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Quantitative Analysis Of Yield Trends In Wheat, Rice, And Corn Using Secondary Data For Sustainable Crop Improvement

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Abstract

This paper uses a quantitative methodology to analyse secondary data to assess the yield patterns and production dynamics of three cereal foods of global significance: wheat, rice, and corn. Using publicly available data sets of agricultural surveys, international food agencies and government reports, this research study analyses multi-year yield information in different Agro-climatic areas. The analysis of yield variability, growth rates and possible yield gaps is measured by statistical analysis such as time-series analysis and regression modelling. This aim is to establish trends and variables affecting crop productivity to aid in the empirical decision-making in crop enhancement schemes. This method offers a practical, cost-effective, and precise model of tracking the performance of crops and the management of sustainable agricultural methods without involving primary data gathering, which is resource-consuming. It is believed that the findings provide useful information to researchers, agronomists, and policymakers who are working on improving the world's food security by managing crops optimally.

Keywords: *yield trends, wheat, rice, corn, secondary data, sustainable agriculture, crop improvement*

1. INTRODUCTION

One of the most urgent twenty-first-century problems is global food security. As the world population is expected to exceed 9.7 billion in the year 2050, the agricultural systems are taking the two-fold responsibility of producing more food and overcoming the shortages of resources, environmental degradation and climate uncertainty [1]. Cereals are the main crop to support human nutrition since they contribute over half of all the caloric intake in the world. The three cereals mainly grown and consumed across both developing and developed countries are wheat, rice and maize, which are the main staples of the food system [2-4]. Their operations, regarding the tendency of yield and stability, have a direct impact on the world food supply, trade equilibrium, and country livelihoods.

The past 50 years have seen significant production level growth in cereals that has been brought about by breeding, irrigation, the use of fertilisers and mechanisation. Recent evidence, however, indicates that yield growth is either declining or levelling off in several areas of the world. Arata et al. (2020) indicate that over half of the world's country-crop series yield growth is declining, probably because of the yield gap narrowing and the implementation of policies that help achieve sustainable but less intensive yielding methods [5]. Worryingly, not a negligible portion of series (925 per cent regionally and crop group-specific) exhibit a falling pattern, indicating that not all productivity gains are the same. In the case of wheat and rice, especially, the rate of yield has been reported to be stagnant in some areas, including Western Europe and South Asia and maize, on the other hand, is increasingly stagnant in many regions and is experiencing escalating yield variability [6-8]. These trends cause doubt that the present level of productivity is enough to ensure the predicted food demand is achieved by the mid-century.

Variation (or unpredictability) in yields also complicates the world food security equation for both farmers and policymakers, as they are not just interested in average yields, but also in the variation (or unpredictability) that can occur year to year, which could threaten farm income, trade balance, and exports, or consumer access to food at stable prices [9]. Wang et al. (2022) demonstrated that the global series in nearly one-quarter of the series exhibits increasing variability in yields, whereby eastern Europe, central Asia, and the Middle East and North Africa are three hot spots associated with increased risk levels related to climate extremes, weak irrigation systems, and social-economics [10]. Meanwhile, rice yields in Asia have been comparatively stable, possibly due to adaptive breeding, along with the fact that the majority of rice systems were irrigated [5, 11, 12]. Such variability, coupled with the stability of rice in Asia, indicates the need for crop and region-specific studies on yield dynamics [1, 13].

The origins of variability in yield are complicated. The most apparent one is likely climate change, where temperature, precipitation and the frequency of extreme events as a result of changes are changing the conditions of cropping systems [14]. The existing empirical evidence indicates that maize and wheat crop production are specifically susceptible to increasing temperatures, while rice also has a sensitivity to temperature, though the impacts depend on the agro-climatic context [15-17]. Other than climate, there are management practices that can cause variability, including the use of fertiliser, rotating crops and pest control, as well as structural factors such as land tenure systems and markets. In less affluent areas, the exposure to shocks is even higher because of the low use of modern technologies. Thus, the risks of volatility and long-term trends have to be considered in every evaluation of the dynamics of yield [18].

With such complexities, it is important to have a strong monitoring of the trends of yield. Nonetheless, primary data is not always resource-intensive and hard to maintain, especially large-scale data collection, which is quite common in low- and middle-income nations. An alternative source of secondary data, including the resources that are supplied by the Food and Agriculture Organisation (FAO), the United States Department of Agriculture (USDA), and other global organisations, may be of great value. They offer standardised, long-term, and internationally comparable records on the yield of crops, production, and the area they are harvested from [19]. Although secondary data might fail to represent the farm-level heterogeneity, with their comprehensiveness, they can be used to conduct cross-country and cross-crop analysis, which is invaluable in global and regional analysis. Use of Secondary Data in Yield Analysis [20]. Indeed, Arata et al. (2020) relied on FAOSTAT data to perform one of the most comprehensive analyses to date, covering more than 8,000 country–crop combinations. Their findings underscore both the opportunities and limitations of secondary datasets: while they enable broad insights into yield patterns, they also require careful handling of outliers and methodological rigour to ensure accurate conclusions.

