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EVALUATIONS ON THE POTENTIAL PRODUCTIVITY OF WINTER WHEAT BASED ON AGRO-ECOLOGICAL ZONE IN THE WORLD

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ABSTRACT:

Wheat is the most widely grown crop globally and an essential source of calories in human diets. Maintaining and increasing global wheat production is therefore strongly linked to food security. In this paper, the evaluation model of winter wheat potential productivity was proposed based on agro-ecological zone and the historical winter wheat yield data in recent 30 years (1983-2011) obtained from FAO. And the potential productions of winter wheat in the world were investigated. The results showed that the realistic potential productivity of winter wheat in Western Europe was highest and it was more than 7500 kg/hm^2. The realistic potential productivity of winter wheat in North China Plain were also higher, which was about 6000 kg/hm^2. However, the realistic potential productivity of winter wheat in the United States which is the main winter wheat producing country were not high, only about 3000 kg/hm^2. In addition to these regions which were the main winter wheat producing areas, the realistic potential productivity in other regions of the world were very low and mainly less than 1500 kg/hm^2, like in southwest region of Russia. The gaps between potential productivity and realistic productivity of winter wheat in Kazakhstan and India were biggest, and the percentages of the gap in realistic productivity of winter wheat in Kazakhstan and India were more than 40%. In Russia, the gap between potential productivity and realistic productivity of winter wheat was lowest and the percentage of the gap in realistic productivity of winter wheat in Russia was only 10%.

1. INTRODUCTION

Over the next few decades, the worldwide demand for agricultural products will grow considerably because of increasing populations, the use of agricultural products as biofuels and changing diets (Sacks et al., 2011; Tilman et al., 2011; Regmi and Meade, 2013). This increasing demand can be satisfied by expanding cultivated areas, however the ecological and social trade-offs of further land expansion are high in most areas (Lambin et al., 2011). Most future increases in agricultural production are therefore likely to be generated by improving the output per unit of land, that is, from higher land productivity (Schierhorn et al., 2014). The range of future increases in land productivity is substantial in many transition and developing countries where the differences between the potential yield under optimum management and the yields that are actually achieved by farmers, that is also to say the yield gaps are large (Hall et al., 2013; Affholder et al., 2013; van Ittersum and Cassman, 2013; Lu and Fan, 2013). Decreases in the yield gaps will typically require higher and more efficient input use (fertilizers, pesticides, and water) and improvements in crop management (Evans and Fischer, 1999). Moreover, to decrease yield gaps necessitate investments in infrastructure, supportive agricultural policies and agronomic research (Tilman et al., 2011; Neumann et al., 2010; George, 2014). In addition, the increased demand for food supply worldwide calls for improved accuracy of crop productivity estimation (Brown et al., 2012).

Wheat is the most widely grown crop worldwide and is an essential component of the global food security mosaic. Wheat provides one-fifth of the total caloric intake of the world population (Reynolds et al. 2011) and is produced on an area of over 200 million hectares worldwide (Ortiz et al. 2008). The area of winter wheat accounts for more than 80% of the total wheat-growing area. Winter wheat is typically grown in winter and spring, seasons where climate warming is anticipated or already occurring. In this paper, based on the historical winter wheat yield data in recent 30 years (1983-2011) and the climate data (temperature, precipitation and), the evaluation model of winter wheat realistic potential productivity was proposed. And the potential productions of winter wheat in the world were investigated.

2. MATERIALS AND METHODS

2.1 Data

The leaf area index (LAI) 15-day data set was generated from 1983 to 2011 at 10 × 10 km pixel resolution and was freely obtained from the NASA Earth Exchange web site (Zhu et al., 2013). Historical daily weather data from 1983 to 2011 were available from Climatic Research Unit (CRU) Time-Series (TS) Version 3.20 of High Resolution Gridded Data (Jones and Harris, 2013), including daily average, maximum and minimum temperatures, rainfall, wind speed, sunshine hours, and relative humidity. Monthly meteorological data including precipitation, solar radiation and average temperature were calculated based on daily data, and then spatial interpolation was implemented by using the ordinary Kriging method. Parameters measured at

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weather stations were interpolated into a 10 × 10 km grid with a projection that was the same as the remote sensing data (LAI).

