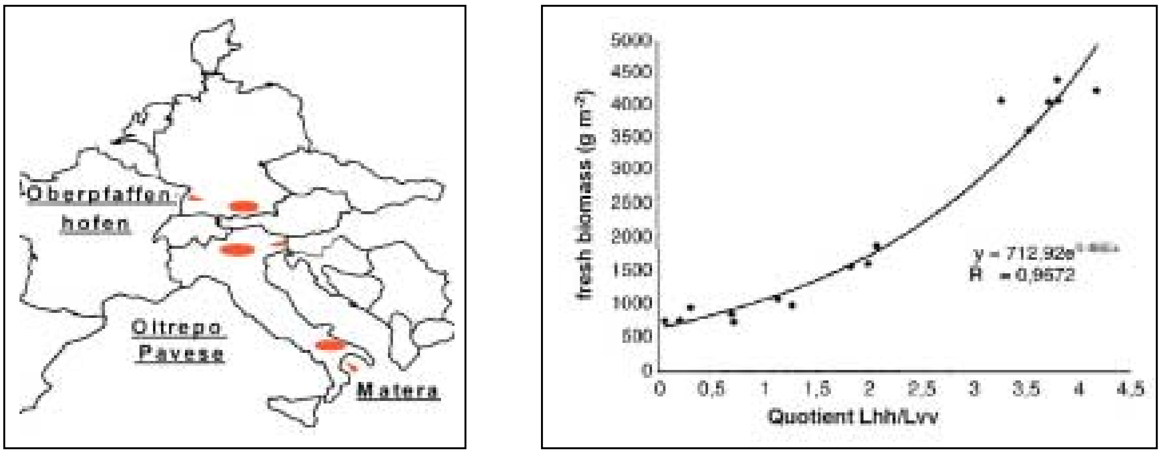

Fig. 3: Relation between fresh winterbarley biomass and the ratio Lhh/Lvv; combination of testsites Oberpfaffenhofen, Oltrepo Pavese and Matera and their location in Europe at steep incidence angles.

From these investigations with multipolar MW's, we learned that radar-backscatter of different polarizations, related to each other, correlated very well with fresh and dry biomass. Based on these results we tried to establish the spatial variation of biomass in individual barley fields within the so-called ProSmart cooperative mission, which was initiated and coordinted by Dornier company (Dornier 1999). From the respective fields we have had pre-information with Landsat images that helped us to find homogenous areas, different in biomass. In these subunits of the barley fields, in situ measurements for biomass have been conducted. In situ data and radar data were compared with different combinations of L-band and X-band polarisation. As best correlating combination between the fresh biomass and radar backscatter resulted the Lhh/Xvv ratio (Hawlitschka et al. 2001) as opposed to the coefficient Lhh/Lvv used by Steingiesser and Kühbauch (1998). This is not surprising due to the fact that in the ProSmart project barley plants have been shorter than in the former SIR-C/X-SAR study, where the coefficient Lhh/Lvv has been used to discriminate between vegetation and soil backscatter. The now shorter crops obviously were penetrated by all L-band polarisations while the shorter X-band waves interacted more with the vegetation, which obviously is essential in crop fields with low biomass.

For a semi automated reproduction of the biomass the data have been filtered with their own speckle filter. A second version of the filter has been developed to detect the regions of high heterogeneity and high intensity of backscatter. Thus, a mask of heterogeneities could be generated to eleminate the unwanted image features caused by the high power line poles, bright stripes due to the row direction and water holes within the fields. EASI/PACE routines have been used to proceed. Backscatter of power line poles and effects of row direction have been eliminated and replaced by values of neighbouring pixels, while masking out the water holes. In the same way the pixels lying outside the fields have been masked out. By the use of the formula found, while correlating the radar data with in situ measurements, the backscatter values have been encoded into amount of biomass. Finally, the scale of biomass has been divided into five classes, small regions (<2000 m^2) have been merged into greater areas to meet the practical needs of the farmers.

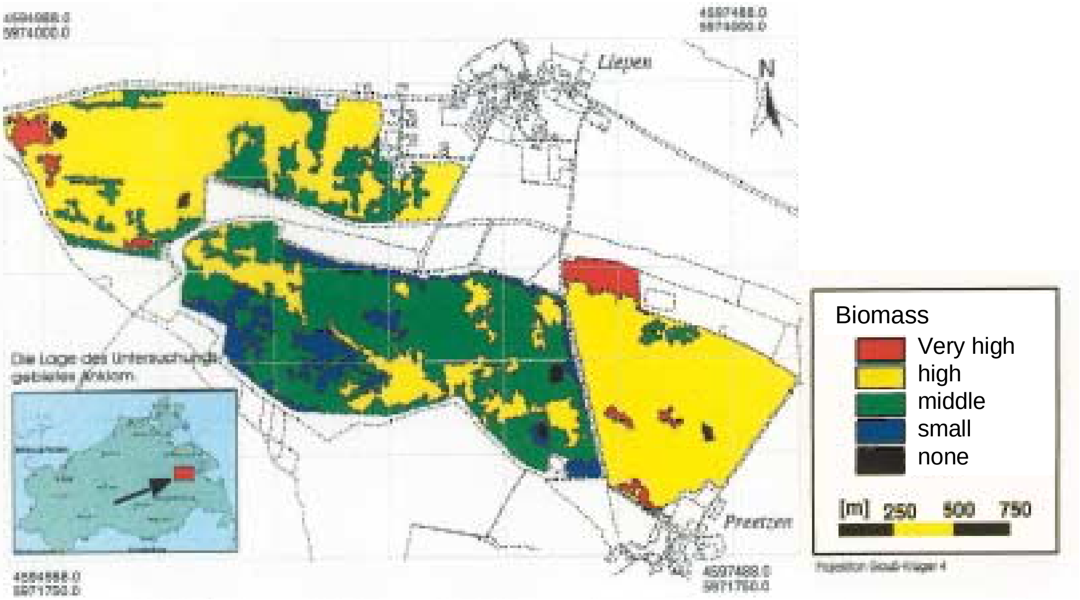

Fig. 4: Pattern of fresh biomass in winter barley plots at the beginning of shooting,

