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# Crop type mapping using spectral–temporal profiles and phenological information

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ABSTRACT

Spatially explicit multi-year crop information is required for many environmental applications. The study presented here proposes a hierarchical classification approach for per-plot crop type identification that is based on spectral–temporal profiles and accounts for deviations from the average growth stage timings by incorporating agro-meteorological information in the classification process. It is based on the fact that each crop type has a distinct seasonal spectral behavior and that the weather may accelerate or delay crop development. The classification approach was applied to map 12 crop types in a 14,000 $km^2$ catchment area in Northeast Germany for several consecutive years. An accuracy assessment was performed and compared to those of a maximum likelihood classification. The 7.1% lower overall classification accuracy of the spectral–temporal profiles approach may be justified by its independence of ground truth data. The results suggest that the number and timing of image acquisition is crucial to distinguish crop types. The increasing availability of optical imagery offering a high temporal coverage and a spatial resolution suitable for per-plot crop type mapping will facilitate the continuous refining of the spectral–temporal profiles for common crop types and different agro-regions and is expected to improve the classification accuracy of crop type maps using these profiles.

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## 1. Introduction

Timely availability of large-scale information on the spatial distribution of crop types is required to support modeling and managing of agro-environmental systems from regional to national scales. Often this information is only available as averages at the level of administrative units and is usually not obtainable for areas with deviating boundaries, e.g. river basins (De Witt and Clevers, 2004). Many agro-environmental applications such as agricultural flood damage estimation or water quality modeling, however, require spatially distributed crop data.

For these applications remote sensing is nowadays an important source of information (Vinciková et al., 2010). Due to the dynamic character of agricultural systems, crop type mapping based on multi-temporal approaches is superior over single-date image analyses. While traditional approaches using parametric or non-parametric classification algorithms require ground truth data to train the classifier (e.g., Yang et al., 2011; Castillejo-González et al., 2009), the use of crop-specific spectral–temporal profiles is independent of ground truth data. The independence of ground truth data nevertheless facilitates operational monitoring of agricultural land use over large areas and longer time periods.

The use of spectral–temporal profiles for crop identification by satellite data was first proposed in the 1980s. Odenweller and Johnson (1984) presented characteristic profiles observed for a variety of crops by use of a vegetation indicator that measures the infrared reflectance relative to the reflectance in the visible range. The term 'spectral–temporal profile' refers to the spectral behavior of a certain crop type throughout the year. Profile-based crop identification is based on the fact that profiles representing a specific crop are usually more similar than profiles representing different crops (Odenweller and Johnson, 1984). Several studies investigated the use of crop-specific seasonal profiles for crop discrimination and mapping at different spatial scales from local to state level (Wardlow et al., 2007; Murthy et al., 2003; Sakamoto et al., 2005; Jakubauskas et al., 2002). Most of the studies are based on temporal profiles of the Normalized Difference Vegetation Index (NDVI) as an effective indicator of the photosynthetically active vegetation (e.g., Bradley et al., 2007; Wardlow and Egbert, 2008). The NDVI is the most commonly used vegetation index applied in agricultural applications, however, several other vegetation indices have been proposed to reduce the influence of the canopy background and the atmosphere (Reed et al., 2003), such as the Soil Adjusted Vegetation Index (SAVI, Huete, 1988) or the Enhanced Vegetation Index (EVI, Huete et al., 1997). The NDVI is a measure

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of photosynthetic capacity of the vegetation cover, while the SAVI is more suitable to reflect the vegetation canopy structure (Reed et al., 2003). The EVI was found to be more sensitive to variations over high biomass areas, e.g. forests, when the NDVI tended to saturate (Huete et al., 2002). Furthermore, EVI may be advantageous in areas with high humidity since it is designed to minimize the effects of the atmosphere. Huete et al. (1997) conclude that each index had its strengths and weaknesses for certain applications.

Depending on the application at hand, satellite imagery ranging from low to high spatial resolution is applied for studying agricultural landscapes (Vinciková et al., 2010). For per-field crop type mapping, the spatial resolution of the imagery should be chosen relative to the typical field size. Apart from an adequate spatial resolution, the temporal resolution of the satellite data is critical for crop discrimination and mapping. Several authors have studied optimal times of image acquisition with respect to the growing stages (Murakami et al., 2001; Van Niel and McVicar, 2004).

The appearance of crop profiles is affected by regional variations in climate and management practices, which should be accounted for by setting-up individual crop profiles for each homogenous agro-region (Wardlow et al., 2007). Crop profiles, however, also vary from year to year resulting from specific weather conditions and, in particular, deviations in the temperature and precipitation distribution throughout the growing season (Siebert and Ewert, 2012). These inter-annual variations have so far hardly been accounted for in crop type mapping approaches.

