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Determination of the age of oil palm from crown projection area detected from WorldView-2 multispectral remote sensing data: The case of Ejisu-Juaben district, Ghana

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ABSTRACT

Information about age of oil palm is important in sustainability assessments, carbon mapping, yield projections and precision agriculture. The aim of this study was to develop and test an approach to determine the age of oil palm plantations (years after planting) by combining high resolution multispectral remote sensing data and regression techniques using a case study of Ejisu-Juaben district of Ghana. Firstly, we determined the relationship between age and crown projection area of oil palms from sample fields. Secondly, we did hierarchical classification using object based image analysis techniques on WorldView-2 multispectral data to determine the crown projection areas of oil palms from remote sensing data. Finally, the crown projection areas obtained from the hierarchical classification were combined with the field-developed regression model to determine the age of oil palms at field level for a wider area. Field collected data showed a strong linear relationship between age and crown area of oil palm up to 13 years beyond which no relationship was observed. A user's accuracy of 80.6% and a producer's accuracy of 68.4% were obtained for the delineation of oil palm crowns while for delineation of non-crown objects a user's accuracy of 65.6% and a producer's accuracy of 78.6% were obtained, with an overall accuracy of 72.8% for the OBIA delineation. Automatic crown projection area delineation from remote sensing data produced crown projection areas which closely matched the field measured crown areas except for older oil palms (13+ years) where the error was greatest. Combining the remote sensing detected crown projection area and the regression model accurately estimated oil palm ages for 27.9% of the fields and had an estimation error of 1 year or less for 74.6% of the fields and an error of a maximum 2 years for 92.4% of the fields. The results showed that 6 and 11 year old oil palm stands were dominating age categories in the study area. Although the method could be reliably applied for estimating oil palm age at field level, more attention is required in improving crown area delineation to improve the accuracy of the approach.

1. Introduction

Palm oil is obtained from the African oil palm (*Elaeis guineensis* Jacq.); monocotyledonous perennial plants that are indigenous to West Africa but are now grown in more than 43 tropical countries mainly between 10°N and 10°S of the equator (Hardter et al., 1997). Annual global production and use of palm oil is over thirty-five million metric tons with Malaysia and Indonesia being leading producers, contributing over 80% of global production (Fitzherbert et al., 2008; Germer and Sauerborn, 2008). The total area under commercial oil palm production is over thirteen and a half million hectares (Butler et al., 2009). Consequently, palm oil is the second most important source of vegetable oil in the world after soybean (Tan et al., 2009). Due to increasing demands for palm oil as a food resource in China, India and South America and as biofuel in the European Union, global production has been increasing at a rate of 9% annually in the last three decades (Koh and Wilcove, 2008; Tan et al., 2009). This is mainly because oil palms have the highest potential yield per hectare of all sources of vegetable oil (Corley, 2009). The growth in area under oil palm has been associated with many and widespread environmental problems such as deforestation and associated biodiversity loss in tropical areas (Butler et al., 2009; Carlson et al., 2012; Fitzherbert et al., 2008; Stone, 2007).

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The ability of remote sensing data to automatically detect and quantify plant biophysical parameters and biochemical properties through direct spectral measurements and/or vegetation indices is very useful in agricultural, forestry, environmental and land governance applications. Remote sensing can be used for producing a resource inventory of location of oil palm fields, size of plantations and age of oil palms. As such, remote sensing techniques have been developed for various management aspects of oil palm production such as disease detection (Santoso et al., 2011; Shafri and Anuar, 2008; Shafri et al., 2011a), counting of number of trees (Jusoff, 2009; Shafri et al., 2011b), recognition of oil palm bunch types (Alfatni et al., 2013), yield estimation (Balasundram et al., 2013), biomass estimation (Morel et al., 2012; Thenkabail et al., 2004) and determination of age (Ibrahim et al., 2000; McMorrow, 1995, 2001). Various sensors and sensing platforms such as Landsat TM satellite imagery (McMorrow, 2001), Quickbird satellite imagery (Balasundram et al., 2013; Santoso et al., 2011), hyperspectral airborne data (Jusoff, 2009; Shafri and Anuar, 2008) and IKONOS satellite imagery (Thenkabail et al., 2004) have been applied in these applications.

Information about the ages of oil palm plantations is important for biomass estimation and carbon stock inventory for oil palm plantations, an important aspect to biodiversity conservation and reducing greenhouse gas emissions from palm oil production (Thenkabail et al., 2004). In addition, some oil palm plantations are very large (exceeding 1000 ha) and therefore detecting age of oil palms is important for ensuring optimal resource utilization and management of farm operations such as fertilization. Efficient farm management results in higher productivity per unit area, and this is important in meeting production targets without expanding area under production. Oil palm age detection is also useful in yield forecasting, which is useful in pre-harvesting and post harvesting operation planning and market intelligence necessary for economic planning at local and regional levels (Balasundram et al., 2013). Furthermore, due to increasing market demand for sustainably produced palm oil, determining age of oil palm at field level is important in assessing certification requirements such as those for Round Table for Sustainable Palm Oil Production (RSPO). Traditional approaches to making these inventories rely only on ground based survey data to obtain this information, which alone is expensive, time consuming, arduous and may not be able to cover large areas. Remote sensing therefore becomes useful as it can complement ground data by extrapolating information from field samples to a wider area.

