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RESEARCH ARTICLE

Adoption and economic assessment of sprinkler irrigation for sustainable groundnut cultivation in the Western dry region of India

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Abstract

Groundnut cultivation under sprinkler irrigation gained attraction at in India, particularly in water-scarce regions, due to its efficiency in optimizing water use and improving crop yields. This study analyzed the adoption of sprinkler irrigation among farmers in Bikaner district during 2022-23, employing Heckmans' two-stage selection model and logit regression. Data was collected from 200 farm households (100 sprinkler-adopted farmers, 100 canal irrigating farmers (a) non-adopters) during 2022-23. The findings revealed that sprinkler irrigation reduced water consumption by 37.11 % compared to canal irrigation while increasing yield by 7.98 per cent. However, excessive seed rates were observed in both irrigation systems, with sprinkler irrigation fields using 202.86 kg/ha, far exceeding the recommended 110-125 kg/ha. This unnecessary input led to higher seed costs, highlighting the need for awareness campaigns on optimal seed usage. Cost analysis showed that while total variable costs were higher for sprinkler irrigation (Rs. 105356.07/ha) than canal irrigation (Rs. 93958.49/ha), net income was significantly higher (Rs. 84156.54/ha vs. Rs. 44008.43/ha). Education, access to credit and farm size significantly influenced adoption, with educated farmers being four times more likely to adopt. Despite the benefits, high initial investment costs remained a barrier. Policy interventions, including improved credit access and awareness of PMKSY subsidies, were essential for promoting sprinkler irrigation and ensuring sustainable groundnut cultivation in India.

Keywords

credit accessibility; farmer decision-making; groundnut cultivation; Heckmans' two-stage model; sustainable agriculture; water efficient irrigation

Introduction

Groundnut (*Arachis hypogaea* L.) is one of Indias' major oilseed crops, contributing significantly to the agricultural economy. In the 2022-23 season, India produced approximately 10.2 million metric tonnes of groundnut, making it the second-largest producer globally (1). The central groundnut-producing states in India include Gujarat, Rajasthan, Tamil Nadu, Karnataka and Andhra Pradesh. Among these, Rajasthan, the western dry region of India, ranks second in production, contributing around 1.36 million metric tonnes, accounting for 13.3 % of the national output (2). The arid climate of Rajasthan in its western part needs efficient irrigation management to ensure sustainable groundnut cultivation. Micro-irrigation, encompassing methods like sprinkler and drip irrigation, offers significant economic and social advantages, such as enhanced crop yields, reduced energy consumption and sustainable water use (3-6). 3.2 million hectares are irrigated by micro-irrigation techniques worldwide, representing 1 % of the total areas irrigated worldwide (7).

Research indicated that drip irrigation improves groundnut yield by 20-30 % while reducing water consumption by 40-50 % compared to conventional flood irrigation (8). Rajasthan has been at the forefront of micro-irrigation adoption under schemes like Per Drop More Crop (PDMC), which has led to the coverage of over 1.9 million hectares under micro-irrigation as of 2023 (9). The Government of India has actively promoted micro-irrigation through initiatives like the National Mission on Micro Irrigation (NMMI) and financial assistance schemes. Despite progress, as of March 2022, micro-irrigation covers only 19 % of the total irrigated land in India, with Rajasthan leading in adoption (10). While contributing to sustainable agriculture and water resource management, increased efforts and support are crucial for widespread adoption, ensuring a resilient and water-efficient future for Indian agriculture. Sprinkler irrigation systems have become integral in modern agriculture, presenting an advanced approach to water distribution across crops. These systems are instrumental in optimizing water use, boosting crop yields and fostering sustainable agricultural practices (11-18). Sprinkler irrigation minimizes water wastage and promotes irrigation accuracy by precisely delivering water to plant roots, contributing to resource conservation and increased agricultural productivity. Adopting sprinkler irrigation systems represents a transformative leap towards farm efficiency and environmental sustainability (13-18). As farmers increasingly recognize the benefits, understanding the factors influencing their adoption becomes paramount for promoting sustainable farming practices. Despite these advancements, challenges such as high initial investment costs and inadequate awareness among farmers continue to hinder large-scale adoption. Therefore, understanding sprinkler systems' economic viability and adoption patterns in Rajasthans' groundnut cultivation is critical for policy interventions and sustainable agricultural development.