In this paper, the statistical data on winter wheat yield were obtained from the Food and Agriculture Orgnization (FAO, 2014) for the period 1982–2011. The climate zone data were built by considering historical climatic conditions, and in the process AEZ (Agro-Ecological Zones) method developed by the Food and Agriculture Organization (FAO) and International Institute for Applied Systems Analysis (IIASA) for rational land use planning and management (IIASA and FAO, 2002) had been also referred. The cropland data that was used to identify arable fields was derived from Global Land Cover SHARE (GLC-SHARE) database, which is released by FAO in 2014 (FAO, 2014).

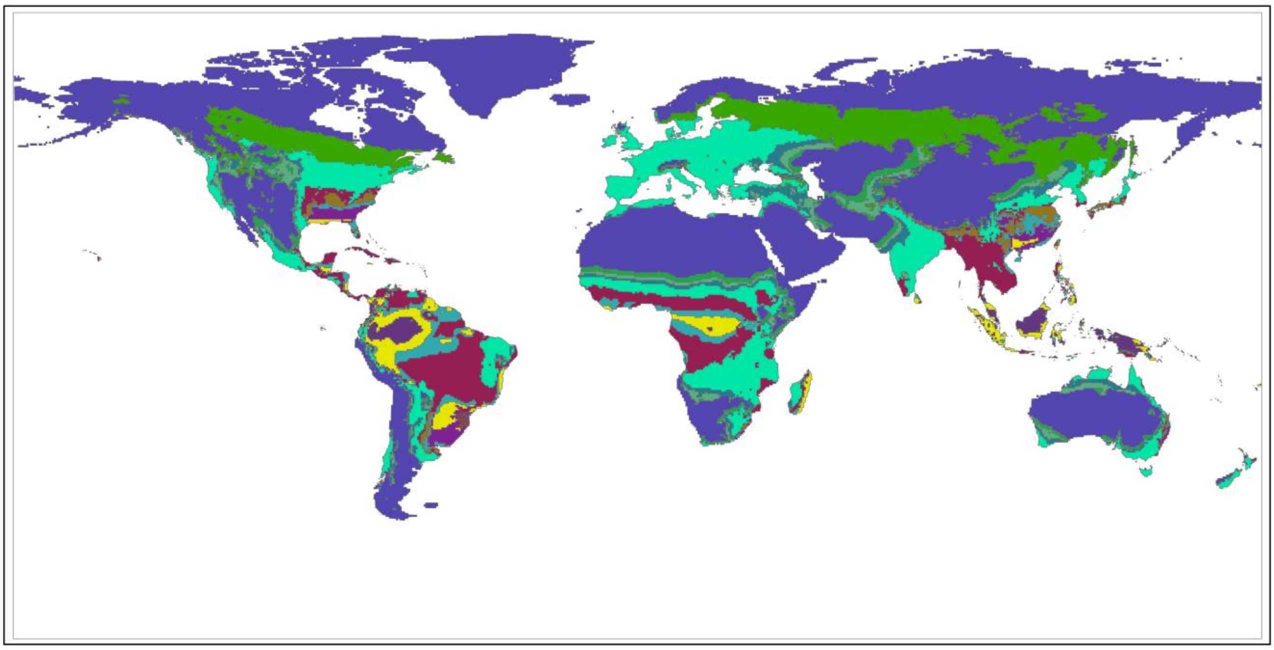

Figure 1. Distribution of Agro-Ecological Zones in the world.

