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Mapping plastic greenhouse with medium spatial resolution satellite data: Development of a new spectral index ☆

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ABSTRACT

Plastic greenhouses (PGs) are an important agriculture development technique to protect and control the growing environment for food crops. The extensive use of PGs can change the agriculture landscape and affects the local environment. Accurately mapping and estimating the coverage of PGs is a necessity to the strategic planning of modern agriculture. Unfortunately, PG mapping over large areas is methodologically challenging, as the medium spatial resolution satellite imagery (such as Landsat data) used for analysis lacks spatial details and spectral variations. To fill the gap, the paper proposes a new plastic greenhouse index (PGI) based on the spectral, sensitivity, and separability analysis of PGs using medium spatial resolution images. In the context of the Landsat Enhanced Thematic Mapper Plus (ETM+) imagery, the paper examines the effectiveness and capability of the proposed PGI. The results indicate that PGs in Landsat ETM+ image can be successfully detected by the PGI if the PG fraction is greater than 12% in a mixed pixel. A kappa coefficient of 0.83 and overall accuracy of 91.2% were achieved when applying the proposed PGI in the case of Weifang District, Shandong, China. These results show that the proposed index can be applied to identifying transparent PGs in atmospheric corrected Landsat image and has the potential for the digital mapping of plastic greenhouse coverage over a large area.

1. Introduction

Since the first generation of plastic greenhouses (PGs) was invented in the 1950s, the practice of PG-oriented agriculture (Fig. 1a) has revolutionized the food industry all over the world. With transparent and energy-saving covering materials, PGs can protect food crops from unfavorable growing conditions, significantly increasing crop yield (Takakura, 1993; Levin et al., 2007; Katan, 1981; Cantliffe, 2001; Picuno et al., 2011; Picuno, 2014). By the year of 2016, PGs has reached a total coverage of 3.019×10^6 ha in the world (Briassoulis et al., 2016), primarily distributed in Europe, North Africa, the Middle East, and China (Wu et al., 2016; Levin et al., 2007; Aguilar et al., 2014). PGs are considered an evolutionary transition from traditional to industrial farming while leveraging the benefits of micro-scale control technologies. On the other hand, PGs are criticized for posing environmental concerns, such as plastic waste, soil pollution, and biodiversity degradation (Knickel and Ehrendorfer, 1999; Picuno et al., 2011), as plastic covers used in PGs cannot be easily decomposed by the natural environment (Sica and Picuno, 2007; Picuno et al., 2012; Picuno, 2014).

Plastic materials primarily used as PG covers have unique characteristics in aspects of optical transparency, gas-tightness, and high-reflectivity (Von Elsner et al., 2000). Such features alter the energy and water exchange between the land surface and the atmosphere (Fig. 1b). First, the transparent plastic materials in PG roofing can increase the land surface reflectance, leading to more solar energy reflected back into space (Von Elsner et al., 2000; Levin et al., 2007). Second, the solar energy reflected back from the vegetation and soil under a PG can be partially intercepted by the plastic cover, weakening the energy reflection from the land surface. Third, plastic PG covers are gas-tight. In the process of evapotranspiration, this unique feature prevents the water vapor from escaping to the atmosphere outside. As a result, the PG-

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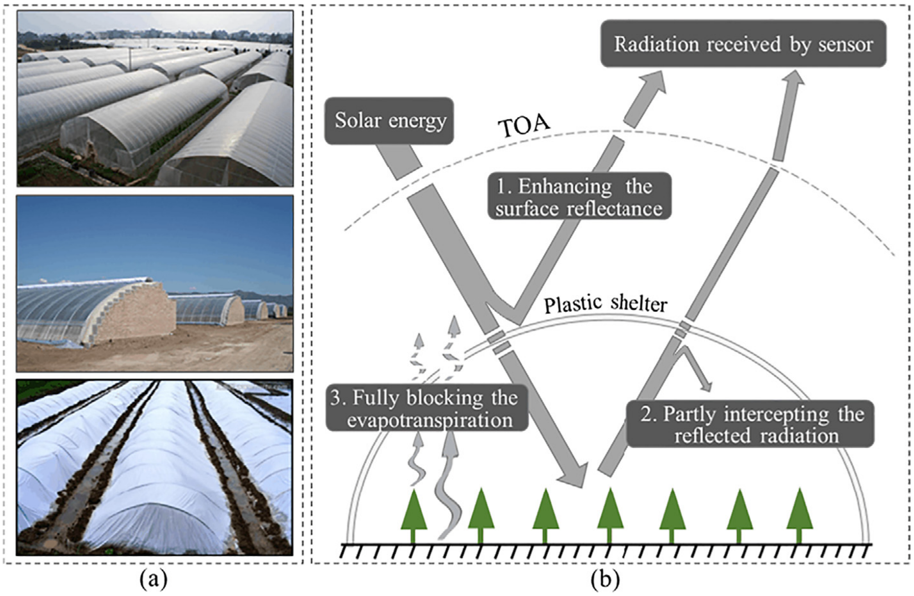

Fig. 1. (a) Examples of PGs; (b) effects of PGs on radiation and evapotranspiration.

oriented agriculture plays a potential role in moderating the regional climate (Campra et al., 2008; Campra and Millstein, 2013). Accurately mapping and estimating PG coverage in an area is crucial to the sustainable development of regional agriculture and the projection of the environmental impacts.