The theoretical contribution of studying the adoption of agricultural technologies encompasses a multidisciplinary approach that draws on various theoretical frameworks. The Technology Acceptance Model (TAM) provides insights into the psychological and perceptual aspects influencing farmers' decisions to adopt new technologies (19). TAM suggests that perceived ease of use and usefulness are critical determinants of technology adoption. Additionally, the Innovation Diffusion Theory (20) emphasizes the role of communication channels and social systems in disseminating innovations. Rogerss' Diffusion of Innovations (DOI) theory identifies factors like relative advantage, compatibility, complexity, trialability and observability that affect the adoption rate. Moreover, the Theory of Planned Behavior (TPB) incorporates behavioural aspects (21), focusing on attitudes, subjective norms and perceived behavioural control. These theoretical perspectives collectively contribute to understanding the intricate dynamics of technology adoption, considering cognitive, social and behavioural factors, thereby enriching the theoretical foundation for agricultural technology adoption studies.

Understanding the factors influencing the adoption of sprinkler irrigation systems is a critical research focus (3, 6, 22). While the advantages of these systems are evident, the determinants and barriers to their adoption pose significant questions that need exploration. The central issue revolves around unravelling the socioeconomic dynamics that influence farmers' decisions regarding the adoption of sprinkler irrigation. This study aimed to uncover the complexities associated with adoption patterns, particularly emphasizing the role of education, access to credit, farm income and farm size. Identifying these factors was crucial for crafting effective policies and interventions that facilitate the widespread adoption of water-efficient irrigation methods.

Materials and Methods

The study relied on first-hand information obtained from farmers regarding their adoption of sprinkler irrigation systems in the Bikaner district of Rajasthan, covering the period 2022-23. A straightforward random sampling technique was employed to choose a group of 100 farmers who adopted sprinkler irrigation and another 100 farmers (Canal irrigated) who did not adopt this system. Data were gathered from 200 farmers using a personal interview approach facilitated by a structured schedule. The cost analysis for groundnut cultivation was performed in this study using the following concepts,

Cost A_1: It includes the value of hired human labour and the value of owned and hired animal labour. value of owned and hired machine labour, the value of seeds (both from produced and purchased), the value of manures, fertilizers, insecticides and pesticides, irrigation charges, depreciation, land revenue, interest in working capital and miscellaneous expenses.

Cost A_2: Cost A_1+ rent paid for leased-in land.

Cost B_1: Cost A_1+ interest on fixed capital assets (excluding land).

Cost B_2: Cost B_1+ rental value of owned land rent paid for leased in land.

Cost C_1: Cost B_1+ imputed value of family labour.

Cost C_2: Cost B_2 + imputed value of family labour.

Cost C_3: Cost C_2 + 10 % of cost C_2 as management cost.

B-C Ratio

It is calculated through Equation 1 Formula.

$$B : C \text{ ratio} = \frac{\text{Gross income/ha}}{\text{Total cost /ha}} \quad \text{(Eqn. 1)}$$

Heckmans' two-stage sample selection model was also employed to investigate the impact of credit on the adoption of sprinkler irrigation systems (23-24) using STATA 14.0. A probit regression model was utilized in the initial equation to discern the factors affecting credit acquisition (25-29). Subsequently, the estimated inverse Mills ratio (IMR) derived from a probit model was incorporated as an explanatory variable in the second equation to address selection bias, allowing for an examination of its influence on the adoption of sprinkler technology in the estimation of Ordinary Least Squares (OLS). STATA 18.0 software was used For this analysis.

The selection equation

Step 1- Estimation of the factor influencing the credit in Equation 2

$$Yi = \sigma + \delta Xi + \mu 1 \quad \text{(Eqn. 2)}$$

Where,

Y_i = credit access (1 if taken; 0 otherwise), X_i = factors that influence to go for credit, X_1 = Age (Years), X_2 = Education (Years of schooling), X_3 = Main Occupation (Farming = 1; otherwise=0), X_4 = Farm size (ha), X_5 = Member in organization =1; otherwise=0, X_6 = Access to training =1; otherwise=0 and X_7 = Farm income (`)

Employing a maximum likelihood estimation procedure, the farmers' probability of accessing credit is obtained from the first stage of the Heckman two-stage model (30-31). This involves a probit regression to predict the probability of getting credit access. Using these estimates, a variable known as Mills ratio is obtained as given in Equation 3

$$\lambda i = (\rho + \delta Xi)/(\rho + \delta Xi) \quad \text{(Eqn. 3)}$$

Where, ϕ is the cumulative distribution function of a standard normal distribution, λ_i is the Mills ratio term

