

Quantitative assessment of maize yield gap in Shush county using comparative performance and boundary line analysis

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ABSTRACT

Grain maize (*Zea mays*) is a strategic crop with a vital role in global food security. Due to a significant yield gap observed in maize farms of Khuzestan Province, this study aimed to assess the yield gap and identify the key agronomic factors contributing to it in Shush County. The research was conducted across 100 maize fields, and data were collected through structured questionnaires and face-to-face interviews. Yield performance was evaluated using Comparative Performance Analysis (CPA) and Boundary Line Analysis (BLA). The average predicted yield was estimated at 8,685 kg ha⁻¹, whereas the potential yield was estimated at 11,557 kg ha⁻¹, indicating a yield gap of 2,872 kg ha⁻¹. The main factors contributing to this gap included insufficient application of poultry manure (29%), inadequate use of insecticides (18%), sulfur fertilizer deficiency (17%), suboptimal disking frequency (22%), and insufficient irrigation frequency (14%). According to the BLA results, optimizing these management variables could substantially improve maize yields. Overall, enhancing farm management practices—particularly the efficient use of organic and chemical fertilizers, improved pest control, and proper scheduling of irrigation and tillage operations—can significantly reduce the maize yield gap and increase productivity in the region.

Highlights

- The maize yield gap in Shush County was quantified as 2,872 kg ha⁻¹ using CPA and BLA methods.
- Five key agronomic factors; poultry manure, insecticide use, sulfur fertilizer, disking, and irrigation, explained most of the yield gap.
- Poultry manure deficiency alone accounted for 29% of the yield gap, highlighting the importance of organic nutrient management.
- Boundary Line Analysis revealed clear yield response patterns to input levels and management frequency.
- Improving fertilizer use, pest control, and irrigation scheduling can substantially increase maize productivity in the region.

1. Introduction

Predictions indicate that the global population will exceed 9 billion by 2050 (De Wrachien et al., 2021; Nuss and Tanumihardjo, 2010). Population growth and the increasing demand for food products represent one of the fundamental challenges in agriculture. Given the limitations of natural resources and environmental pressures, optimizing crop production has become increasingly essential (Van Ittersum et al., 2013). Crop yield is influenced by a variety of factors, including

limiting and reducing factors. When water and nutrients are adequately available and the growth environment is free from weeds, pests, and diseases, plant growth is determined primarily by environmental conditions. Under these circumstances, the plant's yield is referred to as potential yield (Lobell et al., 2009). Actual yield refers to the yield harvested in the field, and the difference between potential and actual yield is known as the yield gap (Bhatia et al., 2008). Studying the quantitative difference between attainable field yield and average actual yield in a region is

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termed yield gap analysis (Torabi, 2011). Variations in actual farm yields compared to attainable yields have prompted researchers to identify and analyze the factors contributing to these differences.

Several factors affect the yield gap, including soil-related factors such as poor soil structure, nutrient deficiencies or imbalances, and soil salinity; water-related problems such as moisture deficiency and water salinity; mechanization practices; and yield-reducing factors such as pests, diseases, and weeds (Hajjarpoor et al., 2018). Various statistical methods have been used to examine and quantify these differences. One of these methods is Comparative Performance Analysis (CPA). CPA has been applied worldwide to evaluate yield gaps in rice (Kayiranga, 2006; Rajapakse, 2003) and maize (Pradhan, 2009). Several studies have employed CPA to assess various crops in different regions of Iran (Gorjizad et al., 2019; Habibi et al., 2019; Abarvan et al., 2017); however, no research has yet applied this method to grain maize cultivation, particularly in Khuzestan Province and Shush County.

