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Yield gaps and their determinates for wheat production in irrigated drylands for Egypt

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1. Introduction

In Egypt, wheat (*Triticum aestivum*) plays a pivotal role in the country's agricultural and economic landscape. It is the major component of the national diet and an essential contributor to food security. Its cultivation in the country has a rich history dating back to ancient times. The Nile Delta has always been an ideal location for wheat cultivation. Historically, Egypt was known as the "Breadbasket of the Roman Empire", highlighting its crucial role in sustaining its population and neighbouring regions. In the country, compared to all crops, it is grown in the largest area (1.33 million ha) and the country produces 9.1 million tons of wheat (average productivity of 6.81 t ha^{-1}) (Source: Economic Affairs Sector, Ministry of Agriculture and Land Reclamation, 2023). Compared to all crops, its cultivation area is increasing in the country. However, it is meeting 50% of the demand from the international market to fill the gap between production and consumption (5.86 million t, one of the top 10th largest importers), where the import value of wheat and wheat products was 2.49 billion USD in 2021 (FAOSTAT, 2023).

In recent years (2018-2021), Egypt has shown prominence in reducing imports, where it imported 9.53 million tons wheat in 2021/2022 while it decreased by 17.5% (7.86 million tons) in 2022/2023 (Source: Agriculture Economic Research Institute (AERC). However, to reduce imports sustainably, the country might need to adopt both approaches, i.e., area expansion in New Land and sustainably closing the yield gap in the Old Lands. Adopting science-led demand-driven and sustainable (economic, environmental, and social) farming practices, including improved crop varieties and efficient agronomic management practices, is the key for the sustainable intensification of wheat production in both new and old lands. By implementing below climate-smart wheat production technology tailored to Egypt›s conditions, farmers can enhance their yields, contribute to the country›s demand, and support its agricultural growth.

2. Methodology

2.1 Farmers production practice survey

To understand the existing production practice, attainable yield gaps and major factors determining those yield gaps in wheat cultivation in irrigated dryland system in Egypt, ICARDA has implemented production practice survey in major wheat growing areas covering both old lands and new lands for 2021/22 wheat growing season.

"Old lands" are the agricultural lands cultivated inside the Nile Valley and the Delta region. It is characterized by clay or silty clay soils, high intensified agriculture system (can be cultivated with 2 or three crops per year), smaller farm holding. "New lands" are the agricultural lands reclaimed and cultivated outside the Nile Valley and the Delta region. It is characterized by sandy soils and more frequent salinity problems, a lower intensified agriculture system compared to old lands, more interest in horticulture and high cash crops, and land holding is medium to larger size**.**

Figure 1. Major wheat growing areas and sampling location in Egypt

2.2 Yield gap computation

The attainable yield gap was derived based on farmers reported yield from the production practice survey implemented in irrigated drylands in Egypt during 2021 crop growing season. Based on the grain yield, farmers were classified into three categories: top (mean of top 10%), middle (mean of middle 80%), and bottom (mean of bottom 10%). The attainable yield gaps (YG) computed as the difference between the average gain yield of the top 10% of the yield distribution (attainable yield) and the population mean yield.

2.3 Yield gap decomposition

To under the major factors determining the yield variation, the Random Forest (RF) which is a binary tree-based machine-learning method (Breiman, 2001; Cutler et al., 2012) was applied to field-level data on crop management practices, soil, and weather information, which is augmented with household level data on selected socio-economic variables to analyze the major determinants of variations in yield under farmers' management practices for major wheat areas in Egypt. We used the 'randomForest' package of the statistical program R (R CoreTeam, 2016) and followed Liaw and Wiener (2002) to set the values of parameters for estimation of the model (mtry = 5, ntree = 1000, and nodesize = 10). Two variable analysis tools available from the package were used for analyzing the importance of variables (Breiman, 2001). First, mean decrease accuracy the percentage increase in mean square error (%IncMSE) was used as a measure of variable importance. The %IncMSE plot shows the average increase of MSE in nodes that use a predictor in the model when values of the predictor are randomly permuted. To assess the performance of the model, we used R^2, root mean square error (RMSE), and slope which we also visualized by making an observed vs. predicted plot.