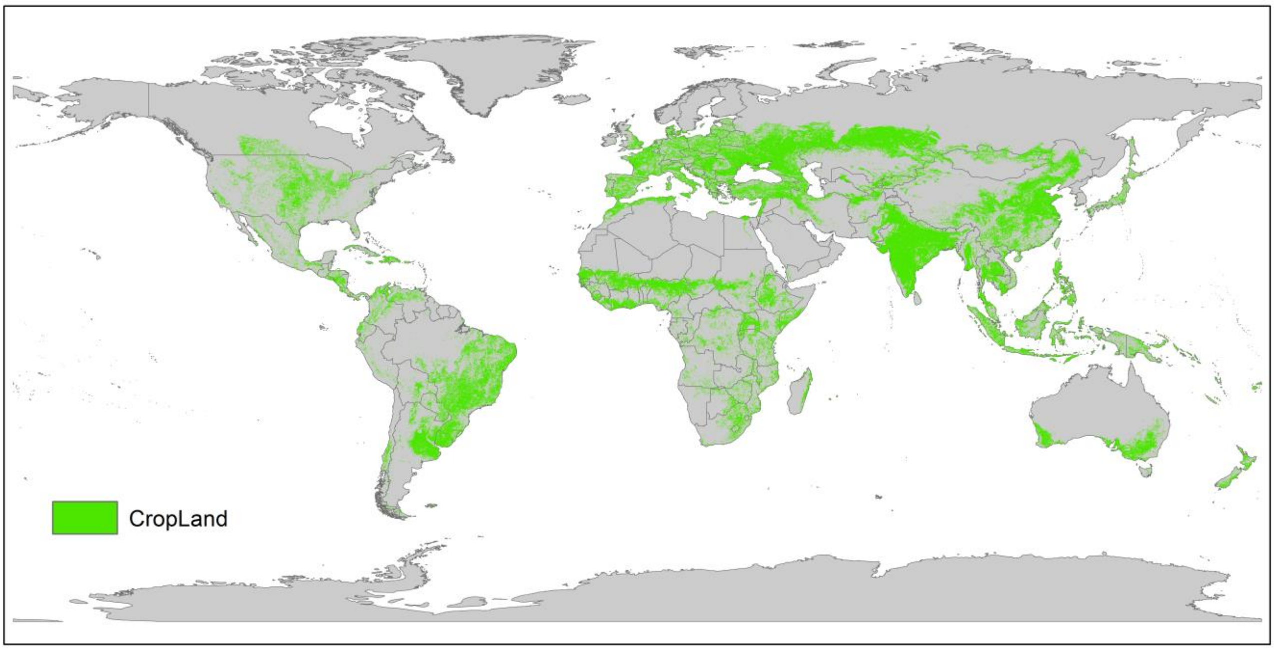

Figure 2. Distribution of cropland in the world.

2.2 Methods

2.2.1 Crop yield distribution based on remote sensing data

The vegetation indices derived from the visible and near infrared wavelength of canopy reflectance, such as normalize difference vegetation index (NDVI), enhanced vegetation index (EVI) and wide dynamic range vegetation index (WDRVI) (Sakamoto et al., 2011, 2013), can obtain priory crop productivity. In this research, LAI dataset was derived from NDVI data, therefore, a year of winter wheat productivity was considered as the accumulation of LAI in the grown season of the winter wheat (mainly include anthesis and maturity). The time windows for calculating crop productivity were roughly defined based on the periodic characteristics of winter wheat growth in the world. With the historical winter wheat yield data and the cropland data from FAO, the distribution of winter wheat yield (WY_d) was estimated based on the following equation:

$$WY_d = WY_h \times \frac{WP_d}{AVE(WP_d)}$$

where WY_h is the historical winter wheat yield data and the cropland data from FAO. WP_d is the distribution of winter wheat productivity derived from the accumulation of LAI, and $AVE(WP_d)$ represented the average value of WP_d.

2.2.2 Evaluation of winter wheat potential productivity

In our study, the evaluation model of winter wheat realistic potential productivity based on ago-ecological zone was proposed. And the potential productions of winter wheat in the world were investigated as the steps illustrated in Fig. 3.