Yousefian et al. (2018), using CPA in the Sari region, estimated the actual and potential rice yields at 4,495 and 9,557 kg ha⁻¹, respectively, resulting in a yield gap of 5,062 kg ha⁻¹. In a study in western Golestan Province, Soltani et al. (2023) used CPA to identify managerial factors limiting cotton yield. The results indicated that nine variables, including planting date, nitrogen application, foliar nutrient spraying, and irrigation volume and timing, contributed most to the yield gap (61%). Torabi et al. (2011), by examining the effect of irrigation regimes on wheat yield gaps in Gorgan, reported an optimal wheat yield of approximately 7,500 kg ha⁻¹, while actual yields ranged from 4,200 to 5,800 kg ha⁻¹. This study, using CPA and Boundary Line Analysis (BLA), showed that improving irrigation management could reduce the yield gap by up to 40%. In another study, agronomic factors affecting grain maize yield in Iran were analyzed using meta-analysis, showing an average yield gap of 20–30% of the potential yield, with seed quality, fertilizer type, and irrigation management being the main limiting factors (Mahrokh et al., 2021). A study in China, evaluating summer and spring maize production potential through simulation models, reported maximum yields of 10–12 t ha⁻¹, with yield gaps of 20–30% (Binder et al., 2008).

Among the factors influencing improvements in crop yields, farmers' experience plays an important role, as farmers' experience and learning through production activities have been shown to have a significant effect on enhancing crop performance (Goodwin et al., 2002).

Khuzestan Province, particularly Shush County, is one of the main maize production hubs in Iran, supplying a significant portion of the country's demand annually. However, the region's specific environmental conditions—including soil and water salinity, water scarcity due to recurring droughts, and high temperatures during the growing season—pose significant challenges to optimal crop management. Moreover, the economic and livelihood importance of maize for local farmers underscores the need

to study the factors affecting yield gaps. This research aimed to investigate the factors contributing to grain maize yield reductions in Shush County and to propose management strategies to mitigate them. For this purpose, Comparative Performance Analysis (CPA) was employed to identify factors influencing the yield gap and to improve agronomic management for increased production. Alongside CPA, some studies (Hajjarpoor et al., 2018; Gorjizad et al., 2019) have independently used Boundary Line Analysis (BLA) to examine the relationship between yield and agronomic factors. Accordingly, in this study, BLA was also applied complementarily to better understand crop yield responses to key variables.

2. Materials and Methods

2.1. Climatic conditions of the study area

Shush County, with an area of approximately 3,630 km², is located in the northwest of Khuzestan Province and the southwest of Iran, between longitudes 47°40' and 48°41' E and latitudes 31°31' and 32°40' N (Figure 1). The average elevation is about 45 m above sea level. According to data from the Shush synoptic station, the long-term annual average temperature is 29 °C, and the long-term annual rainfall is 250 mm. Shush County possesses extensive arable land, with an average of 15,000 ha allocated annually to grain and forage maize cultivation.

2.2. Data collection

This study was conducted during 2020–2021. The statistical population comprised all maize farmers in Shush County. Initially, a complete list of maize farmers was obtained from local service centers. Using systematic sampling and considering geographical distribution, 135 farmers were selected. Finally, using Cochran's formula, a sample size of 100 was determined and randomly chosen from the selected farmers.

$$n = \frac{z^2 pq}{d^2} \frac{1}{1 + \frac{1}{N} \left[\frac{z^2 pq}{d^2} - 1 \right]} \quad (1)$$

The values of p and q were set at 0.5, z at 1.96, and d at 0.05. N represents the population size, and n denotes the sample size. Data were collected through comprehensive questionnaires and face-to-face interviews. The questionnaire included various factors such as farmer age, education level, experience in maize cultivation, farm size, crop rotation and fallow practices, use or non-use of subsoilers, dry or wet planting methods, seedbed preparation operations, plowing date and frequency, number of disc harrowings and leveling operations, number of ridges, planting date, seed rate per hectare, seed variety, type and amount of fertilizers, type of seed disinfectant, row spacing, planting density, frequency and type of herbicide, insecticide, and fungicide applications, irrigation frequency, soil and water salinity, and growth period duration.

