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Efficiency assessment of using satellite data for crop area estimation in Ukraine

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ABSTRACT

The knowledge of the crop area is a key element for the estimation of the total crop production of a country and, therefore, the management of agricultural commodities markets. Satellite data and derived products can be effectively used for stratification purposes and a-posteriori correction of area estimates from ground observations. This paper presents the main results and conclusions of the study conducted in 2010 to explore feasibility and efficiency of crop area estimation in Ukraine assisted by optical satellite remote sensing images. The study was carried out on three oblasts in Ukraine with a total area of 78,500 km^2. The efficiency of using images acquired by several satellite sensors (MODIS, Landsat-5/TM, AWiFS, LISS-III, and RapidEye) combined with a field survey on a stratified sample of square segments for crop area estimation in Ukraine is assessed. The main criteria used for efficiency analysis are as follows: (i) relative efficiency that shows how much time the error of area estimates can be reduced with satellite images, and (ii) cost-efficiency that shows how much time the costs of ground surveys for crop area estimation can be reduced with satellite images. These criteria are applied to each satellite image type separately, i.e., no integration of images acquired by different sensors is made, to select the optimal dataset. The study found that only MODIS and Landsat-5/TM reached cost-efficiency thresholds while AWiFS, LISS-III, and RapidEye images, due to its high price, were not cost-efficient for crop area estimation in Ukraine at oblast level.

1. Introduction

Agricultural statistics has always appeared as one of the most obvious and promising applications of earth observation (EO). In the initial steps of remote sensing many scientists believed that satellite images would be able to produce reliable agricultural statistics with very few field data (Mac Donald and Hall, 1980). Since the late 1970s the serious risk of bias of direct area measurement or pixel counting on classified or photo-interpreted images is clearly identified and solutions are proposed on the basis of traditional statistical survey techniques. Calibration estimators (Brown, 1982) are applied to solve the bias problem of area estimation by pixel counting. Calibration estimator exploits commission and omission errors computed on a confusion matrix that are used to correct the bias (GEOSS, 2009). In the remote sensing literature calibration for area estimates initially appears without making reference to the statistical literature and without using the term “calibration” (Bauer et al., 1978; Card, 1982; Hay, 1988; Czaplewski, 1992; Czaplewski and Catts, 1992; Walsh and Burk, 1993). The more traditional regression estimator (Hansen et al., 1953; Cochran, 1977) has also been widely used and probably more than the calibration estimator in large operational projects for crop area estimates with remote sensing (Hanuschak et al., 1980; Wall et al., 1984; Chhikara et al., 1986; Germain and Julien, 1988; González et al., 1991; González and Cuevas, 1993; Gallego et al., 1993). The regression estimator corresponds to the same principle of the calibration estimator: combining approximately unbiased information observed on the ground (or accurate photo-interpretation) for a sample, with less accurate information coming from classified mages but available for the whole population. The classified satellite image is used as an auxiliary variable in the regression estimator to correct estimates derived from ground surveys only (Carfagna, 2001). Pure

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remote sensing approaches provide sufficiently accurate results only for crops that can be clearly distinguished on the images, such as paddy rice (Fang, 1998). Methods without a statistically consistent ground survey (including sampling) are also useful when the access to the fields is problematic. For example, coarse area estimates could be made for Kosovo only based on image analysis at the end of war, when sending surveyors to the fields was dangerous or required difficult to obtain authorisations (Geosys, 2000; Terres et al., 1999; Kerdiles et al., 2013).

The efforts to set up large operational applications seem to find serious difficulties, with a few exceptions. One of the reasons for the limited operational use of EO for agricultural statistics is the difficulty to reach cost-efficiency in a field in which traditional survey methods are relatively inexpensive (FAO, 2008). There has been a long debate on the cost efficiency of the regression and calibration estimators. Different conclusions are reached depending on the price of ground surveys and remote sensing (image acquisition and analysis). While some authors (Taylor et al., 1997; Wall et al., 1984) give a positive answer, others (Allen, 1990; Meyer-Roux and Vossen, 1994) consider that the cost of remote sensing has to go down to reach the cost-efficiency thresholds. The free access policy for several types of medium resolution images, such as Landsat-5/TM, and the fast progress in computing have contributed to the revision of conclusions of some sceptical analysts (Carfagna, 2001). In the particular case of the U.S. Department of Agriculture (USDA) National Agricultural Statistical Service (USDA-NASS) program, the cost-efficiency that was considered insufficient in the late 1980s (Allen, 1990), became later clearly positive (Hanuschak et al., 2001) and enhanced by the free distribution of the cropland data layers (CDL), a by-product that has become very popular amongst analysts (Johnson, 2008; Boryan et al., 2011).

