Science of the Total Environment 541 (2016) 756–764

Contents lists available at ScienceDirect

Science of the Total Environment

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

Maize yield gaps caused by non-controllable, agronomic, and socioeconomic factors in a changing climate of Northeast China

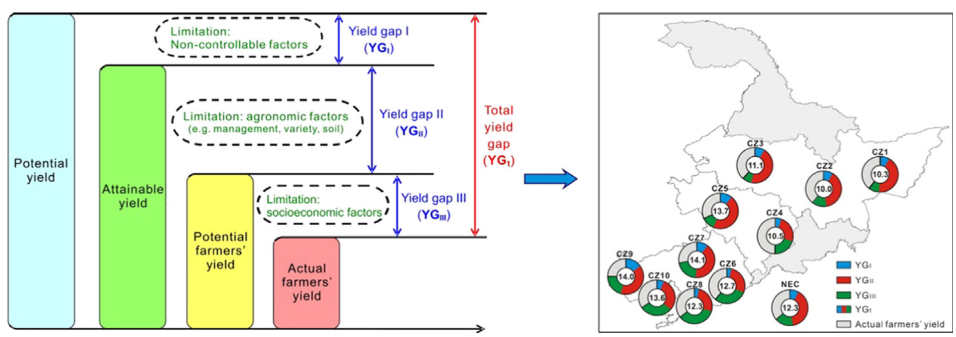
Zhijuan Liu [a], Xiaoguang Yang [a,*], Xiaomao Lin [b], Kenneth G. Hubbard [c], Shuo Lv [a], Jing Wang [a,d]

[a] College of Resources and Environmental Sciences, China Agricultural University, No. 2 Yuanmingyuan West Rd., Haidian District, Beijing 100193, China
[b] Department of Agronomy, Kansas State University, 2108 Throckmorton Hall, Plant Sciences Center, Manhattan, KS 66506, USA
[c] School of Natural Resources, University of Nebraska-Lincoln, 3310 Holdrege Street, Lincoln, NE 68583, USA
[d] Ningxia Institute of Meteorological Sciences, Yinchuan 750002, China

HIGHLIGHTS

- The actual farmers' yield showed a tendency to increase by 1.27 t ha^{-1} per decade.
- Maize yield gaps due to non-controllable, agronomic, and socioeconomic factors were identified.
- We suggest government and farmers focus on reducing yield gap by improving agronomic practices.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 18 May 2015
Received in revised form 20 August 2015
Accepted 30 August 2015
Available online xxxx

Editor: D. Barcelo

Keywords:
Maize
Northeast China
Yield gaps
Yield constraints
Climate zone
Up-scaling

ABSTRACT

Closing the gap between current and potential yields is one means of increasing agricultural production to feed the globally increasing population. Therefore, investigation of the geographic patterns, trends and causes of crop yield gaps is essential to identifying where yields might be increased and quantifying the contributions of yield-limiting factors that may provide us potentials to enhance crop productivity. In this study, the changes in potential yields, attainable yields, potential farmers' yields, and actual farmers' yields during the past five decades in Northeast China (NEC) were investigated. Additionally the yield gaps caused by non-controllable, agronomic, and socioeconomic factors were determined. Over the period 1961 to 2010 the estimated regional area-weighted mean maize potential yield, attainable yield, and potential farmers' yield were approximately 12.3 t ha^{-1}, 11.5 t ha^{-1}, and 6.4 t ha^{-1} which showed a decreasing tendency. The actual farmers' yield over NEC was 4.5 t ha^{-1}, and showed a tendency to increase ($p < 0.01$) by 1.27 t ha^{-1} per decade. The regional mean total yield gap (YG_t), weighted by the area in each county dedicated to maize crop, was 64% of potential yield. Moreover, 8, 40, and 16% reductions in potential yields were due to non-controllable factors (YG_I), agronomic factors (YG_{II}), and socioeconomic factors (YG_{III}), respectively. Therefore, the exploitable yield gap, considered here as the difference between the potential yield and what one can expect considering non-controllable factors (i.e. YG_t–YG_I), of maize in NEC was about 56%. The regional area-weighted averages of YG_t, and YG_{III} were found

* Corresponding author.
E-mail address: yangxg@cau.edu.cn (X. Yang).

http://dx.doi.org/10.1016/j.scitotenv.2015.08.145

to have significant decreases of 11.0, and 10.7% per decade. At the time horizon 2010, the exploitable yield gaps were estimated to equal 36% of potential yield. This led to the conclusion that the yield gap could be deeply reduced by improving local agronomic management and controlling socioeconomic factors.

1. Introduction

Crop production is dependent on solar radiation, precipitation, atmospheric vapor pressure, temperature, soil fertility, and management decisions such as hybrid selection, planting date, and inputs (fertilizers and irrigation) (Kucharik, 2008; Ramankutty et al., 2002). A trend in any of these climatic variables can therefore possibly lead to a trend in crop production. Potential yield is the yield ceiling of the crop for a given variety in a given location (Evans and Fischer, 1999). Accurate estimates of crop potential yield are essential for assessing regional crop production capacity on existing farm land given best management practices. Average farm yields in a region or country are inevitably lower than potential yields because achieving yield potential requires near perfect management of crop and soil factors that influence plant growth and development throughout the crop growth cycle (Lobell et al., 2009). Therefore it is important to investigate maize yield constraints to improve our understanding of how to ensure increased yields in the future.