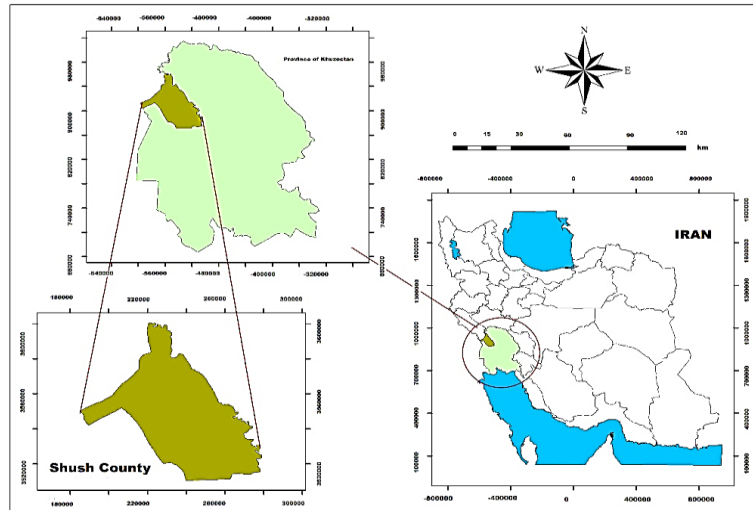


Figure1. Study area location in Shush County, Khuzestan Province

2.3. Data Analysis

For data analysis, the information collected via questionnaires was first organized in an Excel file and coded in tabular form (qualitative variables were coded as 0 or 1). Pearson correlation tests were then applied to examine the relationships among variables. Highly correlated variables were removed based on agronomic knowledge and the importance of each variable. The yield model was determined using stepwise regression, which assessed the relationship between all measured variables (both quantitative and qualitative) and yield. The final model was established through controlled trial-and-error procedures. To calculate yield, the mean values of each variable were input into the model to estimate average yield. Maximum attainable yield was calculated by inputting the best observed values for each variable into the model. The difference between optimum and average yield was identified as the yield gap. This yield gap was calculated as the difference obtained by multiplying the mean and optimum values of each variable by its regression coefficient. The contribution of each variable to the yield gap was expressed as a percentage of the total gap (Torabi

et al., 2011). Furthermore, to complement the analysis and assess the potential yield of each variable independently, Boundary Line Analysis (BLA) was employed. In this method, instead of fitting a regression line to the central tendency of the data, the upper boundary of the data is considered. Scatter plots of yield versus independent variables were constructed, and data were categorized into regular or irregular groups. Outliers were removed, and the highest yield in each group was identified. Finally, a suitable function was fitted to the selected data to estimate model coefficients and parameters. All data analysis were performed using Microsoft Excel 2016 and SAS version 9.4 (Soltani, 2015).

3. Results and Discussion

As shown in Figure 1, the observed yield range across the 100 studied farms varied between 6,000 and 11,800 kg ha⁻¹. Sixteen percent of the maize farmers achieved yields between 6,000 and 7,000 kg ha⁻¹. Moreover, 52% of farmers had yields ranging from 8,000 to 11,000 kg ha⁻¹, while only 10% exceeded 11,000 kg ha⁻¹ (Figure 2).

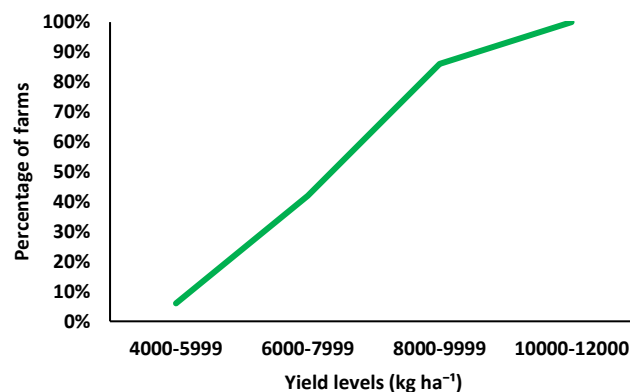


Figure 2. Cumulative frequency of yield of studied fields

Table 1. Descriptive Statistics of the Studied Variables in 100 Grain Maize Farms

