Journal of Arid Environments 124 (2016) 150–159

Contents lists available at ScienceDirect

Journal of Arid Environments

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

Analysing irrigated crop rotation patterns in arid Uzbekistan by the means of remote sensing: A case study on post-Soviet agricultural land use

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ARTICLE INFO

Article history:
Received 19 April 2014
Received in revised form
28 July 2015
Accepted 4 August 2015
Available online xxx

Keywords:
Remote sensing
Central Asia
Cotton
Irrigation systems
Crop rotations
MODIS

ABSTRACT

In Central Asia, actual cotton rotation practices are repeatedly believed to resemble “Soviet cropping conditions” with continuous cotton sequences of six years or more. We investigated current cotton growing patterns in Khorezm, one representative cotton production region in Uzbekistan utilizing time series of 250-m MODIS satellite data. A Random Forest model was established using reference data of 2004–2007 to generate annual crop maps in 2000–2009. A linear model was applied to assess the spatial distribution of the longest observed cotton sequence within the ten-year observed observation period. All cotton-growing sequences were compared to the national crop rotation recommendations.

The classification achieved an overall accuracy of 82%. We found that cotton remains the major crop in the region. It was cultivated for more than five out of the ten years on 46.5% of the cropland. But “Soviet cropping conditions” on less than 20% and officially recommended cotton sequences on more than 50% of the cropland challenge the notion that cotton mono-crop dominates Central Asia. Statistical analysis revealed that long cotton sequences preferably occur on fields far from settlements and under reduced soil suitability for irrigation. The results enable decision makers to better explain unfavourable cotton cultivation practices and to stimulate improvements.

1. Introduction

Over centuries, cotton has been the main provider of textile fibres worldwide (Meyer and MacDonald, 2001). This cash crop is cultivated in more than 100 countries on a total area of ~31 million ha (Mha), mainly under irrigation. Slightly more than three quarters of all cotton is produced in six countries only: China, USA, India, Pakistan, Brazil and Uzbekistan (Kooistra and Termorshuizen, 2006). The cotton value chain ensures job employment and income in both the producing and processing countries and provides a wide variety of products. The latter range from commodities such as clothing, lines and carpets to cotton wads for cosmetics and medical purposes and cotton seed oil for cooking. To maintain cotton production on a high level, sustainable cultivation practices are relevant.

The Soviet Union period (1924–1991) in Central Asia is recurrently referred to as a prominent example for unsustainable cotton production (e.g. Wehrheim and Martius, 2008; Djanibekov et al., 2012). In 75 years, the area of irrigated cropland along the rivers in Central Asia increased about ten-fold, from 0.725 Mha in 1915 (Létolle, 1993) to 7.6 Mha in 1990 (Roll et al., 2006). The pre-Soviet cultivation practices in Central Asia included rotation schemes that contained multi-annual cotton sequences of a maximum of two years, followed by several years of cultivation of alfalfa, wheat, sorghum, maize, melon, or pumpkin. Leaving fields fallow for several years between production sequences was also part of the cultivation practices in the pre-Soviet phase (Mukhamedjanov 1959). During the Soviet Union phase, however, these cultivation schemes were replaced by rotations including six-year sequences of cotton (or longer) followed by three years of alfalfa (Cave, 1958). In the former Soviet Union Republic Uzbekistan, cotton was grown on almost half of all sown land, whilst in other Soviet Union Republics, rotations were even completely omitted (Allworth, 1994).

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http://dx.doi.org/10.1016/j.jaridenv.2015.08.008
0140-1963/

Cotton production in the Soviet Union increased from 1.96 million tons in 1940 to an average of 7.92 million tons between 1976 and 1980 (Létolle, 1993). This placed the Soviet Union among the top cotton producers in the world.

The unprecedented intensification of cotton production in the former Soviet Union replaced historical crop rotation patterns. Crop rotations are globally among the oldest-known cultural practices to prevent soil degradation, maintain soil fertility, or reduce soil erosion (Bullock, 1992; Wright et al., 2005). They are also declared means to avoid pest propagation and harvest damage (Bellinger, 2010). Cotton rotations with wheat, irrespectively if one or two years of cotton are followed by the grain crop, have been more economically profitable than other cotton rotating schemes (Hullugalle et al., 1998). However, attempting to reach economic sustainability by solely implementing rotations for maximizing the profits has been critically discussed. Hake et al. (1991) for instance emphasized that cotton mono-sequences can be supported by rotations in areas suffering from soil-borne diseases or weed problems, and where these cannot be managed otherwise. The same authors state, however, that cotton in rotation with other profitable crops can support economic stability. Cotton rotation systems are thus considered an important instrument for economically sustainable and soil conserving crop production.

The neglect of fundamental agricultural rules, i.e. the quasi-monoculture of the "white gold" cotton during the Soviet Union era, was made possible with an excessive use of irrigation water and under high input of chemicals such as fertilizers, yet these practices contributed to the "Aral Sea Crisis" and led to widespread soil degradation. In Uzbekistan raw cotton yields declined from 2.9 t ha^{-1} during the peak period between 1971 and 1980 to around 2.5 t ha^{-1} between 1981 and 1987 (Létolle, 1993). According to many studies, the prime reason for this declining productivity was soil degradation triggered by extensive and highly water demanding cotton monocultures (e.g. Giese et al., 1998; Orlovsky et al., 2001). In particular Uzbekistan was seriously alarmed by declining cotton yields and on-going soil degradation because during the peak of the Soviet Union cotton production, this former Soviet Union Republic provided ~70% of the entire Central Asian raw cotton harvest (Pomfret, 2000).

