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Resources Use Efficiency and Resources Utilization Efficiency of Major Crops in North Gujarat, India

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Authors' contributions

This work was carried out in collaboration among all authors. Author UBP designed the study, performed the statistical analysis, developed the protocol and drafted the manuscript. Author AL guided the entire study, while authors PMP and RJ managed and reviewed the statistical analyses. Author MP edited and formatted the research draft. All authors read and approved the final manuscript.

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ABSTRACT

A study was examined to resource use efficiency and resources utilization efficiency of major crops in North Gujarat. Utilizing both canal and tube-well irrigation systems. Cobb-Douglas production function and MVP/MFC ratio was used for calculation of resources use efficiency and resources

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utilization efficiency, respectively. Primary data were collected from 160 respondents with the pretested interview schedule during 2023-24. The research revealed that, nitrogen, phosphorus and machinery as pivotal resources influencing yield outcomes. In wheat production, nitrogen and phosphorus had significant positive effects on yield in canal-irrigated fields, while over-irrigation negatively impacted tube-well-irrigated yields. Cotton analysis highlighted nitrogen's positive yield impact under tube-well irrigation in Mehsana, while excessive machinery uses reduced productivity across both irrigation types. For castor, nitrogen and phosphorus boosted yield in canal-irrigated systems, although machinery use adversely affected output, particularly in Patan. Labor was found to positively influence castor yield under tube-well irrigation, underscoring the need for balanced mechanization. Higher R^2 values in Mehsana and Patan showed a robust model fit. Overall, the resources utilization efficiency revealed that, major input such as nitrogen, phosphorus and machinery was underutilization in selected crops and irrigation and labour was found as over-utilization. Therefore, the research suggests that increasing the use of underutilized inputs and reducing the use of overutilized resources could improve production, farm management and cost-effectiveness

Keywords: Resources use efficiency; resources utilization efficiency; wheat; cotton; castor.

1. INTRODUCTION

The Indian agriculture sector provides livelihood support to about 42.3 per cent of the population and has a share of 18.2 per cent in the country's GDP at current prices. The sector has been buoyant, which is evident from the fact that it has registered an average annual growth rate of 4.18 per cent at constant prices over the last five years. The growth rate of the agriculture sector stood at 1.4 percent. (Economics Survey, 2023-24) In the wake of food shortages, food security was assigned top priority.

Efficiency in food production largely depends upon extent of management of different resources (Daud & Shiyani, 2018; Thakur et al., 2016). Hence the question of allocation of resources needs to consider sustainability, resource use efficiency and optimization of crop plans across regions for production environments management. With the increasing population coupled with progressive shrinkage of arable land reducing the per capita agricultural land availability, crop intensification has become a rule than an exception. Growing stress on water availability, commercialization of production, higher use of energy and other purchased inputs in agriculture necessitate optimum use of resources and reallocation of production choices.

Efficient resource use in agriculture is crucial for enhancing farm production and income (Devi et al., 2020; Malviya, 2016). Key inputs, such as manures and fertilizers, irrigation, manpower, seeds, labour, working capital, farm machinery, and crop protection are play vital roles in productivity (Jayapradha et al., 2020). Farm income largely depends on how effectively farmers manage these limited resources (Gautam et al., 2017). By maximizing efficiency in the use of scarce inputs, farmers can significantly increase their income and savings (Jaiswal et al., 2017).

This study is aimed to exploring the profitability of major crops in North Gujarat as particular through estimation of resource use efficiency and resources utilization efficiency as reflected by production function analysis.

2. METHODOLOGY

To achieve the objectives of the present study the random sampling technique was used for the selection of respondents form study area. A comparative study was conducted to investigate the impact of water users of canal irrigation and tube well irrigation on resources use efficiency and resource utilization efficiency. The study was conducted North Gujarat regions. which was purposively selected. North Gujarat is characterized by low rainfall (average 555 mm) with a high rate of water depletion compared to other regions. According to the Central Ground Water Authority, Ministry of Jal Shakti, Department of Water Resources, River Development and Ganga Rejuvenation, New Delhi, the Mehsana, Banaskantha and Patan districts are categorized as over-exploited groundwater in terms of ground water. Therefore, the Mehsana and Patan districts were purposely selected from North Gujarat. Two water user associations were randomly selected from each district. Thus, a total four water user associations were selected for the study. The Kansa and

Kiyadar irrigation cooperative society were chosen for study. Twenty farmers were randomly selected from each water users' association and an additional 20 farmers were chosen from other sources of irrigation who were not associated with any water users' association. Therefore, a total sample size of 160 respondents were selected for the study. Additionally, three crops, Wheat, Cotton and Castor crops were purposively selected due to their high-water intensity and extensive coverage under water users' associations in this region.

Primary data on various input use such as, labour, seed, FYM, fertilizer, irrigation and machine were collected through selected respondents with a personal interview by help of pre-tested interview schedule.

2.1 Analytical Techniques

2.1.1 Resource use efficiency

Multiple regression analysis was conducted for examine the resource use efficiency in crop yield/production among farmers in functional and non-functional water users' associations. The monetary values of all these inputs were considered. Resource use efficiency was studied by fitting the Cobb-Douglas production function to the farm-level data. The regression equation per farm is as follows (Darker *et al.*, 2015 and Pawar *et al.*, 2016):

$$Y= a\ X_1^{b1}.\ X_2^{b2}.\ X_3^{b3}.\ X_4^{b4}.\ X5^{b5}.\ X_6^{b6}.\ X_7^{b7}C\ X_8^{b8}.\ e^u$$

In logarithmic form, it assumed a log-linear equation as under:

$$\text{Log } Y = \text{Log } a + b_1 \log x_1 + b_2 \log x_2 + b_3 \log x_3 + b_4 \log x_4 + b_5 \log x_5 + b_6 \log x_6\ b_7 \log x_7 + b_8 \log x_8 + u \log e$$

Where,

Y = Yield (per ha)
X_1 = Labour, X_2 = Seed, X_3 = Farm yard manure (FYM), X_4= Nitrogen, X_5 = Phosphorus, X_6 = Potash, X_7 = Irrigation, X_8 = Machine
a = Constant/ intercept term
u = Random variable

Similarly, b1 to b8 regression coefficients of respective inputs. The coefficients of multiple determination (R^2) were worked out to test the goodness of fit of the model.