3. Results and Discussion

3.1 Yield gaps existed in Newlands and old lands in irrigated drylands of Egypt

In the old lands, the average wheat yield stands at 6.46 t ha^{-1} while the average yield for the top (10th) decile was 8.5 t ha^{-1} and the mean yield for the rest of the farmers was 6.2 t ha^{-1} with large variation in yield ranging from 3.6 to 8.5 t ha^{-1} and attainable yield gap of 2.3 t ha^{-1}. Similarly, in new lands, the mean yield of the top performing farmers is 7.42 t ha^{-1} while the mean yield of middle 80% farmers was 4.61 t ha^{-1} showing an attainable yield gap of 3.23 t ha^{-1}. The attainable yield gaps were greater in new lands than in old lands.
(Figure 2).

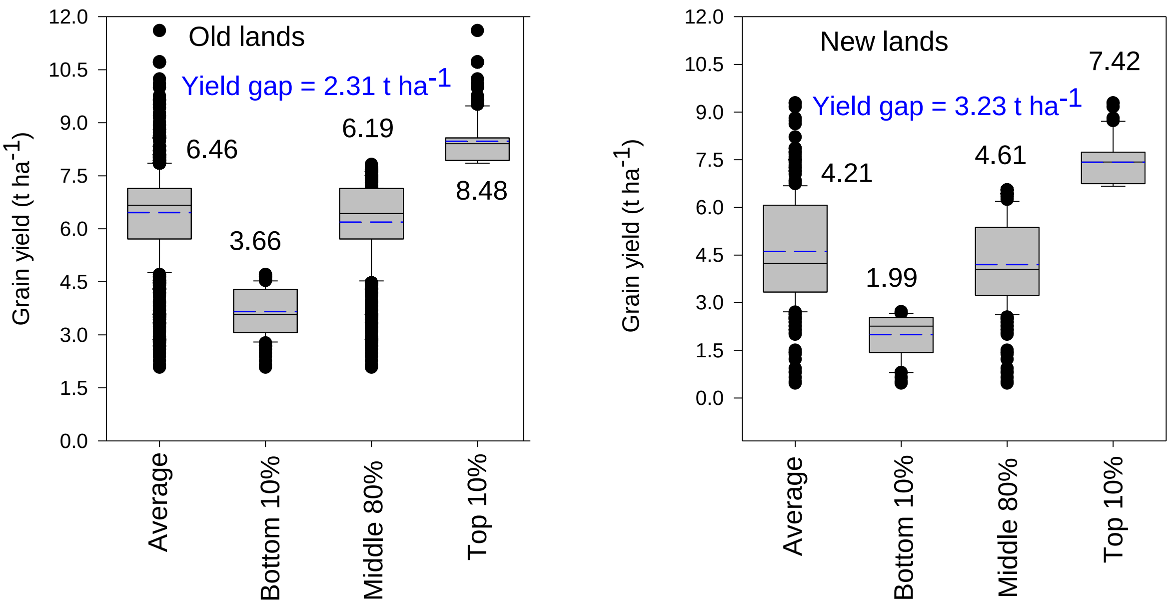

Figure. 2. Variation in attainable wheat yield and yield gaps (t ha^{-1}) in old and new land areas of dryland irrigated wheat production in Egypt from the farmers reported largest plot yield data from famers field survey. Black solid line inside the box the median and the blue dotted line are the mean.

3.2 Major determinates of yield gaps

3.2.1 Overall (combining both new lands and old lands)

Applying Random Forest with twenty-two different predictor variables derived from farmers field surveys with 2042 wheat growing farmers (combined over new land and old lands) the model explained 59% of yield variation (Figure 3). Production environment observed as the most important factor explaining yield variation, followed by the soil type, geographic location, potassium fertilizer rates, total production cost, nitrogen application rates and number of irrigations in a sequence of their importance (Figure 4). As production environment was the major determining factor, hence we have run the Random Forest model in two different production environments, old lands and new lands separately.

