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Mapping and assessing crop diversity in the irrigated Fergana Valley, Uzbekistan

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A B S T R A C T

Crop diversity (e.g. the number of agricultural crop types and the level of evenness in area distribution) in the agricultural systems of arid Central Asia has recently been increased mainly to achieve food security of the rural population, however, not throughout the irrigation system. Site-specific factors that promote or hamper crop diversification after the dissolvent of the Soviet Union have hardly been assessed yet. While tapping the potential of remote sensing, the objective was to map and explain spatial patterns of current crop diversity by the example of the irrigated agricultural landscapes of the Fergana Valley, Uzbekistan. Multi-temporal Landsat and RapidEye satellite data formed the basis for creating annual and multi-annual crop maps for 2010–2012 while using supervised classifications. Applying the Simpson index of diversity (SID) to circular buffers with *radii* of 1.5 and 5 km elucidated the spatial distribution of crop diversity at both the local and landscape spatial scales. A variable importance analysis, rooted in the conditional forest algorithm, investigated potential environmental and socio-economic drivers of the spatial patterns of crop diversity. Overall accuracy of the annual crop maps ranged from 0.84 to 0.86 whilst the SID varied between 0.1 and 0.85. The findings confirmed the existence of areas under monocultures as well as of crop diverse patches. Higher crop diversity occurred in the more distal parts of the irrigation system and sparsely settled areas, especially due to orchards. In contrast, in water-secure and densely settled areas, cotton-wheat rotations dominated due to the state interventions in crop cultivation. Distances to irrigation infrastructure, settlements and the road network influenced crop diversity the most. Spatial explicit information on crop diversity *per se* has the potential to support policymaking and spatial planning towards crop diversification. Driver analysis as exemplified at the study region in Uzbekistan can help reaching the declared policy to increase crop diversity throughout the country and even beyond.

1. Introduction

Crop diversification positively influences ecosystem services and hence agricultural production within agricultural landscapes since such practices can contribute to preventing soil degradation, maintaining soil fertility and soil health, or reducing soil erosion (Bullock, 1992; Dick, 1992; Naeem, Thompson, Lawler, Lawton, & Woodfin, 1994; Thrupp, 2000). Crop diversity is known also to decrease pest propagation and harvest damage (Matson, Parton, Power, & Swift, 1997; Tilman, Cassman, Matson, Naylor, & Polasky, 2002). Growing a mix of different crops can therefore be of paramount relevance for livelihood security (Smale & King, 2005). Consequently, the FAO sees an increasing land use diversity, i.e. the cultivation of wide ranges of annual and perennial plant species such as fruit trees, shrubs, pastures, and crops, as a one approach for improving resilience of agricultural ecosystems (FAO, 2011). This is in particular important in the agrarian landscapes of the Aral Sea Basin in Central Asia (CA) that have inherited a cotton-dominated farming system following seven decades of Soviet reign (1924–1991). The current practice of cotton monoculture has been considered a key culprit to the wide-spread and on-going soil degradation (e.g., Giese, Bahro, & Betke, 1998;

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Orlovsky, Glantz, & Orlovsky, 2001). Given the potential of crop diversification practices such as an increase of crop types, crop rotations, and of the area share of minor crops they can be regarded as an important contribution to reaching more sustainable agricultural production systems in CA.

Concerns about ensuring national food security and sustaining agricultural production stimulated Uzbekistan in CA to diversify crop type composition on its territory (ca. 4.1 Million ha (Mha) of irrigated land). To reduce its dependency from wheat imports, Uzbekistan started to promote irrigated winter wheat production after gaining independence in 1991 (Abdullaev, De Fraiture, Giordano, Yakubov, & Rasulov, 2009). As a consequence, in virtually a decade, cotton-wheat rotation systems covered already 70% of the arable area (Bobojonov et al., 2013). Recently, the national administration extended their crop diversity perspectives by promoting in addition the cultivation of vegetables, vineyards, and fruit trees where possible (Uzbekistan News, 2016) also because recent evidence underlined the potential of tree plantations to increase economic stability on highly unproductive areas in arid CA (Lamers and Bobojonov, 2008). Despite these efforts, spatial sectors of cotton mono-cropping patterns remained underling indirectly the complexity of increasing the current crop mix at the local scale such as suggested for West-Uzbekistan (Bobojonov et al., 2013; Conrad, Lamers, Ibragimov, Löw, & Martius, 2016). When comparing Uzbekistan with other successor states of the Soviet Union, Bobojonov et al. (2013) identified numerous factors that are likely to hamper a further development of crop diversification in Uzbekistan even in case state orders would be eased. These factors include water demand, processing knowledge and technology, as well as market access. Thus, the diversification of crops remains a pressing subject in Uzbekistan certainly in the light of the predicted increase of variability of the climate and in turn water availability due to human and natural impacts (Siegfried et al., 2012).

