532

Soil Resource Mapping for Precision Farming Using Remote Sensing

Thomas Selige & Urs Schmidhalter
Technical University Munich, Department of Plant Sciences,
Am Hochanger 2, 85350 Freising, Germany,
Tel.: +49 8161 71 4528 Fax.: +49 8161 71 4500
Email: selige@weihenstephan.de

Abstract- Multispectral airborne remote sensing was used to improve the inventory of soil heterogeneity at the sub-field level. A bioindicative model was developed, based on cause and effect relationships of the soil-plant-sensor system. The spectral information was transformed into soil information using bioindicative transfer functions. This procedure enables quantitatively the spatial detection of the limiting soil quality e.g. the plant available water capacity of the root zone. Remote sensing based maps as developed in this study will support farmers and agricultural advisors to practice precision farming using site-specific management.

I. INTRODUCTION

Site specific decision support systems require detailed information about the natural resources as they vary across a field. The variability and the spatial pattern of crop growth within fields depends on the variability and the spatial pattern of soil properties. Hence, detailed information about the spatial pattern and the functional properties of the soils is required to enable site specific management.

In this study remotely sensed imagery was used to enable the digital mapping of soil resources with high resolution and timely flexibility. Certainly remote sensing technologies are not able to view into the soil profile but are recording the spectral characteristics of soil-crop surfaces.

The conception of this research is capitalising on these cause-effect relationships of the soil-plant-sensor system. It takes advantage of crop stand characteristics as indicators of soil profile characteristics. The mapping process derives soil quality via the spectral response from crop stand conditions.

II. MATERIALS AND METHODS

The investigated area is located in Sachsen-Anhalt, Germany. The area is characterised as a slightly undulated plain at 70 m altitude with an intensive arable farming. With 450 mm annual precipitation and 9 °C annual temperature, the region has a negative water balance during the vegetation period. Tschernozem is the predominant soil type.

The remote sensing device used for this investigation was the airborne line-scanner Daedalus AADS 1268 ATM. This instrument records wavebands of visible, near, middle and thermal infrared wavelength at 11 spectral channels. The investigation area was recorded with 5 m geometric resolution.

Five fields cultivated with different winter wheat varieties were selected for this paper. Soil properties, plant development and crop stand conditions were measured on the ground at representative soil sites. The available water storage capacity (AWC) and the rootability (rz) were derived from soil texture and texture change within the soil profile. Grain yield and biomass of each soil site were determined with 4 replications at 1 m^2 each.

III. RESULTS

Detecting soil quality by remote sensing has to consider that soil is predominantly covered by vegetation and its surface is most of time not visible. Furthermore, essential soil properties can not be discerned from soil surface appearance. However it is well known that crop growth depends on soil attributes. Hence it should be feasible to use the crop stand condition as a bioindicator of soil productivity and regulatory functions.

Biomass is one of the important parameters to differentiate crop stand conditions. For regions with negative water balance during the growing season, the site specific availability of soil water is the main limiting soil resource. Apart from groundwater and lateral water, plants can only utilise the available water storage capacity of the root zone (AWCrz). This soil parameter has been recognised to be the central regulatory attribute of the soil productivity function. The AWCrz correlates highly with crop biomass (Fig. 1).

Additionally the effects of groundwater and lateral water are included in the crop stand condition. This allows an improved derivation of soil productivity via crop stand conditions compared to classical soil core samplings.

In this study the variability of the plant available water storage capacity of the root zone (AWCrz) accounted for 93 % ($R^2 = 0,93^{***}$) for the variability of winter wheat biomass at the development stage of "milk ripeness" when the leaves started to become yellow.