Outcome equation

Step 2 Estimation of the role of credit in the adoption of sprinkler irrigation system

The second step is adding the mills' ratio to the adoption/ outcome equation (32-33). The factors that determine the adoption of sprinkler irrigation systems are explicit in the literature and they include

W_1=Age (years), W_2= Education (years of schooling), W_3= Main occupation (Farming=1; Otherwise=0), W_4= Farm size (ha), W_5= Member in organization=1; Otherwise=0, W_6= Access to training=1; Otherwise=0, W_7= Access to credit (`); = (1 if taken, 0 otherwise) and λ_i = Inverse Mills ratio

The adoption equation formulae in equation 4;

$$Ai = \beta 0 + \beta j Wij + \lambda i + \lambda 2 \quad \text{(Eqn. 4)}$$

Where,

i= Number of farms ranging from1….200; j = Number of variables; A_1 = Adoption index which indicates the adoption level of farmers; W_i = Vector indicates the factor affecting the adoption of technology; λ_i = Inverse Mills ratio E (u) =0 and $\mu_1 \sim N(0, 1)$; $\mu_2 \sim N(0, \sigma)$ Corr $(\mu_1, \mu_2) = \rho$

When $\rho \neq 0$, the standard regression methods applied to the second equation produce biased results. Heckman provides consistent and asymptotically efficient estimates for all the parameters in these models.

The logit model was used to analyze the factors influencing the adoption of sprinkler irrigation systems, which are derived from the following logistic function (Equation. 5)

$$P_i = P_i(P_i = 1) = \frac{\exp(z)}{1+\exp(z)} \quad \text{(Eqn. 5)}$$

$$Z = \beta_0 + \Sigma^m{}_i \beta_1 X_1 \quad \text{(Eqn. 6)}$$

Pi denotes the probability that the ith farmer has adopted a sprinkler-irrigation system (Yi = 1), β0 is the intercept, βi is the slope parameters in the model and Xi is the independent variable. The natural log transformation of Eq. 5 will result in Equation. 6-7, which is known as the logit regression model.

$$\frac{}{(1+P^iP_i)} \; ln = \beta_0 + \sum_i^m \beta_1 X_1 \ldots\ldots\ldots \text{(Eqn. 7)}$$

Thus, the β are interpreted as the change in the natural log of odds associated with a one-unit change in the explanatory variables and do not directly indicate a change in adoption probability or marginal effects. The marginal effect (or the quantitative importance of the explanatory variables) for the logit model is expressed as follows in Equation 8-9:

$$\delta \frac{\delta P_i}{} \frac{\exp(z)}{} X_i = \frac{1}{1+\exp(z)} [1+\exp(z)] \beta^j \quad \text{(Eqn. 8)}$$

The model estimate:

$$Y_1 = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 \quad \text{(Eqn. 9)}$$

Where -

Y_1 = If the farmers have adopted sprinkler irrigation system in their farms (0 if no, 1 if yes), β_0 = Constant, B_1 -β_8 = Regression coefficient, X_1 = farmers Age, X_2 = Education (literate = 1 and illiterate = 0), X_3 = farm Income (`), $X_4$ = Non-farm Income (`), X_5 = Cropped area (ha), X_6 = Involve in agriculture training (attended =1 and not attended =0), X_7 = Access to credit (If accessed =1, otherwise =0)

Results and Discussion

The data processing comprised a two-step approach. Initially, a socioeconomic overview of the sample farmers in Bikaner district was conducted. Subsequently, the econometric findings are presented in the second section, exploring the impact of sprinkler irrigation system adoption. Table 1 outlines factors expected to affect the adoption of sprinkler irrigation. Education (Year of Schooling), farming as the

Table 1. Hypothesized explanatory factors on the adoption of sprinkler irrigation system and their estimated effect

Variables	Nature of variables	Definition and measurement	Expected effect	Reference
Age	Continuous	Age of the Sample Farmers in Years	±	(36-41)
Year of Schooling	Continuous	Total Years of Formal education attained by the sample farmers	+	(36-40)
Main occupation	Dummy	If Farming=1; otherwise 0	+	(39-40)
Member of organization	Dummy	If Member in any organization=1; otherwise 0	+	(39)
Farm size (ha)	Discrete Variable	Farm Size in hectares	+	(36-41)
Agricultural training	Binary	If Attended Training =1; otherwise 0	±	(40)
Farm income (lakh)	Continuous	Total income gained through farming in the last year	+	(39)
Access credit	Binary	If yes=1; otherwise 0	+	(36-41)
Adoption of Sprinkler Irrigation	Binary	If yes=1; otherwise 0	+	(36-41)

main occupation, organizational membership, farm size, farm income and access to credit had positive effects. Age and Agricultural training might have a variable impact. The binary variable "Adoption of Sprinkler Irrigation" is the key outcome, reflecting adoption (1) or non-adoption (0).

