Agriculture, Ecosystems and Environment 269 (2019) 140–147

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Changes in global cropland area and cereal production: An inter-country comparison

Qiangyi Yu*, Mingtao Xiang*, Wenbin Wu, Huajun Tang

Key Laboratory of Agricultural Remote Sensing (AGRIRS), Ministry of Agriculture / Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing, 100081, China

ARTICLE INFO

Keywords:
Land use change
Cropland
Production potential
Cereal productivity
Food security
Sustainable development

ABSTRACT

Although cereal production is a linear function of cropland area in principle, the relationship between area change and production change is nonlinear at a larger geographical scale due to the spatially heterogeneous use of land. Based on globally gridded land cover maps between 2000 and 2010, this study presents a country-level comparison to understand how cropland area change contributes to cereal production variation across the world's major cereal producers. First, a map of potential cereal productivity is applied to represent the spatially varied biophysical capacity, and the cropland area change in primary and marginal locations are calculated separately for individual countries by adopting the country's average cereal productivity as a reference. Then the area-change-induced potential cereal production change is estimated and correlated with the actual production change at the country level. The results show that most countries increased cropland area in primary locations. A few countries decreased cropland area, and the area losses are mainly occurred in primary locations as well. Moreover, China and USA achieved a marked increase in actual production with an expected decrease in potential production. In contrast, Brazil, Argentina and Nigeria have a higher increase in potential production against a relatively lower increase in actual production. Combining these, a cluster analysis indicates that some countries better exploited cropland productivity (as represented by China), and some countries better allocated cropland area (as represented by Brazil). Although the former group has reduced hunger more significantly, sustainable cereal production requires balanced development in terms of both productivity-improvement and area-optimization, which simultaneously ensure production and minimize environmental effects. Consequently, the current comparative analysis provides a preliminary guideline for developing national-level strategies by comparing the performance of one country to that of others.

1. Introduction

Global demand for food is increasing with the fast-growing population and changed dietary structure; therefore, how to feed the world successfully has always been a big challenge (Foley et al., 2011; Tilman et al., 2011; Yu et al., 2012). Cereals – including wheat, rice, maize, and barley – are essential to global food security (Godfray et al., 2010) because they are not only staple crops with a rich source of proteins, carbohydrates, vitamins, minerals, fats and oils but also crops grown in greater quantities and provide more food energy worldwide than any other type of crop (World Bank Databank, 2018; Parry et al., 2004; Pfeiffer and McClafferty, 2007). Global cereal supply and demand, in terms of production, utilization, stock and trade, have been steadily increasing in the past decades (Dorosh, 2009; West et al., 2014; To and Grafton, 2015; FAO, 2017), and of these, maintaining cereal production has played an even more important role amid the process of global environmental change (Li et al., 2016; Reynolds et al., 2016; Wei et al., 2017).

Crop production (ton) is a linear function of cropland area (hectare) and productivity (ton per hectare), suggesting that any changes in cropland area or productivity could influence the total production (Foley et al., 2011; Reynolds et al., 2017). The production of cereal crops has tripled over the past five decades, with only a small increase in the land area cultivated (Rudel et al., 2009; Pingali, 2012). However, these small changes in area have contributed to approximately 12% of the total cereal production increase globally (Foley et al., 2005), suggesting that the relationship between changes in cropland area and cereal production is nonlinear at a larger geographical scale. This is mainly due to the spatially heterogeneous use of land, e.g., the quality, suitability and management intensity of cropland used for cereal

* Corresponding authors at: Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing, 100081, China.
E-mail addresses: yuqiangyi@caas.cn (Q. Yu), xiangmt_caas@163.com (M. Xiang), wuwenbin@caas.cn (W. Wu), tanghuajun@caas.cn (H. Tang).

https://doi.org/10.1016/j.agee.2018.09.031
Received 25 June 2018; Received in revised form 24 September 2018; Accepted 26 September 2018
0167-8809/

production differ from place to place, causing that the same amount of change in area in different locations would probably have different consequences on cereal production. For example, urban sprawl and cropland retirement both lead to cropland area loss. The former is more likely taking place on existing fertile cropland; thus, a greater production loss is expected (Bren d'Amour et al., 2017; van Vliet et al., 2017), while the latter usually results in converting marginal cropland for ecological restoration; thus, only a limited production loss is expected (Xu et al., 2006). This example demonstrates that at a larger geographical scale, cropland area change would have not only a direct effect on crop production but also indirect effects, which would be induced by the reallocated cropland area and changed average cropland productivity during the process of cropland change.

Due to insufficient data availability in terms of mapping the quality, suitability and management intensity of global cereal croplands, the relationship between cropland area change and cereal production, especially the indirect effects induced by cropland change, is largely unknown at the global level (Verburg et al., 2013). Moreover, given the lack of effective global land governance and compensation mechanisms (Egli et al., 2018), it is likely that more regional-level case studies were designed for domestic policy-making, as the consequences of land use on food, social and ecological systems are largely territory-specific (Sikor et al., 2013). For example, case studies can be found from China (Liu et al., 2015; Li et al., 2017), Brazil (Dias et al., 2016), and India (Behera et al., 2016). Thus comparative analyses, which extend the country-specific perspective by assessing the relative performance to each other, could be helpful to optimizing a country's domestic land use by comparing it to another country's land use (Chen et al., 2018).