One remote sensing approach to determine the age of oil palm and other agricultural and forestry plantation trees is determining the relationship between radiance of individual image bands or derived vegetation indices to age at stand level (Franklin et al., 2003; McMorrow, 1995). It was established for oil palm that there was a negative nonlinear correlation between Landsat TM radiance and age on all image bands meaning that reflectance diminished with age of oil palms at stand level (McMorrow, 1995, 2001). Another approach to determine age is to use supervised or unsupervised image classification algorithms to classify an image into discrete age categories or age classes (Thenkabail et al., 2004). This approach is based on the hypothesis that each age or age class has a significantly different spectral signature that can be used to separate it from the next. With the advent of high resolution imagery and advancement of techniques to handle and process such data, it may be possible to extend the determination of oil palm age to the extraction of plant biophysical properties such as height and crown projection area from high spatial and spectral resolution remote sensing data that are known to be directly related to age.

It has been established in many plantation crops that there is a significant relationship between age and plant biophysical characteristics such as crown diameter, crown projection area, leaf area index, height and stem diameter (Kalliovirta and Tokola, 2005; Peper et al., 2001). The growth characteristics of oil palm can be divided into three stages; young, mature and old depending on the relationship between age and leaf area index as established from field studies (Breure, 1985, 2010; Gerritsma and Soebagyo, 1999). The leaf area index of oil palms has been observed to increase up to 10–12 years, after which the leaf area will remain constant or decrease (Breure, 1985; Van Kraalingen et al., 1989). Given the relationship between age and growth attributes of oil palm, combining a remote sensing method that can accurately detect oil palm crown projection area (or related biophysical attributes) with an empirical model that relate crown projection area to age provides a promising way of determine age of oil palm at field level from high resolution satellite imagery.

Use of high-resolution imagery such as WorldView-2 imagery processed through object-based image analysis (OBIA) provide a promising framework for determining age of oil palm at stand level through automatically extracting age-related parameters. Developments in OBIA have produced robust, reliable and automated routines for implementation of highly advanced algorithms (Blaschke, 2010; Navulur, 2007; Wang et al., 2013). An important aspect of OBIA is the inclusion of ancillary data such as texture, shape, size and relationships to image feature identification decisions (Blaschke, 2010). In feature identification decisions through OBIA, among the most important decision rules is the concept of scale, which defines the thresholds at which individual spatial or temporal features of an image can be treated as functionally homogeneous or heterogeneous (Addink et al., 2007; Blaschke, 2010; Gamanya et al., 2007; Wang et al., 2013). As such, the goal of a segmentation algorithm is to cut-up an image into uneven, non-random units based on spatial, functional and/or temporal heterogeneity functions and the resultant units are referred to as 'candidate objects' and these can be further purified into meaningful object features (Blaschke, 2010; Gamanya et al., 2007; Lang, 2008; Navulur, 2007). These object features can therefore be used in deriving image characteristics and meaning from satellite image data for use in decision making.

There have been significant developments in techniques for individual tree crown delineation from aerial imagery, satellite data and LIDAR data. These include analysis of crown texture in high resolution imagery to distinguish it from surroundings (Wu et al., 2004) and use of geostatistical methods that identify the apex of the crown first and then identify the crown boundary by determining the maximum rate of change across potential crowns (Feng et al., 2010; Pouliot et al., 2002; Song, 2007; Wang, 2010). Region growing techniques that identify and grow the local crown peaks (Brandtberg and Walter, 1998), detecting the local maxima and minima used for identifying the centroids and boundaries of the crowns (Culvenor, 2003b) and template matching algorithms (Erikson, 2004; Komura et al., 2004) have also been used in crown delineation. Other algorithms incorporated use of digital surface models in identification and delineation of individual tree crowns (Mei and Durrieu, 2004; Wolf and Heipke, 2007). Segmentation-based approaches that cut up the image according to spectral heterogeneity or homogeneity and then apply spectral, geometric, morphological, textural and other rules to identify tree crowns are increasingly being developed (Erikson, 2004; Whiteside et al., 2011; Wolf and Heipke, 2007). OBIA platforms have been able to incorporate many of these algorithms (spectral analysis, texture, morphology, geometry, colour) and thus making it possible to either choose one or combinations of techniques for individual tree crown detection. Although work on individual tree crown detection have been done for oil palm (Shafri et al., 2011b), the specific characteristics for mapping oil palm crowns in OBIA are not yet well established and the nature of oil palm crown presents further challenges compared to natural forests and other plantations for which research on crown projection area

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