Table 2 elucidates the disparities in key explanatory variables between farmers who have adopted sprinkler irrigation systems and those who have not. Age revealed adopters have a significantly younger average age (Mean = 45.190 years) than non-adopters (Mean = 47.510 years). This age difference is substantiated by a high t-value of 34.52, indicating a one % level of statistical significance. This age distinction could be attributed to a greater inclination among younger farmers to embrace technological advancements, such as sprinkler irrigation, to improve agricultural practices. Similarly, the variable "Year of Schooling" showcased that adopters possess a higher mean years of formal education (Mean = 7.030 yr) compared to non-adopters (Mean = 6.460 yr), supported by a t-value of 14.40 significant at one % level. This suggested that education plays a pivotal role in the adoption decision, possibly indicating a better understanding and appreciation of the benefits associated with sprinkler irrigation among more educated farmers. The main occupation was a dummy variable denoting whether farming was the main occupation (1) or not (0). Both adopters and non-adopters overwhelmingly identify farming as their primary occupation (Mean = 0.980), yielding a remarkably high t-value of 69.65, significant at the 1 % level.

Furthermore, the "Member of organization" indicated a higher likelihood of adopters being members of agricultural organizations (Mean = 0.910) compared to non-adopters (Mean = 0.770), supported by a t-value of 31.64 significant at one % level. This underscored the influence of community engagement and collective decision-making processes in adopting innovative agricultural practices. The remaining variables - Farm size (ha), Agricultural training, Farm income (lakh) and Access Credit -displayed significant differences between adopters and non-adopters, favouring the adopter group. Larger farm sizes, participation in agricultural training, higher farm incomes and greater access to credit are all associated with a higher likelihood of adopting sprinkler irrigation.

The study highlighted the significant benefits of sprinkler irrigation in groundnut cultivation in arid regions, demonstrating its potential for enhancing agronomic performance and water use efficiency. Table 3 depicts that farmers who adopted sprinkler irrigation achieved an average yield of 40.93 quintals per hectare, compared to 28.62 quintals per hectare under canal irrigation, reflecting a 7.98 % increase in output. This improvement was primarily attributed to better water distribution, enhanced soil moisture retention and efficient nutrient uptake facilitated by the sprinkler system. Despite using fewer irrigations on average (approximately 17 irrigations under the sprinkler method compared to around 22 irrigations under the canal irrigation method), crop water productivity remained higher under the sprinkler system, measuring 2.99 kg/m^3 compared to 1.74 kg/m^3 under canal irrigation. Additionally, total water applied per hectare was significantly lower in the sprinkler system (1091.67 m^3/ha) than in canal irrigation (1735.71 m^3/ha), reflecting a 37.11 % reduction in water usage (34).

Table 2. Description of variables

Variables	Adopters (n=100)			Non-adopters (n=100)		
	Mean	SD	t-Value	Mean	SD	t-Value
Age	45.190	13.09	34.52**	47.510	13.77	34.50**
Year of Schooling	7.030	4.881	14.40**	6.460	4.659	13.87**
Main occupation	0.980	0.141	69.65**	0.980	0.141	69.65**
Member of organization	0.910	0.288	31.64**	0.770	0.423	18.21**
Farm size (ha)	10.832	5.468	19.81**	5.688	3.988	14.26**
Agricultural training	0.460	0.501	09.18**	0.400	0.492	08.12**
Farm income (lakh)	7.740	4.731	16.36**	4.605	2.654	17.35**
Access Credit	0.910	0.288	31.64**	0.750	0.435	17.23**

**- Significant at 1 % level.

Table 3. Agronomic and water use efficiency comparison - sprinkler vs. canal irrigation

