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Revealing the determinants of wheat yields in the Siberian breadbasket of Russia with Bayesian networks

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ABSTRACT

Higher crop yields are critical to satisfy the rising global food demand. Russia holds untapped potential for increasing agricultural production because current grain yields are often far below the potentially attainable yields. Western Siberia is an important breadbasket in Russia, where wheat yields fall particularly short of their potential. Our goal was to assess the determinants of yield variations among farmers in the province of Altai Krai in Western Siberia. We conducted 67 structured in-person interviews with corporate farm managers and individual farmers about the potential determinants of wheat yields and complemented these data with 149 additional observations obtained from the provincial agricultural extension service. We used Bayesian networks (BNs) to represent the relationships between the explanatory parameters and contemporary wheat yields and to examine qualitative future scenarios of future yields. The results revealed higher yields on larger farms than on medium and small farms. Our results corroborated that the application of fertilizers and herbicides and the implementation of new equipment had large positive impacts on the yields. The scenario of higher future production costs and lower precipitation resulted in a yield reduction from 7.6 dt/ha to 5.3. Overall, our results suggest that policies aimed at increasing wheat yields should concentrate on the education of farmers and encourage higher input applications, particularly for small-scale farms. Additionally, policies should address concurrent challenges, such as a higher drought frequency, through the application of new equipment, seed material and tillage practices.

1. Introduction

A growing global demand for agricultural products has resulted in agricultural expansion and intensification. This demand is likely to increase in the future (Foley, 2005; Lambin and Meyfroidt, 2011). To satisfy such growing food requirements, increasing production on existing agricultural land, increasing yields and partially closing yield gaps will be particularly crucial. Crop yields are partially the result of agro-environmental site conditions, such as soil quality, temperature, and water availability during the growing season (Evans, 2004; Mendelsohn et al., 1994). Apart from the Ricardian site conditions, crop yields are crucially impacted by the quality of plant material and by the agronomic management decisions that affect the amount, timing, and quality of input applications (Gooding and Davies, 1997; Licker et al., 2010; Lobell et al., 2009a). Therefore, differences in crop yields can be explained by variations in natural conditions, skills and education of the farmers, input levels, and technology in crop production (Garrett et al., 2013; Kherad et al., 2013; Lobell et al., 2009b). Understanding the determinants of such variations in crop yields can help inform support measures and extension needs that aim to raise crop production in the region.

Russia is particularly interesting in this respect because it is one of the major global producers of grains and wheat since Soviet times due to large areas with fertile soil, such as Chernozems (Dronin and

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Bellinger, 2005). After the breakup of the Soviet Union, post-Soviet Russia became a net importer of wheat for a short period during the mid-1990s due to a stark reduction in productivity (Ennew, 1987; Liefert and Liefert, 2012). However, by 2008, Russia exported 20 million tons of wheat, comprising 13% of the total world wheat exports (Götz et al., 2013; Trueblood and Arnade, 2001). The increase in grain production was partly due to improvements in production efficiency and increased inputs that contributed to rebounding grain yields since the early 2000s (Liefert and Liefert, 2017, 2012; Lioubimtseva and Henebry, 2012). However, despite the gradual recent yield increases, grain yields across the former Soviet Union remain low and typically reach only half of their biophysical potential (Fischer et al., 2008; Mueller et al., 2012; Savin et al., 2001; Schierhorn et al., 2014).

To date, limited knowledge exists about the underlying causes of low wheat yields across Russia at different spatial scales. The existing studies primarily rely on process-based crop growth models that include biophysical site conditions but frequently suffer from the lack of site-specific data on crop management (Boogaard et al., 2013; Pavlova et al., 2014; Savin et al., 2001; Schierhorn et al., 2014). Likewise, econometric approaches frequently rely on provincial-scale agricultural statistics, thus ignoring biophysical site conditions and variations in land management within provinces (Bokusheva et al., 2012; Bokusheva and Hockmann, 2006; Osborne and Trueblood, 2006). While the determinants of wheat yields have been studied at different locales across the globe (e.g., Ali, 1996; Banerjee et al., 2014; Mann and Warner, 2017; Tittonell et al., 2005), studies that integrate farm-level data of agronomic management with biophysical data have been lacking in the countries of the former Soviet Union, including Russia. The paucity of insights about yield limitations is unfortunate because it hampers the ability to develop appropriate land-use policies that can incentivize higher wheat yields.