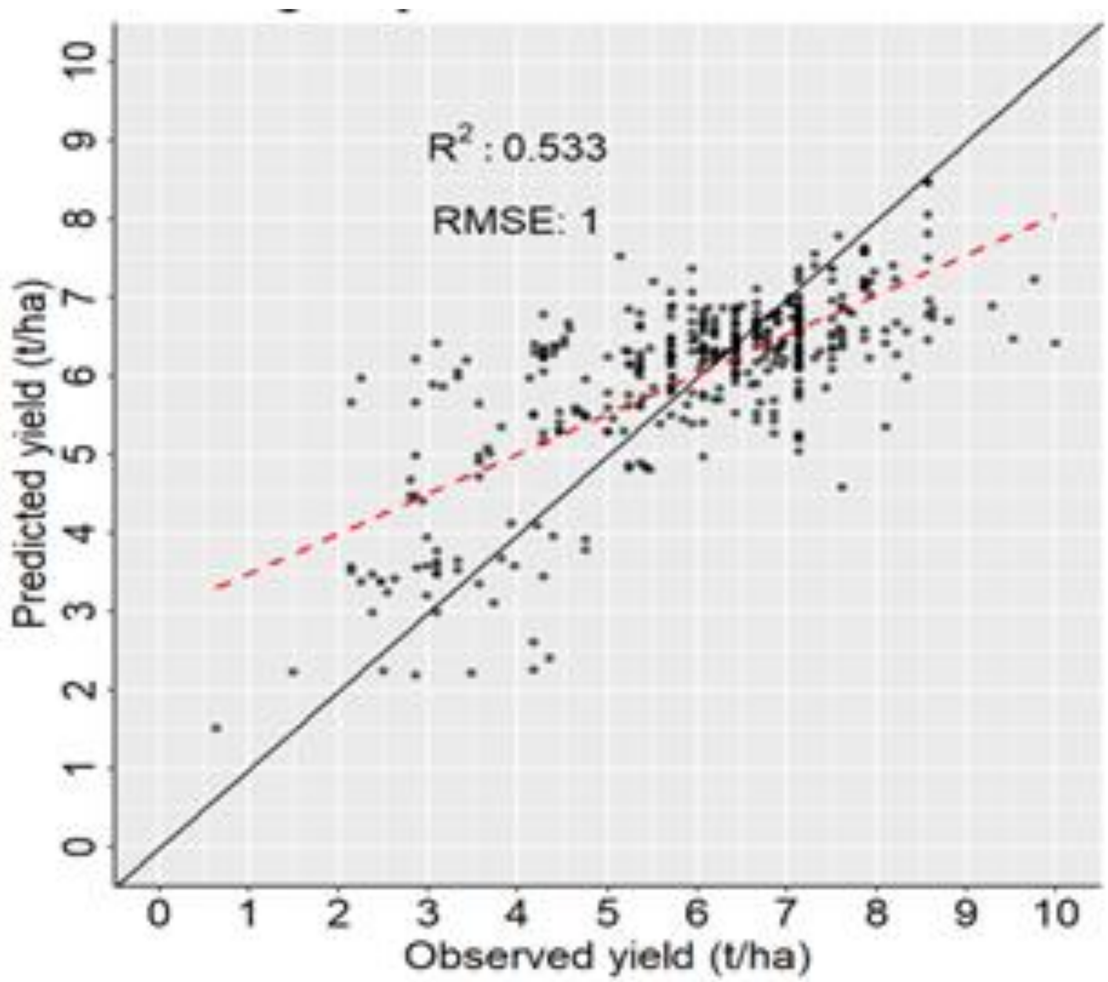

Figure: 3. Performance test for the Random Forests model for grain yield. Black dots are the observed data, red dotted line represents the Ordinary Least Square (OLS) regression of the RF predictions on the observed for which RMSE is also reported.