Variables	Unit	Mean	Minimum	Maximum	Std. Error	Std. Deviation	CV%
Yield	kg ha ⁻¹	8685	4000	12000	171.54	1715.44	19.75
Farm Area	ha	7	2	12	0.28	2.76	40.53
Basal Potassium Fertilizer	kg ha ⁻¹	99	50	150	2.95	29.48	29.93
Number of Irrigations	times	10.5	8.0	13.0	0.15	1.51	14.41
Insecticide Frequency	times	2	0	3	0.09	0.88	51.88
Herbicide Frequency	times	1.8	0.0	3.0	0.09	0.94	51.44
Poultry Manure	kg ha ⁻¹	1008	0	2000	65.31	653.15	64.80
Growth Duration	days	133.3	119.0	149.0	0.71	7.09	5.32
Farmer's Experience	years	10.5	0.0	25.0	0.71	7.05	67.43
Plant Density	plants m ⁻²	11.5	9.0	13.7	0.1	1.1	9.41
Phosphorus Fertilizer	kg ha ⁻¹	85	50	125	2.065	20.65	24.44
Sulfur Fertilizer	kg ha ⁻¹	124	0	200	6.300	63.00	50.89
Urea Fertilizer	kg ha ⁻¹	332	225	400	5.69	56.88	17.13
Number of Diskings	times	3	2	5	0.10	0.98	29.16
Seed Rate	kg ha ⁻¹	25	21	30	0.23	2.33	9.16
Urea Fertilizer Frequency	times	3	2	4	0.07	0.71	22.91
Micronutrient Fertilizer	times	2	0	3	0.086	0.864	51.12
Sowing Date	DAJ	120	103	147	1.03	10.30	8.61
Harvest Date	DAJ	253	231	270	0.99	9.94	3.93
Soil pH of Farms	-	7.93	7.54	8.40	0.02	0.22	2.76

During the studied period, maize cultivation was successfully carried out in the Shush region. The number of irrigation events ranged from 8 to 13 times, with a mean of 10.46, and insecticide applications varied from 0 to 3 times, with a mean of 1.58. Basal potassium application ranged from 25 to 100 kg ha⁻¹, averaging 55.4 kg ha⁻¹. Urea top-dressing ranged from 225 to 400 kg ha⁻¹, with a mean of 332 kg ha⁻¹ (Table 1). The findings indicated that proper fertilizer management, particularly urea top-dressing, and optimal use of water resources can improve crop yield. Additionally, in some farms, the use of sulfur, micronutrients, and insecticides was still irregular, highlighting the need for further training and extension efforts. Farmer experience and planting density also significantly affected yield. Farmers' experience ranged from 0 to 25 years, indicating the necessity for knowledge and experience transfer among farmers.

3.1. Performance Model

After evaluating all the studied variables, the performance model was developed using stepwise regression analysis, in which all independent variables were regressed against the dependent variable (yield). The final model was obtained as follows:

$$Y = 3293.87 + 0.834x_1 + 406.211x_2 + 7.199x_3 + 379.147x_4 + 156.984x_5 \quad (2)$$

In this equation, Y represents the grain maize yield (kg ha⁻¹), while X₁ is the amount of poultry manure applied, X₂ is the number of insecticide applications, X₃ is the amount of sulfur fertilizer, X₄ is the number of disking operations, and X₅ is the number of irrigations. This equation was developed to evaluate the contribution of each factor affecting maize yield. According to the results shown in Table 2, when poultry manure application reaches 2000 kg ha⁻¹, the maximum attainable yield is 5396.6 kg ha⁻¹, and the yield gap attributable to this variable is 827.3 kg ha⁻¹. Similarly, insecticide application at an optimal frequency of 3 times accounted for 1218.6 kg ha⁻¹ of the yield, with a yield gap of 528.1 kg ha⁻¹. Sulfur fertilizer, applied at an optimal rate of 200 kg ha⁻¹, contributed 1439.8 kg ha⁻¹ to the yield, while its associated yield gap was 495.7 kg ha⁻¹. Disking, with an optimal frequency of 5 times, increased yield by 1895.7 kg ha⁻¹, and the yield gap related to this practice was 621.8 kg ha⁻¹. Finally, irrigation applied 13 times contributed 2040.8 kg ha⁻¹ to the yield, with a yield gap of 398.7 kg ha⁻¹.