One Russian region with a significant difference between observed and potential yields is Western Siberia, especially the province of Altai Krai (Fig. 1). Altai Krai contains large areas with fertile soils (Chernozems) that are well suited for wheat production. From 2008 to 2012, Altai Krai had the largest area cultivated with wheat among the 74 grain-producing provinces (oblasts) in Russia, but it ranked only 67th for average wheat yields with 12 dt/ha (1 dt = 100 kg) during this period (Bogoviz et al., 2011; Rosstat, 2013). Altai Krai bears land-use legacies, such as degraded soil from the massive cropland expansion during the Virgin Lands Campaign (Bischoff et al., 2016; Josephson et al., 2013; Lal et al., 2007; McCauley, 1977) and recent economic turmoil following the breakup of the Soviet Union.

In general, one goal of commercially oriented farmers is to maximize their profits from agricultural production, such as achieving the highest possible returns while keeping production costs to a minimum (Duke and Wu, 2014). The yields from crop or livestock production affect farm returns, but increasing yields may increase variable costs (such as fertilizers, herbicides, and fuel) and fixed costs (e.g., buildings or machinery) more than the actual increase in production returns. Thus, yield increases, while being an important production indicator, are not synonymous with better farm performance. Other factors, such as the economic performance of the farms, personal satisfaction, and viability of farming, can be used as a measure of the competitiveness among the farmers; however, such data are often not publicly available at the farm level in Russia.

At the same time, the analysis of potential crop yields and their determinants is an important component of research in how to reduce yields gaps and boost yields in the future (Lobell et al., 2009b; van Ittersum et al., 2013). The risks of agricultural losses due to exogenous factors, such as droughts, and endogenous adverse land-use legacies (i.e., degraded soils) may shape the decision that a farmer makes to reduce inputs. At the same time, the strong adherence to agronomy prerequisites in the production of wheat, such as sowing and planting on time and the application of herbicides and fertilizers, may reduce agricultural losses and thus increase yields (Lobell et al., 2009b). Thus,

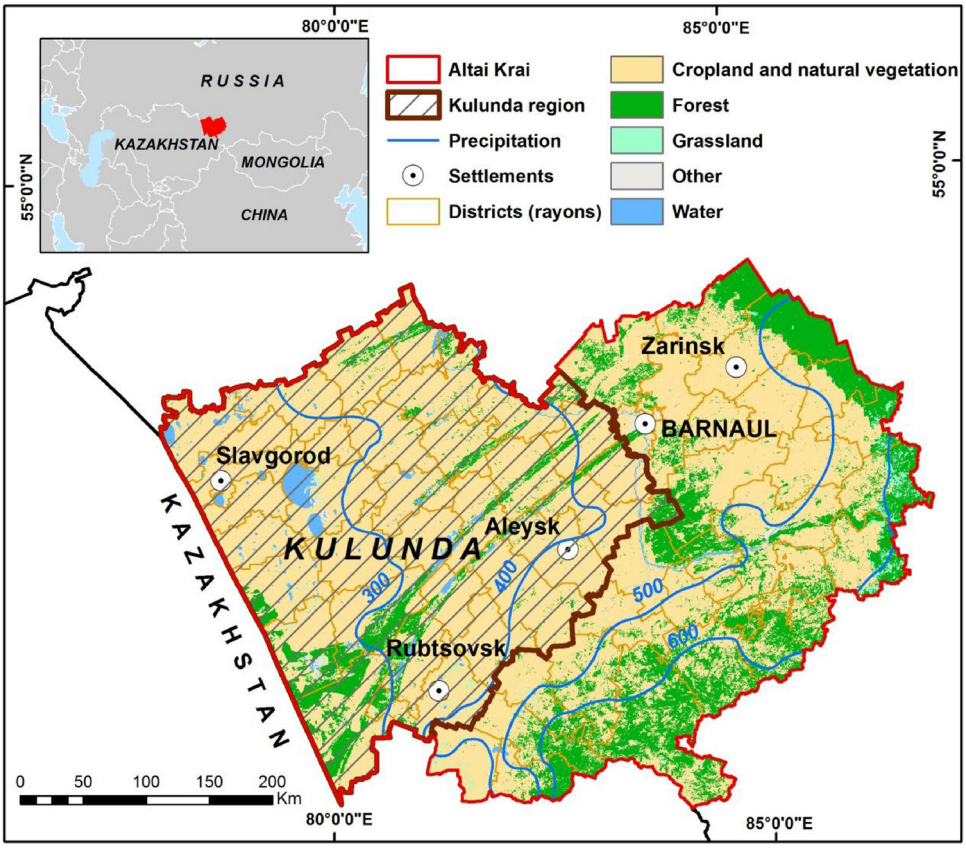

Fig. 1. Study Area. Source of land-cover map Globcover 2009 product v.2.3 (GLOBCOVER 2011). Source for annual mean precipitation Afonin et al. (2008).