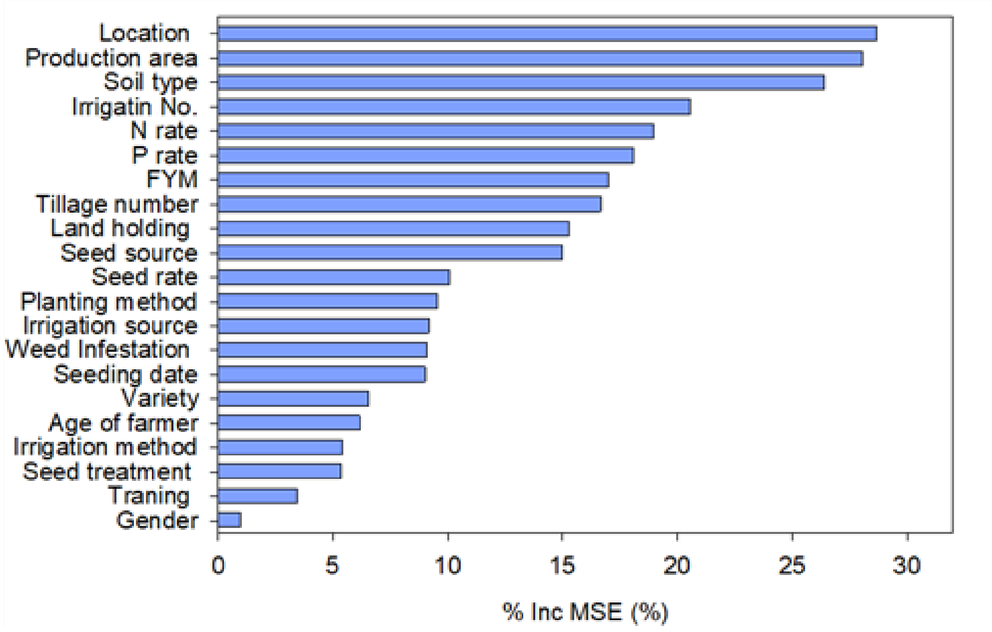

Figure: 4. Importance of different variables in explaining variation in wheat yield results from the random forest (RF) models combined over new lands and old lands.

3.2.2 Major determinants for variation in grain yield in old lands and Newlands in irrigated drylands, Egypt

By applying the RF model to twenty different factors for yield gap, model results showed that there are differences in the relative importance of the variables in explaining yield in old lands and Newlands production environment (Figure. 5).

Old lands: In old lands, nitrogen application rate was the most important factor for explaining variation in wheat yield, followed by application rate of FYM and phosphorus, land holding size, soil type, governorate, source of the seed used, weed infestation, seeding method, number of tillage passage before seeding and variety used, seed treatment (i.e., whether seed was treated or not), irrigation source and number of irrigation applied in the order of their importance (Figure 5).

New lands: Similarly, in the Newlands location, phosphorus application rate, source of irrigation water used were the most influential variables for explaining variation in wheat yield followed by number of tillage pass before seeding, Soil type, land holding size, number of irrigation applied, nitrogen application rate, seed rate used, FYM application rate, severity of weed infestation, seeding date, seeding method and variety in order of their importance (Figure 5)