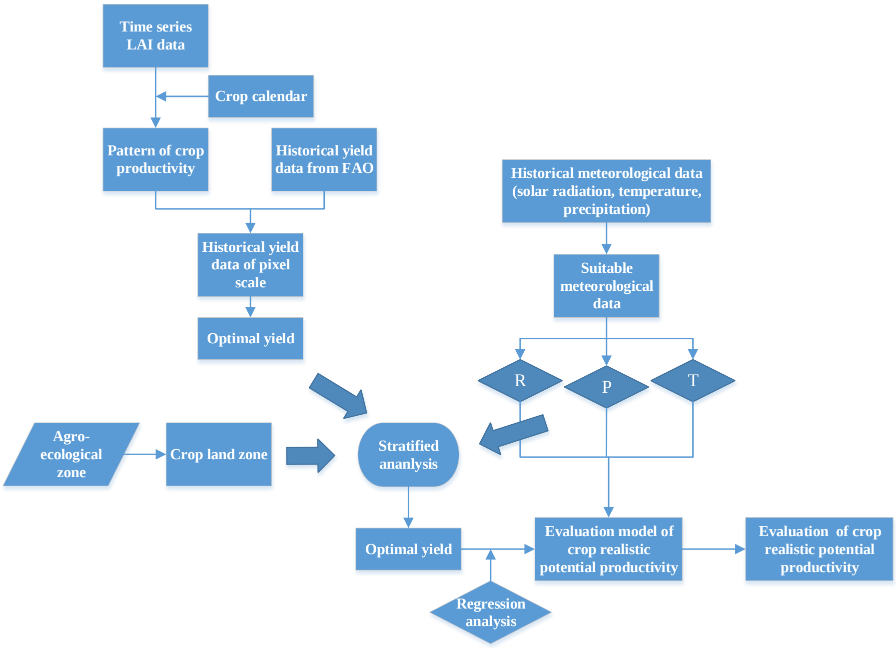

Figure 3. Schematic of the steps to evaluate crop realistic potential productivity.

Step1: the distributions of historical winter wheat productivity were calculated and the optimal yield was selected which was defined as average of the yields of the best three years during 1983-2011 for each pixel. Meanwhile, the suitable meteorological data, mainly include temperature (T), solar radiation (R) and precipitation (P) was defined as average meteorological data of the yields of the best three years during 1983-2011 for each pixel.

Step2: many classes of climate were identified using regular percentiles of the climate frequency distribution over each agro-ecological zone and then extracting the 95th percentiles of winter wheat yield for each of these classes and which was the optimal yield (Y) of the climate zone.

Step3: a function to each of the series was fitted empirically between the optimal yield (Y) and climate class median pairs (T, R and P).

Step4: the resulting functions can then be spatially modelled using the climate layer (T, R and P), and estimating a layer showing the potential production of winter wheat in each pixel.

3. RESULTS AND ANALYSIS

Based on the evaluation model of winter wheat realistic potential productivity which was proposed in the methods apartment, the potential productions of winter wheat in the world were investigated. The distribution of the winter wheat realistic potential productivity was presented in Figure 4. It can be seen from figure 4 that the realistic potential productivity of winter wheat in Western Europe mainly include United Kingdom, Germany and France was highest and it was more than 7500 kg/hm^2. The realistic potential productivity of winter wheat in North China Plain were also higher, which was about 6000 kg/hm^2. In the north-eastern Brazil, the realistic potential productivity of winter wheat was about 4500 kg/hm^2. However, the realistic potential productivity of winter wheat in the United States which is the main winter wheat producing country were not high, only about 3000 kg/hm^2. In addition to these regions which were the main winter wheat producing areas, the realistic potential productivity in other regions of the world were very low and mainly less than 1500 kg/hm^2, like in southwest region of Russia.

In the main producing countries of winter wheat, we conducted statistical analysis on the realistic potential productivity of winter wheat and the results showed in table 1 and figure 5. It can be seen from table 1 and figure 5 that the gaps between potential productivity and realistic productivity of winter wheat in Kazakhstan and India were biggest, which were 1022kg/hm^2 and 1318kg/hm^2. And the percentages of the gap in realistic productivity of winter wheat in Kazakhstan and India were more than 40%. Meanwhile, the gaps between potential productivity and realistic productivity of winter wheat in United Kingdom, Egypt and China were higher, and the percentages of the gap in realistic productivity of winter wheat in the three countries were more than 20%. In Russia, the gap between potential productivity and realistic productivity of winter wheat was lowest and the percentage of the gap in realistic productivity of winter wheat in Russia was only 10%.