Parameter	Sprinkler irrigation (n=100)	Canal irrigation (n=100)	% difference (sprinkler vs. canal)
A. Agronomic parameters			
Average output (q/ha)	40.93	28.62	**+7.98 %**
Average landholding (ha)	2.58	1.88	**+37.78 %**
Labour use (Persons/ha)	19.67	19.50	**+0.85 %**
Seed rate (kg/ha)	202.86	160.00	**+21.13 %**
Fertilizer Use (kg/ha)	379.21	455.00	**-19.98 %**
Plant protection chemicals (L/ha)	5.24	6.15	**-17.46 %**
Number of irrigations	17.36	21.83	**-25.79 %**
B. Water use efficiency (WUE) parameters			
Total water applied (m^3/ha)	1,091.67	1,735.71	**-37.11 %**
Crop water productivity (CWP) (kg/m^3)	2.99	1.74	**+71.74 %**
Water Savings (%)	**37.11 %**	-	**-**

An important observation from the study was the higher seed rate in both irrigation systems, with sprinkler irrigation fields recording 202.86 kg/ha and canal irrigation fields using 160.00 kg/ha. These rates exceeded the recommended optimum seed rate for bunch-type groundnut cultivation under irrigated conditions, which typically ranged between 110-125 kg/ha (35). The excessive seed usage indicated a lack of awareness among farmers regarding appropriate seed rates and spacing. Furthermore, the sandy loam soil, facilitating easier crop establishment, might have led farmers to assume that denser planting would enhance yields. However, this practice increased seed costs, necessitating measures to promote judicious seed use. Raising awareness through extension services and training programs could help farmers optimize seed inputs while maintaining productivity.

The cost analysis revealed that total variable costs under sprinkler irrigation amounted to Rs.105356.07 per hectare, surpassing the costs under canal irrigation (Rs.93958.49 per hectare). The primary cost differences emerged in irrigation charges and seed expenses. Although irrigation charges were higher for sprinkler users, the system ensured better water use efficiency and improved crop health. Despite the increased input costs, sprinkler irrigation generated significantly higher returns. Farmers using sprinkler systems attained a net income of Rs.84156.54 per hectare, compared to Rs.44008.43 per hectare under canal irrigation (Table 4). This substantial income difference reinforced the economic viability of sprinkler irrigation, as the increased yield translated into greater profitability.

Table 5 reports the results of a multicollinearity test through the variance inflation factor (VIF) for explanatory variables taken for the study. The VIF values for each variable were well below 10 (26), indicating no severe multicollinearity issues. Specifically, VIF values range from 1.040 to 1.352, with a mean VIF of 1.229, affirming the absence of high correlation among independent variables. To justify the importance of this test, its' crucial to recognize that multicollinearity could distort the accuracy of regression coefficients, potentially leading to unreliable results (30-31). The low VIF values validate the reliability of the model used to analyze the adoption of sprinkler irrigation. The subsequent analysis involved a two-stage selection process using Heckmans' approach (25-29). In the first stage, a probit regression was employed to identify variables affecting the farmers' access to credit. The second stage utilized the conditional estimation/OLS approach to investigate factors influencing the adoption of sprinkler irrigation systems. The decision to employ Heckmans' two-stage approach was justified when there is potential sample selection bias, indicating that certain farmers might be more likely to adopt sprinkler irrigation. Heckmans' model provides a comprehensive understanding of the adoption process by considering both the access to credit and the decision to adopt. Analysis was done carefully by emphasizing the unique nature of agricultural decisions, where various socioeconomic and institutional factors can influence both the binary accessibility of credit and the decision to adopt. As affirmed by the VIF results, the absence of multicollinearity issues strengthens the models' reliability, ensuring that the estimated coefficients are more robust and dependable.

Table 6 shows the results of Heckmans' two-stage sample selection model analysis. This analysis helped us understand how access to credit was related to adopting sprinkler irrigation systems for groundnut cultivation in the study area. Table 6 comprised two primary equations: the selection equation (Access to Credit) and the outcome equation (Adoption of Sprinkler Irrigation System) and their respective coefficients and standard errors offer insightful implications for agricultural development. The Wald test statistics [Chi^2 (8) = 30.62], indicate that the coefficients of the credit access equation were significant at 1 % level of significance, confirming that the model fulfilled the conditions of good fit. The Inverse mills' ratio (IMR= -47.46) value was non-significant, meaning that error terms of both selection and outcome equations were positively correlated. This shows that the sample selection was unbiased and justifies using Heckmans' two-stage model.

Table 4. Cost, yield and returns of groundnut cultivation under sprinkler and canal irrigation (Rs./ha.)