Table 2. Quantification of Yield Gap in Grain Maize in Shush County

Variable	Coef	Observed		Predicted		Yield gap	
		Average	Max	Average	Best	Yield gap (kg ha ⁻¹)	Yield gap (%)
X ₁		2000	2000	840.67	1668.0	827.3	29
X ₂	0.834	3	3	690.56	1218.6	528.1	18
X ₃	406.211	200	200	944.15	1439.8	495.7	17
X ₄	7.199	5	5	1273.93	1895.7	621.8	22
X ₅	379.147	13	13	1642.05	2040.8	398.7	14
Yield		8734	12000	8685	11557	2872	100

X₁ = poultry manure (kg ha⁻¹); X₂ = number of insecticide applications; X₃ = sulfur fertilizer (kg ha⁻¹); X₄ = number of disking operations; X₅ = number of irrigations.

The coefficient of determination (R²) was found to be 0.92. Additionally, the RMSE value was 471 kg ha⁻¹. These values indicate that the model was highly effective in predicting the actual yield, explaining a large proportion of

the observed yield variability. The high accuracy in yield prediction demonstrates the model's capability to correctly assess the factors affecting production and to accurately estimate the yield gap. Therefore, the model is proposed as

an efficient tool for analyzing and optimizing production conditions.

3.2. Complementary Boundary Line Analysis (BLA) for Key Variables Affecting Grain Maize Yield

To better understand the relationship between grain maize yield and the key management variables identified through the CPA model, Boundary Line Analysis (BLA) was applied to five influential variables: poultry manure application, number of insecticide applications, sulfur

fertilizer application, number of disking operations, and number of irrigations. In this method, scatter plots of yield versus each variable were drawn, and an appropriate function was fitted to the boundary points (representing the maximum yields observed at each level of the variable). The results of this complementary analysis provided deeper insights into crop yield behavior in response to different management practices and helped to identify the optimal input levels or management frequencies.

