Agricultural Systems xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Agricultural Systems

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

Can Bangladesh produce enough cereals to meet future demand?

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ARTICLE INFO

Article history:
Received 2 March 2016
Received in revised form 1 August 2016
Accepted 7 November 2016
Available online xxxx

Keywords:
Food security
Yield potential
Yield gap
Self-sufficiency ratio
Cropland area
Land use change scenarios

ABSTRACT

Bangladesh faces huge challenges in achieving food security due to its high population, diet changes, and limited room for expanding cropland and cropping intensity. The objective of this study is to assess the degree to which Bangladesh can be self-sufficient in terms of domestic maize, rice and wheat production by the years 2030 and 2050 by closing the existing gap (Yg) between yield potential (Yp) and actual farm yield (Ya), accounting for possible changes in cropland area. Yield potential and yield gaps were calculated for the three crops using well-validated crop models and site-specific weather, management and soil data, and upscaled to the whole country. We assessed potential grain production in the years 2030 and 2050 for six land use change scenarios (general decrease in arable land; declining ground water tables in the north; cropping of fallow areas in the south; effect of sea level rise; increased cropping intensity; and larger share of cash crops) and three levels of Yg closure (1: no yield increase; 2: Yg closure at a level equivalent to 50% (50% Yg closure); 3: Yg closure to a level of 85% of Yp (irrigated crops) and 80% of water-limited yield potential or Yw (rainfed crops) (full Yg closure)). In addition, changes in demand with low and high population growth rates, and substitution of rice by maize in future diets were also examined. Total aggregated demand of the three cereals (in milled rice equivalents) in 2030 and 2050, based on the UN median population variant, is projected to be 21 and 24% higher than in 2010. Current Yg represent 50% (irrigated rice), 48–63% (rainfed rice), 49% (irrigated wheat), 40% (rainfed wheat), 46% (irrigated maize), and 44% (rainfed maize) of their Yp or Yw. With 50% Yg closure and for various land use changes, self-sufficiency ratio will be >1 for rice in 2030 and about one in 2050 but well below one for maize and wheat in both 2030 and 2050. With full Yg closure, self-sufficiency ratios will be well above one for rice and all three cereals jointly but below one for maize and wheat for all scenarios, except for the scenario with drastic decrease in boro rice area to allow for area expansion for cash crops. Full Yg closure of all cereals is needed to compensate for area decreases and demand increases, and then even some maize and large amounts of wheat imports will be required to satisfy demand in future. The results of this analysis have important implications for Bangladesh and other countries with high population growth rate, shrinking arable land due to rapid urbanization, and highly vulnerable to climate change.

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1. Introduction

Bangladesh is a deltaic country located in South Asia, with a relatively small land area (147,570 km^2) but with the 8th largest world population (ca. 161 million) and the 13th highest world population density. According to the medium variant UN projection (UN, 2015), Bangladesh' population will further increase to 186 and 202 million by the years 2030 and 2050, respectively. Increasing income level and urbanization may lead to diet changes such as switching from traditional rice to wheat and to livestock, poultry, and fish products, which in turn require large amounts of maize for their production (Alkanda, 2010; Mukherjee et al., 2011). Most land suitable for cropping in the country is already under cultivation. Arable land area is even decreasing over time due to increasing demand for residential and industrial use (Hasan et al., 2013). Bangladesh also suffers from periodic natural calamities such as drought, flooding, and cyclones. Due to its location in a delta, climate change and associated sea level rise is expected to increase risk for flooding and salinization of agricultural lands, especially near the southern coast (Hossain and Silva, 2013; MOA-FAO, 2012).

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http://dx.doi.org/10.1016/j.agsy.2016.11.003
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Please cite this article as: Timsina, J., et al., Can Bangladesh produce enough cereals to meet future demand?, Agricultural Systems (2016), http://dx.doi.org/10.1016/j.agsy.2016.11.003

In irrigated cropping systems, yield potential (Yp) is defined as the yield of an adapted crop cultivar when grown without water and nutrient limitations and kept free of biotic stresses (Evans, 1993). In rainfed systems, water-limited yield potential (Yw) is determined by the soil water availability as governed by the water supply amount and distribution and soil and terrain properties, and no nutrient limitation and free of biotic stresses (van Ittersum et al., 2013). Yield gap (Yg) is defined as the difference between Yp (irrigated systems) or Yw (rainfed systems) and actual farm yield (Ya) (van Ittersum and Rabbinge, 1997; van Ittersum et al., 2013). Although cereal yields in Bangladesh have increased substantially over time, previous studies have documented large Yg in farmers' fields (Hasan and Islam, 2010; Kashem et al., 2012; Khan et al., 2013; Mondal, 2011; Schulthess et al., 2012; Timsina et al., 2010), though these studies were limited to a few locations and did not look at the potential extra grain production in Bangladesh due to Yg closure.

Current production-consumption ratio, hereafter called self-sufficiency ratio (SSR) is 1.09, 0.21, 0.67 for rice, wheat and maize, respectively (FAOSTAT, 2015), indicating that Bangladesh is self-sufficient in rice, but not in wheat and maize, and consequently highly dependent on trade. Given limited room for cropland expansion, there are basically two options to meet future increase in grain demand without increasing reliance on food imports: (i) increasing cereal yields per ha by closing the existing Yg between potential and actual yield, and (ii) increasing cropping intensity (number of crops planted in the same piece of land during a 12-month period). However, since average cropping intensity in Bangladesh is already high (at least two crops per year); it can be hypothesized that future SSRs will depend on the degree of Yg closure on existing land area (Ahmed et al., 2013; BBS, 2013). Approaching 80–85% of Yp or Yw, which are considered to be attainable farm yields under good farm management (Cassman et al., 2003, van Wart et al., 2013), could be an important strategy towards meeting the future food consumption needs of Bangladesh.

