Mapping Global Crop Distribution

Yaojie Yue, Peng Su, Yuan Gao, Puying Zhang, Ran Wang,
Anyu Zhang, Qinghua Jiang, Weidong Ma, Yuantao Zhou,
and Jing'ai Wang

1 Introduction

The latest special report from the Intergovernmental Panel on Climate Change (IPCC), published in 2018 (Anandhi et al. 2016), estimates a 1.5 °C increase in global temperature in 2040 at the current rate of global warming. Such a rise has serious implications for major cereal crop cultivation: unless crop varieties adapted to higher temperatures become available, the areas suitable for cropping are bound to shift in the future. Therefore, to safeguard food security, we need to predict such changes in spatial and temporal terms, which can intuitively reflect the potential distribution of crops under different climate change scenarios and for different time periods, helping to reduce losses according to local conditions (Deng et al. 2009).

Authors: Yaojie Yue, Peng Su, Yuan Gao, Puying Zhang, Ran Wang, Anyu Zhang, Qinghua Jiang, Weidong Ma, Yuantao Zhou, Jing'ai Wang. **Map Designers:** Yichen Li, Qingyuan Ma, Jing'ai Wang, Ying Wang.

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Y. Yue · Y. Gao · P. Zhang · R. Wang · A. Zhang · Q. Jiang · J. Wang (✉)

Key Laboratory of Environmental Change and Natural Disaster of Ministry of Education, Faculty of Geographical Science, Beijing Normal University, Beijing, 100875, China
e-mail: jwang@bnu.edu.cn

P. Su · W. Ma · Y. Zhou
School of Geographic Science, Qinghai Normal University,
Xining, 810008, China

J. Wang
State Key Laboratory of Earth Surface Processes and Resource Ecology, Beijing Normal University, Beijing, 100875, China

Species distribution models (SDMs) have been widely applied in evaluation of land suitability for crop cultivation and the potential distributions of some cereal crops under climate change scenarios (Stansbury and Pretorius 2001; Subbarao et al. 2001; Sun et al. 2012; He and Zhou 2016; Shabani and Kotey 2016), but socioeconomic scenarios have rarely been considered. As an important part of the atlas, the maps of global crop distribution were produced to show the potential distribution of major cereal crops, including wheat, maize, and rice, under the influence of global climate change. These maps cover global distribution of wheat, rice, and maize in the 2000s (baseline period), 2030s (near term), and 2050s (medium term) under the RCP2.6, RCP4.5, and RCP8.5 scenarios.

2 Method

2.1 Wheat Distribution Prediction Method

Environmental variables: This study considered that the cultivation of wheat is affected by climate and soil (Motuma et al. 2016). Hence, on the basis of previous research, we established an environmental variables system, including the following variables: ≥ 0 °C cumulative temperature, annual precipitation, annual average temperature, average temperature of the coldest month (Sun et al. 2012; Wang et al. 2016), pH, drainage, conductivity, exchangeable sodium percentage, soil property, and soil depth (Wandahwa and Van Ranst 1996; Mendas and Delali 2012; Wang et al. 2016). Considering that terrain has a great influence on the convenience of wheat cultivation, this study also chose slope as an environmental variable.

Samples: According to the *Harvested Area and Yield for 175 Crops of Year 2000* (Monfreda et al. 2008), 15,500 samples, which accounted for approximately 5% of all grids, were selected. A total of 75% of these samples were used for

Fig. 1 Research framework for predicting rice suitability. RCP = Representative concentration pathways; ROC = Area under the curve

model training and the remaining 25% were used for validation.

The Maxent model was trained to predict future land suitability for wheat cultivation for the 2000s, 2030s, and 2050s under different future climate scenarios. The specific process of modeling can be found in Yue et al. (2019).

2.2 Rice Distribution Prediction Method

The Maxent model combines the data on the presence of a given species within a grid with environmental variables representing different environmental gradients within that grid to determine whether the area is suitable for a particular species. The overall research framework for the study is shown in Fig. 1.

Environmental variables and Samples: After the selection of sample points and environment variables, a total of 2228 samples and 17 environmental variables were used in predicting future suitable areas for rice cultivation.

The Maxent model was trained to predict future land suitability for rice cultivation for the 2000s, 2030s, and 2050s under different future climate scenarios. In order to reduce errors, the simulation was run for 30 times, and the average result was used as the final result. The specific process of modeling can be found in Su et al. (2021).

