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On-farm data for assessing soybean yield-gap and its causes in Mato Grosso, Brazil

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Dissertation presented to obtain the degree of Master in Science. Area: Agricultural Systems Engineering

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1. Manejo da cultura 2. Atraso no plantio 3. Atraso na colheita 4. Banco de dados de campo 5. Características da área 6. Insumos aplicados 7. Fatores redutores de rendimento I. Título

RESUMO

Dados de cultivo comercial para avaliação da lacuna de produtividade de soja e suas causas no Mato Grosso, Brasil

Reduzir a lacuna de produtividade agrícola é importante para atender às demandas de uma população em crescimento e mudanças nas preferências alimentares, que sinalizam para um aumento expressivo no consumo de proteína per capita. A soja ocupa uma posição de destaque entre as opções proteicas neste contexto. Apesar de sua importância na produção de soja, existem poucos estudos publicados que descrevem os sistemas de manejo adotados e elucidam a lacuna de produtividade no Brasil, especialmente na região do Mato Grosso, a principal área produtora de soja do país. Neste estudo, utilizou-se um banco de dados de campos comerciais composto por informações de 108 áreas de cultivo de soja ao longo de duas safras (2020/2021 e 2021/2022). Esse conjunto de dados consiste em informações específicas de cada área, incluindo características do campo, práticas de manejo da cultura, insumos aplicados e incidência de fatores redutores de produtividade. O objetivo do estudo foi quantificar a lacuna de produtividade da soja na região do Mato Grosso e identificar as principais práticas de manejo adotadas que interferem sobre ela, com o intuito de descrever as causas determnantes subjacentes dessa lacuna. Os resultados revelaram uma alta taxa de adoção do sistema de plantio direto, variando de 60% a 100% em diferentes regiões. Além disso, observou-se o amplo uso de pesticidas e fertilizantes químicos. Deficiências nutricionais foram relatadas em 0% a 60% das áreas analisadas, enquanto atrasos no plantio e na colheita foram relatados por 20% a 83% dos agricultores nas diferentes regiões. Ainda, os resultados demonstraram relação estatisticamente significativa na lacuna de produtividade de aproximadamente numa proporção de 18,5 $kg.ha^{-1}$ por dia de atraso na semeadura. Fatores como aplicação de fungicidas, níveis de nutrientes do solo, deficiências nutricionais e encharcamento também foram identificados como contribuintes significativos para a lacuna de produtividade da soja.

Palavras-chave: Manejo da cultura, Atraso no plantio, Atraso na colheita, Banco de dados de campo, Características da área, Insumos aplicados, Fatores redutores de rendimento

ABSTRACT

On-farm data for assessing soybean yield-gap and its causes in Mato Grosso, Brazil

Closing the agricultural yield gap is important to meet the demands of a growing population and changing dietary preferences, which are increasingly focused on higher protein intake per capita. Among the key crops essential for addressing this challenge, soybean holds a prominent position. Despite its significance in soybean production, there remains few published studies that describe the adopted crop management systems and elucidate the yield gap in Brazil, particularly in the Mato Grosso region, the country's major soybean-producing area, where a substantial yield gap of up to 50% is observed. In this study, we utilized an on-farm database comprising data from 108 soybean fields over two crop seasons (2020/2021 and 2021/2022). This dataset consisted of field-specific information on various factors, including field traits, crop management practices, applied inputs, and the incidence of yield-reducing factors. Our objective was to gain insights into the crop management practices employed and to quantify the soybean yield gap in the Mato Grosso region, with the aim of identifying the underlying causes behind such gaps. Our findings revealed a high adoption rate of the no-tillage system, ranging from 60% to 100% across different regions. Additionally, we observed extensive utilization of pesticides and chemical fertilizers. Nutritional deficiencies were reported in 0% to 60% of the surveyed plots, while sowing and harvest delays were reported by 20% to 83% of farmers. Markedly, our results demonstrated a statistically significant increase in the yield gap of 18,5 $kg.ha^{-1}$ per day of sowing delay. Yet, factors such as fungicide application, soil nutrient levels, nutritional deficiencies, and waterlogging were also identified as significant contributors to the soybean yield gap.