S. No.	Particulars	Sprinkler irrigation (n=100)	Canal irrigation (n=100)
		A. Variable Cost	
1	Machinery power	Rs. 26324.58/ha (20.57)	Rs. 28438.52/ha (23.49)
2	Imputed family labour	Rs. 7910.06/ha (6.18)	Rs. 3806.67/ha (3.14)
3	Casual hired labour	Rs. 3683.86/ha (2.88)	Rs. 5326.18/ha (4.40)
4	Total fertilizer	RS. 8690.08/ha (6.79)	Rs. 11648.20/ha (9.62)
5	FYM	Rs. 14665.61/ha (11.46)	Rs. 10380.14/ha (8.57)
6	PPC	Rs. 5874.12/ha (4.59)	Rs. 6884.46/ha (5.69)
7	Irrigation charges	Rs. 4534.62/ha (3.54)	Rs. 403.81/ha (0.33)
8	Cost of seed	Rs. 26780.69/ha (20.93)	Rs. 20923.69/ha (17.28)
9	Interest on working capital @7 %	Rs. 6892.45/ha (5.39)	Rs. 6146.82/ha (5.08)
	Total variable cost	**Rs. 105356.07/ha (82.33)**	**93958.49**/ha **(77.60)**
		B. Fixed cost	
10	Depreciation	Rs. 2467.59/ha (1.93)	Rs. 2745.39/ha (2.27)
11	Rental Value of Owned Land	Rs. 9000.00/ha (7.03)	Rs. 11000.00/ha (9.09)
12	Rent Paid for Leased Land	Rs. 10000.00/ha (7.81)	Rs. 12000.00/ha (9.91)
13	Interest on Fixed Capital @10 %	Rs. 1146.76/ha (0.90)	Rs. 1374.54/ha (1.13)
	Total Fixed Cost	22614.35/ha (17.67)	Rs. 27119.93/ha (22.40)
	Total Cost (A+B)	Rs. 127970.42/ha (100.00)	Rs. 121078.42/ha (100.00)
		C. Cost Concepts	
14	Cost A1	Rs. 99913.58/ha	Rs. 92897.21/ha
15	Cost A2	Rs. 109913.58/ha	Rs. 104897.21/ha
16	Cost B1	Rs. 101060.34/ha	Rs. 94271.74/ha
17	Cost B2	Rs. 120060.34/ha	Rs. 117271.74/ha
18	Cost C1	Rs. 108970.40/ha	Rs. 98078.41/ha
19	Cost C2	Rs. 127970.42/ha	Rs. 121078.42/ha
20	Cost C3	Rs. 140767.46/ha	Rs. 133186.26/ha
		D. Yield and Income	
21	Yield (q/ha)	40.93 q/ha.	28.62q/ha.
22	By-product Yield (q/ha)	60.99q/ha.	43.23q/ha.
23	Gross Income (Rs/ha)	Rs. 212126.94/ha.	Rs. 165086.84/ha.
		E. Returns	
24	Farm Business Income	Rs. 112213.36/ha	Rs. 72189.63/ha
25	Family Labour	Rs. 92066.60/ha	Rs. 47815.10/ha
26	Net Income	Rs. 84156.54/ha	Rs. 44008.43/ha
F.	**BC Ratio**		
27	Cost A1	2.12	1.78
28	Cost A2	1.93	1.57
29	Cost B1	2.10	1.75
30	Cost B2	1.77	1.41
31	Cost C1	1.95	1.68
32	Cost C2	1.66	1.36
33	Cost C3	1.51	1.24

Table 5. Result of multicollinearity test-variance inflation factor (VIF) (n=200)

Variables	VIF	1/VIF
Age	1.297	0.771
Year of Schooling	1.261	0.793
Main occupation	1.040	0.961
Member of organization	1.219	0.820
Farm size (ha)	1.326	0.754
Agricultural training	1.229	0.891
Farm income (lakh)	1.352	0.739
Access credit	1.208	0.828
Mean VIF	1.229	

Table 6. Determinants of access to credit and their effects on sprinkler irrigation system adoption by the sample farmers (n=200)

S. No.	Particular	Access to credit =1;0 otherwise		Adoption of sprinkler irrigation system =1;0 Otherwise	
		Coefficient	Standard Error	Coefficient	Standard Error
1	Age	0.005	0.008	-0.034	0.030
2	Education	1.001**	0.238	0.840**	0.250
3	Main occupation	0.229	0.438	0.285	0.464
4	Member of organization	-0.004	0.022	-0.024	0.020
5	Farm size (ha)	0.016*	0.008	0.015*	0.008
6	Agricultural training	-0.118	0.206	-0.020	0.201
7	Farm income (lakh)	0.010*	0.005	0.018*	0.008
8	Access Credit			0.033**	0.014
	_cons	-0.958	0.662	-2.54	0.923
	Mills lambda			-47.46	28.63
	Rho			-1.00	
	Sigma			47.46	
	Wald chi2(8)	30.62		2.27	
	Prob > chi2	0.0001		0.971	

* indicating significant at 5 % and ** indicating that highly significant at 1 % level.

