Field Crops Research 143 (2013) 56–64

Contents lists available at SciVerse ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

The use of satellite data for crop yield gap analysis

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ARTICLE INFO

Article history:
Received 19 February 2012
Received in revised form 18 July 2012
Accepted 8 August 2012

Keywords:
Remote sensing
GIS
Agronomy

ABSTRACT

Field experiments and simulation models are useful tools for understanding crop yield gaps, but scaling up these approaches to understand entire regions over time has remained a considerable challenge. Satellite data have repeatedly been shown to provide information that, by themselves or in combination with other data and models, can accurately measure crop yields in farmers' fields. The resulting yield maps provide a unique opportunity to overcome both spatial and temporal scaling challenges and thus improve understanding of crop yield gaps. This review discusses the use of remote sensing to measure the magnitude and causes of yield gaps. Examples from previous work demonstrate the utility of remote sensing, but many areas of possible application remain unexplored. Two simple yet useful approaches are presented that measure the persistence of yield differences between fields, which in combination with maps of average yields can be used to direct further study of specific factors. Whereas the use of remote sensing may have historically been restricted by the cost and availability of fine resolution data, this impediment is rapidly receding.

1. Introduction

Two goals underlie most discussions of crop yield gaps (Van Ittersum et al., 2013). The first is to measure the size of the yield gap, defined as the difference between yield potential (Yp) and average yields, in order to identify the potential scope for raising average yields via management changes. The second is to identify the key causes of the yield gap, in order to prioritize efforts in extension, research, and policy to raise land and labor productivity.

A fundamental challenge in pursuit of either of these goals is the considerable spatial and temporal heterogeneity of agricultural landscapes. In the measurement of yield gaps, for example, actual yields are often reported for administrative units that span hundreds or thousands of fields. Yield potential, meanwhile, is most readily estimated for individual fields, using either agronomic trials or well-tested crop simulation models (Lobell et al., 2009). How should the measurements at these two different spatial scales be compared when computing a yield gap? Some studies ignore the scale mismatch, implicitly assuming that point-level estimates of Yp are a good proxy for average Yp across the spatial domain of the reported average yield. Other studies attempt to estimate Yp at multiple points within the domain and then take an average, a sensible approach provided that data of sufficient quality exist to estimate Yp at multiple points.

Similarly, studies to understand causes of the yield gap may reasonably start by evaluating yield responses to different management changes in an experimental station, or on farmers' fields. However, the fields analyzed may not be representative of the entire region, or the year(s) in which the study was done may not be representative of the full range of conditions that farmers face.

Agronomists have long appreciated the challenge of generalizing results from a small handful of sites and years to the broader scales relevant to regional measures of performance. Over the past two decades, remote sensing has emerged as a useful tool for dealing with heterogeneity, to complement more traditional approaches such as field trials or simulation models. In particular, remote sensing from airplane- or satellite-mounted sensors can potentially provide observations for every single field in a region for every single growing season. Although remote sensing-based estimates of quantities such as crop yield are often less accurate than field-based measures, the unprecedented spatial and temporal coverage of remote sensing can often outweigh the negatives for many applications.

The goal of this paper is to specifically address the potential value of satellite-based remote sensing for efforts to measure and explain crop yield gaps. The premise of the paper is that as efforts to understand yield gaps intensify, new approaches that can complement the traditional toolbox of agronomists have great potential value, and remote sensing may be one such tool.

The promise of satellite data is enhanced by at least two recent developments. One is the decision in 2008 by the United States Geological Survey to make the entire archive of Landsat data available at no charge (http://landsat.usgs.gov/products_data_at_no_charge.php). This change, coupled with improvements

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http://dx.doi.org/10.1016/j.fcr.2012.08.008

