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Continuous estimation of canopy leaf area index (LAI) and clumping index over broadleaf crop fields: An investigation of the PASTIS-57 instrument and smartphone applications

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ABSTRACT

Automatic leaf area index (LAI) measurements are important for obtaining sufficient amounts of field data over an extended period of time. A seasonal field campaign was carried out to obtain continuous LAI measurements over maize, soybean, and sorghum fields in northeast China in 2016. Field LAI measurements were acquired with the automatic PASTIS-57 (PAI Autonomous System from Transmittance Instantaneous Sensed from 57°) instrument and two smartphone applications, PocketLAI and LAISmart. These measurements were compared with data obtained using the LAI-2200 Plant Canopy Analyzer, digital hemispherical photography (DHP), and destructive sampling measurements.

The effective plant area index (PAI_{eff}) estimates from LAI-2200 and DHP are consistent over the season, with the overall relative errors (RE) of less than 5%. The PASTIS-57 data exhibit a small underestimation of the LAI-2200 and DHP values (RE < 20%). The relative errors for the LAISmart data are between −20% and −30%. PocketLAI significantly underestimates the LAI-2200 values (RE > 40%) and saturates at around PAI_{eff} = 3.5. The canopy clumping index (CI) exhibits an S-shaped seasonal variation that decreases with the increase of PAI_{eff} during the vegetative growth stage but increases after this stage. PASTIS-57 shows great potential for obtaining continuous LAI measurements in agricultural crop fields, but the smartphone applications should be further examined before they can be used for research purposes. The data collected in this study are valuable for the validation of remote sensing products.

1. Introduction

The leaf area index (LAI), defined as one-half of the total green leaf area per unit horizontal ground surface area, is one of the most widely used canopy attributes (GCOS, 2016). An accurate estimate of the canopy LAI is central for a wide range of studies including ecology, hydrology, carbon and nutrient cycling, and global change. Field-based LAI estimation has largely relied on handheld optical instruments, such as the LAI-2200 Plant Canopy Analyzer (PCA), digital hemispheric photography (DHP), TRAC, and AccuPAR (Fang et al., 2012b; Garrigues et al., 2008; Jonckheere et al., 2004; Weiss et al., 2004). The clumping index (CI) describes the spatial distribution of canopy foliage elements and is calculated as the ratio of the effective leaf area index (LAI_e) to the true LAI (Fernandes et al., 2014). CI has been used in many land surface models to characterize the radiation penetration and photosynthetic process in clumped canopies (Chen et al., 2012; Haverd et al., 2012; Ni-Meister et al., 2010; Nouvellon et al., 2000). In the field, CI is usually obtained through optical instruments when making LAI measurements. These optical methods are efficient for the occasional LAI and CI measurement but are usually labor and time consuming and difficult to deploy over large areas for long-term real-time measurements.

The study of vegetation growth and canopy exchange processes often requires continuous estimation of LAI and CI over time. Recent technological advances have led to an upsurge in the availability of several automatic instruments. These instruments estimate LAI through radiance transmittance or image gap fraction based on the Beer-Lambert law (Eq. (1)). For example, the PASTIS-57 (PAI Autonomous System from Transmittance Instantaneous Sensed from 57°) system allows continuous monitoring of the plant area index (PAI) from concurrent above and below canopy blue band illuminations at 57° (Baret et al., 2010). PAI estimates from PASTIS-57 have been compared with those derived from DHP and ceptometers and have been used to validate the GEOLAND version 1 (GEOV1) biophysical products (Camacho et al., 2013; Raymaekers et al., 2014). Qu et al. (2014a; 2014b)

