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Soil organic carbon and texture retrieving and mapping using proximal, airborne and Sentinel-2 spectral imaging

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ABSTRACT

Soil Organic Carbon (SOC) is a useful representative of soil fertility and an essential parameter in controlling the dynamics of various agrochemicals in soil. Soil texture is also used to calculate soil's ability to retain water for plant growth. SOC and soil texture are thus important parameters of agricultural soils and need to be regularly monitored. Optical satellite remote sensing offers the potential for frequent surveys over large areas. In addition, the recently-operated Sentinel-2 missions provide free imagery. This study compared the capabilities of Sentinel-2 for monitoring and mapping of SOC and soil texture (clay, silt and sand content) with those obtained from airborne hyperspectral (CASI/SASI sensors) and lab ASD FieldSpec spectroradiometer measurements at four agricultural sites in the Czech Republic. Combination of 10 extracted bands of the Sentinel-2 and 18 spectral indices, as independent variables, were used to train prediction models and then produce spatial distribution maps of the selected attributes. Results showed that the prediction accuracy based on lab spectroscopy, airborne and Sentinel-2 in the majority of the sites was adequate for SOC and fair for clay; however, Sentinel-2 imagery could not be used to detect and map variations in silt and sand. The SOC and clay maps derived from the airborne and spaceborne datasets showed similar trend, with both performing better where SOC levels were relatively high, though at the highest levels Sentinel-2 was able to create the SOC map more precisely than the airborne sensors. Taken across all SOC levels measured in the reference data, Sentinel-2 results were marginally lower than lab spectroscopy and airborne imagery, but this reduction in precision may be offset by the extensive geographical coverage and more frequent revisit characteristic of satellite observation. The increased temporal revisit and area are expected to be positive enhancements to the acquisition of high-quality information on variations in SOC and clay content of bare soils.

1. Introduction

Understanding variability of soil attributes allows the improvement of environmental and agricultural management as well as a more effective usage of resources. The qualitative information of available soil maps is often not adequate for site-specific management of water and fertilizers (Castaldi et al., 2016). For these purposes, the quantitative assessment and mapping of important soil attributes such as soil texture, Soil Organic Carbon (SOC), soil Nitrogen (N) and soil Moisture Content (MC) over the field is essential.

The emersion of proximal and remote sensing techniques has been documented as efficient detection methods for assessing and mapping some soil attributes (Ben-Dor, 2002; Viscarra Rossel et al., 2006). Proximal sensing is defined as the use of different sensors to obtain signals from the object when the sensor's receiver is in contact with or close to (within 2 m) the object (Viscarra Rossel et al., 2010). However, remote sensing has been explained as using electromagnetic radiation in order to acquire information about an object or phenomenon without physical contact (Elachi and Van Zyl, 2006). The spectral resolution of the aforementioned optical sensors largely depends on the numbers, sampling and position of bands. This study uses the following definitions for multispectral, superspectral, hyperspectral and ultraspectral sensors: The multispectral sensors offer 3 to 7 bands, the superspectral sensors offer 7 to 20 bands, the hyperspectral sensors offer from 20 to 500 bands and the ultraspectral sensors offer more than 1000 bands (Gholizadeh et al., 2018). Laboratory Visible-Near Infrared-Short Wave

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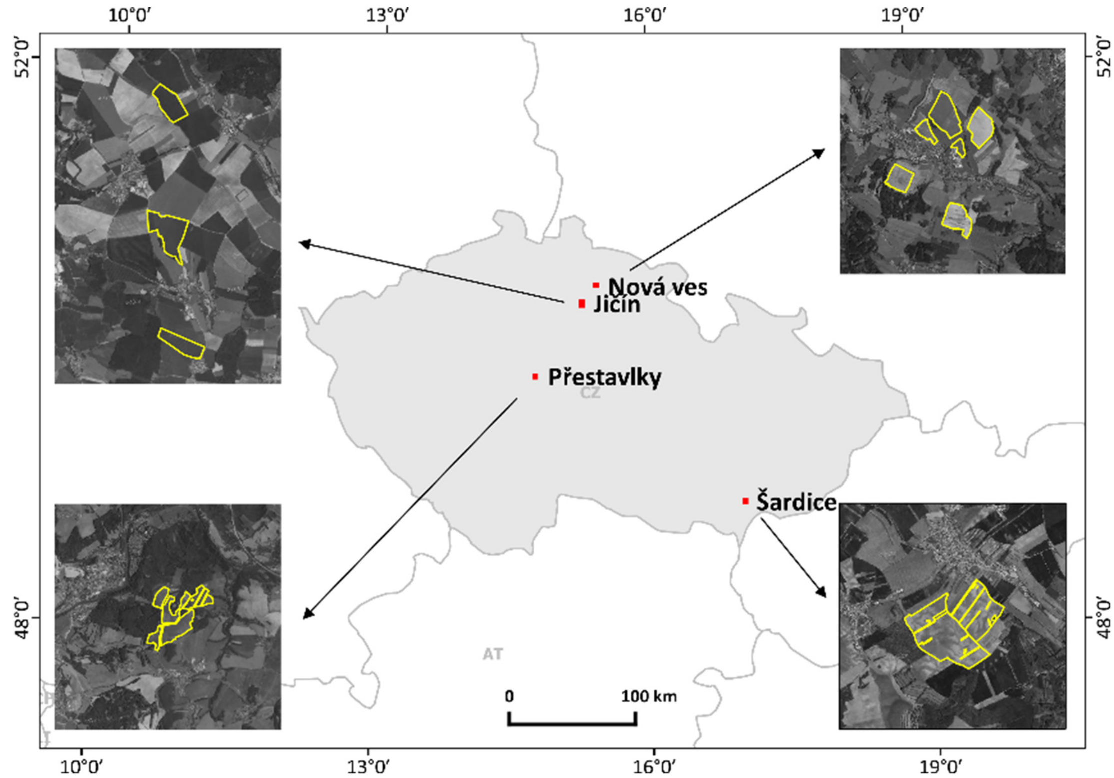

