University of São Paulo
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The Brazilian case as a beacon to increase crop production in sub-Saharan Africa

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Thesis presented to obtain the degree of Doctor in Science. Area: Agricultural Systems Engineering

Piracicaba
2023

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versão revisada de acordo com a Resolução CoPGr 6018 de 2011

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Dados Internacionais de Catalogação na Publicação
DIVISÃO DE BIBLIOTECA – DIBD/ESALQ/USP

Gasparotto, Leticia Gonçalves

The Brazilian case as a beacon to increase crop production in sub-Saharan Africa / Leticia Gonçalves Gasparotto. - - versão revisada de acordo com a Resolução CoPGr 6018 de 2011. - - Piracicaba, 2023.

48 p.

Tese (Doutorado) - - USP / Escola Superior de Agricultura “Luiz de Queiroz”.

1. Yield-gap 2. Eficiência 3. Milho 4. Clima 5. Manejo I. Título

Resumo

O caso brasileiro como um exemplo para aumentar a produção agrícola na África Subsaariana

O milho é uma das principais culturas do mundo, sendo a principal fonte de alimento da África, representando 30% da área total de produção e 30% das calorias e proteínas consumidas. Apesar da dependência da África Subsariana em relação ao grão de milho, a produtividade real (Ya) da cultura é baixa quando comparado ao seu potencial, com média de aproximadamente 2 Mg ha^{-1}, que representa 27% da produtividade potencial limitada por água (Yw). Já no Brasil, a diferença de rendimento é de aproximadamente 50% de Yw. Desse modo, o objetivo deste trabalho foi realizar um estudo de caso, utilizando o milho de sequeiro como referência, para identificar um conjunto de áreas agrícolas com solo e clima semelhantes no Brasil e na África Subsahariana (ASS) e, então, comparar a resposta agronômica entre as duas regiões produtoras. Para isso, verificou-se a similaridade climática entre o Brasil e países da ASS, buscando zonas climáticas homogêneas que ocorrem em ambas as regiões. Os dados de Yw obtidos no âmbito do projeto Global Yield Gap Atlas (GYGA, www.yieldgap.org) foram utilizados. As estimativas de Yw foram realizadas com o modelo Hybrid Maize em ambos os continentes e as simulações foram baseadas no clima local, solo e nas práticas de manejo, como data de semeadura e ciclo das cultivares. Foram selecionados seis países pertencentes a ASS: Gana, Uganda, Kênia, Nigéria, Zâmbia e Etiópia. A Ya foi determinada incluindo a produtividade de pelo menos os últimos três anos e foram retiradas da base de dados dos institutos nacionais de estatística agrícola. Os dados climáticos mostraram que a ASS apresentou precipitação bem distribuída durante todo o ano, sendo superior à do Brasil, bem como a temperatura média. No entanto, a radiação incidente foi menor quando comparado ao Brasil, porém o suficiente para assegurar altas produtividades. A Yw média foi de 11,3 e 7,4 Mg ha^{-1} para o Brasil e ASS, respectivamente. A Ya média do milho na ASS foi de 1,4 Mg ha^{-1}, enquanto no Brasil a Ya = 5,2 Mg ha^{-1}. A Ya representou aproximadamente 9% de Yw na ASS. A baixa Ya explica a grande lacuna de produtividade (ou *yield-gap*, do inglês, Yg) encontrado na ASS. Com isso, fica evidente que as tecnologias de manejo utilizadas e a forma do cultivo são as grandes responsáveis pela diferença de produtividade entre os países.

Palavras-chave: Yield-gap, Eficiência, Milho, Clima, Manejo

ABSTRACT

The Brazilian case as a beacon to increase crop production in sub-Saharan African

Maize is one of the main crops in the world, being the main source of food in Africa, representing 30% of the total production area and 30% of the calories and proteins consumed. Despite Sub-Saharan Africa's dependence on maize grain, the crop yield is low compared to its potential, with an average yield of approximately 2 Mg ha^{-1}, which represents 27% of water-limited productivity (Yw). In Brazil, the difference in yield is approximately 50% of Yw. Thus, the objective of this study was to carry out a case study, using rainfed maize as a reference, to identify a set of agricultural areas with similar soils and climates in Brazil and Sub-Saharan Africa (SSA) and then compare the response agronomy between the two producing regions. For this, we identified the similarity of SSA between Brazil and the SSA countries, looking for both occurrences as regions. The Yw data used for this study were estimated by Hybrid Maize crop model and simulations were performed using the local climate data, soil and practices of both continents, such as sowing data and cultivar cycle. Six SSA countries were selected: Ghana, Uganda, Kenya, Nigeria, Zambia and Ethiopia. Actual yields (Ya) were determined by including yields of at least 3 years and were taken from the official databases of the National Statistical Institutes of each country. Climatic data from SSA showed that rainfall and temperature was well distributed at the time, as well as in Brazil. However, the incident radiation was lower than in Brazil, but enough to ensure high Yw. Yw averaged 11.3 and 7.4 Mg ha^{-1} for Brazil and SSA, respectively. The Ya of maize in SSA was 1.4 Mg ha^{-1}, while in Brazil the Ya was 5.2 Mg ha^{-1}. Ya represented approximately 9% of Yw in SSA. Low Ya explained the large yield gap (Yg) found in SSA. With this, it is evident that the management technologies used and the way of cultivation are largely responsible for the difference in yield between countries.

Keywords: Yield-gap, Efficiency, Maize, Climate, Management

1. INTRODUCTION

Maize is produced on nearly 100 million hectares in developing countries, with 70% of total maize production coming from low- and middle-income countries (FAO, 2010). It is believed that by 2025 maize will become the crop with the highest global production and, by 2050, the demand for maize will double in developing countries (Rosegrant et al., 2008).