2.1.2 Resource utilization efficiency

RUE was assessed by examining how effectively resources such as, labor, seed, FYM, fertilizer, irrigation and machine were utilized in the production of these crops. Resources utilization efficiency measured by comparing the marginal value product to marginal factor cost and the ratio greater than one indicates under-utilization of resources. Whereas, a ratio less than one suggests over utilization of resources.

The Marginal Value Products (MVPs) of the individual resource was estimated and compared with the Marginal Factor Cost (MFC) was estimated by using the following formula (Choudhri et al., 2023),

Marginal Value Product (MVP) of $\mathbf{X_1} = \mathbf{b_i} \times \frac{\bar{\mathbf{X}}}{\bar{\mathbf{Y}}} \times \mathbf{P_y}$

Where,

b_i = Elasticity of production of i^{th} input
$\bar{Y}$ = Geometric mean of output
$\bar{X}$ = Geometric mean of i^{th} input
P_y = Per unit price of input (₹)

The economic efficiency of resource used was determined by using the MVP and MFC ratio. The estimated coefficients were used to compute the MVP and its ratio (r) with MFC.

The model used for estimation of r was as follows: $\mathbf{r} = \frac{\mathbf{MVP}}{\mathbf{MFC}}$

Where,

r = Efficiency ratio
MVP = Marginal Value Product of variable inputs
MFC = Marginal Factor Cost (Considering as 1)

3. RESULTS AND DISCUSSION

3.1 Resources Use Efficiency

Resource use efficiency refers to how effectively farmers utilize their resources in the production process (Kumar et al., 2018). It is crucial to ensure efficient use of resources because they are always limited. This study analysed the resource use efficiency of three crops i.e., wheat, castor, cotton was represented in Tables 1 to 6.

3.1.1 Resources use efficiency for wheat in Mehsana and Patan districts

Resource use efficiency of wheat in Mehsana and Patan districts are given in Table 1. The result revealed that for Mehsana district regarding water users of canal irrigation, nitrogen was positive and significant at 1 per cent level with coefficient of 1.015, indicating a highly positive impact on wheat yield. Other variables, including seed, FYM (farmyard manure), phosphorus and machine use had a positive effect on wheat yield but were statistically non-significant. In contrast, only two variables, labour and irrigation had a negative effect on wheat yield. For tube-well irrigation, phosphorus and machine use were positive and significant at the 1 percent level with coefficients of 0.578 and 0.155, respectively. However, the irrigation variable was negatively significant at the 5 percent level, suggesting that over-irrigation might reduce yield. Conversely, nitrogen had a positively significant effect on wheat yield at 10 per cent level under tube-well irrigation.

In case of Patan district, under water users of canal irrigation, the results show that nitrogen and phosphorus were highly significant and positive impact on wheat yield at the 1 per cent level with coefficients of 0.477 and 0.420, respectively. While other variables, such as labour, seed, FYM and machine use have positive effects on wheat yield but statistically non-significant. Whereas irrigation has a negative non-significant effect on wheat yield. In case of tube-well irrigation, the results show that seed, phosphorus and machine use were positively significant at the 10 percent level. Whereas FYM, nitrogen and irrigation had a negative but non-significant effect on wheat yield.

Overall analysis concluded that for Mehsana district R^2 values were 0.85 for canal irrigation and 0.80 for tube-well irrigation, indicating that the model explained a substantial portion of yield variability. In case of Patan district R^2 values were 0.79 for canal irrigation and 0.69 for tube-well irrigation. It reflects from the table that the irrigation variable was negatively impacting on the wheat yield and significantly in Mehsana, it revealed that over utilization of resources.

3.1.2 Resources use efficiency of wheat in North Gujarat

Table 2 presented by resources use efficiency of wheat crop in North Gujarat. In canal irrigation, the results reveal that nitrogen and phosphorus highly positive and significantly at the 1 per cent level to enhance wheat yield. While the irrigation variable shows a positive significant effect at 10 per cent. Although labour, seed, FYM and machine use had positive but statistically non-significant effects on wheat yield. In case of tube-well irrigation, phosphorus and machine use have significant positive impacts on wheat yield at the 1 per cent level. While the irrigation variable has a significant negative effect at the 5 per cent level, suggesting that over-irrigation may reduce yield. However, labour and nitrogen showed positive effects but they are statistically non-significant. Were, FYM showed negatively non-significant effect on wheat yield.

The R^2 values were 0.80 for canal irrigation and 0.69 for tube-well irrigation, indicating that the models explained a substantial portion of the yield variability. Nitrogen was the most significant input under canal irrigation, while phosphorus and machine use were particularly important under tube-well irrigation. Excessive irrigation under tube-well systems could negatively impact yield. The results revealed that, wheat users of canal irrigation were positively and significant impacting on wheat yield with tube well irrigation was negatively and non-significant impact in wheat yield. Similar results also found by Ahmad *et al.* (2018) and Verma *et al.* (2023).

3.1.3 Resources use efficiency of cotton in Mehsana and Patan districts

The resource use efficiency of cotton in Mehsana and Patan districts were illustrated in Table 3. In Mehsana district, the analysis of cotton cultivation under water users of canal irrigation revealed that, machine use had a significant negative impact at the 1 per cent level with a coefficient of -0.959. While, FYM and nitrogen had positively significant effects on cotton yield. Whereas phosphorus and irrigation had positively but non-significant effects.

For tube-well irrigation, nitrogen had highly significant positive effects on cotton yield, with coefficients of 0.580. while phosphorus and irrigation had positively significant effect at 5 per cent level on cotton yield. Labour and FYM also had positive effects, while seed and machine use had negative impacts, with coefficients of 0.392, 0.038, -0.026 and -0.109, respectively. The R^2 values for canal and tube-well irrigation systems were 0.63 and 0.59, respectively, indicating that the model explained a larger portion of the variability in productivity under canal irrigation compared to tube-well irrigation.

In Patan district, canal irrigation results indicated that nitrogen had a highly significant positive impact at the 1 per cent level with a coefficient of 1.095, In contrast, Machine use had a significant negative impact at the 1 per cent level with a coefficient of -0.380. While irrigation showed significance at the 5 per cent level with a coefficient of 0.345. Under tube-well irrigation, nitrogen had significant positive effect at the 1 per cent level, with a coefficient of 0.876. While, FYM had positive and statistically significant effects at 10 per cent level on cotton yield. In contrast machine use had negatively significant effect at 10 per cent level. The R^2 values were 0.60 for canal irrigation and 0.67 for tube-well irrigation, demonstrating the model's effectiveness in explaining variations in cotton yield. These results highlight the critical role use nitrogen and irrigation management will increase yield and the need for reduces the machine use to optimize cotton productivity in Patan district.

