Exploring the impact of rainfall and irrigation on rabi and kharif crops yields: A regression analysis of Rajasthan (2000-2024)

[1]GAGAN TANWAR, [2]Dr. H.N. KOLI

[1]Research Scholar, [2]Professor,

[1]Department of Geography, Government Arts College, Kota, University of Kota,

Kota, Rajasthan, India.

[1]Geetanjali1911@gmail.com, [2]hnkoligck@gmail.com

Abstract

Agriculture in Rajasthan is generally rainfed and monsoon season is very short. This paper investigates the dynamic relationship between climatic and hydrological variables—specifically rainfall and irrigation—and the yield patterns of major Rabi (Wheat and Mustard) and Kharif (Bajra and Groundnut) crops in Rajasthan over a 25-year period (2000–2024). Through the application of multiple linear regression analysis, the study quantifies the extent to which fluctuations in rainfall and irrigated area contribute to crop yield variations. The results presented underline the need for region-specific crop planning and targeted irrigation management strategies, particularly in Rajasthan's arid and semi-arid region of agro-climatic zones. This study provides empirical evidence for enhancing agricultural resilience and optimizing resource use in the face of climate variability.

Keywords: Forecasting, Irrigation, Crop yields, Rabi crops, Kharif crops, regression analysis

INTRODUCTION

Agriculture in Rajasthan contributes 26.76% to Rajasthan's Gross Value added at current price. This region is highly delicate to climatic factors, particularly to rainfall, due to its arid and semi-aridity nature. The state experiences high inter-annual variability in rainfall, which poses significant challenges to crop productivity. Given the growing uncertainties caused by climate change, there is an urgent need to understand how variations in rainfall and irrigation patterns affect the yields of major crops. This research focuses on four major crops cultivated in Rajasthan: Rabi season crops – wheat and mustard, and Kharif season crops – bajra (pearl millet) and groundnut. These crops are essential for food security, economic development, and rural livelihoods. By applying regression analysis over a 25-year dataset (2000-2024), we aim to identify the critical determinants of crop yield fluctuations and explore predictive relationships that can inform future agricultural planning.

STUDY AREA

Rajasthan, the largest state in India by area, lies in the northwestern part of the country between 23°3'N to 30°12'N latitude and 69°30'E to 78°17'E longitude. It is characterized by a predominantly arid and semi-arid climate, with large spatial and temporal variability in rainfall and a heavy dependence on irrigation for agriculture. This climatic diversity makes Rajasthan a compelling case for studying the influence of rainfall and irrigation on crop productions. Rajasthan's economy, employing over 60% of its population. Agriculture and allied sectors contributed approximately 24–26% to Rajasthan's Gross State Value Added (GSVA) in recent years. The sector provides direct and indirect employment to over 60% of the state's population. Major crops: Wheat, Bajra, Mustard, Groundnut, Gram, and Barley. Rajasthan ranks: 1st in mustard production in India and 2nd in coarse cereals (like Bajra). There is a increased use of drip and sprinkler irrigation in Rajasthan. Government schemes like PM-KISAN, Soil Health Cards, and Sub-Mission on Agriculture Mechanization support farmers in both state and country. Climate variability and water scarcity pose ongoing challenges, particularly in Rajasthan. Rajasthan has witnessed significant growth in irrigation infrastructure, especially after the 1990s. The gross irrigated area has increased substantially, largely due to the proliferation of tubewells and canal networks. However, dependence on erratic rainfall continues in many parts, making wheat yield vulnerable to monsoon fluctuations. This variability offers a crucial basis for evaluating the correlation between rainfall, irrigation availability, and wheat yield trends.