After independence in 1991, Uzbekistan maintained the State order system for agricultural production on cotton and extended the quota system to irrigated wheat production in order to reduce Uzbekistan's dependency from wheat imports (Kienzler et al., 2011). This state order system requires cotton and wheat farmers to produce prescribed quotas and to deliver these at fixed prices to government agencies (Djanibekov et al., 2012). Mounting concerns for the on-going environmental damage and increasing food insecurity in Uzbekistan resulted in reducing the area devoted to cotton from 1.8 to 1.3 Mha between 1990 and 2010 (USDA, 2011), which, however, still is about 30% of the total irrigated land area in the country (4.4 Mha). Consequently, Uzbekistan still produces about 6% of the annual global cotton volume (Kooistra and Termorshuizen, 2006).

The current rationale assumes that diversified crop rotations are, in the long run, more sustainable by providing better soil and water-preserving land management options. Therefore, official state recommendations in Uzbekistan promote cotton–wheat rotations, with cotton sequences of 1–3 years followed by 1–2 years of winter wheat and summer crops such as mung bean, soybean, maize, sunflower or vegetables (Kienzler, 2010; Khalikov and Tillaev, 2006). Official statistics indicate significant reduction of cotton areas in Uzbekistan during the beginning 21st century (Abdullaev et al., 2009) and were recently confirmed by remote sensing based case studies (e.g. Conrad et al., 2013). However, is often critically questioned if these recommendations are actually followed. For instance, observations by state organisations, mandated to monitor land use and yields, were often assessed as unreliable and therefore not useful for planning (Giese et al., 1998; Rücker et al., 2012). On the other hand, conclusions such as those by the International Crisis Group (2005) that "crop rotations are rarely applied in Central Asia", are also questionable, for being based mainly on single observations and interviews with farmers. Notwithstanding, objective information about the cotton-based rotation practices in the current cropping systems of Central Asia has not been reported. Such information would shed new light on the current state of Uzbekistan's cotton production systems and in turn may support better decision-making on sustainable agricultural practices.

Geographical Information Systems (GIS) and remote sensing tools are widely recognized for their efficiency in providing reliable information on land use over large areas and periods of time (see e.g. De Wit and Clevers, 2004; Buenemann et al., 2011; Löw et al., 2013, 2015). Crop mapping techniques have been developed and applied for detecting intra-annual cropping cycles (e.g. Murakami et al., 2001; Wardlow and Egbert, 2008), for instance multiple rice growth cycles within one year (e.g. Sharma et al., 2011). Remote sensing also allows for continuously crop mapping and hence for multi-year assessments of crop rotations, but such studies are rare due to the still existing trade-off between temporal and spatial resolution. Moderate-resolution data (pixel size $\geq$250 m) offer the temporal resolution and continuity required for gapless and accurate multi-annual maps, but in many cases pixel sizes exceed the sizes of the fields. The latter could be better matched by high resolution data (<250 m). Martinez-Casasnovas et al. (2005) for instance used high resolution Landsat TM and ETM + data (30) for a multi-annual analysis of crops in a 33,000 ha irrigation system in Spain but had to cope with undesirable data gaps. However, recent systematic studies about effects of pixel size on supervised image classification demonstrated that crops can be identified even when the pixel size exceeds the field size. For instance, accurate crop classification in irrigated landscapes in Khorezm was still possible at 300 m spatial resolution (Löw and Duveiller, 2014).

This study aims to map and analyse the cotton rotation practices over the last decade in the Khorezm region in northwest Uzbekistan, an area that is typical for cotton production systems in arid Central Asia (Martius et al., 2012), using remote sensing and GIS. Therefore, the cotton cultivation patterns derived from our model (see below) were statistically analysed to understand whether cotton dominance varied spatially alongside two variables: (i) soil suitability for irrigated crop production and (ii) distance to settlements. Proximity to settlements is supposed to indicate low cotton production, because fields in short distances to settlements are favoured for the cultivation of food crops (reduced transportation and management requirements). Next, the retrieved regional information about sequences of cotton with and without rotation was compared to the official recommendations for cotton-based crop rotations in the Khorezm region. Special attention was paid to areas under long cotton sequences, presuming the persistence of former Soviet Union cotton cultivation practices.

2. Study area

The Khorezm region is located in North-West Uzbekistan bordered by the Amu Darya River in the North-East, and Turkmenistan in the South and West (Fig. 1a). Being part of the Aral Sea Basin with a low annual precipitation of only 100–150 mm, all arable land in Khorezm is irrigated. Covering 6400 km^2, the Khorezm region is the second smallest administrative district in Uzbekistan. Roughly 230,000 ha are cultivated. During the study period, the region was divided into 11 administrative regions (so called