The population increase, economic development and urbanization will result in a fast rise of per capita consumption of grains and livestock products in the world, and such increase will be more pronounced in developing countries, where more than 95% of the population growth will occur (Rosegrant et al., 2001). Average crop yields need to increase substantially during the next decades to meet such expected food demand while avoiding massive crop area expansion (Cassman et al., 2003). Yet, producing adequate food to meet global demand by 2050 is widely recognized as a major challenge. Increased price volatility of major food crops and an abrupt surge in land area devoted to crop production, since approximately 2002, reflect the powerful forces underpinning this challenge (van Ittersum et al., 2016).

Maize is one of the world's three major crops, along with rice and wheat. The major maize-producing countries in 2016 were led by the USA, China and Brazil (FAOSTAT, 2018). In the period between 2006-2016, world maize production increased c.a. 350 Mtons and more than 30% of such amount came from tropical environments, and Brazil alone explained 20% of such production increase (FAOSTAT,2018).

Yield potential assumes unconstrained crop growth and perfect management that avoids limitations from nutrient deficiencies and water stress, and reductions from weeds, pests, and diseases (Evans & Fisher, 1999; Van Ittersum & Rabbinge, 1997). Yield potential is therefore location-specific and depends on solar radiation, temperature, and water supply during the crop growing season and can be calculated for both rainfed (water-limited yield potential) and irrigated conditions. The difference between the yield potential and actual farm yield is called the yield gap (Van Ittersun et al., 2013). The yield gap can be divided into three components (Tran, 2004). The first component is the difference between potential yield and experimental station yields for which scientists breed varieties. The second component of yield differences is the difference between experimental station yields and potential farm yield (Tittonell et al., 2008). The third component is the difference between potential farm income and actual farm income (Subedi and Ma, 2009), which is mainly caused by differences in land management practices and input use (Tran, 2004). This type of yield gap can be reduced by increasing research and extension efforts in crop management or by appropriate institutional and policy interventions that improve access to inputs (Tran, 2004).

In Brazil, the yield gap is around 50% of yield potential (Yw) (Marin et al, 2022). Still, most tropical environments around the world are producing well below their potential, especially those located in Sub-Saharan Africa (SSA, van Ittersum et al., 2013). Maize is the principal staple crop in SSA, accounting for 30 % of the total area under cereal production in the region and for over 30 % of the total calories and protein consumed (Cairns et al., 2013). Van Ittersum et al. (2016) showed that actual rainfed maize yields range from 1.2 to 2.2 t/ha, which represents only 15–27% of the water-limited yield potential.

Many factors can lead to such stagnation in maize production in SSA, as the soils on which smallholders are dependent have been subjected to erosion, loss of organic matter and therefore low crop productivity (Sanchez, 2002, Stocking, 2006). While mineral fertilizers may partially overcome the problem, rapid increases in world fertilizer prices have severely limited farmers' access to this input (Hargrove, 2008). Furthermore, opportunities for expansion of cultivated land are limited, as rapid population growth has led to the progressive encroachment of marginal lands (Bojo, 1996), even against technical advice (Mubiru and Coyne, 2009). Therefore, the improvement in maize production are highly dependent of gains in productivity through technological innovations that might reduce the yield gap.

Literature has been suggesting it will be challenging for SSA to feed itself, and projected the increase of cereal imports in the coming decades (van Ittersum et al., 2016; Pradhahn et al. 2015; Sulser et al., 2015). Closing the yield gap would reduce the dependence on cereal imports and avoid a vast expansion of rainfed cropland area, especially because population in SSA is projected to further increase between 2050 and 2100 by a factor 1.9 (Van Ittersun et al., 2016). East Africa is not only highly heterogeneous spatially, but is characterized by a rapidly-expanding human population, increasing urbanization, and changing socio-economic circumstances and expectations, which would create a highly dynamic situation, with potential economic growth opportunities as well as potential increases in vulnerability for sectors of the population (Thornton et al., 2010). With fairly similar weather and soil conditions than SSA, Brazil has significantly closed the Yg in the past 40 years. Moreover, Brazil's influence in agricultural development in Africa has become noticeable in recent years (Shankland & Gonçalves, 2016). Soil and climate similarities among countries can foster agricultural technology transfer (Cabral, 2016). Similar work was carried out with wheat crops comparing Yw in North America, Africa and Western European countries. Non-water factors (i.e. management deficiencies, biotic and abiotic stresses and their interactions) were found to restrict yield more than water supply. These findings highlight the opportunity to produce more food with the same amount of water, provided that limiting factors other than water supply can be identified and alleviated with better management practices. (Edreira et al., 2018). We then argue here that Brazil can be used as a benchmark to rationalize the use of resources and get advantage from the learning of Brazil by expanding its agricultural production over the last 40 years by increasing the crop yield aside from the land expansion.

2. CONCLUSIONS

- Eleven climatic zones were found that occur in Africa and Brazil, of which only four presented Yg lower than the uncertainty of the model;
- Yw average was 11.3 and 7.4 Mg ha^{-1} for Brazil and SSA, respectively;
- Solar radiation was lower in SSA when compared to Brazil, but enough to produce as much as Brazil;
- The SSA minimum and maximum rainfall and air temperature were higher when compared to data from Brazil for the same period.
- The production areas of SSA are generally in the hands of small producers, who do not have low income for investment in technologies, which leads to higher Yg;
- The lack of investment in management and technology can be the main factors increasing the Ya of the SSA areas.

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