3.1.4 Resources use efficiency of cotton in North Gujarat

Resources use efficiency of cotton in North Gujarat are presented in Table 4. In water users of canal irrigation, nitrogen has a highly significant positive effect at 1 per cent with a coefficient of 0.414. In contrast machine use was significantly negatively impacts on yield at 1 per cent with a coefficient of -0.421. While FYM and irrigation had significant positive effect at 10 per cent on cotton yield. Whereas, labour, seed and phosphorus had positive but statistically not significant effects. The model explains 49 per cent of the variability in cotton yield. For tube-well irrigation, labour and nitrogen both have highly significant positive effects at 1 per cent with coefficients of 0.366 and 0.737, respectively, while machine use had negatively significant at 10 per cent. Whereas, FYM, phosphorus and irrigation show positive but statistically non-significant effects. The model explains 53 per cent of the variability in cotton yield, reflecting a moderate fit. Similar results were reported by Satashia *et al.* (2017) Visawadia *et al.* (2005), and Makadia *et al.* (2014).

3.1.5 Resources use efficiency of castor in Mehsana and Patan districts

Table 5 represented of resources use efficiency of water users of canal irrigation for castor in Mehsana and Patan districts. In Mehsana district under, water users of canal irrigation, the analysis of castor cultivation reveals several key insights. Nitrogen and phosphorus have a highly significant positive effect on castor yield with a coefficient of 0.540 and 0.281, respectively. Conversely, machine use significantly negative impacts yield with a coefficient of -0.398. Other variables, including FYM, Potash and irrigation show positive but statistically non-significant effects on yield. While, labour and seed have a negatively non-significant effect. Under tube-well irrigation, Nitrogen has a highly significant positive impact with a coefficient of 0.574. In contrast, machine use also has a highly significant negative effect with a coefficient of -0.533 at 1 per cent. While FYM has negatively significant at 10 per cent level. Other variables, such as seed, phosphorus and potash show positive effects, but they are statistically non-significant. However, labour and irrigation have a negatively non-significant effects on yield. The R^2 values for canal and tube-well irrigation systems were 0.68 and 0.67, respectively, indicating that the models explained a substantial portion of the variance in castor productivity.

In Patan district under water users of canal irrigation, labour has a highly significant positive impact at 1 per cent level on castor yield with a coefficient of 0.712. While, machine use has a significant negative impact with a coefficient of -0.292. Seed, FYM, nitrogen, phosphorus and potash show positive but statistically non-significant effect on castor yield. Irrigation variables was also found non-significant negative effects on castor yield. Under tube-well irrigation, Phosphorus has a highly significant positive impact on castor yield with a coefficient of 0.783 at 1 per cent. Conversely, machine use also has a highly significant negative effect at 1 per cent with a coefficient of -0.037. while potash had negatively significant at 5 % level on castor yield. Whereas, labour, seed and FYM have positive effects on yield but are statistically non-significant. While nitrogen and irrigation had negative and non-significant effect on yield. The R^2 values for castor production in water users of canal irrigation was 0.60 and 0.78 for tube-well irrigation, indicating a good fit, suggesting better resource management under both groups.

3.1.6 Resources use efficiency of castor in North Gujarat

Table 6 showed that, the resource use efficiency analysis of castor cultivation in North Gujarat revealed significant findings under water users of canal irrigation and tube well irrigation. For water users of canal irrigation, the analysis showed that machine use had a highly significant negative impact with 1 per cent level, indicating that mechanization adversely affected productivity. while labour variable has positively significant at 10 per cent level. Whereas, FYM, nitrogen, phosphorus and potash were positive non-significant effect on yield. While seed and irrigation were negatively non-significant effect on castor yield. Under tube-well irrigation, labour was positively highly significant with 1 per cent level with coefficient of 0.236. In contrast, Machine use continued to have a significant negative impact with 1 per cent level. Whereas FYM, potash and irrigation has negatively non-significantly effect. While seed, nitrogen and phosphorus has positively non-significant effect on castor yield. The R^2 values for water users of canal irrigation and tube-well irrigation systems were 0.21 and 0.58, respectively, indicating that the model explained a less substantial portion of the variability in productivity under waters users of canal irrigation. Similar findings were also observed by Kumar *et al.* (2019) and Joshi (2023).

3.2 Resource Utilization Efficiency

RUE was assessed by examining how effectively resources such as, labor, Seed, FYM, Fertilizer, irrigation and machine were utilized in the production of these crops. Resources utilization efficiency measured by comparing the marginal value product to marginal factor cost and the ratio greater than one indicates under-utilization of resources. Whereas, a ratio less than one suggests over utilization of resources (Meher et al., 2022).

3.2.1 Resources utilization efficiency of wheat in Mehsana and Patan districts

Table 7 represents key insights into the resource utilization efficiency in wheat cultivation in the Mehsana district under both canal and tube-well irrigation systems by comparing the marginal value product to marginal factor cost and the ratio greater than one indicates under-utilization of resources. Whereas, a ratio less than one suggests over utilization of resources. In the canal irrigation system, the coefficients for seed (0.015), FYM (0.036), nitrogen (1.015), phosphorus (0.091), and machinery (0.050) are positive, indicating that these inputs positively impact output. The MVP to MFC ratio for these inputs suggests potential under-utilization, especially for nitrogen, where the coefficient is significant at the 1% level. This suggests that increasing the use of inputs, particularly nitrogen could improve productivity. Conversely, the negative coefficients for labour and irrigation under canal irrigation indicate that these inputs currently reduce output. The negative MVPs for labour (-3.36) and irrigation (-0.012) suggest potential over-utilization, and reducing their use could enhance profitability. Under tube-well irrigation, the scenario is different. While the coefficients for seed (0.029), nitrogen (0.249), phosphorus (0.578), and machinery (0.155) are positive and significantly influence output, the MVP values indicate under-utilization, particularly for phosphorus and machinery, where the coefficients are significant at the 1% level. Increasing these inputs could lead to higher output. On the other hand, labour and irrigation inputs again show negative coefficients under tube-well irrigation, with negative corresponding MVP/MFC value which indicates over-utilization of these inputs. Therefore, it indicates that reducing the use of these inputs could optimize resource use and improve economic returns. Overall, the findings suggest that farmers should consider reallocating their resources by increasing under-utilized inputs like seeds, nitrogen, phosphorus, and machinery, while reducing over-utilized inputs like labour and irrigation.

