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Review

Applications of satellite ‘hyper-sensing’ in Chinese agriculture: Challenges and opportunities

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ABSTRACT

Ensuring adequate food supplies to a large and increasing population continues to be the key challenge for China. Given the increasing integration of China within global markets for agricultural products, this issue is of considerable significance for global food security. Over the last 50 years, China has increased the production of its staple crops mainly by increasing yield per unit land area. However, this has largely been achieved through inappropriate agricultural practices, which have caused environmental degradation, with deleterious consequences for future agricultural productivity. Hence, there is now a pressing need to intensify agriculture in China using practices that are environmentally and economically sustainable. Given the dynamic nature of crops over space and time, the use of remote sensing technology has proven to be a valuable asset providing end-users in many countries with information to guide sustainable agricultural practices. Recently, the field has experienced considerable technological advancements reflected in the availability of ‘hyper-sensing’ (high spectral, spatial and temporal) satellite imagery useful for monitoring, modelling and mapping of agricultural crops. However, there still remains a significant challenge in fully exploiting such technologies for addressing agricultural problems in China. This review paper evaluates the potential contributions of satellite ‘hyper-sensing’ to agriculture in China and identifies the opportunities and challenges for future work. We perform a critical evaluation of current capabilities in satellite ‘hyper-sensing’ in agriculture with an emphasis on Chinese sensors. Our analysis draws on a series of in-depth examples based on recent and on-going projects in China that are developing ‘hyper-sensing’ approaches for (i) measuring crop phenology parameters and predicting yields; (ii) specifying crop fertiliser requirements; (iii) optimising management responses to abiotic and biotic stress in crops; (iv) maximising yields while minimising water use in arid regions; (v) large-scale crop/cropland mapping; and (vi) management zone delineation. The paper concludes with a synthesis of these application areas in order to define the requirements for future research, technological innovation and knowledge exchange in order to deliver yield sustainability in China.

1. Introduction

The production of food in China is a fundamental component of the national economy and a key driver of agricultural policy. The maintenance of food security in China is a critical issue for the country and this has significant ramifications globally. However, China’s ability to sustain and increase crop yield is threatened by the effects of climate change, increasing population, agricultural land loss and competing demands for water (Fan et al., 2012; He et al., 2017; Kang et al., 2017; Wei et al., 2009; Zhao et al., 2008). Notably, the Chinese government has identified the conversion of farmlands to industrial and residential use, particularly across productive agricultural regions of the country, as the major threat to the nation’s already inadequate levels of staple cereals production (Lichtenberg and Ding, 2008). According to the office of statistics in China, over 14.5 million hectares of arable land in the country was lost between 1979 and 1995. Though this loss was counterbalanced by an addition of 10.1 million hectares of arable land from reclamation activities, this additional land was of lower quality

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and located in unsuitable areas incapable of promoting agricultural production (Ash and Edmonds, 1998). Furthermore, several studies have attributed the loss of farmland across China to a combined effect of population growth, rapid economic development, urbanisation, agricultural restructuring, government stimulated conversion of marginal croplands to forests or pastures, natural hazards and land degradation (Ding, 2003; He et al., 2017; Smil, 1999; Tan et al., 2005; Yang and Li, 2000). He et al. (2017) provides background information on the impact of urban expansion on food security in China, particularly from decreased cropland net primary productivity.

With regards to food production, the global importance of China is measured by the capacity of the country's agriculture to support staple food supply for most of its population (approximately 20% of global population) and the world simultaneously. Based on existing statistics, in 2013 China contributed 19, 17, and 22% of global rice, wheat and maize production, respectively (FAO, 2014); providing an indication of the country's strategic position in the global food market. However, Fred et al. (2014) observed that though the Chinese authorities have policies to encourage domestic production of grain as a means of promoting self-sufficiency, grain exports (particularly for rice, wheat and maize) have declined while imports have consistently risen between 2009 and 2013 (Fig. 1). Irrespective of China's global production ratings, the country's level of rice imports increased from 0.6 million tonnes in 2011 to 2.6 million tonnes in 2012 (China Import Export, 2014; Ewing and Zhang, 2013). Ewing and Zhang (2013) attribute this substantive rise in China's rice importation to a combination of factors, namely a rapid rise in consumer demand, over reporting of domestic rice production by government officials, poor transportation links between rice-producing and consuming regions of the country and concerns over safety of domestically produced rice due to high fertiliser contamination levels.

The accelerated agricultural growth rate experienced in China over the years can be attributed to increased yield per unit area rather than expansion of arable or cultivated land (Fan et al., 2012) (Fig. 2A). All of the country's key grain crops (rice, maize and wheat) have experienced a steady rise in production and yield over the last 50 years (Fig. 2B and C).