In Western Europe, the use of satellite images for crop area estimation was tested in several projects, such as the AGRIT project in Italy and the Monitoring Agricultural Resources (MARS) project (Gallego, 2004; Carfagna and Gallego, 2005; Gallego et al., 2010). The most frequently used approach was the regression estimator combining classified images with field surveys on samples of square segments (Taylor et al., 1997). Attempts to produce rapid estimates of inter-annual crop area for the EU using images without current field data showed that the results had depended more on the a priori belief of the analyst than on the information provided by the images (Gallego, 2006).

In spite of the cost reduction of images with a resolution around 20 or 30 m and the faster and more user-friendly computational tools, none of the large applications in Europe has survived in an operational way. There are several reasons for that, including a relatively complex agricultural landscape and lack of confidence of many institutions after the too optimistic marketing of the private sector in past decades (Carfagna, 2001; Gallego, 2006; Gallego and Delincé, 2010). The 2008 agricultural commodities crisis increased the interest on the use of remote sensing for agricultural monitoring. The Global Earth Observation System of Systems (GEOSS) has elaborated a simplified recommendations document that may be useful both for the EO community and for statistical services and other users (GEOSS, 2009).

Ukraine is one of the most developed agricultural countries in the world. According to the USDA Foreign Agricultural Service (FAS) statistics, Ukraine is the sixth largest wheat exporter (after USA, EU (EU-27), Canada, Russia, Australia), on average accounting for 6% of total wheat exports between 2007 and 2009 (FAS, 2009). Estimating the area, yield and consequently, production of agricultural crops in Ukraine represents a major task (Kussul et al., 2012b; Kogan et al., 2013a,b; Shelestov et al., 2013). Yet, the use of satellite images to crop area estimation in Ukraine has been limited in terms of methodology applied and study area. In particular, no regression or calibration estimators have been previously applied to crop area estimation in Ukraine. Most studies have been conducted just at a district-level scale (Lyalko et al., 2010), i.e. less than 3616 km^2, the maximum area of a district in Ukraine. These did not give possibility to assess the use of satellite images to crop area estimation in Ukraine in an operational way. Taking into account the availability of a wider range of satellite imagery with various spatial and spectral characteristics, it is reasonable to test the cost-efficiency improvement with new tools and new image types, while exploiting the experience gained in the past. Therefore, the particular objectives of this paper are as follows:

(i) to adapt and apply the established in the EU methodology of crop area estimation for the territory of Ukraine by combining optical satellite images and ground surveys;
(ii) to assess efficiency of using optical satellite images acquired by different instruments for crop area estimation in Ukraine.

The presented study was conducted in 2010 on three oblasts in Ukraine with a total area of 78,500 km^2, and a cropland area of 2.45 M ha according to the official statistics. (Oblast is a subnational administrative unit that corresponds to the NUTS2 level of the nomenclature of territorial units for statistics (NUTS) of the European Union). The efficiency of using optical satellite images acquired by several sensors (MODIS, Landsat-5/TM, AWiFS, LISS-III and RapidEye) for crop area estimation in Ukraine is assessed. Regression estimator combining classified images with field surveys on a stratified sample of square segments is applied to correct survey estimates. The main criteria that are used for efficiency analysis are as follows: (i) relative efficiency that shows how much time the error of area estimates can be reduced with satellite images, and (ii) cost-efficiency that shows how much time the costs of ground surveys for crop area estimation can be reduced with satellite images. These criteria are applied to each satellite image type separately, i.e., no integration of images acquired by different sensors was made, to select the optimal datasets. The obtained crop estimates are also compared to the official statistics available from the State Statistics Service of Ukraine.

2. Study area description

The study covered three administrative regions (Kyivska, Khmelnytska and Zhytomyrska oblasts, Fig. 1) for a total geographic area of 78,500 km^2 with 2.45 M ha of cropland. Major crops in the study area are: wheat (32% of total cropland), barley (21%), vegetables (15%), maize (12%), oilseed rape (8%), sugar beet (6%), soybeans (4%), and sunflower (2%).

The proportion of different land cover types significantly changes across the study area: the Northern part of Kyivska and approximately half of Zhytomyrska oblasts contain more than 30% of the forest area. The central part is densely populated. Khmelnytska oblast is relatively uniform in crop land percentage except for the small Northern part. None of the oblasts has a strongly dominant crop. Field size generally ranges up to 250 ha (Fig. 2), and land cover classes are quite heterogeneous (including crop, forests, grassland, rivers, lakes and wetlands). A large part of the area (approximately 10–15%) is occupied by small private farms with field size below 50 ha (Fig. 2), and the so called family gardens, which represent mixed cultivations at small scale mainly for self-consumption. These farms are primarily responsible in Ukraine for potatoes and vegetables production (about 90% of total production).

3. Materials description

This section describes ground data and satellite images used in the study.