Further in case of Patan district, the results of detailed analysis of resource utilization efficiency in wheat cultivation by comparing canal and tube-well irrigation systems was depicted in Table 4. From the results, it can be seen that, under canal irrigation, positive coefficients are observed for labour (0.120), seed (0.114), FYM (0.051), nitrogen (0.477), phosphorus (0.420), and machinery (0.030), suggesting these inputs contribute positively to output. Notably, nitrogen and phosphorus, with significant coefficients at the 1% level, indicate substantial under-utilization reflected by the ratio of MVP to MFC, which was 2.27 and 17.09, respectively. This implies that increasing the usage of these inputs, particularly nitrogen and phosphorus, could enhance yield and profitability. In contrast, irrigation shows a negative coefficient (-0.007) under canal irrigation, with a corresponding negative MVP/MFC, suggesting that this input was over-utilized. Hence, it was concluded that reduction in irrigation use could optimize resource allocation and improve overall efficiency. Looking to the tube-well irrigation, positive coefficients for

Table 1. Resources use efficiency of wheat in Mehsana and Patan districts (n=40)

Sr. No	Variables	Mehsana						Patan					
		Water users of canal Irrigation			Tube-well Irrigation			Water users of canal Irrigation			Tube-well Irrigation		
		Coefficients	Standard Error	t Stat	Coefficients	Standard Error	t Stat	Coefficients	Standard Error	t Stat	Coefficients	Standard Error	t Stat
1	**Intercept**	-0.731	0.320	-2.282	0.529	0.793	0.667	-0.727	0.335	-2.167	-0.620	0.811	-0.765
2	**labour**	-0.019	0.049	-0.397	-0.080	0.064	-1.260	0.120	0.080	1.503	0.081	0.131	0.620
3	**Seed**	0.015	0.072	0.203	0.029	0.171	0.168	0.114	0.102	1.118	0.685*	0.384	1.784
4	**FYM**	0.036	0.062	0.577	-0.079	0.187	-0.422	0.051	0.034	1.513	-0.050	0.073	-0.678
5	**Nitrogen**	1.015***	0.127	8.014	0.249*	0.126	1.984	0.477***	0.150	3.183	-0.025	0.254	-0.099
6	**Phosphorus**	0.091	0.081	1.128	0.578***	0.202	2.869	0.420***	0.127	3.307	0.512*	0.277	1.849
7	**Irrigation**	-0.012	0.061	-0.197	-0.189**	0.086	-2.191	-0.007	0.041	-0.176	-0.163	0.123	-1.324
8	**Machine**	0.050	0.047	1.053	0.155***	0.055	2.807	0.030	0.024	1.272	0.145*	0.084	1.713
	R^2	0.85			0.80			0.79			0.69		

*Note: ***, ** and * represent significant at 1%, 5% and 10%, respectively*

Table 2. Resources use efficiency of wheat in North Gujarat (n=80)

Sr. No	Variables	Water users of canal Irrigation			Tube-well Irrigation		
		Coefficients	Standard Error	t Stat	Coefficients	Standard Error	t Stat
1	**Intercept**	-0.812	0.199	-4.083	-0.014	0.487	-0.028
2	**labour**	0.071	0.036	1.985	0.037	0.062	0.592
3	**Seed**	0.029	0.059	0.491	0.340*	0.194	1.754
4	**FYM**	0.050	0.031	1.648	-0.043	0.052	-0.835
5	**Nitrogen**	0.799***	0.078	10.196	0.139	0.127	1.098
6	**Phosphorus**	0.186***	0.059	3.144	0.419***	0.138	3.034
7	**Irrigation**	0.058*	0.032	1.831	-0.173**	0.071	-2.431
8	**Machine**	0.031	0.022	1.379	0.180***	0.048	3.707
	R^2	0.80			0.69		

*Note: ***, ** and * represent significant at 1%, 5% and 10%, respectively*

Table 3. Resources use efficiency of cotton in Mehsana and Patan districts (n=40)

Sr. No	Variables	Mehsana						Patan					
		Water users of canal Irrigation			Tube-well Irrigation			Water users of canal Irrigation			Tube-well Irrigation		
		Coefficients	Standard Error	t Stat	Coefficients	Standard Error	t Stat	Coefficients	Standard Error	t Stat	Coefficients	Standard Error	t Stat
1	**Intercept**	0.839	0.894	0.938	-1.529	0.916	-1.669	-0.833	0.960	-0.868	-1.084	0.552	-1.963
2	**labour**	-0.082	0.277	-0.295	0.392	0.255	1.536	-0.136	0.248	-0.550	0.094	0.148	0.639
3	**Seed**	-0.053	0.144	-0.369	-0.026	0.067	-0.390	0.029	0.066	0.435	-0.068	0.070	-0.967
4	**FYM**	0.298*	0.149	1.991	0.038	0.194	0.195	0.022	0.160	0.137	0.180*	0.102	1.769
5	**Nitrogen**	0.302*	0.153	1.972	0.580***	0.161	3.592	1.095***	0.338	3.244	0.876***	0.164	5.344
6	**Phosphorus**	0.189	0.113	1.669	0.239**	0.099	2.414	-0.047	0.166	-0.285	0.077	0.098	0.786
7	**Irrigation**	0.050	0.161	0.312	0.246**	0.119	2.066	0.345**	0.147	2.339	-0.014	0.100	-0.137
8	**Machine**	-0.959***	0.239	-4.017	-0.109	0.138	-0.785	-0.380***	0.098	-3.881	-0.248*	0.126	-1.963
	R^2	0.63			0.59			0.60			0.67		

*Note: ***, ** and * represent significant at 1%, 5% and 10%, respectively*

Table 4. Resources use efficiency of cotton in North Gujarat (n=80)