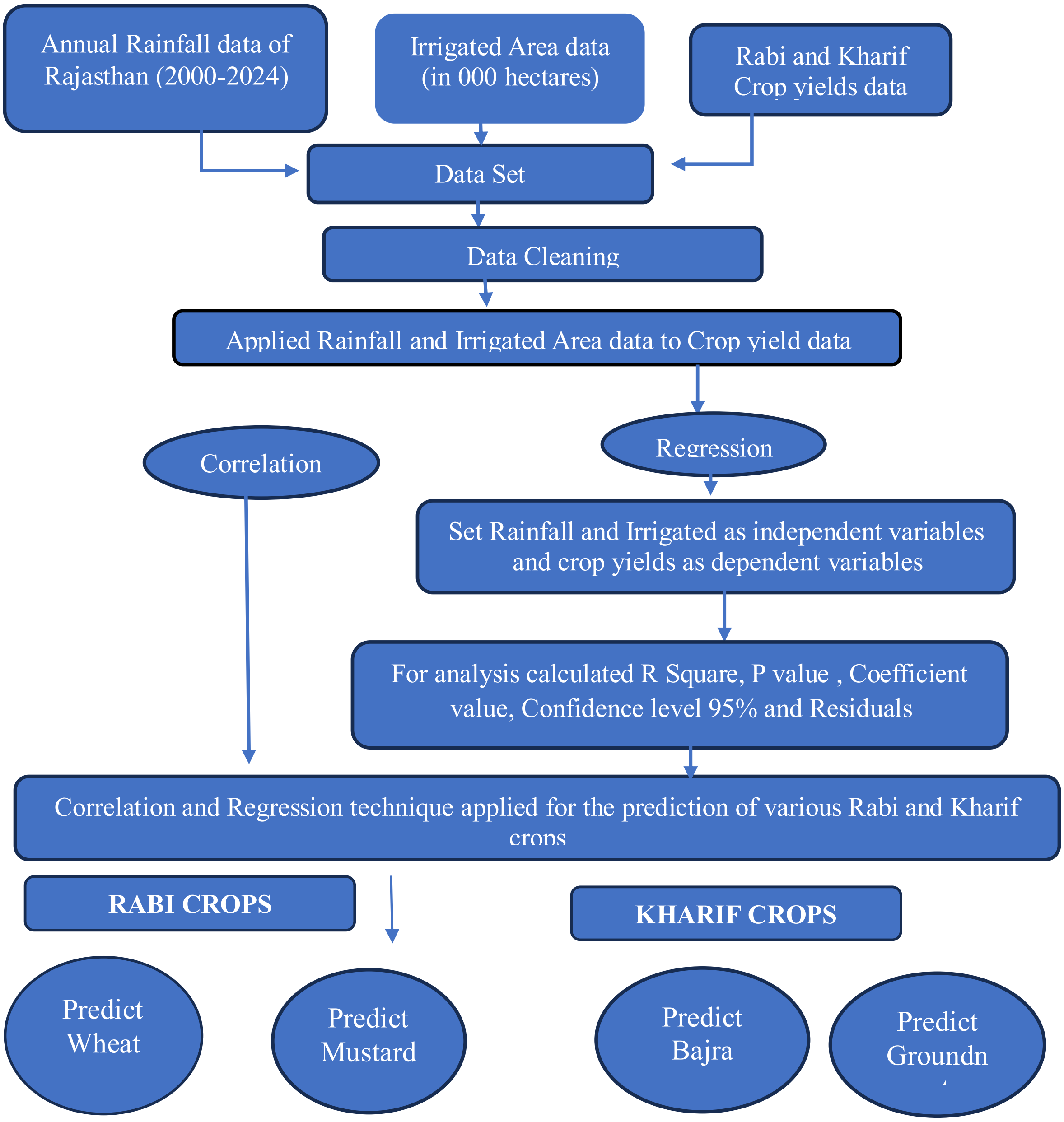
OBJECTIVES

1. To assess the influence of rainfall and irrigated area on the yield of major Rabi (wheat and mustard) and Kharif (bajra and groundnut) crops.
2. To use multiple regression models for forecasting crop yields based on rainfall and irrigated area variables.