Remote sensing imagery has been widely used for land use mapping at different spatial resolutions and temporal frequencies. In recent years, PG mapping using high spatial resolution images (i.e., between 0.5 and 2 m, Navulur, 2006) has drawn increasing attentions. For example, Levin et al. (2007) explored the feasibility of using remotely sensed data for monitoring plasticulture landscape, where plastic materials were identified by field spectrum measurements and hyperspectral AISA-ES images. Agüera et al. (2006) proposed a classification method for new PG detection using Quickbird images. This approach identified that the best band combination for PG extraction is green, blue, and near infrared. After that, Agüera et al. (2008) improved the pixel-based PG classification method using high resolution images along with texture analysis. Koc-San (2013) evaluated the performance of different classification techniques for the detection of glass and plastic PGs from the WorldView-2 imagery. Aguilar et al. (2014) proposed an object-based PG classification approach for GeoEye-1 (0.5 m) and WorldView-2 (0.5 m) stereo imagery. These methods, although identifying PGs in a relatively efficient manner, suffer from several issues inherent in high spatial resolution images. These issues include the limited spatial extent, time-consuming data processing, and costly data procurement. Therefore, medium spatial resolution satellite data (2–30 m, Navulur, 2006), such as Landsat sensors, serve as a more suitable instrument for large-area PG mapping. Case study areas in this realm include the Netherlands (Van der Wel, 2001; Mesev et al., 2000), Southeastern Spain (Sanjuan, 2004), Southern Italy (Picuno et al., 2011), and China (Lu et al., 2014).

Several methods have been proposed to improve the rigor of PG detection using medium spatial resolution imagery. For example, one of the earliest attempts refers to Zhao et al. (2004) that proposed an index-based method (V_I) for PG mapping in the Shandong province of China using Landsat Thematic Mapper (TM) imagery. Lu et al. (2014) put forward a decision tree classifier for extracting the transparent plastic-mulched landcover (PML). In their work, a new PLM index (PMLI) was presented to facilitate the extraction of PML. Aguilar et al. (2015) identified PGs using object-based image analysis (OBIA) and decision tree technique. More recently, Wu et al. (2016) extracted suburban PGs using an object-based approach in the Landsat-8 imagery. Novelli et al. (2016) compared the performance of Sentinel-2 multi spectral instrument (MSI) and Landsat-8 operational land imager (OLI) for greenhouse detection. One existing gap of these methods is the little consideration of spectral variations. The spectral information of PGs can be constantly altered by the growth cycle of the crops underneath. Therefore, using the same standard to identify PG parcels lacks the flexibility to capture seasonal variations and may obfuscate the true pixel information. To overcome this problem, Chen et al. (2016) employed the Landsat-8 OLI imagery to map the plastic-mulched cotton fields by considering both the spectral and texture information. They found that middle and late April is the most appropriate time period for PG detection. Aguilar et al. (2016) addressed this problem by combining very high resolution satellite data and multi-temporal Landsat-8 OLI imagery within a context of an OBIA and decision tree classification. The capability of a moment distance index (MDI) for PG extraction was also explored in their work. However, the existing methods can only estimate the existence of PGs within a pixel but are unable to approximate the percentage of PG areas in a mixed pixel (i.e., the PG fraction). Considering the limited spatial information presented in medium spatial resolution satellite data, using the PG fraction is a more reliable estimate of PG areas. However, deriving the PG fraction is relatively challenging, mainly due to three factors: (1) the spectral properties of PGs change over time and are highly dependent on the crops beneath the PGs; (2) the spectral and textural features are similar between PGs and some other man-made infrastructures (Levin et al., 2007); and (3) the mixture of different land covers within the same pixel makes the PG detection intractable (Aguilar et al., 2014, 2015; Levin et al., 2007)

To this end, the paper proposes a new method for large-scale PG mapping using medium resolution satellite data (e.g. Landsat series). This method is a two-step procedure: first, a new PG index is designed to distinguish the PG areas from the background containing open cropland, soil and man-made surfaces (e.g., building, roads, roofs); second, the PG fraction is estimated by applying a logarithmic model.