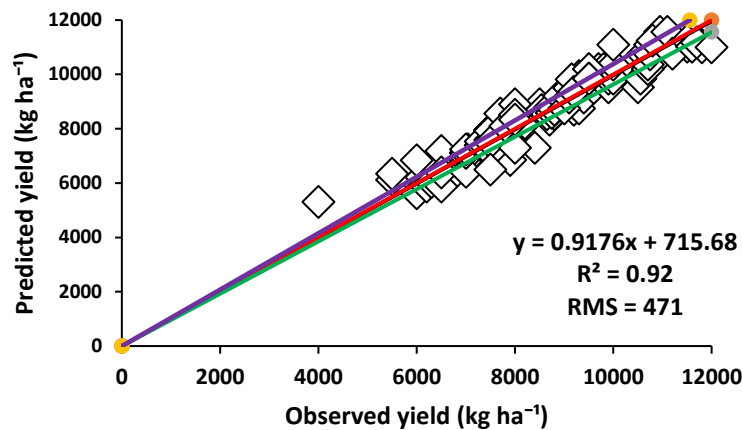


Figure 3. The relationship between observed and predicted yield

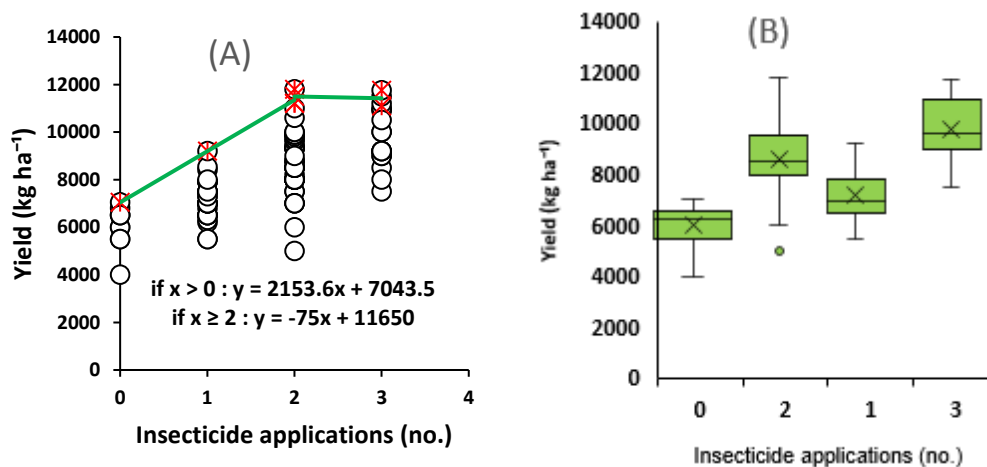


Figure 4. (A): Relationship between maximum yield and number of insecticide applications; (B): Comparison of mean number of insecticide applications in the study area

Poultry manure application: The relationship between grain maize yield and poultry manure application, based on boundary line analysis, revealed that increasing poultry manure up to 1500 kg ha⁻¹ was associated with the highest yield, reaching 12,000 kg ha⁻¹ (Figure 3). In contrast, the lowest yield, 6800 kg ha⁻¹, was observed in fields where no poultry manure was applied. Beyond the application rate of 1500 kg ha⁻¹, further increases in manure had no significant effect on yield. The application rate of 1500 kg ha⁻¹ had the highest frequency among the surveyed fields (28%), whereas 16% of the fields did not use poultry manure at all. These findings confirm the effective and positive role of balanced poultry manure application in enhancing grain

maize yield. The results of this study indicated that insufficient application of poultry manure played a significant role in reducing maize yield. Similar findings were reported by Singh and Prasad (2025), who emphasized that farmers often overlook the nitrogen contribution from poultry manure, leading to suboptimal nitrogen management and reduced crop productivity.

3.3. Number of Insecticide Applications

The boundary line analysis of grain maize yield in relation to the number of insecticide applications indicated that the highest yield, approximately 11,650 kg ha⁻¹, was achieved at the application level of two times (Figure 1).

The lowest yield, about 7000 kg ha⁻¹, was observed in fields with no insecticide use. The trend showed that increasing insecticide applications up to two times led to improved yield; however, beyond this level, no significant changes in yield were detected.

The comparison of mean yields among farms also revealed significant differences across application frequencies, with the most notable difference occurring between zero and two applications. Moreover, the application of insecticides twice was the most common practice, representing 44% of the surveyed fields, and it

was also associated with higher yield levels compared to other application frequencies. In the present study, timely and moderate application of insecticides was associated with higher maize yields. This finding aligns with previous research highlighting the importance of proper pesticide management. For instance, Oyeyemi and Nwagbo (2025) demonstrated that excessive and combined use of insecticides (Dichlorvos, Dimethoate, and Cypermethrin) significantly impaired maize growth and oxidative homeostasis. These findings underscore the importance of balanced insecticide use to enhance crop performance.