To more realistically represent future global rice cultivation distribution, this study also considered the balance of the supply and demand of rice among countries. On the supply side, we used suitability changes to predict the initial rice harvest area as the starting value of the extended simulation. The rice harvest area was adjusted by comparing the countries' rice supply and demand. If the supply exceeded demand, we reduced the rice harvest area, and vice versa. Besides, we calculated irrigated and non-irrigated areas separately. This model can be expressed as a multi-objective optimization model (Eqs. 1–4).

$$D = S + I \quad (1)$$

where D , S , and I represent the countries' rice demand, supply, and net import, respectively,

$$A_{i,\text{rice}} \leq A_{i,\text{c3}} \quad (2)$$

where $A_{i,\text{rice}}$, $A_{i,\text{c3}}$, respectively, represent the rice harvest area and C3 crop harvest area of the i th grid.

$$\sum (A_{i,n+1} \cdot Su_i) \geq \sum (A_{i,n} \cdot Su_i) \quad (n = 1, 2, 3, \dots) \quad (3)$$

where n is the number of iterations, $n = 1$ is the initial situation inferred from the change in the suitable area, and Su is the suitability.

$$Ir_{\text{FAO}} = \frac{\sum A_{i,\text{Ir}}}{\sum A_{i,\text{rice}}} \quad (4)$$

where Ir_{FAO} is the national rice irrigation rate predicted by FAO and $A_{i,\text{Ir}}$, $A_{i,\text{rice}}$ are the rice irrigation area and rice harvest area in grid i . Finally, socioeconomic changes in crop planting are mapped in the atlas to reflect the adjusted global distribution of rice cultivation.

2.3 Maize Distribution Prediction Method

Applying the same prediction method using the Maxent model and following the procedure described in Fig. 1, we selected 5548 maize sample points and 16 environment variables to predict the potential distribution of maize. Then we redistributed maize cultivation among countries on the basis of natural maize potential distribution by following the redistribution method of rice cultivation.

3 Results

3.1 Latitudinal Distribution of Crops

The latitudinal distributions of the cultivated areas of the three crops in the historical period (red bar) and the RCP8.5 scenario (blue bar) are shown in Fig. 2.

During the two study periods, the three crops are cultivated mainly in the northern hemisphere. The most important areas for wheat, rice, and maize planting are between 20°N–60°N, 20°N–30°N, and 30°N–60°N, respectively. The comparison of the planting areas in the two periods shows that under the RCP8.5 scenario, the cultivated areas of the three crops in the northern hemisphere will move to higher latitudes and the cultivated areas of rice and maize will have a significant increase.

3.2 Country Distribution of Crops

Figure 3 shows the ranking of the top 20 countries based on the statistics of the cultivated areas of the crops in each country in the historical period and under the RCP8.5 scenario.

In both periods, China's wheat planting area is the largest globally, followed by the United States and Russia. Rice planting area is the largest in India, and China's rice planting area is the second largest and much larger than other countries. Maize planting area is the largest in the United States, and China has the second largest maize planting area. In both time periods, China's wheat, rice, and maize planting areas are all among the highest globally. On the other hand, in the future once the high temperature for crops intensifies, China will also face greater losses than other countries.

Fig. 2 Latitudinal distribution of the cultivated areas of wheat, rice, and maize (unit: million ha)

Fig. 3 Ranking of the top 20 countries by cultivated area of wheat, rice, and maize (unit: million ha)

4 Maps

Global wheat distribution (Baseline)

Projected global wheat distribution (2030s, RCP2.6)

Projected global wheat distribution (2030s, RCP4.5)

Projected global wheat distribution (2030s, RCP8.5)

Projected global wheat distribution (2050s, RCP2.6)

Projected global wheat distribution (2050s, RCP4.5)

Projected global wheat distribution (2050s, RCP8.5)

Global rice distribution (Baseline)

Projected global rice distribution (2030s, RCP2.6)

Projected global rice distribution (2030s, RCP4.5)

Projected global rice distribution (2030s, RCP8.5)

Projected global rice distribution (2050s, RCP2.6)

Projected global rice distribution (2050s, RCP4.5)

Projected global rice distribution (2050s, RCP8.5)

Global maize distribution (Baseline)

Projected global maize distribution (2030s, RCP2.6)

Projected global maize distribution (2030s, RCP4.5)

Projected global maize distribution (2030s, RCP8.5)

Projected global maize distribution (2050s, RCP2.6)

Projected global maize distribution (2050s, RCP4.5)

Projected global maize distribution (2050s, RCP8.5)

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