Several studies on food security have been conducted for Bangladesh (e.g., Amarasinghe et al., 2014; Ganesh-Kumar et al., 2012; Mainuddin and Kirby, 2015). All these studies, however, considered only one or two crops (typically rice and/or wheat) for a limited number of locations. Likewise, they did not account for potential changes in land use due to urbanization, climate change or other factors. Perhaps more important, these previous estimates of Yg are biased because Yp or Yw were calculated from highest-yielding treatments in research farms (Ali et al., 2008; Hasan and Islam, 2010; Kashem et al., 2012; Khan et al., 2013; Mondal, 2011). Well-validated crop simulation models, coupled with local weather, soil, and management data can provide more robust estimates of average Yp, Yw, and Yg because these models can account for major environment x management x genotype interactions (van Ittersum et al., 2013; Grassini et al., 2015). With the proper spatial framework, estimates of Yp, Yw, and Yg can be upscaled to larger spatial domains (van Wart et al., 2013, van Bussel et al., 2015) and serve as foundation for assessing food security scenarios (e.g., van Oort et al., 2015).

Performing a solid food security analysis for Bangladesh is important due to its high population, limited room for cropland expansion, and vulnerability to climate change. Results of this analysis can be used by policymakers to prioritize further research and/or to focus on regions with high potential production. The methodology applied in this study will also be relevant for other regions of the world where population is high, cropland area expansion is not possible, and climate change impact is predicted to be substantial. The objective of this paper is to assess the degree to which Bangladesh can be self-sufficient for maize, rice and wheat by years 2030 and 2050 for different levels of Yg closure, accounting for changes in cropland area, irrigation development, and changes in the relative share of cropland area among the different crop species.

2. Materials and methods

2.1. Cropping system features

Cropping systems in Bangladesh are very complex, highly intensive and diverse, and are continuously evolving and changing (Timsina and Connor, 2001). There are three main cropping seasons: (i) aman or kharif or monsoon (also called kharif-2) from June/July to September/October, (ii) rabi or winter from October/November to February/March, and (iii) spring or pre-kharif or pre-monsoon (also called kharif-1) from March/April to June/July (Fig. 1). In kharif-2, rice (called transplanted aman or T. aman) is the predominantly grown crop (>90% of area), mostly under rainfed conditions. During the dry rabi season a wide range of crops, including rice (called boro), wheat, maize, pulses (chickpea, lentil and field peas), potatoes and oilseeds (e.g., mustard) are grown. In kharif-1, short-duration cultivars of maize, pulses (mungbean, cowpea) and rice (called aus) are grown. Boro and rabi (winter) maize are either fully or partially irrigated, while aman and aus rice and kharif-1 (spring) maize are predominantly rainfed, with some crops applied with partial irrigation. Wheat is also predominantly grown with full irrigation (~80%), with remaining 20% under either partial irrigation or strictly rainfed. Thus, rice-rice (R-R), rice-wheat (R-W), and rice-maize (R-M) are the dominant systems, which often include an additional crop such as aus rice or maize in kharif-1 mostly grown under partial irrigation or rainfed conditions. While R-R is the common rotation in tropical and sub-tropical areas with warm climate in Bangladesh and entire South Asia, R-W and R-M rotations are practiced in the subtropical areas with mild winters (Timsina and Connor, 2001; Timsina et al., 2010, 2011).

2.2. Calculation of yield potential and yield gaps

Average Ya of rice, maize and wheat for 2010 in Bangladesh were calculated based on Ya data reported over the 2008–2012 time period (BBS, 2013). Yp (for all irrigated crops) and Yw (for rained rice) were simulated using ORYZA (v3) for rice (Bouman et al., 2001), Hybrid-Maize for maize (Yang et al., 2004), and WOFOST for wheat (Wolf et al., 2011). These models were calibrated and validated for Bangladesh based on primary and secondary data for crop phenology, and soil and yield data recorded from well-managed experiments conducted in major agriculture districts (Comilla, Dinajpur, Gazipur, Rajshahi, Rangpur) during 2010 to 2014 (Hossain and Silva, 2013; Islam, 2016). Yw was not simulated for wheat and maize in this study because <20% of the total area cultivated with these two crops is rainfed. Instead, we estimated Yw of maize and wheat based on existing field and modelling data from literature (Ali et al., 2008; Carberry et al., 2011; Timsina and Humphreys, 2006).

After compilation of all the data, we followed the protocols of the Global Yield Gap Atlas (GYGA) project for estimating the Yg of all crops (www.yieldgap.org, Grassini et al., 2015; van Bussel et al., 2015). Briefly, a number of locations were selected for each crop-water regime combination based on their relative share of the cultivated area for each crop. Selected locations were representative of >80% of the area cultivated with rice, wheat, and maize in Bangladesh. Yp and Yw were estimated by using long-term measured weather data and dominant soil types and management practices (planting date, variety maturity, plant density). Measured daily weather data (daily maximum and minimum temperature, rainfall and solar radiation) for 1990 to 2010 were retrieved from the Bangladesh Bureau of Meteorology (BBM, 2015). Detailed management and soil data for each selected location were provided by local agronomists and official statistics. Yg was calculated by subtracting Ya from Yp or Yw. Yp, Ya and Yg were upscaled to country level following a bottom-up approach based on crop area distribution and a climate zone scheme (Van Wart et al., 2013; van Bussel et al., 2015).

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