Fig. 1. Location of the study areas (yellow borders). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Infrared (VIS-NIR-SWIR) spectroscopy using ultraspectral sensors proved to be a suitable alternative substitute for conventional laboratory analysis of soil chemical parameters including SOC (Ji et al., 2015), N, Phosphorus (P), Potassium (K), Cation Exchange Capacity (CEC), pH (Viscarra Rossel et al., 2006) and some physical parameters such as soil structure, bulk density and texture (Bellon-Maurel et al., 2010; Gholizadeh et al., 2014). Several researchers have also studied the potential of hyperspectral airborne sensors to attain quantitative assessment of soil parameters. Some have used the HyMap sensor to predict SOC content (Selige et al., 2006) and soil texture (Gomez et al., 2008). For this purpose, other hyperspectral airborne sensors such as DAIS-7915 (Ben-Dor et al., 2002), AHS-160 (Stevens et al., 2010), MIVIS (Casa et al., 2013), CASI and SASI (Zizala et al., 2017) have also been employed.

The application of multispectral and superspectral satellite remote sensing data into soil monitoring and digital mapping have advantages over proximal and airborne hyperspectral remote sensing including availability of high revisit cycles, comprehensive monitoring of large-scale sites, better classification of results and data reduction (Gianinetto and Lechi, 2004; Yokoya et al., 2016). Over the last several years, analysis of data obtained from optical spaceborne techniques derived from various hyperspectral, multispectral and superspectral sensor imagery has proven to be an efficient way to assess surface soil characteristics (Castaldi et al., 2016; Danoedoro and Zukhrufiyati, 2015; Gomez et al., 2018; Vagen et al., 2016; Zhang et al., 2013). The large frequent data streams provided by spaceborne sensors enables the development of soil monitoring and mapping techniques from the local to the regional scale in an effective, fast, frequent and economical way for vast areas (Berger et al., 2012; Malenovsky et al., 2012). However, the use of satellite data in quantitative soil estimation is still challenging due to considerable limitations of some of these sensors (Gholizadeh et al., 2018). For example, Hyperion data suffer due to the very low Signal to Noise Ratio (SNR) in the SWIR region especially around 2200 nm, where the spectral features of clay minerals are located (Castaldi et al., 2016) or Landsat-8 revisit cycle of 16 days can result in only a limited number of opportunities to observe bare soil in any given crop calendar as well as time-series studies (Immitzer et al., 2016).

The recently-operated European Space Agency (ESA)/European Union Copernicus program's superspectral Sentinel-2A was successfully launched on 23 June, 2015. Sentinel-2 offers exceptional perspectives on land with a combination of wide coverage (swath width of 290 km), spatial resolution (10–60 m), and minimum five-day global revisit-time (with twin satellites in orbit) (Drusch et al., 2012; Immitzer et al., 2016). Sentinel-2 produces useful information for a wide range of land applications (Malenovsky et al., 2012). Some simulation studies have been conducted to explore the potential of Sentinel-2 for a variety of land surface parameter estimations. For instance, Van der Meer et al. (2014) assessed the potential of Sentinel-2 for geological mapping by simulating a dataset from HyMap airborne hyperspectral image using Sentinel-2 band characteristics. They confirmed the capability of Sentinel-2 for presenting data endurance for ASTER in terms of generating reproducible and consistent data, which can differentiate surface mineralogy. Mielke et al. (2014) studied the potential of OLI, synthesized Sentinel-2 and synthesized EnMap data for mapping the mining areas. They proved that these data had potential for soil monitoring and mapping. However, these findings need to be confirmed by real data. Castaldi et al. (2016) used simulated Sentinel-2 data to estimate and compare SOC and soil texture prediction models with Hyperion, HyspIRI, EnMAP, PRISMA, Landsat-8 and ALI retrieved models. They showed that Sentinel-2, Hyperion and Landsat-8 provided higher accuracies than the other sensors. The experiment conducted by Van der Werff and Van der Meer (2016) in southeast Spain was a pioneering study in terms of using Sentinel-2 actual data, which showed that the Sentinel-2 mission could provide data continuity for Landsat-8 OLI, when exploring mineralogy at the Earth's surface.

Clearly, using Sentinel-2 real data requires to be tested in order to prove its capability for various soil attributes monitoring and mapping worldwide. To this end, the main objectives of the current study on the