Sr. No	Variables	Water users of canal Irrigation			Tube-well Irrigation		
		Coefficients	Standard Error	t Stat	Coefficients	Standard Error	t Stat
1	**Intercept**	-0.314	0.583	-0.539	-1.586	0.426	-3.722
2	**labour**	0.133	0.190	0.699	0.366***	0.125	2.927
3	**Seed**	0.058	0.062	0.933	-0.041	0.048	-0.864
4	**FYM**	0.177*	0.103	1.716	0.127	0.096	1.325
5	**Nitrogen**	0.414***	0.134	3.102	0.737***	0.099	7.405
6	**Phosphorus**	0.064	0.092	0.697	0.088	0.058	1.529
7	**Irrigation**	0.197*	0.113	1.746	0.120	0.079	1.512
8	**Machine**	-0.421***	0.097	-4.337	-0.138*	0.077	-1.781
	R^2	0.49			0.53		

*Note: ***, ** and * represent significant at 1%, 5% and 10%, respectively*

Table 5. Resources use efficiency of castor in Mehsana and Patan districts (n=40)

Sr. No	Variables	Mehsana						Patan					
		Water users of canal Irrigation			Tube-well Irrigation			Water users of canal Irrigation			Tube-well Irrigation		
		Coefficients	Standard Error	t Stat	Coefficients	Standard Error	t Stat	Coefficients	Standard Error	t Stat	Coefficients	Standard Error	t Stat
1	**Intercept**	0.262	0.545	0.481	1.685	0.848	1.988	0.495	0.609	0.812	0.575	0.420	1.369
2	**labour**	-0.086	0.134	-0.639	-0.008	0.095	-0.081	0.712***	0.139	5.110	0.125	0.094	1.332
3	**Seed**	-0.096	0.178	-0.537	0.113	0.106	1.062	0.020	0.026	0.748	0.072	0.128	0.561
4	**FYM**	0.141	0.146	0.964	-0.218*	0.128	-1.700	0.004	0.163	0.024	0.046	0.077	0.593
5	**Nitrogen**	0.540***	0.121	4.482	0.574***	0.177	3.236	0.008	0.119	0.065	-0.060	0.098	-0.615
6	**Phosphorus**	0.281***	0.088	3.207	0.191	0.176	1.087	0.100	0.066	1.512	0.783***	0.155	5.054
7	**Potash**	0.019	0.015	1.254	0.036	0.027	1.337	0.013	0.011	1.146	-0.037**	0.016	-2.346
8	**Irrigation**	0.037	0.100	0.366	-0.168	0.187	-0.900	-0.051	0.084	-0.606	-0.105	0.102	-1.033
9	**Machine**	-0.398***	0.086	-4.618	-0.533***	0.115	-4.628	-0.292**	0.117	-2.492	-0.407***	0.100	-4.051
	R^2	0.68			0.67			0.60			0.78		

*Note: ***, ** and * represent significant at 1%, 5% and 10%, respectively*

Table 6. Resources use efficiency of castor in North Gujarat (n=80)

Sr. No	Variables	Water users of canal Irrigation			Tube-well Irrigation		
		Coefficients	Standard Error	t Stat	Coefficients	Standard Error	t Stat
1	**Intercept**	1.379	0.559	2.467	-3.665	4.204	-0.872
2	**labour**	0.236*	0.130	1.821	0.236***	0.066	3.561
3	**Seed**	-0.043	0.033	-1.303	0.078	0.088	0.888
4	**FYM**	0.009	0.153	0.062	-0.106	0.076	-1.402
5	**Nitrogen**	0.032	0.104	0.308	0.171	0.103	1.657
6	**Phosphorus**	0.048	0.063	0.761	6.230	5.164	1.206
7	**Potash**	0.006	0.013	0.513	-22.659	19.702	-1.150
8	**Irrigation**	-0.056	0.093	-0.597	-0.141	0.098	-1.439
9	**Machine**	-0.261***	0.094	-2.765	-0.350***	0.071	-4.952
	R^2	0.21			0.58		

*Note: ***, ** and * represent significant at 1%, 5% and 10%, respectively*

seed (0.685), phosphorus (0.512), and machinery (0.145) was observed which indicate their significant contribution to output. The MVP/MFC ratio values for these inputs suggest under-utilization of these resources, especially for seed (6.27) and phosphorus (20.24), which indicates that increasing use of these inputs could provide better returns. On the other hand, labour, FYM, nitrogen, and irrigation showed either negative coefficients or low positive coefficients value with their respective MVP/MFC value indicates over-utilization under tube-well irrigation. Therefore, reducing use of these inputs could lead to better resource management and cost-effectiveness. In summary, the findings suggest that farmers in the Patan district should consider increasing the use of under-utilized inputs like nitrogen and phosphorus, particularly under canal irrigation, while reducing over-utilized resources like irrigation to optimize productivity and profitability.

3.2.2 Resources utilization efficiency of wheat in North Gujarat

The efficiency of resource utilization in wheat cultivation across North Gujarat for both canal and tube-well irrigation methods is given in Table 8. In case of canal irrigation, it was found that, the positive value of regression coefficients for labour (0.071), seed (0.029), FYM (0.050), nitrogen (0.799), phosphorus (0.186), and machinery (0.031) suggest that these inputs were contribute positively in wheat production. The significant coefficient values for nitrogen and phosphorus at the 1% level revealed under-utilization of these inputs, as indicated by their MVP/MFC values. Therefore, increasing the application of these inputs, particularly nitrogen and phosphorus, could enhance productivity. In contrast, the relatively low positive coefficient for irrigation (0.058) under canal irrigation, despite its positive impact, suggests a marginal under-utilization of irrigation. However, reallocation of this input could potentially optimize resource efficiency. Under tube-well irrigation, the coefficients for seed (0.340), nitrogen (0.139), phosphorus (0.419), and machinery (0.180) are positive, indicating these inputs are beneficial to output. The MVP/MFC values for these inputs also revealed under-utilization, especially for phosphorus and machinery input, where increasing their use could lead to improved yields and profitability. Further, FYM and irrigation hours under tube-well irrigation show either negative coefficient, with corresponding MVP/MFC of -0.043 and -0.173 indicating over-utilization of them. Hence, it was suggested that, adjusting the use of these inputs could result in better resource management and cost-efficiency. Therefore, the results suggest that farmers in North Gujarat should focus on increasing the use of under-utilized inputs like nitrogen and phosphorus, especially under canal irrigation, while reducing the use of over-utilized inputs such as irrigation under tube-well system which could significantly improve the overall efficiency and profitability of wheat cultivation in the region (Parmar et al., 2015; Sapkota & Bajracharya, 2018).

