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Combined use of multi-seasonal high and medium resolution satellite imagery for parcel-related mapping of cropland and grassland

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ABSTRACT

A key factor in the implementation of productive and sustainable cultivation procedures is the frequent and area-wide monitoring of cropland and grassland. In particular, attention is focused on assessing the actual status, identifying basic trends and mitigating major threats with respect to land-use intensity and its changes in agricultural and semi-natural areas. Here, multi-seasonal analyses based on satellite Earth Observation (EO) data can provide area-wide, spatially detailed and up-to-date geo-information on the distribution and intensity of land use in agricultural and grassland areas. This study introduces an operational, application-oriented approach towards the categorization of agricultural cropland and grassland based on a novel scheme combining multi-resolution EO data with ancillary geo-information available from currently existing databases. In this context, multi-seasonal high (HR) and medium resolution (MR) satellite imagery is used for both a land parcel-based determination of crop types as well as a cropland and grassland differentiation, respectively. In our experimental analysis, two HR IRS-P6 LISS-3 images are first employed to delineate the field parcels in potential agricultural and grassland areas (determined according to the German Official Topographic Cartographic Information System – ATKIS). Next, a stack of seasonality indices is generated based on 5 image acquisitions (i.e., the two LISS scenes and three additional IRS-P6 AWiFS scenes). Finally, a C5.0 tree classifier is applied to identify main crop types and grassland based on the input imagery and the derived seasonality indices. The classifier is trained using sample points provided by the European Land Use/Cover Area Frame Survey (LUCAS). Experimental results for a test area in Germany assess the effectiveness of the proposed approach and demonstrate that a multi-scale and multi-temporal analysis of satellite data can provide spatially detailed and thematically accurate geo-information on crop types and the cropland-grassland distribution, respectively.

1. Introduction

A key aspect of the agricultural production in the European Union (EU) is the implementation of productive, sustainable and ecologically compatible cultivation forms. The cultivation forms as well as the related land-use intensity are mainly driven by environmental, economic and political factors that lead to constantly changing conditions and transformation processes in the cultivated landscape. Hence, a frequent and area-wide monitoring of the (agri-) cultural landscape is required in order to assess the current status, identify basic trends and mitigate major threats. This in turn is a prerequisite to warrant a sustainable development or implement effective adaptation and mitigation strategies. An established European-wide reporting system collecting key figures such as the acreage and type of crops is the statistical land-parcel identification system (LPIS) that is based on figures delivered by farmers (Devos and Milenov, 2010). The Land Use/Cover Area Frame Statistical Survey (LUCAS) aims at the frequent provision of land-use/land-cover (LULC) information for the EU member states (Martino and Fritz, 2008). However, the potential to characterise the spatial pattern of main crop types and grassland and their annual changes in a spatially detailed and comprehensive manner at local and regional scales is limited.

Satellite-based Earth Observation (EO) provides an ideal basis for the area-wide and spatially detailed provision of geo-data on the actual LULC and its changes in agricultural and grassland areas. In addition, the derived geo-information can be easily integrated into Geographical Information Systems (GIS) and/or combined with statistical or topographic data. The CORINE Land Cover (CLC) programme has been established as a pan-European EO-based LULC mapping initiative (EEA, 2007) delivering LULC data referring to 44 classes at a scale of 1:100,000. CLC data is available for 1990, 2000 and 2006, and an update for 2012 has been initiated. However, the actual updating interval of CLC is too static and the information on

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agricultural classes is too limited to assess key developments affecting the cultural landscape. These developments include changes in agricultural land use or land-use intensity, adaptations to changes in agricultural policy, increased use of biofuels or the loss of biodiversity in agricultural areas (Henle et al., 2008; Stoate et al., 2009).

The use of multi-seasonal EO data allows for the description of the type and intensity of agricultural land use, the quantitative and qualitative characterisation of changes in the cultural landscape or the updating and supplementation of geospatial or topographic databases (Hildebrandt, 1996; Bradley et al., 2007; Stoate et al., 2001, 2009). At the same time, cropland and grassland monitoring requires EO data covering large geographic areas at high temporal and spatial resolution with minimal costs (Wardlow and Egbert, 2008). However, currently available data covering large geographic areas have limited spatial resolution. Nevertheless, methods have been developed applying medium resolution (MR) data like NOAA-AVHRR or MODIS and derived vegetation indices to describe the phenological behaviour of vegetation and different crops (Lunetta et al., 2010; Bradley et al., 2007; Wardlow and Egbert, 2008). Nevertheless, a limitation of these methods is their poor performance in areas characterised by small field parcels as it occurs in many regions within Europe. Accordingly, recent studies have started investigating the employment of high resolution (HR) data. Sai and Rao (2008) use IRS-P6 LISS-III and AWiFS data to discriminate rice, cotton, maize, sugarcane, mango, and forest within four study areas in India. Singh et al. (2011) describe the cropping pattern in the Indo-Gangetic plain of Uttar Pradesh, India, using seasonal IRS-P6 AWiFS data. Lobo et al. (1996) showed that the accuracy of cropland and grassland classification can be improved by focussing the analyses on objects (field parcels) instead of analysing the characteristics of single pixels. Bock et al. (2005) proved the effectiveness of object-oriented methods for habitat mapping at multiple scales for case studies in Germany and the United Kingdom. Conrad et al. (2010) classify irrigated crops based on field parcels in arid central Asia using SPOT and ASTER data. In another study, Conrad et al. (2011) investigated the potential of RapidEye time series data for the classification of crop rotations in the heterogeneous agricultural landscapes of irrigation systems in Central Asia. Turker and Ozdarici (2011) perform a comparative study of field-based crop classification using SPOT-4, SPOT-5, IKONOS and QuickBird data. Itzerott and Kaden (2006a,b) present an approach to approximate a universal class description for crops by means of multi-temporal satellite data, trying to reduce the influence of particular weather and soil conditions. Franke et al. (2012) discriminate between semi-natural, extensively-used, intensively-used and tilled grasslands using multi-temporal RapidEye data for a study area in southern Germany.