0-7803-7033-3/01/$17.00 (C) 2001 IEEE S. 3138 - 3140

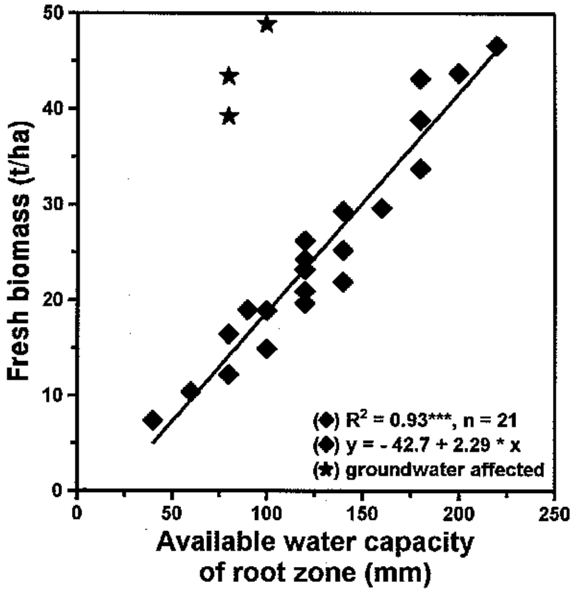

Fig. 1. Relationship between plant available water capacity of the root zone and the winter wheat biomass at the development stage of early yellowing

The biomass at this development stage indicates also the pattern of the later harvested grain yield. The crop stand at development stage "milk ripeness" accounted for 96 % (R^2 = 0,96***) for the grain yield variability of winter wheat. These results suggest that the crop stand condition can also be used to forecast the grain yield and its pattern across fields. The correlation between the plant available water capacity and the grain yield underlines the important role of the water availability as the main soil resource to be considered in site specific management (Fig 2).

The normalised differential vegetation index (NDVI) is widely used to differentiate crop stand conditions (e.g. crop vigour maps). This relationship is shown in Figure 3 for the winter wheat data of this study. The NDVI correlates strongly with the fresh weight biomass (R^2 = 0.89***). But the difference of 30, 40 or 50 t/ha of fresh weight biomass does not cause significant differences in the NDVI. From the non-linearity of this correlation follows that higher biomass of winter wheat can not be differentiated properly when using the NDVI relationship.

Other wavebands and spectral indices have to be investigated for the aptitude to differentiate biomass more precisely. The statistical analysis so far identified the thermal range as the spectral range with the best linear correlation to the fresh weight biomass. The condition of a crop stand is best described by its transpiration activity. Caused by the surface cooling effect of transpiration the surface temperature of crop stands differentiates in accordance with the biomass (Fig. 4).

The linearity of this relationship enables to differentiate also higher biomass and to map soil resources of sub-fields over a wider range and more precisely than using the NDVI relationship. The thermal property of the soil-plant surface should be preferred to distinguish soil qualities and productivity on the sub-field level.

Based on these model functions the soil resource maps of winter wheat fields have been processed. Figure 5 shows the classification example of one of the investigated fields. Classes with width of 50 mm AWCrz could significantly be delineated. The results have been validated to be non-sensitive to the five different winter wheat varieties that were used in this study.

V. CONCLUSION

The pattern of crop stand conditions at specific „indicative" development stages is reflecting soilborne heterogeneities within fields. The most indicative stages of plant development to derive soilborne crop stand conditions and site properties were identified for winter wheat. Differences in crop stand conditions were correlated with their spectral response.

The plant available soil water capacity and the rooting depth were identified as the most important soilborne site properties for crop stand development. Hence the relationship of the soil-plant-sensor system allows to derive soilborne site properties from multispectral and remotely sensed imagery via scanning crop stand conditions. The soil map derived from remote sensing and bioindicative transfer functions explained the pattern of grain yield formation and enables grain yield forecast.

The combination of a few ground check plots and multispectral remote sensing provided a flexible and operational technique to detect quantitatively the spatial pattern of soil properties at the field level for extended regions.

The presented procedure will support site specific farming with basic informations about functional soil properties. This enables a site specific crop and risk management with targeted resource application of seed, fertilizer and growth regulation.

ACKNOWLEDGMENT

This research was supported by the Bundesministerium f. Bildung und Forschung (BMBF), Bonn, Germany (PREAGRO, project number 0339740).

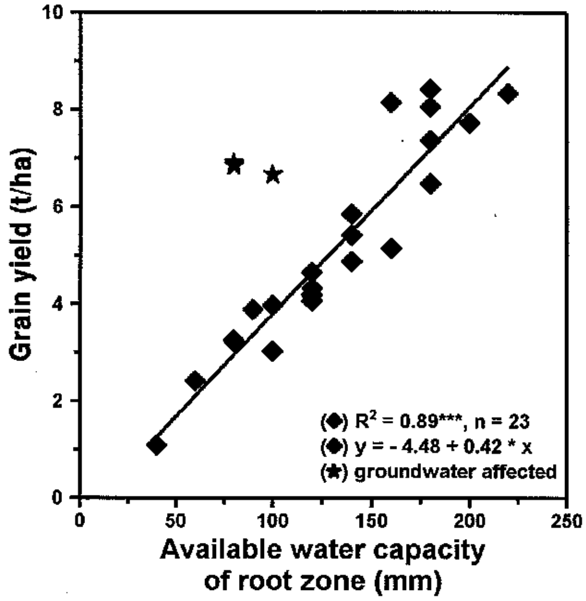

Fig. 2. Relationship between plant available water capacity of the root zone and the grain yield of winter wheat