Table 7. Logit estimates and Marginal effects of factor affecting the adoption of sprinkler irrigation system. (n=200)

S. No.	Particular	Logit estimates				Marginal effects			
		Odds ratio	Std. Err.	z	P>|z|	Marginal effect	Std. Err.	z	P>|z|
1	Age	0.943	0.047	-1.18	0.237	-0.015	0.012	-1.18	0.237
2	Education level	4.220	1.753	3.47	0.001**	0.342	0.089	3.84	0.000**
3	Farm Income	1.030	0.014	2.25	0.025*	0.007	0.003	2.25	0.025*
4	Non-farm income	1.000	0.000	-0.19	0.847	0.000	0.000	-0.19	0.847
5	Cropped Area (farm size)	1.025	0.013	1.99	0.047*	0.006	0.003	1.99	0.047*
6	Agricultural training	0.944	0.311	-0.18	0.861	-0.014	0.082	-0.18	0.861
7	Access to credit	1.055	0.024	2.37	0.018**	0.013	0.006	2.37	0.018**
	Constant	0.020	0.027	-2.92	0.004**				

* indicates 5 % significance and ** indicates 1 % level of significance.

In the selection equation, several key factors determining credit access were examined. Education was the vital factor, with a coefficient of 1.001 and significant at the 1 % level. This implies that respondents with higher levels of education are more likely to access credit, potentially due to their improved financial literacy and ability to navigate the complexities of financial institutions. Additionally, farm size and farm income also played essential roles. A positive coefficient of 0.016 at the 5 % significance level for farm size suggests that more significant agricultural operations are more likely to secure credit. Similarly, a positive coefficient of 0.010 at the 5 % level of significance level for farm income indicates that individuals with higher farm incomes have better access to credit resources.

Meanwhile, in the outcome equation, the primary focus was on the impact of access to credit on the adoption of sprinkler irrigation systems for groundnut cultivation. Here, access to credit stands out with a positive coefficient of 0.033 at the 1 % significance level. This finding underscores the crucial role of credit in facilitating the adoption of irrigation technologies, as farmers with easier access to financial resources are more likely to invest in these systems, which could significantly enhance agricultural productivity.

In the outcome equation, education, farm size and farm income were three critical factors that positively affected the adoption of sprinkler irrigation systems. Specifically, education had a strong impact, with a coefficient of 0.840 at a 1 % significance level. Farm size and farm income had a medium effect, with a coefficient of 0.015 and 0.018, respectively, at a 5 % significance level. The analysis showed higher education levels are associated with a greater likelihood of adoption, as educated farmers were more likely to comprehend the benefits and technicalities of modern irrigation methods. Moreover, farm size played a significant role, with larger farms more inclined to adopt sprinkler systems due to their potential for increased agricultural production and economies of scale. Similarly, higher farm incomes are positively linked to adoption, as they provide the financial means to invest in the infrastructure and operational costs associated with sprinkler irrigation. In essence, these three factors underscored the importance of knowledge, scale and financial capacity in driving farmers' adoption of efficient irrigation technologies.

Comparing these findings with Table 2 and 6, where factors like education (year of schooling), farm size and farm income positively affected the adoption of sprinkler irrigation, Table 4 provided a comprehensive picture.

Education positively influences adoption directly and indirectly by facilitating access to credit. Larger farm sizes and higher incomes, identified in Table 2 as promoting adoption, were reiterated in Table 7 as factors enhancing access to credit, further supporting their role in driving technology adoption. The Heckman analysis offered some new insights, emphasizing the interconnected influence of education, farm size and income in promoting credit access and adopting sprinkler (water-efficient) irrigation systems.

This study expanded further by adding the logit regression, which allows for the estimation of odds ratios and provides a clearer understanding of the relationships between the explanatory variables taken for this study and the likelihood of adoption of sprinkler irrigation systems for groundnut cultivation. This was especially valuable in identifying the factors contributing to adopting sprinkler irrigation systems. Also, logit regression can account for the potential presence of non-linearity in the relationship between predictor variables and the log odds of adoption. This flexibility was essential in capturing complex relationships in agricultural decision-making processes. The results of logit regression analysis for factors affecting the adoption of sprinkler irrigation systems for groundnut cultivation in Bikaner district have been enlisted in Table 5.