It is worth noting that weather conditions (e.g., cloud cover) still hinder the employment of optical data for operational applications (Blaes et al., 2005). To overcome this drawback, some recent studies have been presented employing weather-independent synthetic aperture radar (SAR) data for cropland and grassland monitoring (Smith and Buckley, 2011; Lin et al., 2009; McNairn et al., 2009; Schuster et al., 2011; Metz et al., 2012).

The EC and European Environmental Agency (EEA) have initiated several programmes such as the FP7 Geoland2 project (Geoland, 2012) or the recently started GMES Initial Operations Land programme (GIO Land, 2012) which specifically address the development of EO-based service elements for the frequent provision of different agriculture and grassland layers at European level. In the framework of Geoland2-Euroland, Brodsky et al. (2011) use multi-seasonal IRS-P6 LISS-3 and/or AWiFS imagery to evaluate the influence of the temporal EO data coverage on the grassland/arable-land classification. In particular, they obtain overall accuracies of 93% when considering five images and 85% when using three scenes acquired in April, July and October, respectively. A central element in this approach is the analysis of the seasonal behaviour of bio-physical parameters such as the fraction of green vegetation cover (FCover) presented by Lacaze et al. (2011). In parallel to this, the research activities in the context of the Geoland2-Euroland project also included the application and assessment of the technique for cropland and grassland classification proposed by Metz (2009) demonstrated in a diploma study in the context of CORINE Land Cover 2006 in Germany.

However, the experience gained in the Geoland2-Euroland project with respect to large scale operational production of HR grassland products has shown that the tested methodologies still show certain potential for improvement. Here we identified three major directions of enhancement, (i) the capability to perform multi-sensor/multi-scale analyses in order to increase the temporal coverage with EO data takes (as a basis for an optimal description of seasonal characteristics), (ii) to classify grassland and crops at the level of field-parcels in order to provide more homogeneous and significant spectral and spatial properties (e.g., due to minimised spatial and temporal noise effects caused by outliers), and (iii) to allow for the integration of ancillary data available from currently existing geo-databases. Such geo-databases might be used to geometrically and thematically focus the analyses on specific areas or LULC categories of interest (e.g., using official topographic data or CORINE vector information), or to increase the degree of automation by minimising efforts to manually collect training data through the implementation of already available and frequently updated data sources at European-wide level (e.g., LUCAS point data). By integrating area-wide training data such as LUCAS point, the classification procedure can also be adapted more effectively to local geographical and landscape-specific conditions.

To realise these optimizations, this paper introduces an object-oriented approach for an effective multi-resolution analysis of seasonal EO data at field-parcel level. Thereby, the presented study aims at innovation in terms of effectively combining and enhancing existing base techniques in form of a specifically optimised and tailored workflow (and therewith increasing the applicability with respect to an operational production scenario) rather than introducing innovative algorithms or classification methods. To this aim, Section 2 introduces the methodological framework and workflow (with Section 2.1), the segmentation of the actual land parcels, and the identification of main crops and grassland. Section 3 presents the results of a quantitative accuracy assessment, whereas in Section 4 the conclusions are drawn and future perspectives are presented.

2. Multi-scale analysis of seasonal time series data

The differentiation of grassland and crop types can hardly be based on the mere interpretation of spectral properties alone, since the spectral characteristics of these LULC types significantly vary within the vegetation period. Moreover, spectral signatures of different crop types and grassland are quite similar to each other in some periods of the year, depending on their individual growth status, which in turn, are determined by phenology and cultivation. Crops show highly variable seasonal characteristics depending on the geographical region, local climate, sowing dates, weather conditions during the vegetation period, equipment and behaviour of the farmer, or cultivation cycle and harvesting times. In contrast, grassland features a more continuous seasonal development with some variation due to the management intensity (see Fig. 1). While the behaviour of natural grassland mostly follows the natural phenology as a function of the climatic conditions, semi-natural and managed grassland shows a more variable development subject to the influence of grazing cattle or mowing for fresh forage, silage or hay production.