METHODOLOGY

The study relies on secondary data of 25 years (2000 – 2024) from government sources including Department of Agriculture Rajasthan, India Meteorological Department (IMD) and Directorate of Economics and Statistics, Rajasthan. The data includes:

- Annual rainfall (in cm)
- Irrigated Area (in 000 hectares)
- Crop yield for Wheat, Mustard, Bajra, and Groundnut (in kg/hectare)



ANALYSIS, RESULTS and DISCUSSIONS

I. RABI CROPS: Correlation Analysis of Wheat yield and Mustard Yield

Wheat indicates a moderate positive correlation with rainfall (r= 0.54). Explains higher rainfall generally leads to increased wheat yield, though other factors may also influence yield outcomes. While the irrigated area contributes towards strong positive correlation (r=8.1). Suggesting that expansion of irrigation significantly enhances wheat production. Irrigation appears to be a more influential factor than rainfall. A moderate correlation (r=0.43) between Mustard yield and rainfall indicating that rainfall has some influence on mustard yield, but the relationship is not very strong. A perfect positive correlation (r=1) is shown, which is highly unusual in natural datasets. This may indicate a data artefact or an overly linear relationship, but if accurate, it suggests mustard yield is almost entirely dependent on irrigation availability.

Irrigation plays a stronger role than rainfall in determining both wheat and mustard yields**,** especially for mustard. Rainfall still has a moderate influence, especially in less irrigated or dryland areas. The findings support a policy focus on irrigation infrastructure development to stabilize Rabi crop production.

Table 1: Correlation Analysis: Wheat yield and Mustard Yield with Rainfall and Irrigated Area

	RAINFALL (IN CM)	***Irrigated Area (in 000 hectares)***	***WHEAT***
RAINFALL (IN CM)	1.00		
Irrigated Area (in 000 hectares)	0.64	1.00	
WHEAT YIELD	0.54	0.81	1.00
	RAINFALL (IN CM)	***Irrigated Area (in 000 hectares)***	***MUSTARD***
RAINFALL (IN CM)	1.00		
Irrigated Area (in 000 hectares)	0.56	0.58	1.00
MUSTARD YIELD	0.43	1.00	

Table 2: Regression Summary for Wheat and Mustard (2000–2024)

Crop	***R^2***	***Adjusted R^2***	***Coefficient (Rainfall)***	***P-value (Rainfall)***	***Coefficient (Irrigation)***	***P-value (Irrigation)***
Wheat	0.657	0.626	1.49	0.823	0.76	< 0.001
Mustard	0.452	0.402	21.93	0.041	1.21	0.026

Prediction of wheat Yield:

From table 1 and 2, the correlation and regression analysis for wheat indicates a moderately strong model ($R^2 = 0.657$), with irrigated area emerging as a statistically significant predictor ($p < 0.001$). The coefficient of irrigation (0.76) shows that with every additional 1,000 hectares of irrigated land, wheat yield increases by approximately 760 kg/hectare. In contrast, figure 1, rainfall was not found to be a significant contributor ($p = 0.823$), suggesting that wheat in Rajasthan relies more heavily on assured irrigation rather than natural precipitation denoted from figure 2. This trend aligns with Rajasthan's agro-ecological profile where wheat cultivation is concentrated in canal- and tube-well-irrigated zones.