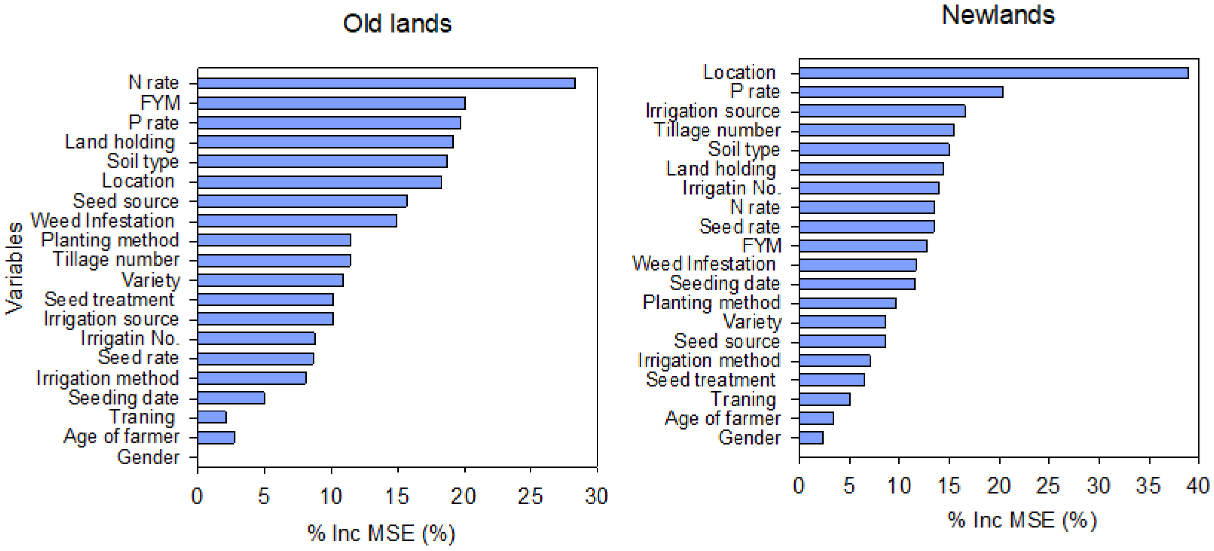

Figure 5. Importance of different variables in explaining variation in wheat yield results from the random forest (RF) models in irrigated wheat production in new lands and old lands.

3.2.3 Variables of importance for grain yield in different government in oldlands

Major factor determining variation in yield varied with different governate.

i. ***Asyout Governorate***: In Asyout, irrigation method was the most important factor for explaining variation in wheat yield, followed by planting method, N rate applied, amount of FYM applied, amount of phosphorus applied, and source of irrigation applied in the order of their importance (Figure 6).

ii. ***ElManiya Governorate:*** In ElManiya, phosphorus and N application rate were the most important factors for explaining variation in yield followed by planting methods, land holding size, No. of irrigation applied, and FYM application rate in the order of their importance (Figure 6).

iii. ***Fayoum Governorate:*** Similarly, in Fayoum, type of soil remained the most important factor explaining variation in yield followed by amount of seed rate used, weed infestation, P application rate, land holding size and type of variety in the order of their importance.

iv. ***Karl El Sheikh Governate:*** In Karl El Sheikh, phosphorus and nitrogen application rates were the major factor determining yield variation followed by number of tillage pass before seeing, land holding size, FYM application rate, number of irrigation applied and source of irrigation in the order of their importance (Figure 6).

v. **Bensuief *Governorate***: In Bensuief, FYM application, seed treatment remained the major factor determining variation in yield followed by irrigation number, variety used, N rate applied, soil type, weed infestation, land holding size and P application rate in the order of their importance (Figure 6).

vi. Menofia Governorate: In Menofia, land holding size remained major factor determining variation in wheat yield followed by nitrogen fertilizer application rate, FYM application rate, variety used and phosphorus application rate in the order of their importance (Figure 6).