Subsequent to the rice yield gap studies in IRRI during the 1970s (Barker et al., 1979), numerous studies successfully quantified yield gaps and gap variations in the intervening decades at different study scales (Lobell and Ortiz-Monasterio, 2006; Neumann et al., 2010; Ortiz-Monasterio and Lobell, 2007; Sadras et al., 2002). Originally, the total yield gap was defined as the yield difference between potential and actual farmers' yield (Herdt, 1996). According to the constraints, yield gaps can be broken down further into three components (Fig. 1). Potential yield in a given location is defined as the yield of a crop cultivar when grown under non-limiting water and nutrient supply, and in the absence of pests and diseases (Evans and Fischer, 1999; Grassini et al., 2009). Attainable yields are less than absolute biophysical 'potential yields', and represent the yield achievable using current best-known technology and management techniques at a given time and in a given ecosystem. Attainable yield is commonly less than, or at best equal to, potential yield (Mueller et al., 2012). The attainable yield does not take into account the cost of achieving best management practice. Potential farmers' yield, on the other hand, is obtained by adjusting management so that crop profitability is optimized. Thus, potential farmers' yield is commonly lower than and at best equal to attainable yield (Teng and Revilla, 1996). Actual farmers' yield is the average of farmers' yields in a given target area at a given time and in a given ecosystem. Therefore, the first component of yield gaps (YG_I—Fig. 1) is mainly due to factors that are generally not controllable such as environmental conditions and some technologies unavailable in the farmers' field (Van Tran, 2001). The second component of yield gaps (YG_{II}—Fig. 1) is mainly due to differences in agronomic factors. This gap exists because farmers may use suboptimal doses of inputs and cultural practices. The YG_{II} can be narrowed by deploying more efforts to improve the management. The third component of yield gaps (YG_{III}—Fig. 1) was caused by socioeconomic factors.

Several studies have revealed the constraints limiting maize, wheat, and rice production in some regions in China (Li et al., 2014; Meng et al., 2013; Zhang et al., 2014; Zhu, 2000). The total area sown to maize in Northeast China (NEC) accounts for 29% of China's total. The production of maize in NEC accounted for more than 30% of the nation's total (National Bureau of Statistics of China (NBSC) 2008–2010). However, there are few comprehensive documentations of maize yield gaps in NEC. Furthermore, there are no regional analyses of the constraints due specifically to non-controllable factors, agronomic factors, and socioeconomic factors for maize yield in NEC in recent years. This knowledge gap makes it difficult for maize producers and decision makers to improve and plan maize productivity in current and future climate conditions. The objectives of this study are to (1) identify the trends of potential yield, attainable yield, potential farmers' yield, and actual farmers' yield of maize first at the climate zone level and then over the entire NEC region; and (2) evaluate maize yield gaps caused by non-controllable factors, agronomic factors, and socioeconomic factors under the changing climate in NEC. To accomplish these objectives, we used the Agricultural Production Systems Simulator (APSIM), which is considered to be the most effective means to estimate crop

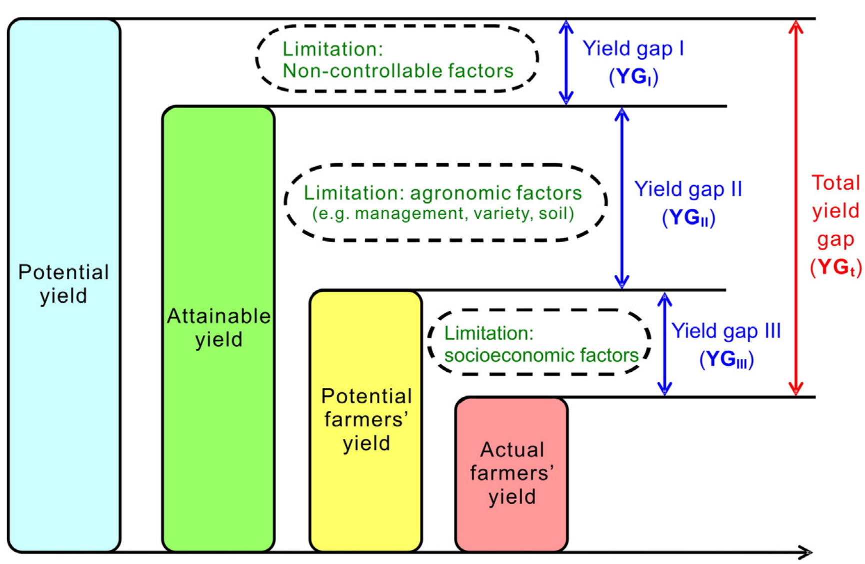


Fig. 1. A conceptual framework depicting the relative rankings of yield. Different measures of the yield gap (YG) and limitation are indicated at the right side of the figure and are as follows: YG_t, total yield gap (between potential yield and actual farmers' yield); YG_I, yield gap I (between potential yield and attainable yield); YG_{II}, yield gap II (between attainable yield and potential farmers' yield); YG_{III}, yield gap III (between potential farmers' yield and actual farmers' yield).