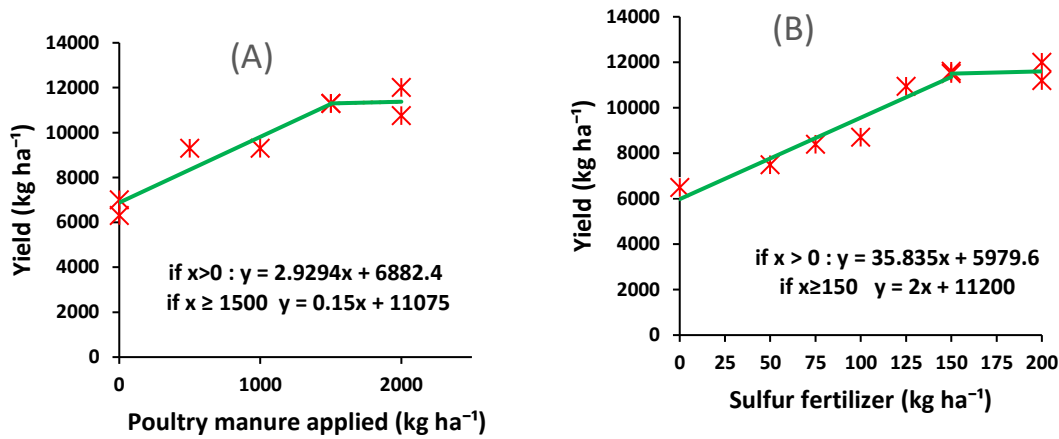


Figure 5. (A): Relationship between maximum yield and poultry manure application; (B): Relationship between maximum yield and sulfur fertilizer application.

Sulfur Fertilizer: The boundary line analysis of the relationship between maize grain yield and sulfur fertilizer application revealed that increasing the sulfur rate up to 150 kg ha⁻¹ was associated with a continuous rise in yield, reaching a maximum of approximately 12,000 kg ha⁻¹ at this level (Figure 5). In contrast, farms that applied lower amounts of sulfur exhibited yields below the average. Moreover, the highest frequency of sulfur application was observed in the range of 150–200 kg ha⁻¹, covering 48% of the surveyed farms. These findings highlight the positive and significant role of appropriate sulfur fertilizer application in enhancing maize grain yield. The results of the present study indicated that insufficient application of

sulfur fertilizer played a significant role in reducing maize yield. Similar findings were reported by Sohrabi et al. (2019), who, in a study conducted under drought stress conditions, observed that sulfur application improved physiological traits such as photosynthesis, relative leaf water content, and reduced membrane damage, ultimately leading to a significant increase in grain yield. Notably, under severe drought stress, sulfur application increased yield by up to 45% compared to the control. These findings highlight the importance of proper nutrient management in improving maize performance, even under adverse environmental conditions.

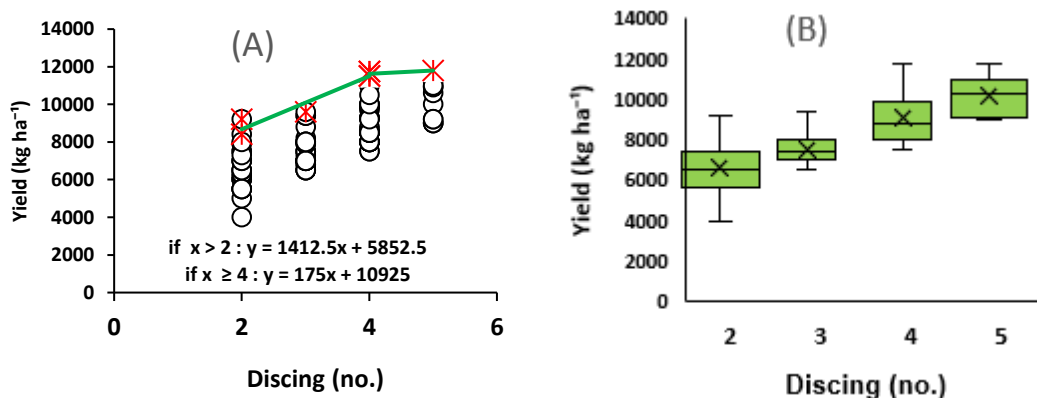


Figure 6. (A): Relationship between maximum yield and number of disking operations; (B): Comparison of the mean number of disking operations in the study area.

Disking Frequency: Based on the boundary line analysis, increasing the number of disking operations up to four times led to improved maize grain yield, reaching a peak of approximately 12,000 kg ha⁻¹ at this level (Figure 5). The lowest yield, around 7000 kg ha⁻¹, was observed in fields with two disking. Further increases beyond four times had no significant effect on yield.