Fig. 1- Showing relation between rainfall and wheat Yield

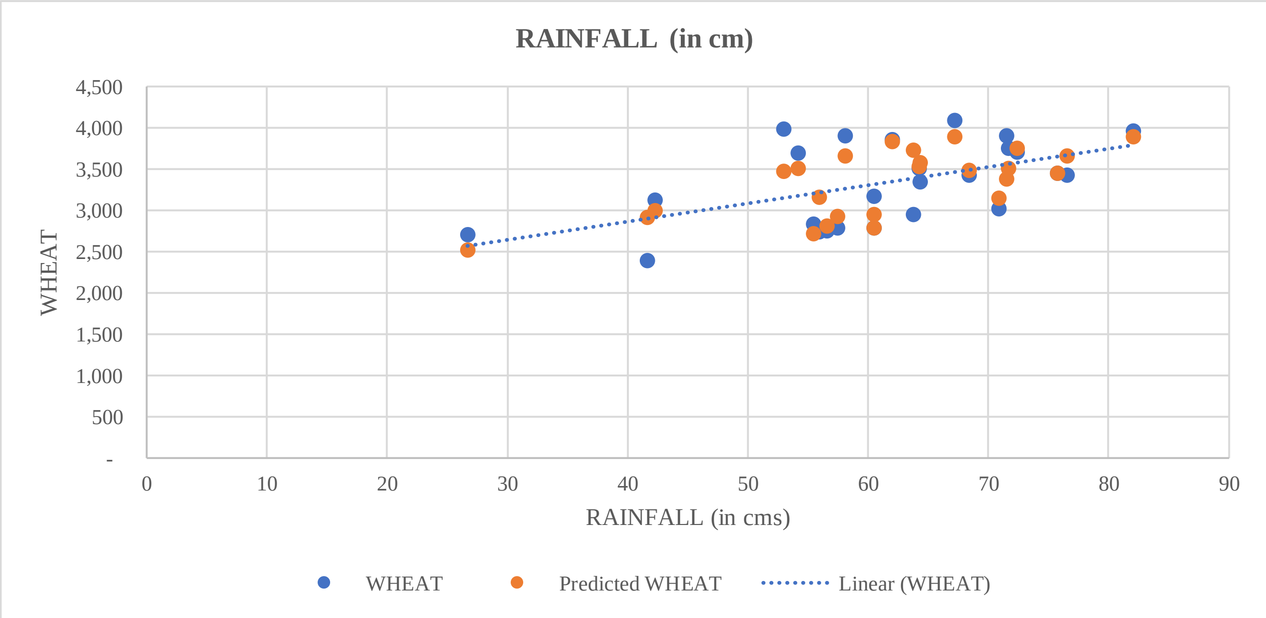
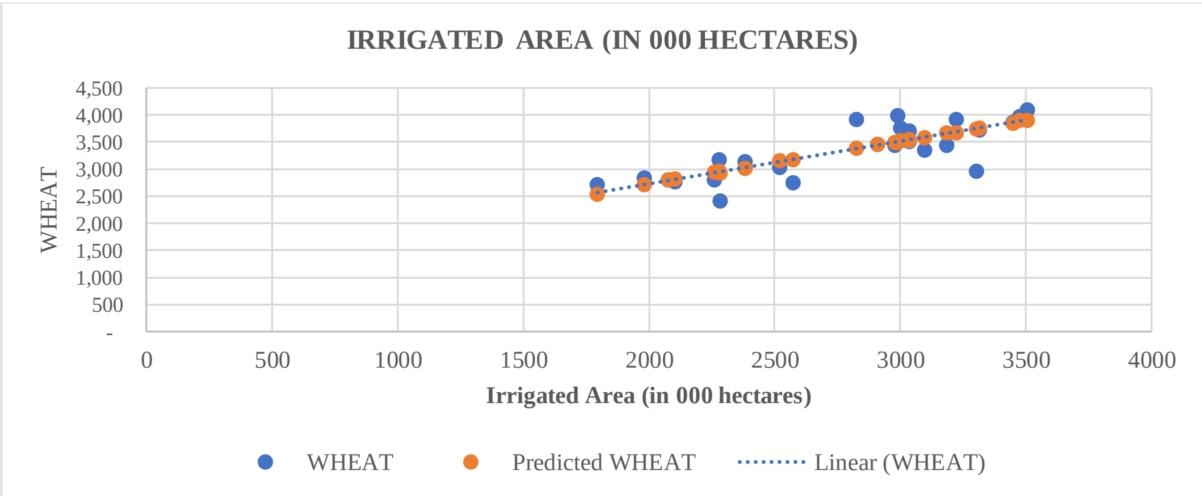


Fig. 2: Showing line fit plot between irrigated area and wheat Yield.



Prediction of Mustard Yield

From table 2, Mustard yield displays a lower explanatory power ($R^2 = 0.452$), yet both rainfall and irrigation show statistical significance. Rainfall's coefficient (21.93) and p-value (0.041) indicate a meaningful impact, while irrigation also contributes positively with a coefficient of 1.21 ($p = 0.026$). Figure 3, suggests that mustard is moderately influenced by both natural and controlled water sources, making it a relatively resilient crop under semi-irrigated conditions. The dual sensitivity of mustard yield to both rainfall and irrigation underscores the need for integrated water resource planning.

Fig. 3: Showing line fit plot between irrigated area and Mustard Yield.