Keywords: Crop management, Sowing delay, Harvest delay, On-farm database, Field traits, Applied inputs, Yield-reducing factors

1. INTRODUCTION

As the global population continues to grow and per capita income and food demand increase, there is a growing need to increase food production to meet the rapidly expanding population (MARIN et al., 2022). At the same time, diet patterns are changing, with an increasing demand for animal protein and high-value crops such as nuts, fruits, and vegetables (FAO, 2012). These trends represent a challenge for food production, including the need to increase efficiency and productivity in agriculture.

Soybean is widely cultivated in many parts of the world, with the United States, Brazil, and Argentina being the top producers; it is versatile and a valuable commodity for both human consumption and animal feed, contributing to food security as an important source of protein for both humans and livestock (SILVA et al., 2021). Yet, soybean is a major export commodity for many countries, supporting millions of jobs around the world. By improving soybean production and increasing its yields, we can not only improve food security but also contribute to economic stability and growth in communities around the world (SILVA et al., 2023).

Yield potential (Yp) is defined as the maximum yield of an adapted crop determined only by solar radiation, temperature, atmospheric carbon dioxide (CO2) concentration, and genetic traits. In the case of rainfed crops, water-limited yield potential (Yw) represents the yield ceiling and the rainfall amount and distribution during the crop growing season (Evans, 1993). Actual yield (Ya) is the average yield obtained by producers within a defined geographic region. Therefore, for rainfed cropping systems, the yield gap (Yg) is defined as the difference between Yw and Ya, and the size of Yg ultimately determines the additional production capacity that is possible on existing production areas for a given crop and region (MARIN et al, 2016).

Although the yield increase observed in Brazil in the last decades, the soybean yield gap in Brazil is still relatively high according to Global Yield Gap Atlas (GYGA, www.yieldgap.org) data. In Mato Grosso, the main soybean producer of Brazil, with an estimated production area of 10.8 million hectares in 2023, representing around 27% percent of the Brazilian soybean production total area, with average yield of 3.5 $Mg.ha^{-1}$ and almost 39 million tons of soybean produced (CONAB, 2022), historical yield gap of rainfed soybean is around 50% of Yw, meaning that production could potentially double if production gaps would be assessed. These numbers evidence the opportunity to increase Brazilian production without deforestation by adopting better crop management practices (MARIN et al., 2022).

Identifying yield-limiting and yield-reducing factors in crop management is a key information to reduce yield gaps. A common approach is the application of different input levels or crop management practices in experimental plots implemented in on-farm trials of multiple producer fields. In such experiments, null treatment corresponds to the one matching producer field management, and the difference between the various applied treatments can be considered as a replicated estimate of the Yg related to the varied factor. A different approach is to use self-reported data from commercial producers, that with the help of well-known statistical tools can reliably be used to estimate the causes of yield difference between various management practices (GRASSINI, 2015).

Understanding and measuring the causes of soybean yield gap variation amongst fields has been in the interest of research for a long time. Self-reported data from soybean producers has been used to identify causes of yield and yield gap variation for only a few published studies. Villamil et al. (2012), using data from 131 paired soybean plots in Illinois (central US Corn Belt), found that 54% of yield variation was explainable by a multiple-regression model including soil chemicals parameters and management practices. In this study, the main factors explaining the observed variation were sowing date, tillage, interrow space, fungicide application, soil phosphorus (P), and pH.