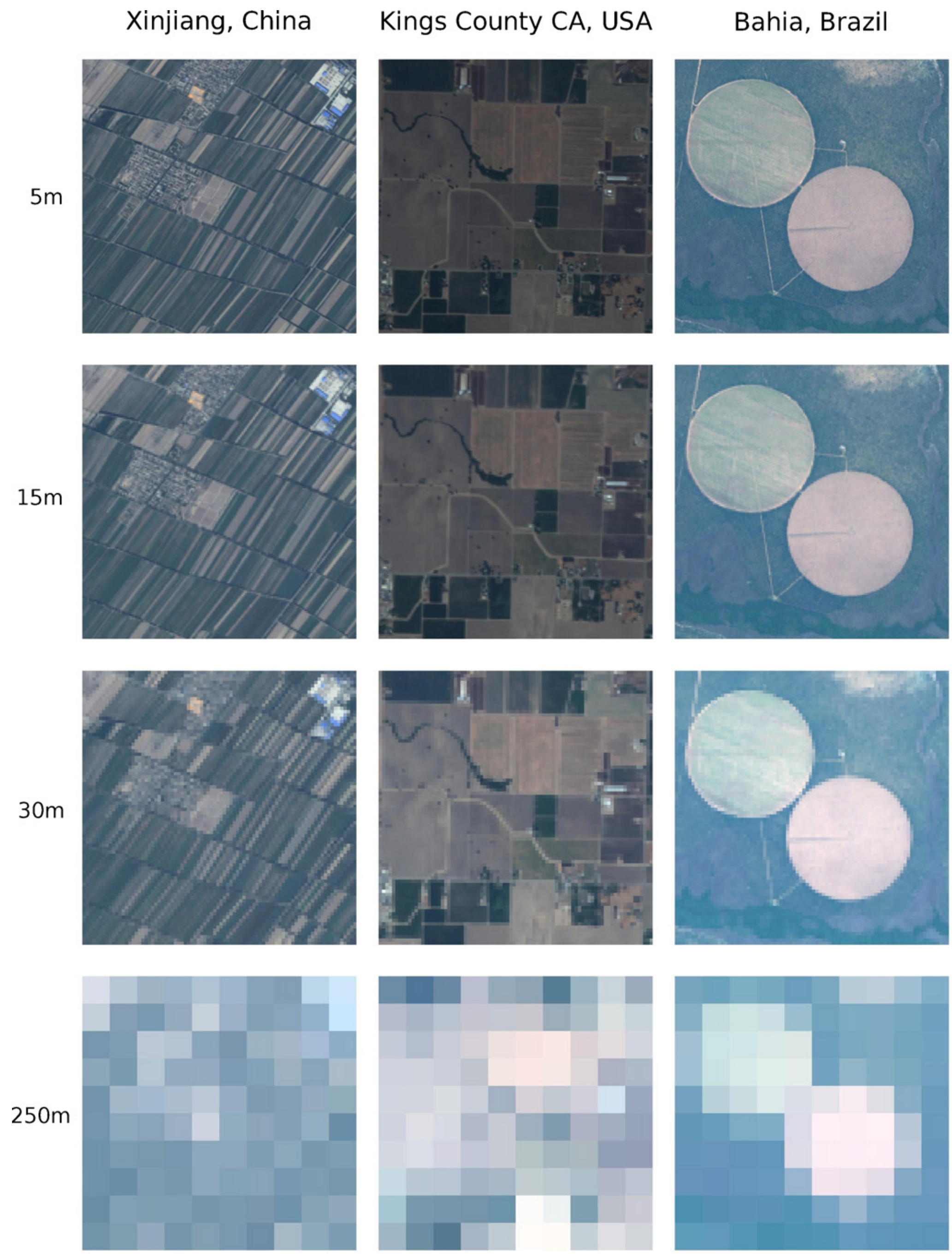

Fig. 1. Examples of the effect of image resolution on the ability of remote sensing to monitor individual fields. The top row displays a 2.5 km × 2.5 km section of a RapidEye 5 m × 5 m resolution image of (left) Xinjiang, China, (middle) Kings County, United States, and (right) Bahia, Brazil. Lower rows show images resampled to represent the coarser resolutions of some other common sensors: ASTER (15 m, second row), Landsat (30 m, third row), and MODIS (250 m, bottom row).

in preprocessing algorithms to geographically register the images, have vastly reduced the expense and time required to obtain images at relatively fine spatial resolution (30 m × 30 m) for the period of 1982 to present. This resolution is sufficient to delineate individual fields that are roughly 1 ha in size or greater, which includes many regions of the world (see Fig. 1). Second, new commercial systems are delivering even higher spatial resolution (5 m × 5 m or finer) at costs that are approaching 1 USD$ per km^2 (or $0.01 per ha). In the next decade, it should be increasingly feasible to obtain multiple years of data for regions where field sizes have been too small to distinguish with traditional sensors like Landsat.

The next section briefly summarizes the capabilities and limitations of remote sensing for measuring crop yields. The following two sections discuss examples and potential uses of remote sensing for the two main goals of crop yield analysis: measurement and explanation. Finally, some conclusions and recommendations for future work are presented.

2. Remote sensing of crop yield

2.1. Approaches

Numerous approaches exist for estimating crop yields with remote sensing. Several reviews on this topic are available (Moulin et al., 1998; Gallego et al., 2010), and so only a brief summary of approaches is given here. Early efforts relied on simple