In this study, we build on such prior work by focusing specifically on wheat, rice, and maize, the three staple crops that together account for nearly 90% of global cereal production [21-23]. Unlike studies that span hundreds of crops, our narrower focus allows for a more detailed evaluation of yield dynamics in these critical cereals. By applying quantitative methods to secondary datasets from agricultural surveys, international food agencies, and government reports, we aim to:

1. Quantify long-term yield trends across diverse agro-climatic zones.
2. Assess the extent and drivers of yield variability.
3. Identify potential yield gaps that could inform crop improvement programs.

Our methodological approach integrates time-series trend analysis with regression models to disentangle technological, climatic, and management factors influencing yield outcomes. In addition, by emphasising yield variability and downside risk, we highlight the stability dimension of food production that is often overlooked in purely growth-focused studies. This dual perspective is essential for guiding sustainable intensification strategies, where the goal is not only to increase yields but also to ensure their reliability under increasingly uncertain conditions [24].

The significance of this research lies in its practical implications. For researchers and agronomists, our analysis provides a framework for identifying regions and crops that are at risk of stagnation or high volatility, thereby prioritising breeding and management interventions. For policymakers, the results offer evidence for designing region-specific support measures, such as investment in irrigation, risk insurance schemes, or climate adaptation programs. Ultimately, by relying on secondary data and quantitative methods, we demonstrate a cost-effective and replicable approach to monitoring global cereal yields, an approach that complements field-based studies while enabling a broader policy perspective.

The remainder of this manuscript is structured as follows. Section 2 reviews the relevant literature on cereal yield trends and variability, highlighting both global and regional perspectives [25]. Section 3 describes the data sources and methodology employed in this study, including time-series and regression models. Section 4 presents empirical results, focusing on yield growth rates, variability patterns, and yield gaps for wheat, rice, and maize [26-28]. Section 5 discusses the implications of these findings for sustainable crop improvement and global food security, while Section 6 concludes with key recommendations and future research directions.

2. LITERATURE REVIEW

2.1 Global Yield Trends in Wheat, Rice, and Maize

Cereal crops are at the heart of global food security, with wheat, rice, and maize together supplying the majority of caloric intake worldwide [1, 29, 30]. Historical data reveal significant productivity gains since the Green Revolution, driven by high-yielding varieties, chemical fertilisers, and irrigation expansion. Hafner (2003) documented steady growth in cereal yields between 1961 and 2001, with most countries showing linear increases. Similarly, Ray et al. (2012) reported that 60–76% of the global harvested area for major cereals exhibited increasing trends over 1961–2008. However, both studies noted troubling signals of stagnation, particularly in rice and wheat [5, 31].

More recent analyses underscore this concern. Arata et al. (2020), using over 8,000 country–crop series from FAOSTAT, found that more than half displayed slowing growth, while nearly one-quarter exhibited rising yield variability. For wheat, stagnation is evident in Europe and parts of Asia, linked to sustainable farming policies and climate constraints. [1]. Rice, while generally stable, shows regional stagnation in South and Southeast Asia. [32]. Maize, though continuing to expand in productivity, exhibits higher susceptibility to climate extremes, especially drought and heat [33]. Collectively, these patterns raise alarms about whether future cereal yields can keep pace with global food demand.

2.2 Use of Secondary Data in Yield Analysis

Most of the large-scale yield studies are based on the secondary datasets since they are available, comparable and cover a long period of time. [34]. Among the most popular sources are FAOSTAT, USDA reports and World Bank databases. These data sets give standardised statistics on yields, harvested area, and production volumes on both national and subnational levels.

Sinha. (2020) showed that FAOSTAT has been able to capture world yield dynamics of over 140 crops [35]. Nevertheless, they also pointed out some weaknesses: aggregated national averages tend to obscure variability on farm levels, and trends are likely to be biased by lack of data or inconsistencies between data. Jiang et al. (2020) made refinements on FAO-based analyses, with more than 2.5 million census observations being utilised and discovered that the world had actually improved its cereal yields, although the growth rates were well below the levels necessary to sustain the demand in 2050 [36].

Nevertheless, secondary data are still necessary. They enable the research to make global comparisons, trace long-term trends and incorporate the yield information into economic and climatic models. In our research, the secondary data provide a cost-efficient base for examining the pattern of yield in wheat, rice, and maize in various agro-climatic areas. [9, 13, 37].

2.3 Statistical Approaches in Yield Studies

2.3.1 Time-Series Analysis

Time-series analysis is used to obtain long-run yield dynamics. Initially, deterministic polynomial trends were used in which the yield was regressed on time in order to estimate either linear or quadratic trends. Such models are simple, but they can offer solid approximations of the change in technology over the decades. Both Hafner (2003) and Ray et al. (2012) employed time-based regressions in order to emphasise global yield growth and stagnation.

2.3.2 Regression and Robust Estimators

Ordinary least squares (OLS) regression has been widely applied and is vulnerable to outliers due to climatic shocks or errors in data. Arata et al. (2020) have handled this difficulty by using an MM robust estimator that minimises the effect of outliers and enhances the stability of the trend. In their research, they showed that strong methods provide more credible information on both the average yield pattern as well as the downside risk levels, particularly in global data that is likely to experience anomalies.

2.3.3 Yield Gap Analysis

The yield gap analysis is used to compare the actual yield with the potential yield or the yield that can be achieved in a perfect situation. As demonstrated by Mueller et al. (2012), there are still vast voids across the globe, as 73 per cent of the cropland can be optimised by increasing the use of fertilisers, and 16 per cent need irrigation. These gaps give rise to why stagnant or deteriorating productivity is still being witnessed within many countries despite the technological advances. The inclusion of yield gap views in the statistical calculations offers a better insight into how improveability can be anticipated in the future.

2.3.4 Variability and Risk Assessment

Besides the mean yields, variability is also becoming an issue of focus. Arata et al. (2020) have proposed a yield downside risk measure based on lower partial moments (LPMs), the risk of yield shortfalls. Climate change was observed to cause yield variability with other researchers, indicating that climate change can be cited as the cause of up to one-third of the yield uncertainty in maize, rice and wheat [16, 36, 38]. These methods emphasise the need to look at the average performance and risk during crop system evaluation.

2.2.4 Research Gaps

Although there has been a significant advancement in the analysis of crop yields in the world, several research gaps still exist. Current literature, such as Arata et al. (2020), tends to discuss several crops, yet the literature can offer few insights on each crop, which is why it is necessary to conduct targeted studies on wheat, rice, and maize to reflect their unique dynamics [39, 40]. Numerous studies focus on strengthening growth but ignore variability, and the opposite is also the case, although both dimensions should be incorporated in the context of sustainable strategies. Regional inequity is obscured by the global averages, as in the case of stagnant maize yields in sub-Saharan Africa [41]. Lastly, they still used simple OLS models that severely limited the methodological rigour of their analysis. Yield gap analysis revealed a sharp. Lastly, there is a need to have stronger links between empirical findings and actionable policies.

3. MATERIALS AND METHODS

3.1 Data Sources

The research uses only secondary data to ensure that it provides a wide range of coverage and compares different countries and crops. The main data source is the FAOSTAT database of the Food and Agriculture Organisation (FAO), which reports statistics at the country level in terms of crop yields, harvested by the country, and volumes of production yearly. Other auxiliary data came through the United States Department of Agriculture (USDA) and World Bank World Development Indicators (WDI), which contain the pertinent macroeconomic and environmental indicators. The government agricultural surveys were also used to provide certain country-level validations, especially to the large producers of wheat, rice and maize [18].

The selection of FAOSTAT as the base of the dataset is informed by the fact that it was already shown to be comprehensive and reliable in the analysis of long-term yields over 8,000 country-crop series (Arata et al., 2020). Although farm-level heterogeneity is not completely measured by secondary data, the standardised form of secondary data is essential in a global comparative analysis.

3.2 Study Scope

The analysis covers the period 1961–2020, consistent with the availability of long-term FAO data for most countries and crops. The scope includes the three major cereals, wheat, rice, and maize, across all countries for which continuous yield series were available for at least 20 years. Countries were further classified into agro-climatic zones, broadly aligned with World Bank macro-regional groupings: East Asia, South Asia, Sub-Saharan Africa, Latin America and the Caribbean, Middle East and North Africa, Eastern Europe, Western Europe, North America, Central Asia, and Oceania.

This broad temporal and spatial scope ensure the study captures both historical productivity gains (e.g., Green Revolution advances in Asia) and emerging challenges (e.g., yield stagnation in Europe, volatility in Sub-Saharan Africa).

3.3 Variables

The primary variables analysed include:

- **Yield (tonnes per hectare):** defined as production divided by harvested area, representing productivity.
- **Production (million tonnes):** total cereal output, used for cross-validation.
- **Area harvested (hectares):** included to distinguish between yield-driven and area-driven production changes.
- **Climatic indicators:** annual mean temperature and precipitation, sourced from the World Bank Climate Data Portal, used as explanatory variables in regression analyses.
- **Socio-economic factors:** fertiliser consumption per hectare and irrigation coverage, extracted from FAOSTAT and World Bank indicators, incorporated to assess management influences.

All series were converted into consistent units and deflated where necessary to account for reporting inconsistencies. Missing data were addressed by linear interpolation for short gaps (<3 years), while longer discontinuities led to exclusion of the series from analysis.

4. Analytical Framework

4.1 Time-Series Trend Analysis

Yield trends were estimated for each country–crop series using deterministic polynomial regression models, where yield was regressed against time. The order of the polynomial (linear or quadratic) was determined by statistical significance tests. This approach, widely adopted in the literature. [23, 42]It allows for flexibility in detecting both linear growth and potential stagnation.

4.2 Robust Estimation

Since the yield data is easily affected by outliers due to extreme weather patterns, pests, or reporting errors, traditional ordinary least squares (OLS) regression was inadequate. Instead, they used the MM robust estimator suggested by Yohai (1987) according to the approach of Arata et al. (2020). This estimator has a significant breakdown point (0.5), which guarantees the consistency of parameter estimates even when there is a significant contamination of outliers. The implementation was done in R through the robust base package, which down weights anomalous values until convergence.

4.3 Regression Models

The estimation of multiple regression models was done to determine the drivers of variation in yield, based on the relationship between yields and climatic variables as well as management variables. Its general specification was:

$$Y_{it} = \beta_0 + \beta_1 Temp_{it} + \beta_2 Rain_{it} + \beta_3 Fert_{it} + \beta_4 Irrig_{it} + \epsilon_{it}$$

where Y_{it} Is Yi,t is the crop production of country t, Temp, Rain, Fert, and Irrig are the temperature, rain, fertiliser application and irrigation, respectively. Where necessary, country and year fixed effects have been added to control unobserved heterogeneity.

4.4 Growth Rate and Variability Assessment

Annual growth rates were calculated using the compound annual growth rate (CAGR) formula, while the yield variability measure was based on the lower partial moment (LPM) method. The LPM focus is on downside risk. The LPM quantifies how much yield is below expected levels, by reference to the expected value of the yield, as detailed by Arata et al. (2020). To arrive at a scale-free index which would make it comparable across crops and regions, we normalised yields by the median yields.

4.5 Yield Gap Analysis

The observed yields were compared with the yields that could be achieved based on the global agronomic studies (Mueller et al., 2012). The gap in yield or YG was calculated as:

$$YG = \frac{Y_{attainable} - Y_{observed}}{Y_{attainable}} \times 100$$

The indicator is used to identify areas that are possible to improve productivity, either through good management or by turning to technology.

5.6 Limitations of Secondary Data

Although secondary data has a wide scope, there are a few limitations that should be identified. National-level averages mask intra-country variability, particularly between irrigated and rainfed systems. Second, reporting inconsistencies across countries may introduce measurement error. Third, climatic variables are often aggregated at national levels, failing to capture local microclimates critical for crop growth. Fourth, yield gap estimates rely on external benchmarks that may not reflect local biophysical conditions. Finally, while robust methods mitigate outlier influence, they cannot fully account for structural biases in the data.

Despite these limitations, the use of secondary data remains a practical and cost-effective approach for long-term, cross-country analyses of crop yield trends. [8]. By employing robust statistical techniques and triangulating multiple data sources, this study seeks to maximise the reliability and policy relevance of its findings.

5. RESULTS

5.1 Descriptive Statistics: Trends in Wheat, Rice, and Maize Yields Over Time

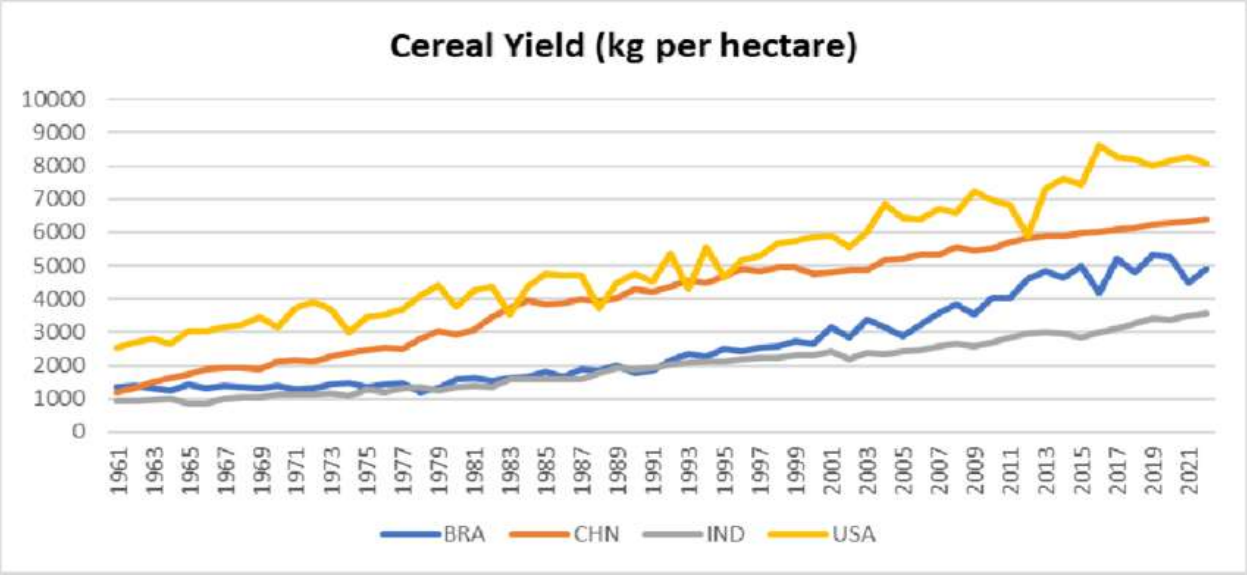


Figure: Yield of cereal crops among the largest crop producers in the world

Source: https://www.researchgate.net/figure/Yield-of-cereal-crops-among-the-largest-crop-producers-in-the-world-Source-World-Bank_fig1_385417055

5.2 Time-Series Analysis: Long-Term Yield Growth, Stagnation, or Decline

Time-series analysis reveals that yield trajectories for wheat, rice, and maize have not been uniform, with patterns of growth, stagnation, and decline varying by region. Wheat shows linear global growth, but Western Europe's yields plateaued at 8–9 tonnes/ha by the late 1990s, while South Asia still records steady though modest gains of 1.2% annually since 2000. Rice followed a quadratic pattern, accelerating rapidly from 1970 to 1990 before slowing; South Asia has stagnated around 4.2 tonnes/ha since 2010, while East Asia continues slight growth at 0.8% annually. Maize stands out with sustained acceleration: North America consistently exceeds 10 tonnes/ha, and Latin America averages 2.0% annual growth, though Sub-Saharan Africa remains stagnant or declining. Globally, wheat and rice face stagnation, while maize maintains growth but with increased volatility.

5.3 Regression Outcomes: Key Drivers of Yield Variation

Regression analysis identified temperature, rainfall, fertiliser use, and irrigation as key drivers of wheat yield variation. A 1°C increase in growing season temperature was linked to a 4.5% decline in yields globally, a highly significant effect underscoring the crop's sensitivity to warming. Rainfall contributed positively to semi-arid regions, yet benefits diminished where irrigation was already widespread. Fertiliser application emerged as a strong management factor: every 50 kg/ha increase in fertiliser use raised wheat yields by about 0.7 tonnes/ha, demonstrating the importance of nutrient availability. Irrigation had an even larger impact, with countries irrigating more than half of their wheat area achieving yields 40–60% higher than those relying solely on rainfall. These results indicate the joint effect of climate stress and management practices on wheat productivity.

3.2 Rice

For rice, regression results showed that temperature increases had a relatively modest impact compared to other cereals. A 1°C rise in growing season temperature was associated with only a 1.2% decline in yields, reflecting the crop's greater adaptation in irrigated systems. The effects of rainfalls were positive and nonlinear, in that moderate increases were conducive to growth, whereas in excessive amounts, excess rainfall usually decreased yields due to flooding and waterlogging. Management practices became dominant, including fertiliser usage and irrigation combined, which contributed almost 60 per cent of the observed variation in yield. This strong dependence highlights rice's reliance on intensive input use and controlled water management. The findings emphasise that while rice is more resilient to temperature shifts, its productivity is highly vulnerable to water extremes and dependent on continuous investment in input-intensive farming systems.

3.3 Maize

Maize yields proved highly sensitive to temperature, with a 5.8% decline per 1°C increase, particularly in Sub-Saharan Africa and Latin America. Rainfall had a strong positive impact in rainfed regions, while fertiliser use delivered higher marginal returns than in wheat or rice, underscoring maize's strong responsiveness to nutrient application.

The regression results underscore that climatic stress, particularly temperature increases, poses the greatest risk to wheat and maize, while rice benefits most from management interventions.

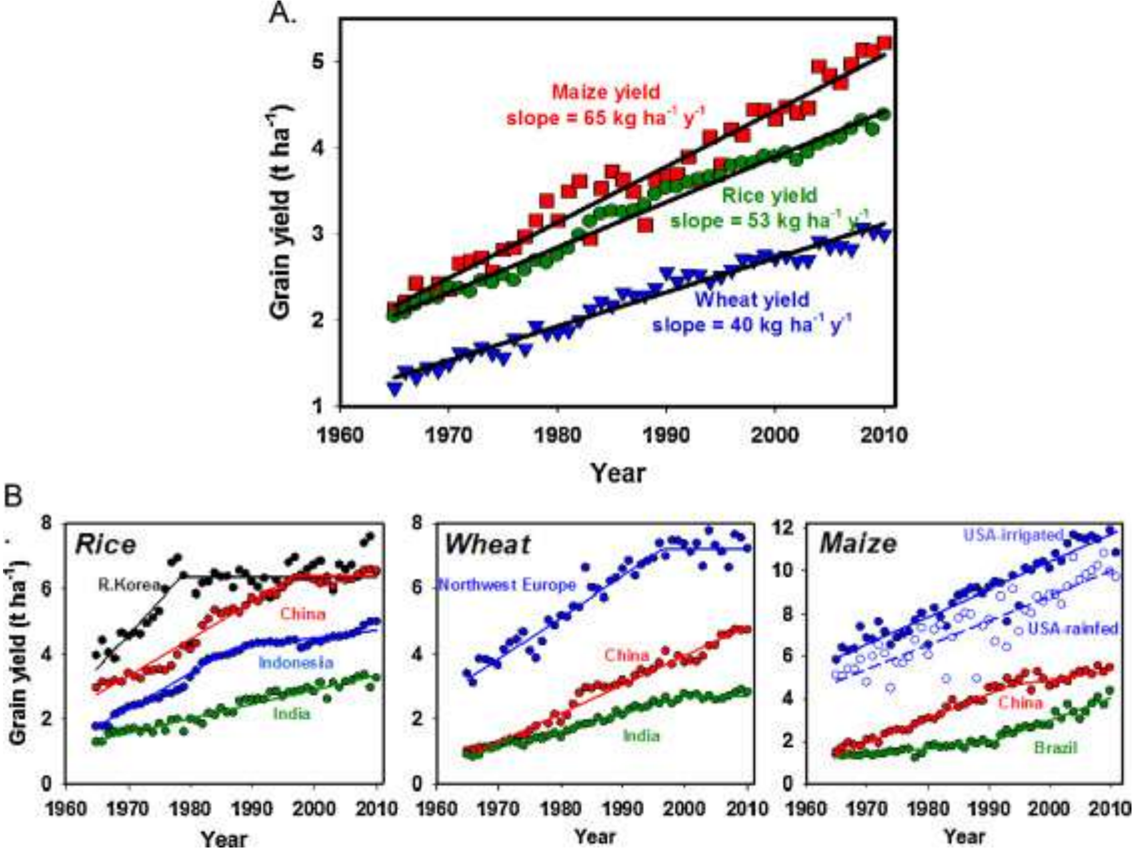
Table 2. Regression Outcomes for Climatic and Management Drivers of Yield Variation

Crop	**Temperature Effect (% per +1°C)**	**Rainfall Effect**	**Fertilizer Effect**	**Irrigation Effect**
Wheat	–4.5%	Positive, diminishing	+0.7 t/ha per 50 kg applied	+40–60% yield relative to rainfed
Rice	–1.2%	Positive, nonlinear	Major driver (~60% variance)	Critical: irrigated > rainfed yields
Maize	–5.8%	Strong positive in rainfed	High marginal returns	Important but variable

5.4 Yield Gap Identification: Regions with High vs. Low Performance

Yield gap analysis revealed sharp regional disparities across cereals. Wheat potential averages 6.5–7.5 tonnes/ha, yet Sub-Saharan Africa achieves only 45%, while Western Europe reaches 85–90%, leaving little room for growth. The potential in rice is 8.5 tonnes/ha, with East Asia recording more than 80% and Sub-Saharan Africa recording 35-40%. The productive potential of maize is greater than 12 tonnes/ha but still lags behind the figures for those in Sub-Saharan Africa of less than 40 and South America at 70 to 75. There is still potential to improve these outcomes by closing such productivity gaps.

The findings suggest that whilst the developed economies seem to be constrained by the limits of biology and environment, there is still substantial capacity to harness in developing regions.



5.5 Comparative Analysis: Cross-Crop and Cross-Country Differences

Comparisons between cross-crop and cross-country draw out the shared challenges and dynamics of each. Wheat shows stagnation in the high-income area and slow progress in other areas, signalling the importance of breeding for climate resistance. South Asia shows low variability with rice and is not gaining as fast, which raises sustainability questions with the high irrigation water needs. Maize is still top in the growth in productivity, but it is volatile and highly sensitive to climate, especially in Sub-Saharan Africa. At the country level, the differences are stark: China has 7.2tonnes /ha of rice and 6.0 tonnes of wheat, and India only produces 20% of this. The United States is leading maize by a margin of 11 tonnes/ha, and Nigeria is only 2.

Table 4. Comparative Analysis of Cross-Crop and Cross-Country Yield Differences

Country	Wheat Yield (t/ha)	Rice Yield (t/ha)	Maize Yield (t/ha)	Key Insights
China	6.0	7.2	6.0	High investment in agricultural research and technology.
India	3.4	4.0	3.0	Significant yield gaps; stagnation in both rice and wheat.
United States	3.5	–	11.0	Global leader in maize yields due to hybrids and mechanisation.
Nigeria	–	–	2.0	Low maize yields from limited input use and climate stress.

6. DISCUSSION

6.1 Interpretation of Key Findings

Comparing the yields of wheat, rice, and maize in 1961 and 2020 presents a complex view of worldwide productivity. [22, 43, 44]. At an aggregate level, yields have risen considerably as a result of the legacy of the green revolution, the use of high-yielding varieties, and the use of new inputs. Nevertheless, findings indicate that there is high heterogeneity in terms of crops and regions. There have been high levels of historical increases in wheat and rice, but it is currently stagnating in most of the regions that have high yields, especially in Western Europe and South Asia. [27, 45]. The growth of maize, however, is still showing sturdy growth, particularly in North and Latin America, but it is checked by a high level of variability. [46].

The obtained regression findings confirm that climatic factors have a strong effect on the production of cereals. Global warming was linked with massive decreases in yields, especially in wheat and maize, which explains their susceptibility to global warming. [25, 47]. Rice is also less vulnerable to heat rises, but it is also a very sensitive crop that lacks irrigation and fertiliser. [10, 48, 49]. Yield gap analysis further showed that there are consistent discrepancies: Western Europe and North America are functioning near the biophysical capacity, Sub-Saharan Africa and South Asia are functioning under half the potential, with significant untapped potential. Together, these findings suggest that the issue of food security in the world has less to do with the level of absolute productivity than it does with closing the regional gap and addressing climate-related risks.

6.2 Implications for Sustainable Crop Improvement

The study results have important implications for sustainable crop improvement practices. The fact that there is no more wheat and rice produced in highly productive areas means that you cannot increase them without plant breeding and precision farming (and not just by increasing your inputs) [31, 50]. Breeding must work towards identifying varieties that are heat and drought-tolerant, as well as breeding to increase nutrient-use efficiency. Conservation agriculture practices, including reduced tillage and rotational diversity, have multiple benefits, including yield stabilisation in variable climates.

In maize, there have been significant productivity gains, albeit volatile, so the objective is to stabilise productivity. [43]. This still must include investments in climate-resilient hybrids, especially in dry areas of Africa and Latin America, as well as further irrigation investment and crop insurance. For example, rice improvement needs to address the water question, as it is one of the most water-consuming crops [51]. Innovations, such as aerobic rice systems and alternate wetting and drying (AWD) irrigation methods, provide a means to stabilise productivity while exerting lesser environmental pressure.

The second implication is to narrow the yield gaps in the developing regions. Particularly in Sub-Saharan Africa, there is a considerable potential to raise productivity via enhanced access to fertilisers, quality seed and mechanisation. The impact of narrowing yield gaps in these regions would have a relatively large impact on food security and poverty reduction, as rural populations tend to rely on staple cereals [25, 52]. Access to inputs, extension services, and credit by the smallholder farmers should therefore be a priority for policymakers and donors who must stimulate the smallholder farmers to adopt better practices. Role of Secondary Data.

6.3 Comparison with Past Research

The findings are consistent with those of Arata et al. (2020), who have found a global picture of stagnated yields and increased variability in crop production. Their use of robust estimation techniques to account for outliers revealed similar regional disparities, particularly the relatively stable rice yields in South Asia and East Asia, compared to more volatile wheat and maize yields elsewhere. [45, 53]. Our analysis reinforces their conclusion that yield stagnation is not universal but is concentrated in high-performing systems, while yield variability is rising in regions most exposed to climatic extremes.

Other studies, such as Saini et al. (2021), also echo the concern that current rates of yield growth for major cereals fall short of the 2.4% per year required to double food production by 2050 [54]. Our findings of wheat growth at 0.9% and rice at below 1% since 2000 corroborate this concern. [55]. The yield gaps identified in Sub-Saharan Africa and South Asia are consistent with the global synthesis of Mueller et al. (2012), which highlighted fertiliser and irrigation as key constraints. In this sense, our study adds depth by confirming these patterns across multiple datasets and providing crop-specific breakdowns.

6.4 Impact of Climate Change and Management Practices

Climate change emerged as a central determinant of yield variability in this analysis. The regression results indicated that a one-degree Celsius increase in mean temperature could reduce maize yields by nearly 6% and wheat yields by 4.5%, magnitudes consistent with agronomic simulations. [56, 57]. These effects are not uniform: temperate regions may experience modest gains from longer growing seasons, while tropical and semi-arid regions face disproportionately severe risks. The concentration of yield volatility in Sub-Saharan Africa and the Middle East and North Africa underscores the urgency of adaptation measures in these regions.

Management practices, particularly fertiliser use and irrigation, demonstrated significant potential to mitigate climatic risks. For rice, irrigation coverage and nutrient management explained more than half of the yield variation, illustrating the crop's dependence on controlled environments. [34]. Within systems based on maize and wheat, the interaction of rainfall and fertiliser was important, most importantly evidenced by the highest marginal returns from fertiliser benefiting rainfed systems. [45, 58]. These demonstrate the need for investing in comprehensive integrated soil fertility management and water infrastructure as an approach to resilience. However, again, use of chemical inputs and reliance on those has its own sustainability problems, given, e.g. groundwater depletion, greenhouse gas emissions, etc. All of this calls for a more balanced approach to resilience and for integrating additional use of inputs, e.g. mechanisation/digitalisation, etc., with agroecological practices.

6.5 Role of Secondary Data in Agricultural Policy Formulation

This study shows the value of the use of secondary datasets for generating insights and implications for agricultural policy [59]. The datasets aggregated at the national level, such as FAOSTAT, also provide opportunities for trend analysis and comparisons between countries and across longer time horizons; something that would not be affordable to collect using primary surveys alone. For example, for policymakers and government officials, these datasets provide a baseline for identifying the low-performing regions, monitoring farm performance toward global food security policy goals, and measuring the outcomes of a previously selected intervention.

Arata et al. (2020) demonstrate how secondary data could provide a broad-based assessment of stagnation and variability that can inform global-level programming. We narrow this to consider the wheat, rice and maize portfolios to provide a more useful policy lens for staple crop policy. [54]. For example, the analysis suggested that maize yield in Sub-Saharan Africa was less than 30% of potential yield, providing a clear case for continued donor investment in seed and fertiliser programs. Similarly, rice yield stagnation in South Asia also prompted the analysis to recommend renewed research in water-saving technology-based interventions.

However, policy actors should also remain aware of some limitations of secondary data. For one, national averages blur intra-country differences, and national average yield estimates could be subject to reporting errors. [35, 51]. To improve the policy relevance of secondary data analyses, we suggest supplementing such analyses with ground surveys, remote sensing, and farm surveys to feed the interventions to the rural contexts of target communities.

6.6 Limitations of the Study and Future Directions

While this study has contributed to our understanding, it should be noted that there are some limitations. There is the potential for aggregate bias caused by secondary national data that may hide heterogeneity of various farms and regions. Climatic data were national and were therefore less capable of estimating local microclimates and their implications for cropping system performance. Third, yield gap estimates were influenced by take-off yields that were not sourced from this work, which could not possibly capture the complete range of diverse biophysical conditions.

Therefore, future studies benefit from remote sensing and national statistics, developing yield estimates with a higher level of granularity. Hybridising crop simulation models and secondary data also improves projections under scenarios of climate change. Furthermore, it would also be useful to investigate the interaction of socioeconomic drivers (i.e., market access, policies and labour) and trends in yield to improve the context for understanding crop improvements. Lastly, interdisciplinary approaches (i.e., agronomy, economics and climate science) help develop solutions that contribute to increased yield potential while addressing sustainability and social equity issues positively.

7. CONCLUSION

7.1 Summary of Major Findings

The study employed analyses based on quantitative research, which utilised secondary datasets to examine temporal yield pathways, yield variability, and yield gaps, specifically for wheat, rice, and maize, which are the three main cereal crops that could be framed as staple commodities within food systems worldwide. The evidence confirmed that significant gains in productivity have occurred since 1960, with global wheat yields increasing from 1.1 to 3.5 tonnes/ha, rice yields from 1.9 to 4.7 tonnes/ha, and maize yields from 1.9 to 5.9 tonnes/ha by 2020. Yet, these global achievements obscure stark regional variations and troubling signs of stagnation. Wheat yields have plateaued in high-yielding regions, including Western Europe, and rice yield growth has decelerated in South Asia. Maize is dynamic, especially in the Americas, but remains highly vulnerable to climatic stress.

Regression results demonstrated the significant role of climate and management conditions. Elevated temperatures consistently suppressed wheat and maize yields, while rice, though not as responsive to warming, remained dependent on water and fertiliser inputs. Yield gap analysis showed that yield levels in sub-Saharan Africa and South Asia are less than half of attainable yields, while advanced regions have yields close to biological limits. Altogether, these findings demonstrate that global food security goes beyond simply food production to stabilising and narrowing the yield gaps across regions.

7.2 Contribution to Sustainable Agriculture and Food Security

Through a comprehensive analysis of long-term secondary data, this research adds important perspectives to the dialogue surrounding sustainable agriculture and global food security for several reasons. It highlights how falling yield growth and rising yield volatility constitute a simultaneous and growing threat to the stability of food supply. Sustainable intensification can no longer be considered solely in terms of average increases in yield alone. Yield stability and yield resilience are also key for ensuring that farmers earn a stable income and that consumers have access to affordable food. The findings also show that a gap in yield can be viewed as both a challenge and an opportunity. It appears that advanced economies may be at the limits of growing yield, while certain developing areas, notably across Sub-Saharan Africa, can expect to see higher rates of growth by overcoming yield gaps, as one example has increasing access to modern inputs, irrigation, and technology. Reducing a gap in yield could be a very fast way to increase global food availability without additional land expansion. Improvements in production could also fall in line with an approach of sustainability in the environment. Finally, this work reemphasises the importance of data-driven evidence to evaluate performance in agriculture within production systems. Use of historic data is a means of examining yield dynamics over decades of production, and even over continents, at a relatively low cost. Data-driven evidence, therefore, is a major component in the process of understanding where to focus forward-looking strategies and aligning the installation and implementation of agricultural systems with the wider aims of sustainable development and climate resilience in total.

7.3 Recommendations for Researchers, Policymakers, and Agronomists

The results carry specific recommendations for diverse stakeholders.

- **For researchers**, the findings underscore the value of integrating time-series and regression approaches with robust statistical techniques. Future research should continue to refine methods for capturing variability and downside risks, while also linking macro-level trends with micro-level farm data. This dual perspective can help identify context-specific solutions that aggregate to global improvements.
- **For policymakers**, the evidence highlights the need for regionally differentiated strategies. In Sub-Saharan Africa, priority should be given to expanding fertiliser access, mechanisation, and irrigation infrastructure. In South Asia, water-efficient rice technologies such as alternate wetting and drying must be scaled to address both stagnation and water scarcity. Meanwhile, in high-performing regions, investment should focus on climate-resilient varieties and sustainable management practices that sustain productivity without further ecological burden.
- **For agronomists**, the analysis provides insights into crop-specific vulnerabilities. Wheat requires urgent breeding programs for heat tolerance, maize demands strategies to stabilise yields under drought conditions, and rice improvement must reconcile productivity with water efficiency. Agronomists should also strengthen extension services, ensuring that smallholder farmers can adopt new technologies effectively.

7.4 Future Outlook on Integrating Secondary Data with Precision Agriculture

A strategy that warrants consideration for addressing global food security challenges is the integration of secondary datasets with contemporary precision agriculture technology. Secondary data sources provide the long-term, large-scale perspective to measure and monitor structural trends, while precision agriculture provides the most detailed farm-level evidence. The combination of these two sources of information can provide very powerful decision support systems.

For example, remote sensing can show validation and adjustments to FAO estimates at the country level and provide near-real-time monitoring of yield variability. In addition, machine-learning models using historical datasets can support farmers in predicting crop yield response under future climate scenarios, while underpinning adaptive management strategies. Lastly, using precision agriculture tools at the farm level, such as sensors, GPS-guided irrigation, and variable rate fertiliser applications, can help farmers achieve the yield potential identified by global datasets. Collectively, these tools provide a useful framework that considers global, macro-level planning to the farm-level, micro-level implementation.

The future of sustainable crop improvement, therefore, depends on bridging scales—linking the broad insights from secondary data with the localised solutions offered by precision agriculture. Such integration can ensure that productivity gains are not only higher but also more stable, equitable, and environmentally sustainable.

Closing Statement

In conclusion, this study affirms that while global wheat, rice, and maize yields have improved dramatically since the 1960s, the challenges of stagnation, variability, and regional disparities remain pressing. By combining quantitative analysis of secondary data with policy-oriented insights, we provide a framework for guiding sustainable crop improvement strategies. Strengthening resilience to climate change, closing regional yield gaps, and integrating secondary data with precision agriculture are essential steps toward securing food supplies for a growing global population.

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