Table 7. Resources utilization efficiency of wheat in Mehsana and Patan district (n=40)

Variable	Water users of canal Irrigation		Tube-well Irrigation	
	Coefficient	r = MVP/MFC	Coefficient	r = MVP/MFC
For Mehsana district				
Labour	-0.019	-3.36	-0.080	-14.01
Seed	0.015	0.15	0.029	0.27
FYM	0.036	0.002	-0.079	-0.005
Nitrogen	1.015***	4.88	0.249*	1.02
Phosphorus	0.091	4.10	0.578***	23.06
Irrigation	-0.012	-0.30	-0.189**	-13.38
Machine	0.050	86.43	0.155***	57.85
For Patan district				
Labour	0.120	27.02	0.081	16.76
Seed	0.114	1.11	0.685*	6.27
FYM	0.051	0.003	-0.050	-0.003
Nitrogen	0.477***	2.27	-0.025	-0.10
Phosphorus	0.420***	17.03	0.512*	20.24
Irrigation	-0.007	-0.23	-0.163	-13.97
Machine	0.030	12.36	0.145*	60.04

*Note: ***, ** and * represent significant at 1%, 5% and 10% respectively*

Table 8. Resources utilization efficiency of wheat in North Gujarat (n=80)

Variable	Water users of canal Irrigation		Tube-well Irrigation	
	Coefficient	r = MVP/MFC	Coefficient	r = MVP/MFC
Labour	0.071	14.10	0.037	6.99
Seed	0.029	0.30	0.340*	3.17
FYM	0.050	0.004	-0.043	-0.003
Nitrogen	0.799***	3.82	0.139	0.55
Phosphorus	0.186***	7.95	0.419***	16.66
Irrigation	0.058*	1.64	-0.173**	-13.53
Machine	0.031	13.02	0.180***	70.79

*Note: ***, ** and * represent significant at 1%, 5% and 10% respectively*

3.2.3 Resources utilization efficiency of cotton in Mehsana and Patan districts

A comprehensive analysis of resource utilization efficiency in cotton cultivation in the Mehsana district for canal and tube-well irrigation systems are illustrated in Table 9. In case of canal irrigation, the regression coefficients values were found positive i.e., 0.298 for FYM, 0.302 for nitrogen, 0.189 for phosphorus, and 0.050 for irrigation, with FYM being significant at the 10% level of significance which indicates that these inputs had positive impact on cotton production. Further, MVP to MFC ratio which was positive and less than one suggested under-utilization of these inputs. Hence, increasing the application of these inputs could potentially enhance cotton yields and profitability. Conversely, labour (-0.082), seed (-0.053), and machinery inputs (-0.959) had negative coefficients significance at the 1% level of significane. The corresponding MVP/MFC ratios indicate over-utilization, especially for machinery, which has a highly negative impact on output. Farmers may benefit from reducing the use of these over-utilized inputs to optimize costs and improve efficiency. Under tube-well irrigation, positive coefficients were observed for labour (0.392), FYM (0.038), nitrogen (0.580), phosphorus (0.239), and irrigation (0.246). Nitrogen, being significant at the 1% level, highlights substantial under-utilization, implying that increasing its use could significantly boost production. Moreover, seed (-0.026) and machinery (-0.109) show negative coefficients with corresponding negative MVP/MFC ratios, suggesting over-utilization which means adjusting these inputs could enhance overall resource efficiency under tube-well irrigation. Overall, in Mehsana district, increasing the use of under-utilized inputs like nitrogen could significantly benefit cotton cultivation, especially under tube-well irrigation. While, reducing over-utilized inputs like machinery under canal irrigation could also optimize resource use and improve profitability.

Table 9 provides a detailed assessment of resource utilization efficiency in cotton cultivation in the Patan district, comparing the impact of canal and tube-well irrigation systems. For canal irrigation, the coefficients for seed (0.029), FYM (0.022), nitrogen (1.095), and irrigation (0.345) are positive, with nitrogen being highly significant at the 1% level of significance. The MVP/MFC ratios suggest under-utilization of these inputs, especially nitrogen, which has a strong positive influence on output. Increasing their application could result in enhanced productivity and profitability. On the contrary, labour (-0.136), phosphorus (-0.047), and machinery (-0.380) show negative coefficients, with machinery being significant at the 1% level. The negative MVP/MFC ratios indicate over-utilization of these inputs, particularly machinery, which could be reducing overall efficiency. Reducing the use of these over-utilized resources could help optimize costs and improve net returns. Looking to the tube-well irrigation, positive coefficients for nitrogen (0.857), phosphorus (0.101), and machinery (0.180) suggest these inputs positively contribute to output. Nitrogen, significant at the 5% level, is particularly under-utilized, as indicated by its positive MVP/MFC ratio. Therefore, increasing the use of these inputs could lead to better yields. However, labour (0.061), seed (-0.077), and FYM (0.207) show varying regression coefficients, with seed having a negative impact on output under tube-well irrigation. These inputs, especially seed, appear to be over-utilized, as reflected in the negative MVP/MFC ratio. Adjusting the usage of these inputs could enhance overall resource efficiency. In conclusion, the results suggest that in Patan district, optimizing the use of under-utilized inputs like nitrogen could greatly benefit cotton production, particularly under canal irrigation. Reducing the over-utilization of inputs like machinery could also lead to more cost-effective farming practices and improved profitability.

3.2.4 Resources utilization efficiency of cotton cultivation in North Gujarat

Table 10 presents the ratio of Marginal Value Product (MVP) to Marginal Factor Cost (MFC) for cotton cultivation in North Gujarat divided by canal and tube-well irrigation methods. In case of canal irrigation, the coefficients for labour (0.133), seed (0.058), FYM (0.177), nitrogen (0.414), phosphorus (0.064) and irrigation (0.197) indicated postive impacts on output, with corresponding postive MVP/MFC values for these inputs. This suggests under-utilization, particularly for FYM and nitrogen where significant postive coefficients highlighted increasing the use of these input could substantially improve productivity. Conversely, machine (-0.421) was negative coefficients with MVP/MFC values (-72.78), suggesting over-utilization. Under tube-well irrigation, the coefficients for labour (0.366), FYM (0.127), nitrogen (0.737), phosphorus (0.088) and irrigation (0.120) were positive, with high MVP/MFC value indicating under-utilization, especially for labour (20.67) and nitrogen (1.42). These inputs could be increased to boost returns. However, the coefficients for seed (-0.041) and machine (-0.138) was negative with negative MVP/MFC values, indicating over-utilization. Overall, the findings suggest that for cotton cultivation in North Gujarat, increasing the use of under-utilized inputs such as nitrogen, seed, and phosphorus, especially under canal irrigation, could enhance productivity and profitability. For tube-well irrigation, increasing the use of labour and nitrogen, while reducing over-utilized inputs like seed and machine, could lead to better resource management.