In this study we therefore propose an efficient hierarchical classification algorithm that is based on spectral–temporal profiles of crop types and accounts for weather-induced inter-annual variations in the spectral–temporal behavior through the use of agro-meteorological information. The proposed approach was tested using multi-temporal LANDSAT satellite imagery for the per-field crop type mapping of a large lowland river catchment in Germany.

## 2. Data basis and pre-processing

To set up characteristic temporal profiles for each crop, NDVI data from a sixteen year satellite image time series were combined with cultivation data collected from farming companies for the same time period and agro-meteorological data provided by the weather service. The spectral–temporal profiles were then used to map crop types in the study area, the Havel River catchment, for the years 1994–2000 utilizing agro-meteorological data from the same period.

The study area is located in the north east of Germany (Fig. 1). It comprises the catchment of the Havel River, a tributary of the Elbe River, excluding the Spree catchment, and covers a total area of 14,000 km$^2$. Arable land is the dominant land use covering 37.7% of the total area. Soils are predominantly sandy with areas of high and low ground water. The average plot size is 21 ha. Major crops are winter rye (15%), winter wheat (12%), maize (12%) and oilseed rape (10%) (Amt fuer Statistik Berlin Brandenburg, 2010).

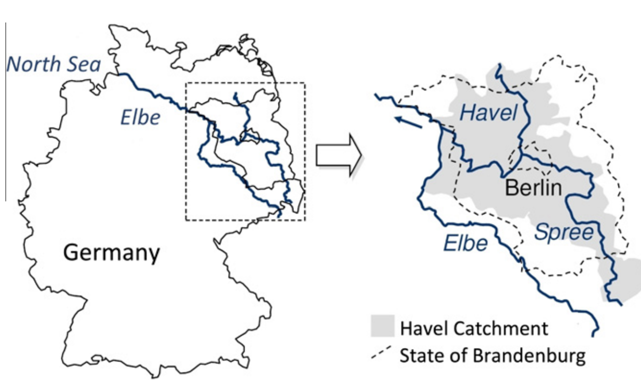


**Fig. 1.** Location of study area.

### 2.1. Crop cultivation data

Cultivation data from the years 1987 to 2002 of 424 agricultural plots with a total area of 9021 ha were collected from six agricultural companies in the study area. More specifically, for each of these 424 plots information on the specific crops grown in the years of satellite image data acquisition was made available, resulting in a total of 3745 reference plot data (Table 1). These data served the development of the spectral–temporal profiles and were used to validate the final crop type map.

For the per-plot crop type mapping, a data set of the agricultural plots present in the study area is required in order to exclude other land use types from the classification process and enable a crop type identification at the plot level. This plot map may be either derived from official land cover data sets or from object-based image analysis (Blaschke, 2010). For our study area a digital land cover data set based on mapping CIR aerial photographs was available from the state ministry of environment.

### 2.2. Satellite image time series

Spectral information from 35 LANDSAT TM/ETM images acquired between the years 1987 and 2002 was used to set up the temporal crop type profiles. The image acquisition dates are listed in Table 2. LANDSAT images were chosen for this study for different reasons. They are available for several years to decades and are therefore suitable for long-term monitoring studies (Wulder et al., 2008). The spatial resolution of 30 m allows for single plot crop type identification and the image size of approximately 175 by 175 km encompasses the whole study area. The repetition rate of 16 days results in approximately two to five cloud-free coverages of our study area per year. The LANDSAT images were atmospherically and geometrically corrected to allow for multi-temporal analyses (Richter, 1996) and the NVDI was then computed for each image. We chose the most commonly used NDVI for this study, since our agricultural study area in Central Europe is characterized by low biomass and no particularly high humidity.

### 2.3. Agro-meteorological data

The different crop types undergo certain specific growth stages and agro-technical treatments throughout the growing season. These are for the example of cereals, sowing, seedling growth, tillering, stem elongation, flowering, grain-fill period (milk and dough development), ripening and harvest. As a result of specific weather patterns throughout individual years, particularly the temperature and precipitation characteristics, the onset and duration of the growth stages and the times of agro-technical treatments may

**Table 1**
Cultivation data collected from six agricultural companies between the years 1987–2002 used for setting up the spectral–temporal profiles.

| Crop type | Total number of plots |
|---|---|
| Fallow | 760 |
| Field grass (perennial and first year) | 120 |
| Winter rye | 890 |
| Winter wheat | 345 |
| Winter barley | 320 |
| Oilseed rape | 270 |
| Summer grain | 125 |
| Sugar beets | 60 |
| Maize | 365 |
| Oilseed crops and legumes | 325 |
| Overall sum of plots | 3745 |

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