Additionally, the frequency of four disking was the most common among farms, accounting for 36% of the fields, while only 12% of farms applied disking five times. The mean comparison results also confirmed a gradual increase in yield with the rising number of disking operations. According to findings from multiple studies, the frequency of disking as a secondary tillage practice has a significant impact on maize grain yield. A study by Rostami et al. (2012) showed that conventional tillage involving at least two passes with a disk significantly increased maize grain yield compared to reduced tillage or insufficient disking. This improvement was attributed to better soil structure, reduced bulk density, and improved seedbed preparation. These results are consistent with the findings of the present study in Shush County, where

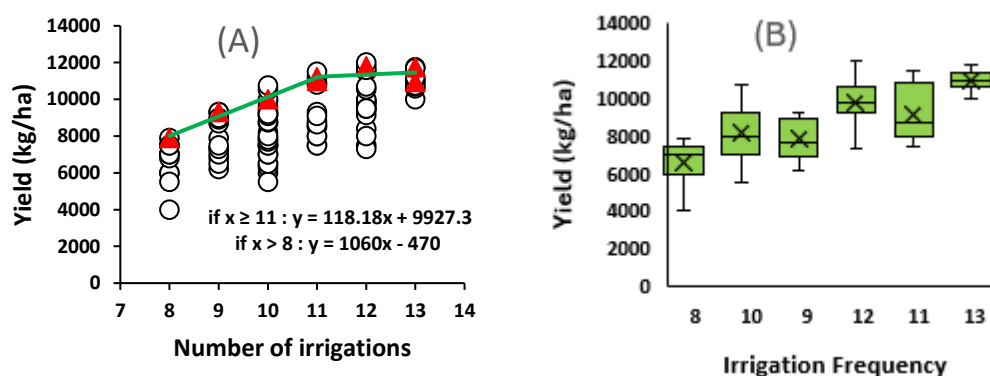


Figure 7. (A): Relationship between maximum yield and number of irrigations; (B): Comparison of the mean number of irrigations in the study area.

4. Conclusion

This study quantified the maize yield gap in Shush County at 2,872 kg ha⁻¹ using Comparative Performance Analysis and Boundary Line Analysis, identifying poultry manure application, insecticide use, sulfur fertilizer, disking frequency, and irrigation scheduling as the main contributors. Beyond reiterating these results, the findings highlight two broader implications. First, organic nutrient management—particularly poultry manure—emerges as a critical but often overlooked lever for closing yield gaps in semi-arid systems. Second, the integration of CPA and BLA provides a complementary framework for diagnosing yield-limiting factors and for designing context-specific interventions.

From a practical standpoint, targeted improvements in fertilizer management, pest control, and irrigation scheduling could substantially increase maize productivity and resource-use efficiency in Khuzestan Province. At the policy level, these results underscore the importance of strengthening extension services to promote balanced input use and knowledge transfer among farmers. Future research should evaluate the economic feasibility of these

farmers who used the disk fewer than two times experienced lower yields due to inadequate soil preparation.

Irrigation Frequency: Results from the boundary line analysis showed that increasing irrigation frequency from 8 to 12 times significantly enhanced maize grain yield, with the maximum yield approximately 12,200 kg ha⁻¹ achieved at 13 irrigations (Figure 9). The lowest yield, averaging around 6800 kg ha⁻¹, was associated with 8 irrigations. Moreover, the mean comparison chart (Figure 10) indicated a statistically significant increase in average yield with more frequent irrigation, although the improvement rate diminished beyond 12 irrigations. The highest frequency of irrigation was 10 times, accounting for 30% of the surveyed farms, which also resulted in a relatively favorable yield. The findings of this study are consistent with those of Muhumed et al. (2014), who reported that increasing drip irrigation frequency, particularly in combination with poultry manure, significantly improved dry matter accumulation and yield components of sweet corn.

interventions, explore their environmental sustainability, and test their applicability under changing climatic conditions.

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