Table 9. Resources utilization efficiency of cotton in Mehsana and Patan district (n=40)

Variable	Water users of canal Irrigation		Tube-well Irrigation	
	Coefficient	r = MVP/MFC	Coefficient	r = MVP/MFC
For Mehsana district				
Labour	-0.082	-4.33	0.392	18.78
Seed	-0.053	-1103.2	-0.026	-516.48
FYM	0.298*	0.004	0.038	0.0005
Nitrogen	0.302	0.71	0.580***	1.14
Phosphorus	0.189	6.07	0.239**	7.35
Irrigation	0.050	0.52	0.246**	9.18
Machine	-0.959***	-162.02	-0.109	-15.55
For Patan district				
Labour	-0.136	-9.11	0.061	3.99
Seed	0.029	549.34	-0.077	-1863.27
FYM	0.022	0.0003	0.207	0.003
Nitrogen	1.095***	2.36	0.857**	1.63
Phosphorus	-0.047	-1.42	0.101	2.47
Irrigation	0.345**	3.68	0.073	3.08
Machine	-0.380***	-67.09	-0.169	-27.26

*Note: ***, ** and * represent significant at 1%, 5% and 10% respectively*

Table 10. Resources utilization efficiency of cotton in North Gujarat (n=80)

Variable	Water users of canal Irrigation		Tube-well Irrigation	
	Coefficient	r = MVP/MFC	Coefficient	r = MVP/MFC
Labour	0.133	7.99	0.366***	20.67
Seed	0.058	1146.85	-0.041	-902.47
FYM	0.177*	0.002	0.127	0.001
Nitrogen	0.414***	0.93	0.737***	1.42
Phosphorus	0.064	2.00	0.088	2.41
Irrigation	0.197	2.07	0.120	4.78
Machine	-0.421***	-72.78	-0.138*	-20.97

*Note: ***, ** and * represent significant at 1%, 5% and 10% respectively*

3.2.5 Resources utilization efficiency of castor in Mehsana and Patan district

The results of resource utilization efficiency in castor cultivation in the Mehsana district for both canal and tube-well irrigation systems are presented in Table 11. For canal irrigation, the regression coefficients for FYM (0.141), nitrogen (0.540), phosphorus (0.281), and potassium (0.019) are positive, with nitrogen and phosphorus being significant at the 1% level of significance. These results indicate that these inputs positively impact castor production. The MVP/MFC ratios for these inputs, although positive, are less than one, signifying under-utilization. Increasing the application of these inputs, particularly nitrogen, could lead to enhanced yields and profitability in castor cultivation. However, labour (-0.086), seed (-0.096), and machinery (-0.398) show negative coefficients, with machinery being significant at the 1% level. The negative MVP/MFC ratios for these inputs, especially machinery, indicate over-utilization, which could be diminishing returns. Farmers could benefit from reducing the use of these over-utilized inputs to optimize costs and improve production efficiency. Under tube-well irrigation, the coefficients for seed (0.113), nitrogen (0.574), phosphorus (0.191), and potassium (0.036) are positive, with nitrogen being significant at the 1% level, highlighting substantial under-utilization. This implies that increasing the use of these inputs, particularly nitrogen and phosphorus, could significantly boost castor production. On the other hand, labour (-0.008), FYM (-0.218), and machinery (-0.533) show negative coefficients, with machinery again being significant at the 1% level. The negative MVP/MFC ratios for these inputs suggest over-utilization, indicating that adjustments in their usage could enhance overall resource efficiency under tube-well irrigation. Overall, it was concluded that, optimizing the use of under-utilized inputs like nitrogen and phosphorus could greatly benefit castor cultivation in the Mehsana district, particularly under tube-well irrigation. At the same time, reducing over-utilized inputs like machinery could improve cost-effectiveness and profitability.

Table 11 illustrates the resource utilization efficiency in castor cultivation in the Patan district, comparing canal and tube-well irrigation systems. For canal irrigation, the regression coefficients for labour (0.712), seed (0.020), phosphorus (0.100), and potassium (0.013) are positive, with labour and phosphorus being significant at the 1% level. These positive coefficients indicate that these inputs have a beneficial impact on castor production. The MVP/MFC ratios for these inputs suggest under-utilization, especially for labour and phosphorus, implying that increasing their application could lead to improved productivity and profitability. Whereas, FYM (0.004), nitrogen (0.008), and machinery (-0.292) exhibit negative coefficients, with machinery being significant at the 5% level of significance. The negative MVP/MFC ratio, particularly for machinery, indicate over-utilization, which could be reducing overall efficiency. Therefore, reducing the use of these over-utilized resources could help optimize costs and improve net returns. In the case of tube-well irrigation, the coefficients for seed (0.072), phosphorus (0.783), and potassium (0.037) are positive, with phosphorus being highly significant at the 1% level. This suggests that these inputs positively contribute to output, with phosphorus showing substantial under-utilization as indicated by its positive MVP/MFC ratio. Therefore, increasing the use of these inputs could lead to better yields. However, labour (0.125), FYM (0.046), and machinery (-0.407) present varying coefficients, with machinery again showing a negative impact on output, significant at the 1% level of significance. The negative MVP/MFC ratios for these inputs, particularly machinery, suggest over-utilization, which means that adjusting their usage could enhance overall resource efficiency. In summary, the findings indicate that in Patan district, optimizing the use of under-utilized inputs like phosphorus could significantly benefit castor production, especially under tube-well irrigation. Additionally, reducing over-utilization of inputs like machinery could lead to more cost-effective farming practices and improved profitability.