Grassini (2015), using on-farm database collected during three crop seasons of both irrigated and rainfed soybean fields in Nebraska (USA), identified sowing date as the key crop management factor in determining yield potential for a specific site, although other practices such as tillage method, P and N fertilization and in-season fungicide application were also associated with yield variation. Calviño and Sadras (1999) found strong associations between soybean yields and sowing date, depth of the caliche layer, and P fertilization. Di Mauro (2018) used a farmer's compiled survey from Central Argentina with approximately 22,500 field observations from 2003 to 2015 to assess how environment and management affected Yg variability. In this study, it was found that management practices accounted for 66 to 91% of Yg, being the sowing date was the most critical variable.

In Brazil, Sentelhas (2015) determined the Yg for 15 locations in Brazil, finding soybean Yg around 42%, 29% explained by water deficit and 13% by crop management practices. Tagliapietra (2021) used actual yield data collected from the Brazilian Statistic and Geography Institute (IBGE, 2021) and simulated potential and water-limited yield for quantifying the Yg in Southern Brazil to estimate the influence of sowing date and maturity group on soybean Yg in the subtropics of Brazil, finding out that the sowing date as the main crop management factor explaining Yg. In this study, crop management explained from 9% to 39% of Yg variability. In a study conducted over four crop seasons in the southernmost region of Brazil, concluding that the crop yield increase relies on improvements in management practices (46%), crop genotype (42%), and weather conditions (12%).

Accordingly, the current available literature on soybean Yg indicates the importance of crop management to reduce Yg. Nevertheless, no study has ever been conducted in Brazil assessing crop management practices to understand how soybean crops are conducted and to explore what are the most critical practices impacting soybean Yg in the main producing region of the country, which is the State of Mato Grosso. More importantly, to our knowledge, there is no published study using on-farm data showing how much is the average Yg in the region and what are the main causes of soybean Yg.

In this study, we used an on-farm database from soybean fields composed of field-specific data on environment traits, crop management, to better quantify Yg in the Mato Grosso region, and to identify the underpinning causes of such gaps. The objective of our study was (a) provide a description of current soybean management practices in the State of Mato Grosso-Brazil, (b) to estimate current field-specific yield potential and Yg, and (c) identify major agronomic factors that potentially explain observed Yg, thus providing a recommendation framework of crop management based on on-farm validated practices that unlock higher yields.

2. CONCLUSIONS

Based on a sample of 108 commercial fields in the state of Mato Grosso, Brazil, we quantify that the average Yw was 5,651 kg.ha^{-1} between the two crop seasons analyzed. The average value of Ya was 3,705 kg.ha^{-1} and the yield-gap was 1,953 kg.ha^{-1}, which represents ca. 35% Yw. Mean yield for LYG fields was 4,200 and 4,100 kg.ha^{-1} for the first and second crop season, respectively, while 3,700 and 3,400 kg.ha^{-1} for HYG fields. Estimated yield gap as a function of sowing delay ranged from 970 to 3,000 kg, with a mean penalty of 18,5 kg per day of delay. Mostly, producers in Mato Grosso use the technique of the no-tillage system, with extensive use of seed treatment and in-season pesticides applications, and chemical fertilizers. Sowing date is a major yield-gap cause in the region with a sharp drop in productivity, around 16 kg for each day of delay in sowing. Fungicide application, nutritional deficiencies, and waterlogging were also identified as significant contributors to the soybean yield gap.

It is imperative to acknowledge the potential bias in the methodology employed in this study, given that the data relies on self-reported information from commercial soybean producers. This introduces the possibility that producers may be hesitant to disclose certain sensitive details, such as phytosanitary management practices.

Finally, economic feasibility of closing the productivity gap to attain maximum potential yield underscores the importance of a balanced approach for producers. It is essential to recognize that economic equilibrium may not necessarily align with the level of potential productivity. While this specific economic analysis was not undertaken in this study, the findings provide valuable insights that can serve as inputs for future research endeavors. For instance, the observed correlation between a delay in planting and a subsequent reduction in yield by 18.5 kg per day can be utilized to evaluate the additional costs associated with optimizing machinery deployment to minimize planting intervals against the estimated monetary gain from narrowing the productivity gap.

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