19 April 1999 in Mecklenburg-Vorpommern. – ProSmart joint cooperation with Dornier-Daimler Chrysler Aerospace (Dornier 1999, Hawlitschka et al. 2001).

The figure 4 shows the spatial variations of biomass in very large fields of winter barley at Mecklenburg-Vorpommern.

Application Perspectives

Precision farming (PF), in certain fields of agricultural crop production, already happens without RS. In a number of applied precison techniques, RS will not be competitive enough or will not be necessary. Recognition of weed species**,** for instance, will remain with digital cameras, because of the very high spacial resolution required (Sökefeld et al. 2000). Also, the optical Hydro-N-Sensor is working in the near range (Heege and Reusch 1996). Ground based sensors, however, cannot be used repeatedly any time. This, in particular, will be the advantage and the future field of application of RS in PF. The appearance of crop stands and the duration and sequence of the time windows for related actions in the field, are changing very much from year to year and between crop types. Only satellite-RS has the potential to satisfy the requirements of frequent and continuous observations of agricultural crops, or to record the success of each field action applied by the farmer.

Hence, RS in the domain of PF can be taken as a kind of „tactical field inspection“ (Blakeman 2002). The farmer, for instance, knows the symptoms of nutrient deficiencies or diseases. Although, there is a permanent lack of information, when and where these deficiencies start to appear in the field. The related area size of the wanted phenomena will remain unknown. Therefore, the PF requires RS. The following advantage of RS in applied PF may be expected:

- tracing target areas with abnormal appearance; early recording of hidden faults in field crops and on site identification of their causes
- improved partitioning of fields into zones of uniform crop management
- mapping of the spatial expansion of diseases and pest in field crops throughout the growing season; revision and enhancement of measures of pest control

- continuous or stage dependent mapping of the crop nutrient demand, e.g. nitrogen; revision and enhancement of measures of fertiliser application

At present, fertilizing and plant production actions are almost exclusively based on the farmers experience, his personal field inspections, soil and plant samples. Many of these informations/actions are missing detailled resolution over time and across the area of the field plots to the subunits of the field plots. In a number of research projects, the potential of RS to improve the farmers information about his crop, has been demonstrated. In the example of SAR-RS, a shuttle and an aircraft were the platform of the sensor. What we realy need are satellite platforms. Supposedly, only with satellites, the uniform fast and affordable routines can be provided to match and the farmers requirements and to prepare the actions, which have to be done in the field plots during the season. These routines will play the key role for RS application in PF. We are still missing the cheap and fast routines, because there are too many different types of systems and organisations involved and still there is no real profitable market.

Also, most important for RS applied in PF will be, to deliver ready-to-go products for the farmers, where RS-Signals are translated into the state of the respective crop (Fig. 5). In order to achieve very fast routines, it will be crucial to create the field data each day at any time.

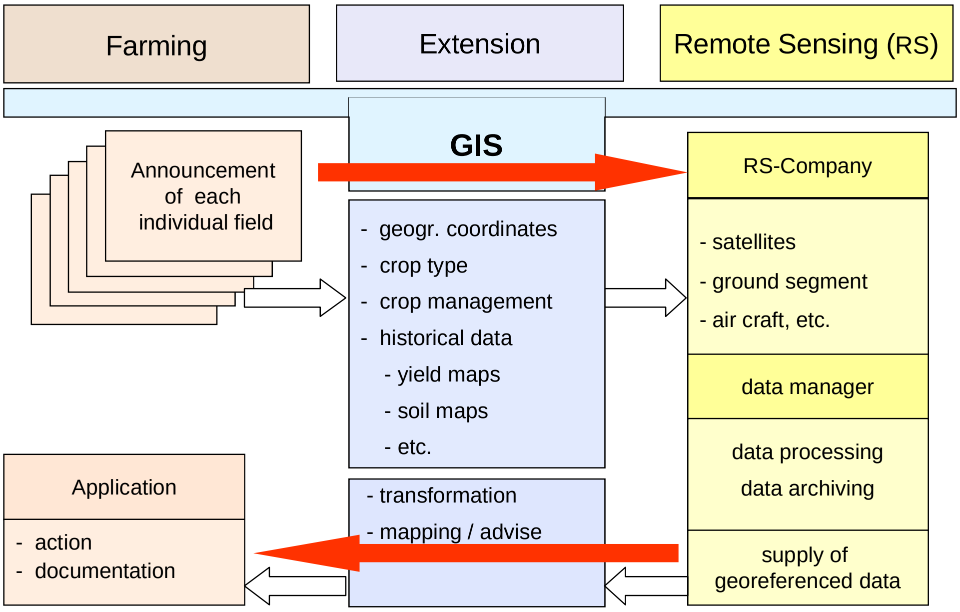

Fig. 5: Proposed data flow to apply remote sensing in precision farming

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