Crop diversity used to be analysed from different perspectives. For instance, ecologists investigated predominantly the effects of crop diversity on soil development (Russell, 2002) or biodiversity (e.g., Duro et al., 2014; Palmu, Ekroos, Hanson, Smith, & Hedlund, 2014) and frequently identified crop diversity as being important for improving ecological conditions. Others explained crop diversity as a result of farmer's decisions in complex causal chains (e.g., Bobojonov et al., 2013; Sichoongwe, Mapemba, Tembo, & Ng'ong'ola, 2014; Singh, Kumar, & Singh, 2006). The results of these studies underscored that such causal chains are linked as well to political, economic, societal, cultural, and environmental or biophysical factors ranging from the world market over higher administrative decisions to local potentials and constraints (e.g., Bowman & Zilberman, 2013). Most studies attempting to explain crop diversity used statistical census data on higher administrative aggregation levels (e.g., Bobojonov et al., 2013; Rahman & Kazal, 2015; Sichoongwe et al., 2014; Singh et al., 2006). Depending on the specific purpose or scale, such statistical data may be sufficient, but when the subject is on understanding the variability of crop diversity, aggregated crop statistics are less suitable. Furthermore, when realizing the recurrently remarked incompleteness and inconsistencies of national agricultural databases once aggregated (e.g., Oberkircher et al., 2012; Forkuor et al., 2014), spatially explicit information about cropping patterns is indispensable when for instance aiming at the implementation of site-specific improvements e.g. for soil and crop conservation, soil degradation mitigation, or crop diversification.

Satellite remote sensing has already proved to be a highly suitable tool for mapping the spatial distribution of crops (e.g., Wardlow, Egbert, & Kastens, 2007; Zhong, Wang, & Wu, 2015). With the availability of multi-sensor data, crop distribution can be mapped with a much higher accuracy at field level than before, irrespective if in heterogeneous agricultural landscapes or over extensive study regions (e.g., De Wit and Clevers, 2004; Forkuor, Conrad, Thiel, Ullmann, & Zoungrana, 2014; Löw, Duveiller, Conrad, & Michel, 2015). Landscape metrics and indices have been frequently applied to such remotely sensed maps, e.g. for analysing spatial patterns as well as the changes thereof (Fahrig et al., 2011). Nevertheless, only few studies are available how such maps were used to process and further analyse information on biodiversity at the landscape scale. Pasher et al. (2013) suggested a scheme for optimizing landscape selection in ecological studies e.g. on biodiversity within agricultural landscapes and included a crop diversity index and field sizes derived from Landsat satellite data to describe landscape heterogeneity. Duro et al. (2014) utilized crop maps derived from Landsat to assess field sizes and crop diversity within a set of explanatory variables to predict the diversity of birds, butterflies, and plants. None of these studies targeted on the explanation of crop diversity within a landscape.

Hence, at the example of the Fergana Valley in Uzbekistan and with the aim of tapping the potential of remotely sensed crop maps, the objective was to disclose not only the diversity of crop types and crop rotations in the existing production systems *per se*, but also the potential environmental and socio-economic drivers of current diversity patterns and its local variability. Diversity patterns were analysed by classifying multi-temporal Landsat and RapidEye data sets from 2010 to 2012. Afterwards, the resulting diversity patterns were regressed against a set of environmental and socio-economic indicators using random forest (RF) regression based on conditional inference trees. It is hypothesised that site-specific information supports decision-makers to phrase and implement means and measures urgently required to reducing a series of environmental and economic risks (Wehrheim & Martius, 2008).

2. Study area

The Fergana Valley is located between two CA mountain ranges, the Alay and the Tien Shan. Cold winters and hot summers characterize the climate. Annual, predominately winter precipitation can be as low as 100–200 mm (Umarov, Kenjabaev, Stulina, & Dukhovny, 2010). Due to the arid climate, agricultural production in the valley depends on irrigation.

Three out of the five countries in CA, Uzbekistan, Tajikistan, and Kyrgyzstan, share the territory of the Fergana Valley (Fig. 1a). With 90 inhabitants per km^2 it is one of the most densely populated parts of the entire region (Reddy, Muhammedjanov, Jumaboev, & Eshmuratov, 2012). Irrigated agriculture is the leading economic activity as evidenced by the ca. 1.653 Mha of land annually supplied with irrigation water (SIC-ICWC, 2014). Main crops are cotton and winter-wheat, followed by orchards, and rice. Minor crops comprise sunflowers, watermelons, alfalfa, maize, sorghum, and vegetables (Conrad, Dech, Hafeez, Lamers, & Tischbein, 2013). Typically, the winter wheat season begins in autumn while maturity is expected in May–June and harvest late June and at the onset of July. The summer cropping season usually spans the period from mid-April till the end of October.

To optimally utilize all available data sets (section 3.1.) this study concentrated on an area of 377,278 ha, covering 58,755 fields, in the inner part of the valley (Fig. 1). The field boundaries were derived based on image segmentation as previously reported (Conrad et al., 2013). Most of the fields are located in the three provinces Fergana, Namangan (Naryn and Syr Darya parts), and Andijan of Uzbekistan (Fig. 1a).