In this study, in terms of the difficulties in upscaling a detailed regional-level analysis to the global level, we use the existing data and implement an inter-country comparative analysis to understand the different cropland use models implemented across countries for cereal production during the last decade. Specifically, we aim to understand the indirect effects of cropland area change on cereal production for individual countries, including (i) how much cropland area has been changed? and how much of this change occurred in primary locations and marginal locations respectively? (ii) how many changes in potential production are expected (i.e., directly induced by area change) against the observed changes in actual production? Using this information, a topology is developed to highlight the different cropland use models, aiming to help develop national-level strategies for sustainable cereal production (e.g., maximizing production while minimizing environmental effects) by comparing one country's performance to that of others.

2. Materials and methods

2.1. The research framework

The assessment is performed quantitatively for the world's major cereal producing countries, aiming to understand which countries have better allocated cropland area for cereal production and which countries have better improved actual average cereal productivity considering the changes in cropland area. According to the Food and Agriculture Organization of the United Nations (FAO)'s definition, the cereal crops included in the study are wheat, rice, maize, barley, pearl millet, small millet, sorghum, and other cereals. A few global gridded datasets are applied to capture the spatial variations in cropland area change and its potential consequences on cereal production at a 5 arc-minute spatial scale, and then, the grid-level values are aggregated to the administrative level for the inter-country comparison and typology analysis (Fig. 1).

2.1.1. Comparing the net cropland area change

The grid-level values of net cropland area change between 2000 and 2010 are computed by using the GlobeLand30 dataset (Chen et al., 2015). With an assumption that the cropland share for cereal production remains relatively stable during the decade, the share of cereal cropland area – derived from the Spatial Production Allocation Model (SPAM) dataset (You et al., 2014) – is applied to adjust the net area changes for cereal cropland (ΔCL) at the grid level.

To investigate which countries have a better allocation of cropland area, the average cereal productivity potential (Y_a) is computed within each administrative unit based on the layer of cereal productivity potential (Y) from the Global Agro-Ecological Zones (GAEZ) dataset (Fischer et al., 2002):

$$Y_a = \sum_{i=1}^{n} Y_i \Big/ n$$

where Y_i denotes to the cereal productivity potential for grid i within the given administrative unit. The zero value (i.e., $Y = 0$) is excluded indicating the grid has no potential for cereal production. n denotes to the number of zero-free grids within the administrative unit.

Y_a is further applied as an intermediate variable to distinguish primary (i.e., Y_i is higher than Y_a) and marginal (i.e., Y_i is lower than Y_a) locations for each unit. Consequently, the ΔCL is separated into ΔCL_{above} and ΔCL_{below}., which represent the changed cropland area in primary and marginal locations, respectively:

$$\Delta CL_{above} = \sum \Delta CL_i \text{ if: } Y_i \geq Y_a$$

$$\Delta CL_{below} = \sum \Delta CL_i \text{ if: } Y_i < Y_a$$

These indicators, in turn, reflect the different characteristics of cropland allocation among countries. For example, if a higher proportion of positive ΔCL_{above} is observed, then this value indicates that this unit not only expanded cropland area but also optimized the cropland allocation; thus the capacity for cereal production might be improved more than those who share the same ΔCL but with a lower proportion of ΔCL_{above}. The flow of the area-related analysis is marked in green boxes in Fig. 1.

2.1.2. Comparing the potential production change

With an assumption that the cereal productivity potential (Y, according to GAEZ) remains relatively stable during the decade, any changes in cropland area (ΔCL) would result in corresponding changes to the potential production (ΔP_p):

$$\Delta P_p = \sum \Delta CL_i \times Y_i$$

By multiplying ΔCL by the intermediate variable Y, Qin et al. (2013) measured ΔP_p and further related ΔP_p to the changes in actual production (ΔP_a) to evaluate the effect of cropland retirement on crop production. Based on this conceptualization, a correlation between ΔP_a and ΔP_p helps to understand the characteristics of cropland productivity exploitation among countries. For example, a higher value of the ratio between ΔP_a and ΔP_p suggests that a small net change in cropland area has resulted in a noticeable production variation; therefore, this unit has better exploits cropland productivity. The flow of the productivity-related analysis is marked in red boxes in Fig. 1.

2.1.3. Clustering countries for a typology

Finally, a cluster analysis is implemented to group countries by considering the abovementioned four variables, including ΔP_a, ΔP_p, ΔCL_{above} and ΔCL_{below}. The cluster analysis applies the complete-linkage clustering method (one of the agglomerative hierarchical clustering), which avoids the drawback of the alternative single linkage method, where clusters are formed via single linkage clustering may be forced together due to single elements being close to each other, even though many of the elements in each cluster may be very distant to each other. The complete linkage function – the distance *D(A, B)* between clusters *A* and *B* – is described by the following expression: