

Analysis of Current Production Status and Yield Increase Potential of Wheat and Maize in Medium- and Low-Yield Areas of the Hebei Plain (Postprint)

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Abstract

Based on MODIS/NDVI remote sensing data and statistical data of major grain crops from 2000 to 2013, this study analyzed the spatiotemporal patterns of winter wheat and maize production in the low-to-medium yield areas of the Hebei Plain. Utilizing annual values of cumulative NDVI during the main growth periods of grain crops at the county level, the 14-year maximum values, and yield statistical data, a remote sensing estimation model for yield was constructed through numerical curve fitting based on the principle of least squares to estimate the yield increase potential of winter wheat and maize in the low-to-medium yield areas of the Hebei Plain. The results showed that: 1) The maximum productivity level of winter wheat was relatively high in Handan and Hengshui, while relatively low in Cangzhou, Langfang, and central Xingtai, meaning that even after tapping the yield increase potential, the latter would hardly reach the maximum productivity level of the former. The maximum productivity level of maize was generally high, and all regions could achieve high productivity levels after tapping the yield increase potential. 2) The total yield increase potential of both winter wheat and maize was substantial in Cangzhou and Handan. The yield increase potential per unit area of winter wheat was mostly below 10%, with an average increase of $356 \text{ kg} \cdot \text{hm}^{-2}$ (5.87%). The yield increase potential per unit area of maize was mostly above 10%, with an average increase of $798 \text{ kg} \cdot \text{hm}^{-2}$ (12.33%). The regional distribution of yield increase potential per unit area differed: for winter wheat it was Langfang > Baoding > Cangzhou > Handan > Xingtai > Hengshui, and for maize it was Xingtai > Handan > Baoding > Cangzhou > Hengshui > Langfang. 3) Based on the maximum values of cumulative NDVI for crops over the past 14 years in the Hebei Plain, the estimated yield increase potential for winter wheat in the

entire region was 390 million kg, and for maize was 962 million kg, with a combined potential increase of 1.352 billion kg, which is approximately equivalent to 1/5 of the theoretically achievable yield increase potential for winter wheat and maize in the region. The method for estimating yield increase potential of grain crops developed in this study can be applied to estimate the yield increase potential at multiple scales and for different crops, and the research results can provide a basis for decision-making and management by relevant departments.

Full Text

Preamble

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Production Status and Yield Potential of Wheat and Maize in Low-to-Medium Yield Farmlands in Hebei Plain*

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Abstract

Based on MODIS/NDVI remote sensing data and statistical data for major grain crops from 2000 to 2013, this study analyzed the spatiotemporal patterns of winter wheat and maize production in low-to-medium yield farmlands in Hebei Plain. Using annual accumulated NDVI values during the main growing periods, 14-year maximum values, and county-level yield statistics, a yield estimation model was constructed through numerical curve fitting based on the least squares principle to estimate the yield-increasing potential of winter wheat and maize in the region. The results showed that: (1) The maximum productivity of winter wheat was relatively high in Handan and Hengshui, but lower in Cangzhou, Langfang, and central Xingtai, meaning that even after exploiting their yield potential, the latter regions would struggle to reach the productivity levels of the former. In contrast, maize exhibited generally high maximum productivity across the region, with all areas capable of achieving high productivity levels after potential exploitation. (2) The total production increase potential for both crops was substantial in Cangzhou and Handan. The yield gap for

winter wheat was generally below 10%, averaging $356 \text{ kg} \cdot \text{hm}^{-2}$ (5.87%), while the yield gap for maize mostly exceeded 10%, averaging $798 \text{ kg} \cdot \text{hm}^{-2}$ (12.33%). The spatial distribution of yield gaps differed between crops: for winter wheat, the ranking was Langfang > Baoding > Cangzhou > Handan > Xingtai > Hengshui; for maize, it was Xingtai > Handan > Baoding > Cangzhou > Hengshui > Langfang. (3) Based on the 14-year maximum accumulated NDVI, the regional yield-increasing potential was estimated at $3.90 \times 10^8 \text{ kg}$ for winter wheat and $9.62 \times 10^8 \text{ kg}$ for maize, totaling $13.52 \times 10^8 \text{ kg}$, which represents approximately one-fifth of the theoretical achievable yield potential for both crops. The method developed in this study can be applied to estimate yield-increasing potential across multiple scales and for different crops, providing a scientific basis for policy-making and agricultural management.

Keywords: Winter wheat; Maize; Yield-increasing potential; NDVI; Yield estimation model; Low-to-medium yield farmland; Bohai Granary project

Introduction

Food security in China has long been a major concern for the government and scholars both domestically and internationally [1-5]. While China achieved eleven consecutive years of grain production increases from 2004 to 2014, the country has simultaneously shifted from occasional grain imports to large-scale imports [5]. With ongoing social development, population growth, and improvements in dietary structure, China's grain demand will continue to increase [6]. Under these circumstances, grain production increases are crucial for ensuring food security. Currently, the primary approaches to increasing grain production are improving yield per unit area and expanding cultivated area [7-8]. However, given China's limited arable land resources and intensive land use, transforming low-to-medium yield farmlands has become an important strategy for enhancing grain production capacity [9]. Analyzing the spatiotemporal patterns and yield potential of these farmlands provides a scientific foundation for government grain trade strategies and agricultural policy formulation.

Previous studies have investigated yield potential using various methods including the "mechanism method," balanced yield increase method, model simulation, and field experiments, consistently demonstrating substantial room for yield improvement. Feng et al. [7] employed the Agricultural Ecological Zone (AEZ) model based on mechanism method principles to study yield potential, finding significant potential for improvement in light, temperature, water, and land resources. Liu et al. [10] and Bai et al. [11] analyzed balanced yield increase potential in Henan and Shandong provinces by setting historical maximum yields as target yields for different regions, identifying distinct yield increase zones. Chen et al. [12] studied balanced yield increase potential in the Huang-Huai-Hai Plain by using average yields from higher-yielding regions as target yields for lower-yielding areas. Xin [13] simulated yield potential of wheat and maize in Hebei Plain using the APSIM crop model and calculated yield gaps based on actual yields. Huang and Li [14] demonstrated through field experiments that

actual dryland winter wheat yields in the Loess Plateau only reached 41.6% of the light-temperature potential, indicating enormous yield increase potential. Most existing studies have focused on regional light, temperature, water, and soil factors to estimate theoretical yield potential, involving complex calculations and large datasets. While yield gap estimates based solely on yield per unit area can reflect recent yield improvement capacity, the regional averaging process masks the diversity of yield potential at county and finer scales.

Remote sensing offers advantages of broad coverage, rapid acquisition, and objectivity, making it one of the most effective techniques for crop yield estimation [15–16]. The Normalized Difference Vegetation Index (NDVI) not only reflects vegetation growth status and coverage but also partially eliminates effects of illumination changes related to solar elevation angle, topography, cloud/shadow, and atmospheric conditions [17]. NDVI has been widely applied in yield prediction research, though primarily for forecasting yield 1–2 months before harvest [18–21], with limited studies on yield-increasing potential.

This study utilizes Terra/MODIS remote sensing data from 2000 to 2013, using the maximum accumulated NDVI during the main growing periods to characterize yield potential. Combined with a yield estimation model, this approach estimates the yield-increasing potential of major grain crops in low-to-medium yield farmlands of Hebei Plain. The method is simple and practical, capable of revealing realistic yield potential achievable through field management practices to eliminate yield fluctuations, while reflecting crop productivity and yield potential at both county and pixel scales (250 m × 250 m). Additionally, this study compares regional realistic yield potential with theoretical yield potential by referencing APSIM-simulated results [13]. The findings provide methodological insights for yield potential research and a foundation for regional grain increase strategies and agricultural policy formulation.

1.1 Study Area

The low-to-medium yield farmland region of Hebei Plain is located between 114°29'–117°52' E and 36°03'–39°28' N, encompassing 49 counties (cities, districts) across all of Cangzhou and Hengshui, and parts of Baoding, Langfang, Xingtai, and Handan [Figure 1: see original paper]. The region features a warm temperate continental monsoon climate with annual mean temperatures of 12.5–13.6 °C and annual precipitation of 450–550 mm. The terrain is flat with elevations mostly below 20 m. Freshwater resources are scarce, with per capita water availability of only 190 m³, one-twelfth of the national average. The cropping system is dominated by winter wheat–summer maize double cropping, supplemented by salt-tolerant cash crops such as cotton and pear-jujube trees. The soil is generally poor, with extensive areas of low-to-medium yield farmland and saline-alkali wasteland, representing important reserve cultivated land resources [22–23]. This region serves as the Hebei project area for the “Bohai Granary” scientific and technological demonstration project, making yield potential assessment increasingly important as the project advances.

1.2 Data Sources

Grain crop yield and sown area data were obtained from the *Hebei Rural Statistical Yearbook (1995-2014)*, providing nearly 20 years of statistical data. Remote sensing data consisted primarily of Terra/MODIS NDVI data at 250 m spatial resolution for the period 2000-2013, composited as 16-day maximum values. These data were used to analyze crop distribution, yield increase ratios, yield estimation models, and yield potential.

2.1.1 Extraction of Crop Distribution Ranges

Winter wheat distribution was extracted using NDVI images from late March to early April, when winter wheat had resumed growth while other crops (e.g., cotton, spring maize) had not yet been sown and fruit trees and other woody plants had not leafed out [24]. Maize distribution was extracted using NDVI images from early June, when winter wheat had been harvested, summer maize had just been sown, spring maize was in early growth stages, and fruit trees and other crops were growing vigorously. The maize category included both summer and spring maize in the study area.

Using NDVI remote sensing data from 2000 to 2013 and ArcGIS spatial analysis capabilities, the pixel dimidiante model [25] was applied to calculate crop distribution proportions at the pixel scale [24]:

$$f_{ccrop} = (NDVI - NDVI_{soil}) / (NDVI_{crop} - NDVI_{soil}) \quad (1)$$

where f_{ccrop} represents the distribution proportion of a specific crop, $NDVI$ is the actual NDVI value of the pixel, $NDVI_{soil}$ is the NDVI value when the pixel is not covered by crops, and $NDVI_{crop}$ is the NDVI value when the pixel is fully covered by crops. $NDVI_{soil}$ and $NDVI_{crop}$ were determined based on statistical characteristic values of NDVI images for the specific period, with f_{ccrop} ranging between 0 and 1.

2.1.2 Extraction of Maximum Accumulated NDVI

Based on NDVI remote sensing data from 2000 to 2013, ArcGIS software was used to calculate NDVI values for different grain crops within their distribution ranges. Annual accumulated NDVI values during the main growing period and 14-year maximum accumulated NDVI values were computed for each grid cell. Winter wheat utilized NDVI data from March to May, while maize used data from July to September.

2.1.3 Classification of Crop Productivity Levels

Since NDVI shows a strong positive correlation with vegetation biomass and grain yield [17], accumulated NDVI values during the main growing period were used to characterize crop productivity levels. Productivity was classified into

four grades based on accumulated NDVI values. For comparative purposes, both the maximum accumulated NDVI values and 2013 values were classified using 2013 standards. Specifically, based on the cumulative frequency curve of accumulated NDVI values from the 2013 raster data, values corresponding to cumulative frequencies of 0.25, 0.50, and 0.75 were used as thresholds to divide productivity into four grades, with Grade I representing the highest productivity level and Grade IV the lowest.

TABLE:1 Crop productivity grading standard according to accumulated NDVI in the low-medium yield farmland of Hebei Plain

Crop productivity grade	Winter wheat accumulated NDVI	Maize accumulated NDVI
Grade I	>3.45	>3.73
Grade II	2.83-3.45	3.48-3.73
Grade III	2.12-2.82	3.07-3.47
Grade IV	<2.12	<3.07

2.2.1 Calculation Principle

With stable sown area, maximum yield levels can typically serve as target yields for yield potential assessment [10-11]. This study used the maximum accumulated NDVI during the main growing period from 2000 to 2013 as the target NDVI value for yield potential at the pixel scale. Combined with sown area, production, and yield data, a remote sensing-based yield estimation model was used to calculate yield-increasing potential:

$$Yp = \sum_{i=1}^m \sum_{j=1}^n Yp_{ij} - Ya_{ij} \quad (2)$$

where Yp is the yield-increasing potential, Yp_{ij} and Ya_{ij} are the target yield and actual yield for crop i in county j , m is the number of crop types, and n is the number of counties. Yp_{ij} was derived from the sown area, production, yield, and the yield increase ratio (r) comparing actual and target accumulated NDVI values, combined with the yield estimation model:

$$Yp_{ij} = Ya_{ij} \times (1 + r) \quad (3)$$

$$r = (Xp_{ij} - Xa_{ij}) / Xa_{ij} \quad (4)$$

where Yp_{ij} is as defined above, Xp_{ij} is the target accumulated NDVI value for yield potential, Xa_{ij} is the actual accumulated NDVI value, r is the yield increase ratio, and $F(Xp_{ij})$ is a function with Xp_{ij} as the independent variable.

Notably, when estimating target yields using the remote sensing model, actual accumulated NDVI values and the increase ratio r were used rather than target NDVI values, because target values cannot incorporate model fitting errors for error correction.

2.2.2 Estimation of Yield Increase Ratio (r)

The yield increase ratio (r) was calculated as the ratio of the difference between maximum and actual accumulated NDVI to actual accumulated NDVI:

$$r = (NDVI_{max} - NDVI_{2013})/NDVI_{2013} \quad (5)$$

where r is the yield increase ratio, $NDVI_{max}$ is the maximum accumulated NDVI during 2000-2013, and $NDVI_{2013}$ is the accumulated NDVI for 2013. Since the NDVI increase ratio does not directly equal yield increase ratio, accumulated NDVI values must be fitted with actual yield levels to calculate realistic yield potential.

2.2.3 Remote Sensing-Based Yield Estimation Model Using Accumulated NDVI

Data from 2000 to 2012 were used for model development, with 2013 data for validation. Outliers were removed during simulation. MODIS accumulated NDVI data during the main growing periods (March-May for wheat, July-September for maize) were fitted with county-level yield statistics using least squares method to derive production functions:

$$Y_{i,j} = a_{i,j}X^2 + b_{i,j}X + c_{i,j} \quad (6)$$

where $Y_{i,j}$ represents yield per unit area for crop i in county j , $X_{i,j}$ is the NDVI value, and $a_{i,j}$, $b_{i,j}$, $c_{i,j}$ are regression coefficients.

2.3.1 Evaluation Metrics for Model Accuracy

Coefficient of determination (R^2), relative error (RE), and root mean square error (RMSE) were used to evaluate model performance [16]:

$$RE = \frac{\sum_{i=1}^n (P_i - A_i)}{\sum_{i=1}^n A_i} \times 100\% \quad (7)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (P_i - A_i)^2} \quad (8)$$

where A_i is actual yield from statistics, P_i is model-estimated yield, \bar{A} is mean actual yield, \bar{P} is mean estimated yield, and n is sample size.

2.3.2 Accuracy Validation

The fitted models using county-level average accumulated NDVI (x) and yield (y) were:

$$y_{wheat} = -1,739.8x^2 + 10,206x - 9,056.6 \quad (10)$$

$$y_{maize} = -2,393.8x^2 + 18,952x - 31,059 \quad (11)$$

For winter wheat: sample size $n = 565$, $R^2 = 0.569$, correlation coefficient $R = 0.754$. For maize: $n = 565$, $R^2 = 0.508$, $R = 0.713$. Both correlations were significant at the 0.001 level [Figure 2: see original paper]. The relative error was -7.04% and RMSE was $899 \text{ kg} \cdot \text{hm}^{-2}$ for winter wheat, while maize showed -12.94% relative error and RMSE of $1,348 \text{ kg} \cdot \text{hm}^{-2}$. In 2013, average winter wheat yield was $5,970 \text{ kg} \cdot \text{hm}^{-2}$ (simulated: $5,407 \text{ kg} \cdot \text{hm}^{-2}$), and maize yield was $6,571 \text{ kg} \cdot \text{hm}^{-2}$ (simulated: $5,613 \text{ kg} \cdot \text{hm}^{-2}$). Maize fitting was less accurate primarily because other crops and woody vegetation were also growing vigorously during the maize growing season, causing larger errors in maize distribution extraction and affecting the NDVI-yield relationship.

Ren et al. [17] studied the correlation between NOAA/AVHRR NDVI during key winter wheat growth periods and yield in Shijiazhuang, Xingtai, and Handan, reporting $R^2 = 0.299$, RE = -8.20%, and $n = 567$ for linear simulation of March-May NDVI sum versus total yield, without RMSE calculation. Our study achieved higher accuracy with similar sample sizes.

Results and Analysis

Based on current production status, both realistic and theoretical yield potentials were analyzed. Realistic yield potential was calculated using the maximum accumulated NDVI during 2000-2013 as the target, while theoretical yield potential was estimated by referencing APSIM model predictions [13] combined with regional yield and sown area data under specific natural conditions.

3.1 Current Production Status of Wheat and Maize

Based on 2000-2013 remote sensing data, the 14-year average distribution proportion represented the spatial distribution characteristics of winter wheat and maize. Winter wheat showed higher distribution proportions in the southern and central regions, while maize was more concentrated in the northern and central areas. Water availability was the primary limiting factor for winter wheat growth, making the better-irrigated southern and central regions the main distribution zones with proportions exceeding 0.8. In contrast, northern areas and central Xingtai showed lower winter wheat distribution (mostly <0.4) due to water and soil constraints [Figure 3: see original paper]. Maize distribution was widespread, with high proportions (>0.8) in northern regions, but formed

concentrated low-proportion zones (<0.2) in northern Handan, central Xingtai, and western Hengshui [Figure 3: see original paper].

Over the past two decades, both winter wheat and maize production showed increasing trends [Figure 4: see original paper]. Wheat production increases stemmed primarily from yield improvements, while maize production increases resulted from both yield gains and area expansion. From 1994 to 2013, wheat and maize production increased from 3.86×10^9 kg and 2.79×10^9 kg to 6.65×10^9 kg and 7.79×10^9 kg, respectively (72% and 180% growth). Yield levels increased from $3,614 \text{ kg} \cdot \text{hm}^{-2}$ and $4,371 \text{ kg} \cdot \text{hm}^{-2}$ to $6,059 \text{ kg} \cdot \text{hm}^{-2}$ and $6,471 \text{ kg} \cdot \text{hm}^{-2}$. Maize sown area expanded nearly twofold from $640,000 \text{ hm}^2$ (1994) to 1.20 million hm^2 (2013), while wheat area remained relatively stable (1.07 million hm^2 in 1994 vs. 1.10 million hm^2 in 2013, only 2.8% increase).

Yield per unit area reflects actual productivity levels. In 2013, winter wheat yields were higher in Hengshui and Handan ($>6,000 \text{ kg} \cdot \text{hm}^{-2}$) and lower in eastern Cangzhou and southern Langfang ($<5,000 \text{ kg} \cdot \text{hm}^{-2}$). Maize yields were highest in Handan ($>7,000 \text{ kg} \cdot \text{hm}^{-2}$), moderate in Hengshui and western Cangzhou, and lowest in eastern Cangzhou ($<6,000 \text{ kg} \cdot \text{hm}^{-2}$) [FIGURE:5a, b]. Both crops showed significant productivity improvements over two decades ($P < 0.001$), particularly in Handan where some areas achieved yield increases exceeding $3,000 \text{ kg} \cdot \text{hm}^{-2}$ [FIGURE:5c, d].

3.2.1 Yield Potential Analysis Based on Maximum Accumulated NDVI

Both winter wheat and summer maize demonstrated substantial yield potential, with maize having a larger high-potential area than wheat [FIGURE:5a, c]. Winter wheat maximum productivity was high in Handan and Hengshui but lower in Xingtai, Cangzhou, Langfang, and central Xingtai, where even full exploitation of yield potential would not reach the productivity levels of the former regions. This difference resulted from better irrigation conditions, higher accumulated temperature, and more appropriate management inputs in Handan and Hengshui, whereas Cangzhou and Langfang faced constraints from high shallow groundwater salinity, large saline-alkali soil areas, limited management inputs, and lower accumulated temperature in Langfang. Central Xingtai also suffered from poor soil and water conditions with low management inputs. Maize maximum productivity was generally high across the region, with all areas capable of achieving high productivity after potential exploitation.

Productivity level classification revealed that high-productivity Grade I and II zones for winter wheat still had room for further improvement, while low-productivity Grade IV zones could be upgraded to Grade III or even Grade I/II levels [FIGURE:6a, b]. Maize showed greater potential for productivity improvement, with most regions capable of reaching Grade I productivity except around jujube forests in Cangzhou and parts of eastern Cangzhou [FIGURE:6c, d].

The potential yield increase ratio (r) was calculated using equation (5) [Figure 7: see original paper]. Most winter wheat areas showed increase ratios below 10%, though western Cangzhou exhibited higher potential ratios exceeding 50% locally [Figure 7a: see original paper]. Maize increase ratios were mostly above 10%, with larger potential ratios distributed in Handan, eastern Cangzhou, and parts of Xingtai [Figure 7b: see original paper].

3.2.2 Yield Gap Estimation Based on Maximum Accumulated NDVI

At the county scale, winter wheat yield gaps ranged from 20–864 $\text{kg} \cdot \text{hm}^{-2}$, mostly below 10% of actual yields, while maize yield gaps ranged from 456–1,747 $\text{kg} \cdot \text{hm}^{-2}$, mostly exceeding 10% of actual yields. Regional average winter wheat yield could increase from the current 6,059 $\text{kg} \cdot \text{hm}^{-2}$ to a potential 6,415 $\text{kg} \cdot \text{hm}^{-2}$, representing a yield gap of 356 $\text{kg} \cdot \text{hm}^{-2}$ (5.87% increase). Maize could increase from 6,472 $\text{kg} \cdot \text{hm}^{-2}$ to 7,270 $\text{kg} \cdot \text{hm}^{-2}$, with a yield gap of 798 $\text{kg} \cdot \text{hm}^{-2}$ (12.33% increase). Spatial patterns of yield potential and yield gaps differed: both crops showed highest yield potential in Handan, but yield gaps were larger in northern regions for winter wheat and southern regions for maize [FIGURE:8a-d]. The largest winter wheat yield gap occurred in Langfang (605 $\text{kg} \cdot \text{hm}^{-2}$) and the smallest in Hengshui (200 $\text{kg} \cdot \text{hm}^{-2}$). For maize, the largest gap was in Xingtai (1,109 $\text{kg} \cdot \text{hm}^{-2}$) and the smallest in Langfang (344 $\text{kg} \cdot \text{hm}^{-2}$). Regional ranking by yield gap was: winter wheat: Langfang > Baoding > Cangzhou > Handan > Xingtai > Hengshui; maize: Xingtai > Handan > Baoding > Cangzhou > Hengshui > Langfang.

3.2.3 Total Production Increase Potential

Total production increase potential for winter wheat reached 3.90×10^8 kg, while maize potential was 9.62×10^8 kg, totaling 13.52×10^8 kg. At the county scale, larger potential increases were concentrated in northern regions. Cangzhou represents a key area for future yield increases, with some counties showing winter wheat potential $>0.10 \times 10^8$ kg and maize potential $>0.25 \times 10^8$ kg. Handan counties also showed substantial potential, with some exceeding 0.10×10^8 kg for wheat and 0.25×10^8 kg for maize. Hengshui and Xingtai showed limited total production potential, with most counties below 0.05×10^8 kg for wheat and 0.25×10^8 kg for maize [Figure 9: see original paper]. Over the past 14 years, Hengshui maintained consistently high yields with limited potential for further increases, while Xingtai had persistently low wheat yields and limited maize potential due to constrained sown area despite high yield capacity.

3.3 Theoretical Yield Potential

The yield potential estimated above using the 14-year maximum accumulated NDVI represents realistic potential based on historically achieved maximum productivity levels, which can be realized in the short term through appropriate agricultural inputs, improved management, and advanced technologies. To

further explore the theoretical maximum yield potential under specific natural conditions, this study introduces the concepts of yield potential and theoretical achievable yield for comparison. Yield potential is defined as the maximum achievable yield under specific climate and soil conditions without water or nutrient stress and without any yield-limiting factors (pests, diseases, weeds, lodging, gaps) [27], representing the idealized maximum under perfect conditions. Theoretical achievable yield potential represents the maximum yield attainable under optimal management with minimal stress. Research indicates that major crops (wheat, maize, rice) tend to plateau at 70–85% of yield potential [28–29], which is considered the theoretical achievable yield.

Referencing APSIM model predictions for major crops in Hebei Plain [13], this study used 70% of yield potential as the threshold for theoretical achievable yield. Using 2013 prefecture-level average yields as actual production levels, combined with corresponding sown area and production data, the theoretical achievable yield potential was calculated. Results showed enormous theoretical potential in the region. Actual yields represented only 48–63% of yield potential for winter wheat and 34–52% for maize. Based on 2013 sown areas, theoretical achievable yield potential was 17.6×10^8 kg for winter wheat and 58.1×10^8 kg for maize, totaling 76.0×10^8 kg. The realistic yield potential calculated using maximum accumulated NDVI represented 22% of theoretical achievable potential for winter wheat, 17% for maize, and 18% for both crops combined. This realistic potential is achievable through technological and management improvements, offering stronger practical guidance than theoretical potential.

Conclusions and Discussion

This study estimated yield-increasing potential using maximum accumulated NDVI during main growing periods combined with a yield estimation model. The results indicate that winter wheat yield potential is 3.90×10^8 kg and maize potential is 9.62×10^8 kg in low-to-medium yield farmlands of Hebei Plain, with a combined potential of 13.52×10^8 kg, equivalent to 18% of the regional theoretical achievable yield potential. Overall, maize showed greater yield potential than winter wheat for both total production and yield per unit area. Regions with large total production potential for both crops were located in the northern part of the study area, while yield gap hotspots were in the north for wheat and south for maize. The estimated potential is based on historically achieved maximum productivity levels, providing strong practical relevance.

However, several constraints limit the realization of yield potential. In areas with poor soil, yield increases can be promoted through soil fertility improvement and precision management of water, fertilizer, and pesticides. In freshwater-scarce brackish water zones, brackish water irrigation and rainwater utilization are key strategies. In saline-alkali areas, subsurface drainage, rainwater leaching, and saline water freezing irrigation can enhance yields. In rain-fed areas, water-saving irrigation and rainwater harvesting can ensure production increases. Economic returns are the direct driver for sustained yield increases,

which can be secured through land management, grain subsidies, and incentive policies. Specialized subsidies such as “grain increase subsidies,” “brackish water utilization subsidies,” and “water-saving technology subsidies” could be expanded to establish long-term, stable incentives for grain production.

This study presents a novel approach to yield potential assessment with simple methodology and readily available data. However, several uncertainties remain: (1) The yield estimation model’s accuracy is limited by large sample sizes and regional heterogeneity in water, fertility, soil, and management conditions, resulting in relatively large RMSE values. County-level relative errors were used to correct model estimates and improve accuracy. (2) Without dedicated land use data, crop distribution ranges were extracted using growing season NDVI values, causing larger errors in sparsely cropped areas. The vigorous growth of other vegetation during the maize season particularly affected maize extraction and potential estimation accuracy. (3) The study base year (2013) was selected to represent current productivity rather than using multi-year averages, as yields showed both trend and interannual variation. (4) The assumption of stable sown area may not hold in practice; for example, cotton area in Xingtai decreased significantly in 2015 compared to 2013, which could substantially affect yield potential estimates if converted to maize, given the region’s high maize productivity potential. Additionally, crop variety effects were not considered, which may also affect estimation accuracy.

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