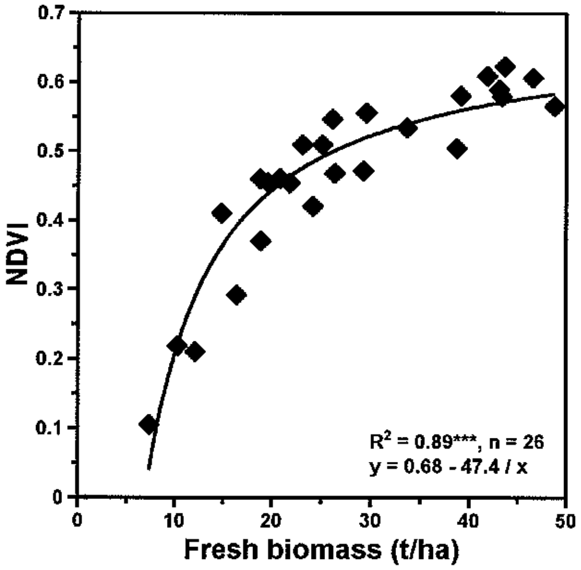

Fig. 3. Relationship between winter wheat biomass at the development stage of early yellowing and the normalized differential vegetation index (NDVI)

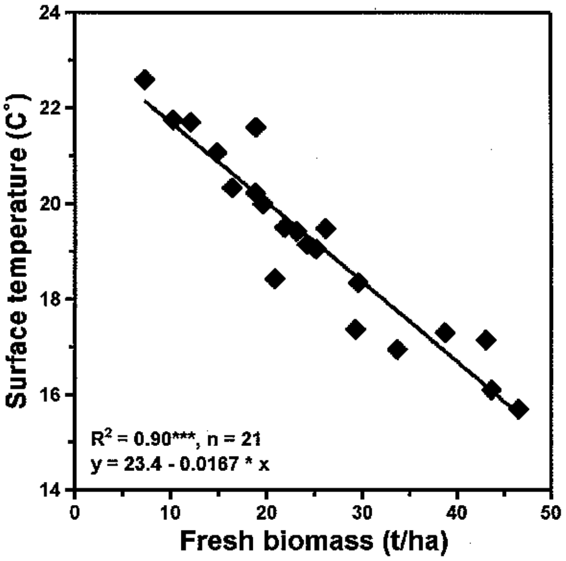

Fig. 4. Relationship between winter wheat biomass at the development stage of early yellowing and canopy surface temperature

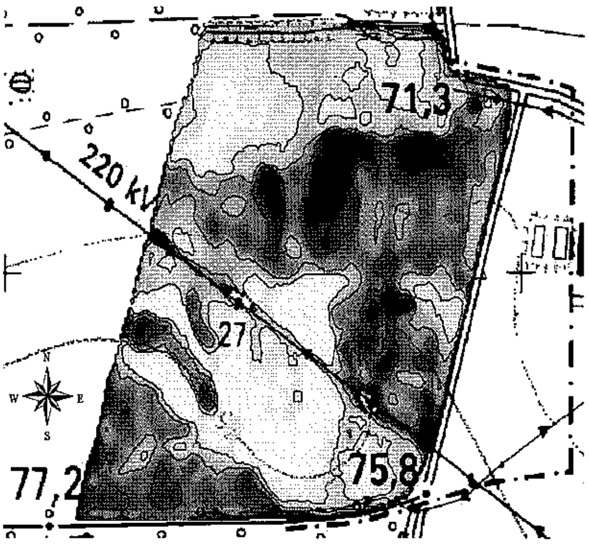

Fig. 5. Map of plant available water storage capacity as it varies across the reference field 1 (<50 mm = black to >250 mm = white)