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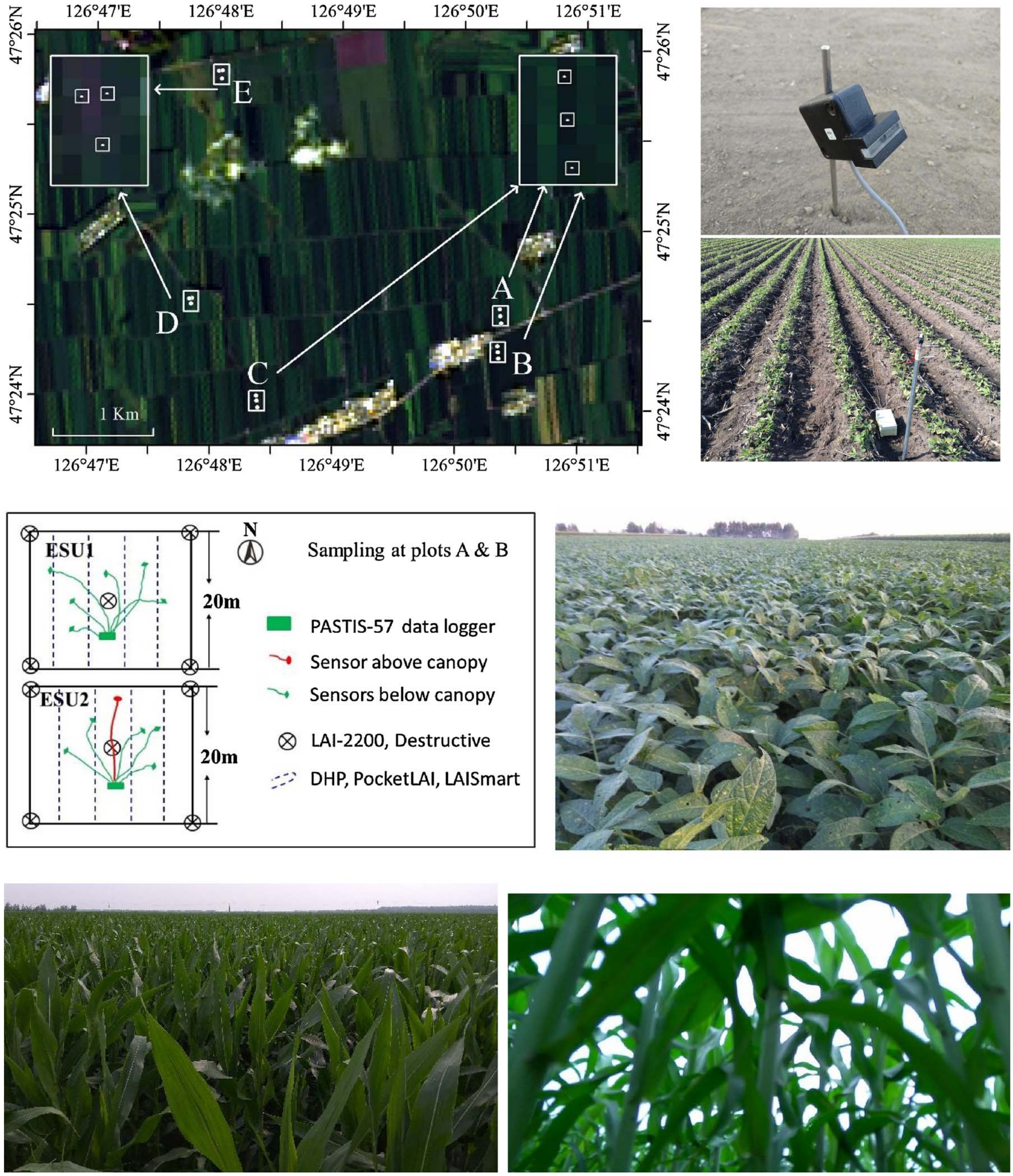

Fig. 1. The study area in the Hailun city, Heilongjiang province, northeast China. The upper panel shows a Landsat OLI image (September 4, 2015) with the locations of the plots and ESUs, a PASTIS-57 sensor, and the PASTIS-57 settings at plot B (June 16, 2016). The middle panel shows the sampling strategy for plots A and B and a field picture at plot B (August 20, 2016). The bottom panel shows a field picture taken at plot D (July 20, 2016) and a PocketLAI image at plot E (July 8, 2016), respectively.

developed an automatic LAI measurement system, LAINet, which uses photodiodes to measure the light transmittance in the red band. LAI is estimated from LAINet based on the directional transmittance collected through a wireless sensor network (WSN). Seasonal continuous observations of LAI have also been conducted with an upward-looking digital cover photography (DCP) (Ryu et al., 2012). Gap fractions derived from the classified DCP images were used to estimate LAI and CI. Due to its high spatial resolution and quick turnaround times, DCP offers an easy and cost-effective approach for continuous LAI monitoring at the ecosystem scale.

With the increasing popularity of smartphones, various applications have been developed to characterize the canopy architecture and LAI in ecological studies (Fuentes et al., 2012; Teacher et al., 2013). Smartphones can be used as portable LAI sensors and represent an alternative to other commercial instruments. One such example of a smartphone application is PocketLAI, which estimates LAI based on the canopy gap fraction derived from the segmentation of images acquired at 57.5° below the canopy (Confalonieri et al., 2013; Francone et al., 2014). The performance of PocketLAI was found comparable to the performance of LAI-2000, DHP, and AccuPAR (Campos-Taberner et al., 2016; Campos-Taberner et al., 2015; Francone et al., 2014). By connecting two smartphone terminals, Qu et al. (2016) designed an integrated LAI measurement system, LAISmart, which provides two image segmentation options based on either the greenness index or the blue band intensity. Similarly, LAI is estimated from the gap fraction model assuming a spherical leaf angle distribution (Qu et al., 2016).