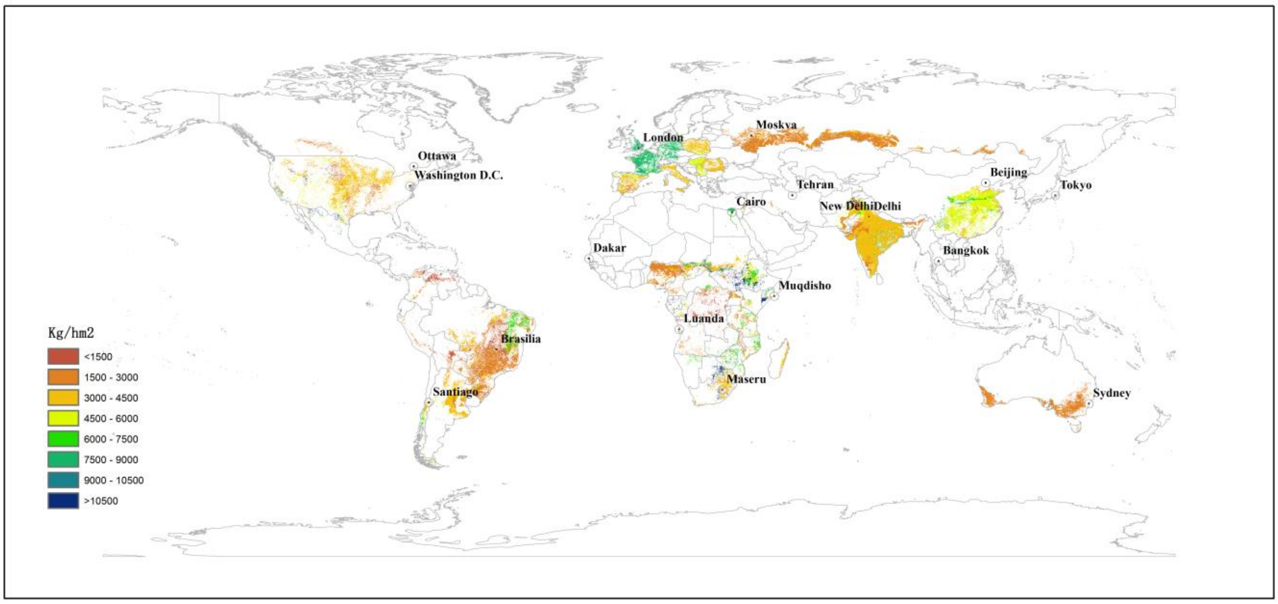

Figure 4. Distribution of the winter wheat realistic potential productivity in the world.

Table 1 The statistic of the realistic potential productivity of winter wheat in the main winter wheat producing countries

Country	Realistic potential productivity (kg/hm^2)	The biggest productivity in 1983-2011 (FAO) (kg/hm^2)	Gap (kg/hm^2)
United Kingdom	8947	7453	1494
Germany	8568	7354	1214
France	8076	6845	1231
Egypt	7757	5924	1833
China	5520	4495	1025
India	4173	2855	1318
Romania	3788	3299	489
America	3327	2805	522
Canada	2999	2661	338
Kazakhstan	2516	1494	1022
Russia	2439	2201	238
Australia	2293	1950	343

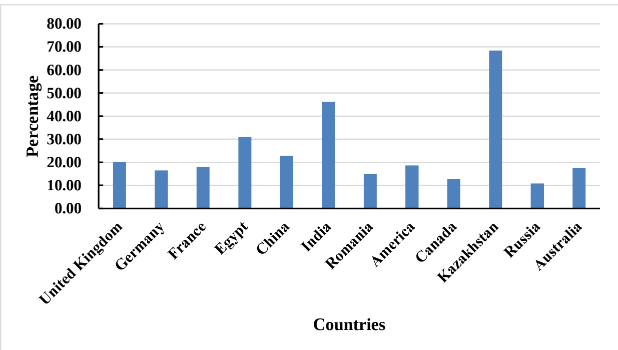

Figure 5. The percentage of the gap in realistic productivity of winter wheat in different countries.

4. CONCLUSION

In this study, the evaluation model of winter wheat realistic potential productivity was proposed based on agro-ecological zone, the historical winter wheat yield data in recent 30 years (1983-2011) obtained from FAO and the climate data. And the potential productions of winter wheat in the world were investigated. The results showed that the realistic potential productivity of winter wheat in Western Europe was highest and it was more than 7500 kg/hm^2. The realistic potential productivity of winter wheat in North China Plain were also higher, which was about 6000 kg/hm^2. However, the realistic potential productivity of winter wheat in the United States which is the main winter wheat producing country were not high, only about 3000 kg/hm^2. In addition to these regions which were the main winter wheat producing areas, the realistic potential productivity in other regions of the world were very low and mainly less than 1500 kg/hm^2, like in southwest region of Russia.

The gaps between potential productivity and realistic productivity of winter wheat in Kazakhstan and India were biggest, and the percentages of the gap in realistic productivity of winter wheat in Kazakhstan and India were more than 40%. Meanwhile, the gaps between potential productivity and realistic productivity of winter wheat in United Kingdom, Egypt and China were higher. In Russia, the gap between potential productivity and realistic productivity of winter wheat was lowest and the percentage of the gap in realistic productivity of winter wheat in Russia was only 10%.

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