Although China has experienced increasing crop yields, it is commonly acknowledged that this has in large part been at the expense of the environment due to inappropriate agricultural practices (Fan et al., 2012). Wasteful production methods in China's agricultural sector have aggravated problems of resource shortage; excessive use of pesticides and fertilisers have led to the contamination of soil and water bodies while the unrestricted use of water for crop irrigation has severely depleted aquifers (Zheng, 2015). In particular, the excessive use of nitrogen (N) fertilisers in intensified agriculture across China has generated environmental problems such as atmospheric, soil and water enrichment (Ju et al., 2009b) leading to elevated NO_3-N concentrations in groundwater and reduced N use efficiency (Wang et al., 2011). The challenge of maintaining or increasing crop production in an environmentally sustainable manner is further exacerbated by issues such as the effects of climate change (Piao et al., 2010) and pressures on agricultural land use from urbanisation.

For the 12th year in a row, China's "No. 1 Central Document" focused on agriculture and rural issues. The document stresses the importance of agriculture in national socioeconomic development stating that '*a strong agricultural sector is a prerequisite for a strong China*'. It called for reforms and innovation in agriculture to speed up the modernisation drive, but emphasised sustainability: "*Instead of mainly pursuing high output and relying on resources consumption, China should put equal emphasis on quantity, quality and benefits, and attach importance to competitiveness, technological innovation and sustainable growth*" (Xinhua, 2015). One of the five areas of concern highlighted in the document was "accelerating the shift of agricultural development pattern with a focus on agricultural modernisation" (MOA, 2015). Over the last decade, China has focused on advancing space-based solutions to addressing different agricultural and environmental problems. This is demonstrated in the establishment of commissioned agencies charged with space-related research and development, such as: China National Space Administration (CNSA), Chinese Academy of Space Technology (CAST), China Centre for Resources Satellite Data and Application (CRESDA), National Remote Sensing Centre of China (NRSCC) and National Satellite Meteorological Centre/Chinese Metrological Administration (NSMC-CMA). These organisations have been exploiting the capabilities of satellite remote sensing to provide information to support decision making in the agricultural sector at various organisational levels. Such information is unique in its capability to provide repeated and complete coverage for different growing seasons and across multiple scales, spanning from small fields to landscapes and regions. In addition to crop type mapping over large landscapes (Chen et al., 2007b; Esch et al., 2014), satellite remote sensing provides critical data on the physiological state of crops (Meng et al., 2009) and its biophysical or biochemical properties (Haboudane et al., 2004; Huang and Blackburn, 2011). Several studies have demonstrated the potential of utilising remote sensing for monitoring crop phenology and provide valuable inputs for crop growth and yield estimation models (Clevers and van Leeuwen, 1996; Hu et al., 2014; Hua et al., 1998; Kurosu et al., 1995; Li et al., 2014b; Onojeghuo and Blackburn, 2011; Pan et al., 2009; Sankaran et al., 2010; Soria-Ruiz et al., 2010; Zhang et al., 2003). However, whilst satellite data has become part of existing agriculture operation systems, the commonly found mismatch between remote sensing products and the information actually required by farmers has led to a slow take-up of this technology within agriculture in many countries.

In China, the deployment of satellite remote sensing in agriculture is particularly challenging because of the generally small field sizes, demands for multiple within-year cropping, the range of crop species and varieties, high spatial heterogeneity in the environment, extreme

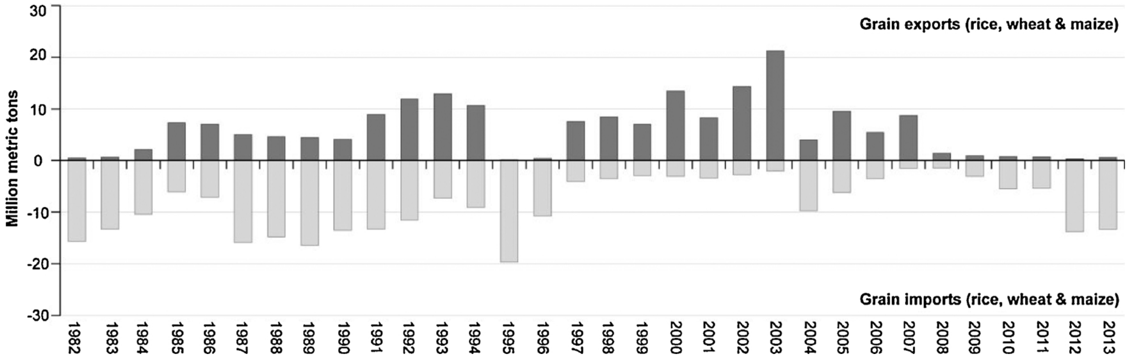

Fig. 1. Cereal grains (rice, wheat and maize) export and import levels from 1982 to 2013 for China.
Sources: Global Trade Atlas (Global Trade Atlas, 2014) and USDA, Economic Research Service analysis of China Customs Administration (1984–1995) (Fred et al., 2014)