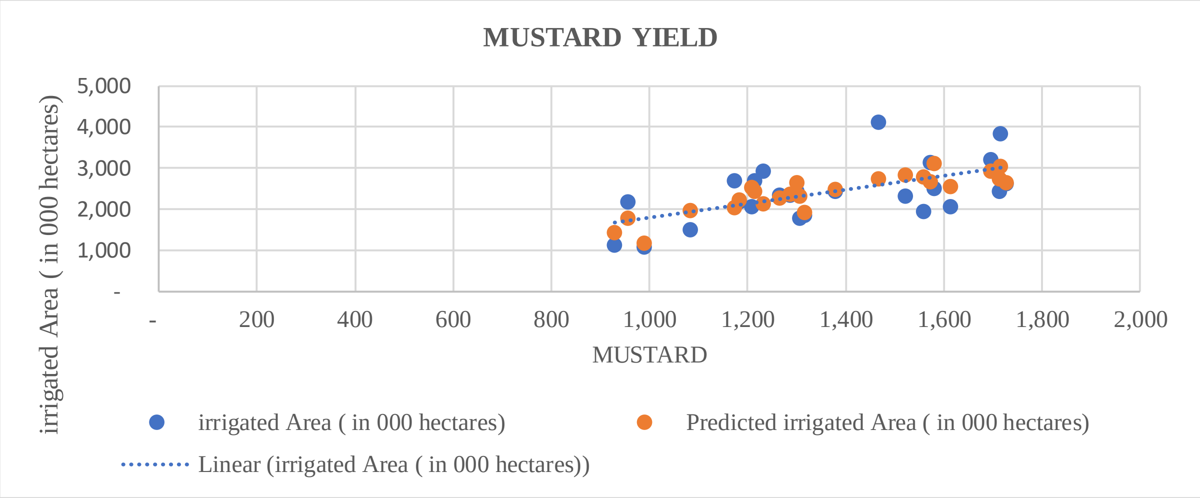


Table 3: Regression Summary for Bajra and Groundnut (2000–2024)

Crop	*R^2*	*Adjusted R^2*	*Coefficient (Rainfall)*	*P-value (Rainfall)*	*Coefficient (Irrigation)*	*P-value (Irrigation)*
Bajra	0.641	0.609	16.71	< 0.001	-1.71	0.033
Groundnut	0.872	0.861	15.07	< 0.001	1.41	< 0.001

II. KHARIF CROPS: Correlation Analysis of Bajra yield and Groundnut Yield

From table 3 and 4, the correlation analysis reveals distinct patterns in how rainfall and irrigation affect the yields of Bajra and Groundnut**,** two important Kharif crops in Rajasthan. For Bajra**,** the correlation between rainfall and yield is strongly positive (r = 0.75)**,** indicating that rainfall plays a critical role in influencing its productivity. In contrast, the correlation between irrigated area and Bajra yield is moderately negative (r = -0.42)**,** suggesting that increased irrigation may not contribute positively to Bajra yield and might even be associated with lower outputs. This could be due to the fact that Bajra is traditionally a rainfed crop, well-suited to arid climates and grown in areas where irrigation is either limited or unnecessary. Additionally, the weak negative correlation between rainfall and irrigation (r = -0.18) for Bajra suggests minimal overlap in their spatial or temporal application.

On the other hand, Table 3 and 4, on Groundnut shows a different trend. There is a strong positive correlation between groundnut yield and rainfall (r = 0.70)**,** as well as an even stronger positive correlation with irrigated area (r = 0.86)**.** This clearly implies that both rainfall and irrigation substantially contribute to increased groundnut production, with irrigation playing a more dominant role**.** The moderate positive correlation between rainfall and irrigated area (r = 0.45) for groundnut suggests that in better rainfall years, more irrigation resources are either available or effectively utilized. Overall, these patterns highlight the crop-specific responses to climatic and water variables—where Bajra is primarily rainfall-dependent and less responsive to irrigation, while Groundnut benefits significantly from both water sources, especially supplemental irrigation.