3.2.6 Resources utilization efficiency of caster in North Gujarat

The analysis of resource utilization efficiency for castor cultivation under canal and tube-well irrigation in North Gujarat, as presented in Table 12. For canal irrigation in the region, the positive regression coefficients for labour (0.236), FYM (0.009), nitrogen (0.032), and phosphorus (0.048) suggest that these inputs positively impact castor production. Among these, labour was found significant, indicating a substantial under-utilization as evidenced by the positive MVP/MFC ratio of 25.48. This suggests that increasing the use of labour could enhance productivity and profitability in castor cultivation under canal irrigation. Conversely, negative coefficients for seed (-0.043), potassium (-0.006), and machinery (-0.261) indicate these inputs were reducing output, with machinery being significant at the 1% level of significance. The strongly negative MVP/MFC ratio for machinery (-344.08) further emphasizes its over-utilization, suggesting that reducing its use could significantly improve resource efficiency. Under tube-well irrigation, Positive regression coefficients for labour (0.236), nitrogen (0.171), and phosphorus (6.230) was found which indicate that these inputs positively contribute to castor production, with labour and phosphorus being highly significant at the 1% level of significance. The MVP/MFC ratios for these inputs 27.75 for labour and 251.03 for phosphorus revealed under-utilization of these resources. In other terms, increasing the application of these inputs could significantly enhance productivity and profitability under tube-well irrigation. Further, negative coefficients for seed (-0.106), potassium (-22.659), and machinery (-0.350) suggest that these inputs are currently reducing output, with machinery being significant at the 1% level. The negative MVP/MFC ratio for machinery (-481.33) highlights a substantial over-utilization, suggesting that reducing its usage could lead to more efficient resource management and improved economic returns. Overall, it was concluded that, in North Gujarat, enhancing the application of under-utilized inputs like labour and phosphorus, especially under tube-well irrigation, could greatly benefit castor cultivation. Meanwhile, reducing the over-utilized inputs such as machinery could lead to more efficient resource use and greater profitability.

Table 11. Resources utilization efficiency of castor in Mehsana and Patan district (n=40)

Variable	Water users of canal Irrigation		Tube-well Irrigation	
	Coefficient	r = MVP/MFC	Coefficient	r = MVP/MFC
For Mehsana district				
Labour	-0.086	-7.61	-0.008	-0.75
Seed	-0.096	-155	0.113	181.18
FYM	0.141	0.007	-0.218*	-0.01
Nitrogen	0.540***	2.23	0.574***	2.42
Phosphorus	0.281***	13.46	0.191	7.32
Potassium	0.019	506.12	0.036	616.59
Irrigation	0.037	0.37	-0.168	-7.42
Machine	-0.398***	-128.38	-0.533***	-185.30
For Patan district				
Labour	0.712***	95.06	0.125	14.84
Seed	0.020	60.60	0.072	116.53
FYM	0.004	0.0002	0.046	0.003
Nitrogen	0.008	0.04	-0.060	-0.27
Phosphorus	0.100	5.98	0.783***	33.15
Potassium	0.013	444.66	-0.037**	-418.10
Irrigation	-0.051	-0.65	-0.105	-5.61
Machine	-0.292**	-98.38	-0.407***	-141.28

*Note***, ** and * represent significant at 1%, 5% and 10% respectively.*

Table 12. Resources utilization efficiency of castor in North Gujarat (n=80)

Variable	Water users of canal Irrigation		Tube-well Irrigation	
	Coefficient	r = MVP/MFC	Coefficient	r = MVP/MFC
Labour	0.236*	25.48	0.236***	27.75
Seed	-0.043	-127.17	0.078	166.26
FYM	0.009	0.0005	-0.106	-0.003
Nitrogen	0.032	0.15	0.171	0.74
Phosphorus	0.048	2.59	6.230	251.03
Potassium	0.006	198.66	-22.659	-312660.95
Irrigation	-0.056	-0.63	-0.141	-6.88
Machine	-0.261***	-344.08	-0.350***	-481.33

*Note***, ** and * represent significant at 1%, 5% and 10% respectively.*

4. CONCLUSION

The study on resource use efficiency in wheat, cotton, and castor cultivation in Mehsana and Patan districts, as well as overall in North Gujarat, revealed the critical role of nitrogen, phosphorus, and machinery in influencing yield outcomes. For wheat, nitrogen and phosphorus showed positive and significant impacts on yield under canal irrigation in both Mehsana and Patan districts, while over-irrigation negatively affected yield, particularly in tube-well irrigation. In the case of cotton, nitrogen was identified as a significant positive factor under tube-well irrigation in Mehsana, while excessive use of machinery reduced productivity in both irrigation methods, highlighting inefficient resource allocation. Similarly, for castor, nitrogen and phosphorus had a positive yield response under canal irrigation, but excessive machinery use, especially in Patan district, had a negative impact. The study also found that labor positively influenced castor yield under tube-well irrigation, indicating the need for balanced mechanization. Overall, higher R^2 values in Mehsana and Patan indicated that the models had substantial explanatory power in accounting for yield variability, whereas the lower R^2 values in North Gujarat suggested room for improvement in resource allocation, particularly under canal irrigation.

The analysis of resource utilization efficiency across wheat, cotton, and castor crops in Mehsana, Patan districts, and North Gujarat overall indicated that specific resources, such as nitrogen, phosphorus, and machinery, were often under-utilized in both canal and tube-well irrigation systems. On the other hand, inputs like labor and irrigation were frequently over-utilized. For wheat and cotton, particularly in Mehsana and Patan, nitrogen and phosphorus were significantly under-utilized, suggesting that increasing their use could substantially enhance yield and returns. Conversely, labor and machinery were over-utilized, especially in canal irrigation systems, indicating a need for more efficient allocation to prevent resource waste and reduce costs. For castor crops, nitrogen and phosphorus were similarly under-utilized, and increasing their application could improve yield and profitability. Over-utilized inputs like labor and machinery should be minimized to avoid diminishing returns.

5. POLICY IMPLICATION

The study suggests that policy initiatives should focus on optimizing input management by promoting the balanced use of nitrogen, phosphorus and machinery to supported by subsidies and extension services. Efficient water management practices, such as adopting water-saving technologies and irrigation scheduling, should be encouraged to prevent over-irrigation. Policymakers should promote appropriate mechanization to avoid over-reliance on machinery, while ensuring that fertilizers are used effectively through subsidies and nutrient management plans. Targeted training programs on efficient resource allocation, coupled with improved data collection and region-specific resource management plans, will help farmers make informed decisions. Financial support, including low-interest loans and subsidies, can facilitate the adoption of best practices, enhancing productivity and sustainability across Gujarat's agricultural sectors.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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