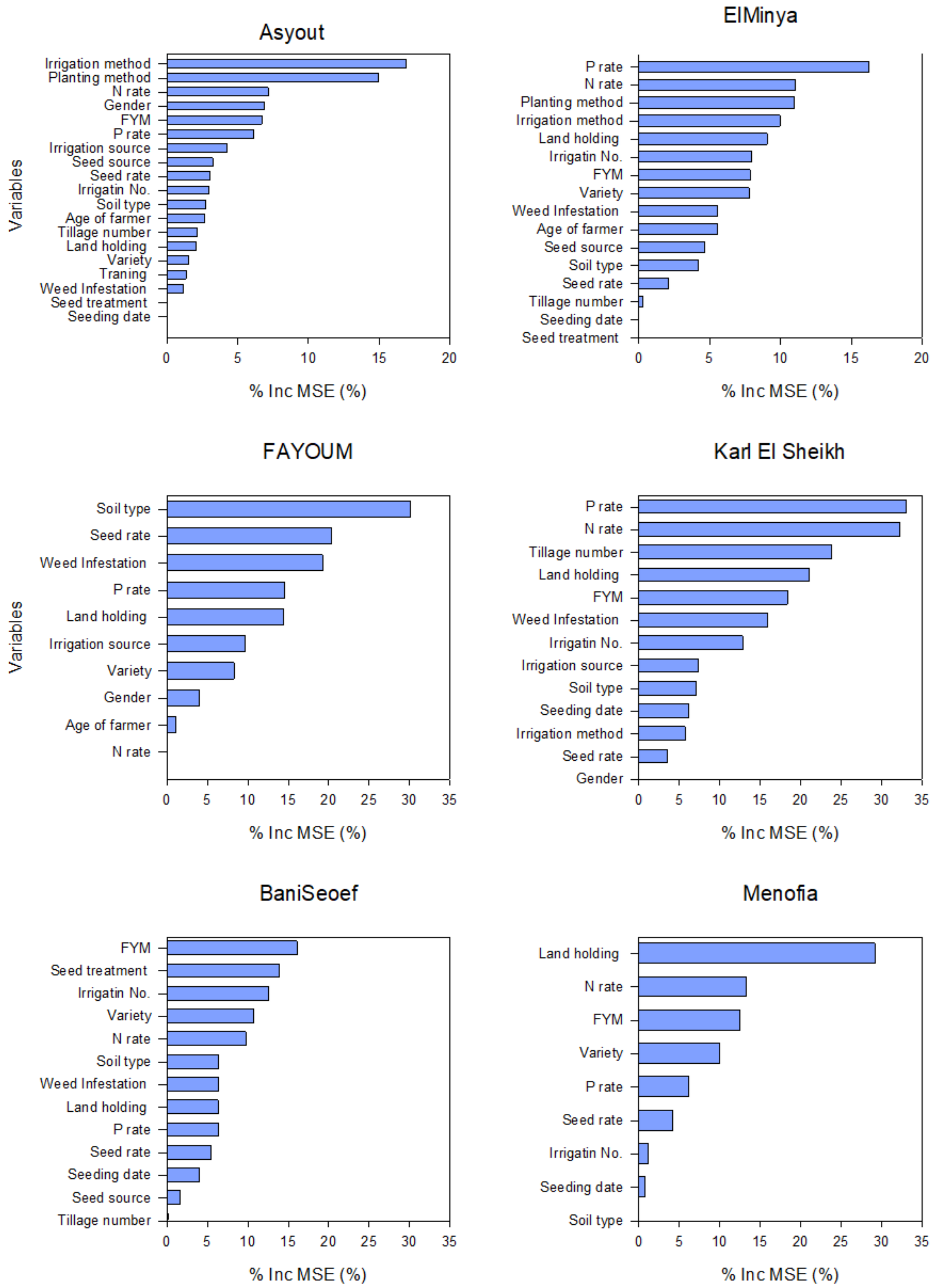

Figure 6: Importance of different variables in explaining variation in wheat yield results from the random forest (RF) models in six major wheat growing governorates in irrigated drylans in Egypt.

4. Summary

This study analyzed data from 2,042 wheat fields across the major wheat-growing governorates of Egypt, which collectively account for more than 90% of the country's total wheat production. The report synthesizes yield variations and attainable yield gaps in both old lands and Newlands in Egypt and uses a random forests (RF) model to identify the main determinants of these gaps. The findings reveal significant yield gaps of 31% in old lands and 43% in Newlands. In old lands, the most critical factor influencing yield variation was the nitrogen application rate, followed by the application rates of FYM (farmyard manure) and phosphorus, landholding size, soil type, and wheat variety used. In Newlands, the most influential variables were phosphorus application rate, source of irrigation water, number of tillage passes, nitrogen application rate, and seeding method. The variation in yield-determining factors across different governorates suggests that developing and implementing context-specific agronomic solutions can sustainably reduce attainable yield gaps, thereby increasing overall wheat production to meet growing demand in the country.

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