Table 4: Correlation Analysis: Bajra yield and Groundnut Yield with Rainfall and Irrigated Area

	RAINFALL (IN CM)	***Irrigated Area (in 000 hectares)***	***BAJRA***
RAINFALL (IN CM)	1.00		
Irrigated area (in 000 hectares)	-0.18	1.00	
BAJRA YIELD	0.75	-0.42	1.00
	RAINFALL (IN CM)	***Irrigated Area (in 000 hectares)***	***GROUNDNUT***
RAINFALL (IN CM)	1.00		
IRRIGATED AREA (in 000 hectares)	0.45	1.00	
GROUNDNUT YIELD	0.70	0.86	1.00

Prediction of Bajra Yield:

The regression model for bajra, Figure 4 and 5 - shows that rainfall is the most significant factor influencing its yield. With an R^2 of 0.641 and a rainfall coefficient of 16.71 ($p < 0.001$), the crop is highly responsive to variations in monsoon patterns. Interestingly, irrigation has a negative coefficient (-1.71), indicating that excess irrigation may adversely affect bajra productivity. This aligns with bajra's traditional role as a drought-tolerant, rainfed crop in Rajasthan. The results advocate for rainwater management rather than irrigation expansion for enhancing bajra productivity.

Fig. 4: Showing line fit plot between Rainfall and Bajra Yield

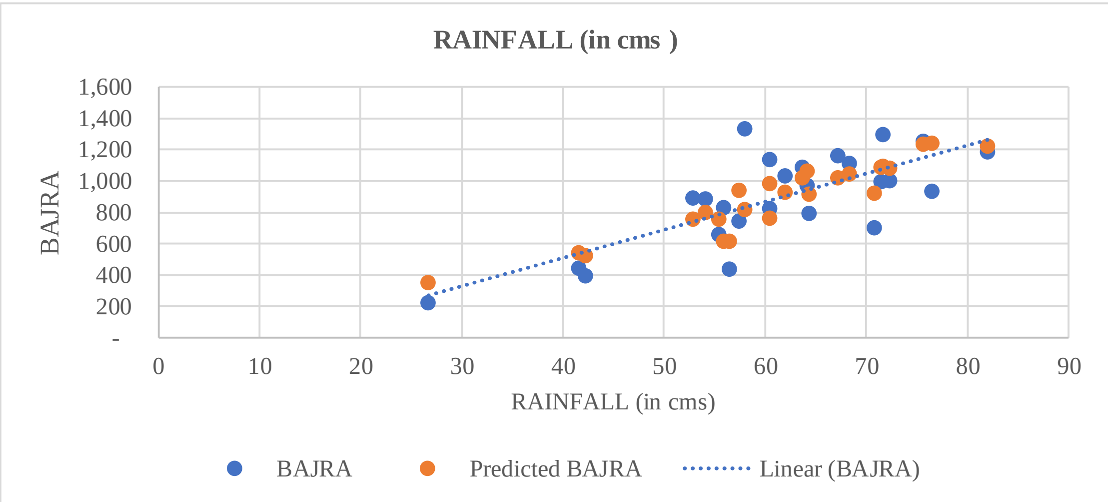
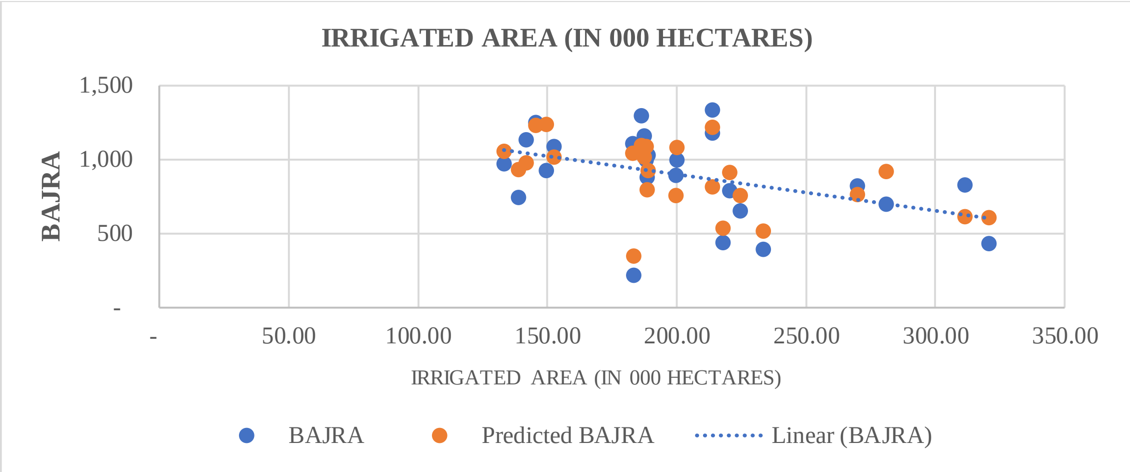


Fig. 5: Showing line fit plot between Irrigated area and Bajra Yield

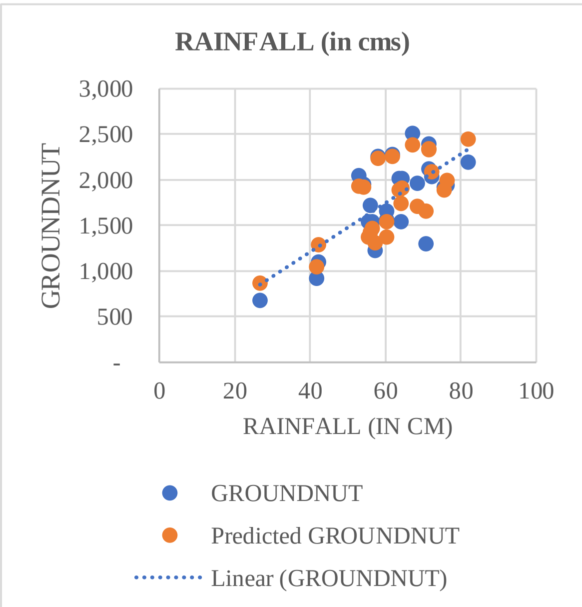


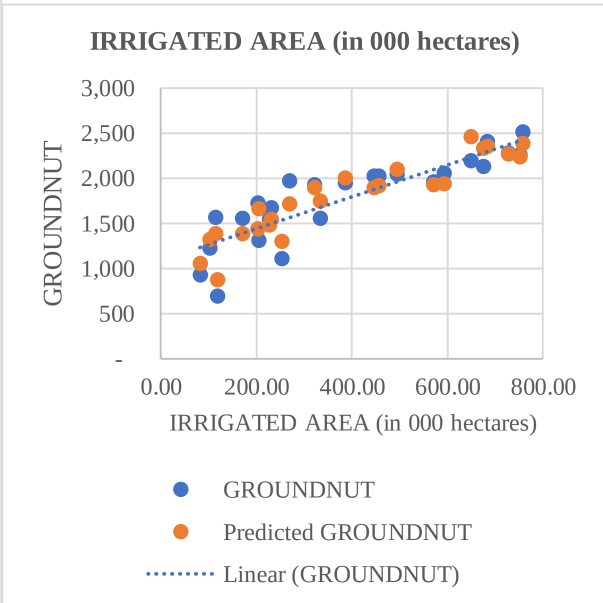
Prediction of Groundnut Yield:

Figure 6 and 7, demonstrates groundnut's the strongest model performance among all crops with an R^2 of 0.872. Both rainfall (coefficient = 15.07) and irrigation (coefficient = 1.41) are highly significant ($p < 0.001$), with irrigation playing a slightly stronger role. This suggests groundnut yield benefits from a combination of adequate monsoon rains and supplemental irrigation. Groundnut's high model fit underscores the importance of water availability and effective irrigation scheduling during the Kharif season. These findings can inform irrigation policies for oilseed crops in semi-arid zones.

Fig.6 Showing line fit plot between Rainfall and Groundnut Yield

Fig.7 Showing line fit plot between irrigated area and Groundnut Yield





CONCLUSION

This study concludes that both rainfall and irrigation are critical determinants of crop yields in Rajasthan, but their influence varies across crop types. Rabi crops such as wheat are more dependent on irrigation, while Kharif crops like bajra are more sensitive to rainfall. Groundnut exhibits dual dependency with strong influence from irrigation. These findings highlight the need for crop-specific planning strategies under climate variability. Policymakers should prioritize irrigation infrastructure for Rabi crops while enhancing rainwater harvesting and moisture conservation techniques for Kharif crops. Future research could integrate remote sensing data and explore non-linear models or machine learning approaches for more precise yield forecasting in Rajasthan's agro-climatic zones.

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