The results from Table 6-7 collectively offered a strong understanding of the factors influencing the adoption of sprinkler irrigation systems among farmers in Bikaner. Education consistently emerges as a pivotal catalyst, significantly affecting access to credit and directly impacting the adoption decision. Farmers with higher education levels were 4 times more likely to adopt sprinkler systems, as indicated in Table 7, also exhibited a 0.342 % increase in adoption rates for every 1 % increase in education level. This underscored the enduring importance of knowledge and awareness in driving the adoption of modern farming practices (36-40). Furthermore, access to credit remained another critical factor, maintaining its significance. Farmers with better access to credit are 1.06 % more likely to adopt sprinkler systems (Table 7) and a 1 % increase in credit access leads to a 0.013 % increase in adoption rates. This consistent significance emphasizes the instrumental role of financial support in facilitating the adoption of water-efficient technologies, providing additional validation for the interconnected relationship between credit access and adoption.

Farm income and farm size collectively contribute to the adoption. While exhibiting a modest impact, higher farm income is associated with a 1.03 % increase in the likelihood of adopting sprinkler irrigation (Table 5) and a 0.007 % increase in adoption rates for every 1 % increase in farm income (37). Additionally, farm size, identified as a significant factor, played a crucial role, with larger cropped areas associated with a 1.03 % higher likelihood of adoption (Table 7) and a 0.006 % increase in adoption rates for every additional hectare of land (37). These findings collectively highlight the interconnected nature of factors influencing adoption, with education acting as a catalyst, credit access as a crucial enabler and financial capacity and farm size playing complementary roles in shaping the adoption.

However, the primary barrier to adopting sprinkler irrigation was the high initial investment required for installation. Many farmers hesitated to shift to this system due to financial constraints and uncertainty regarding immediate returns. The lack of accessible credit and limited subsidy provisions deterred small and marginal farmers from transitioning to sprinkler irrigation. Despite its lower efficiency and profitability, many continued relying on traditional canal irrigation without adequate financial support. Addressing these financial constraints required the implementation of targeted credit and subsidy programs. Providing low-interest credit schemes could ease the burden of high initial investments, making sprinkler irrigation more accessible to farmers. Governments and financial institutions needed to develop special loan packages with flexible repayment options designed explicitly for micro-irrigation infrastructure. Programs such as the Environmental Quality Incentives Program (EQIP) in the United States, which subsidized up to 75 % of sprinkler system installation costs and Australias' irrigation infrastructure grants, which covered 50 % of modernization costs, demonstrated the effectiveness of such policies. Similar initiatives in China and Brazil highlighted the role of government-backed irrigation efficiency programs and subsidized credit in promoting sustainable irrigation practices. In India, the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), an existing scheme that provides ₹ 25000/- per hectare for the installation of Sprinkler / Drip Micro Irrigation Systems, could help reduce upfront costs, enabling wider adoption of sprinkler irrigation without significant financial strain. Still, farmers need to be aware of this.

The Heckman analysis in this study underscored the role of education, credit access and farm size in influencing adoption. Educated farmers were more receptive to new technologies, while those with better financial capacity and more extensive landholdings were more likely to invest in advanced irrigation systems. Education and credit access emerge as key determinants, positively influencing sprinkler irrigation adoption. However, other factors like age, non-farm income and agricultural training showed mixed results supported by other studies (6) and (10). Expanding credit and subsidy mechanisms could bridge the gap between awareness and actual adoption, ensuring that financial limitations did not hinder technological progress in irrigation practices. The cost-benefit analysis reinforced the economic viability of sprinkler irrigation despite its higher initial costs. While the system demanded more significant investment, it ultimately provided superior net income with a BC ratio of 2.12 under Cost A1 and 1.66 under Cost C2 for sprinkler irrigation, compared to 1.78 under Cost A1 and 1.36 under Cost C2 for canal irrigation (Table 4). The BC ratio demonstrated that for every Re.1 invested, farmers earned significantly higher returns under sprinkler irrigation than canal irrigation. A better Benefit-Cost (BC) ratio proves more profitable in the long run. Sprinkler-irrigated farms achieved higher benefit-cost ratios than surface-irrigated farms, demonstrating greater resource efficiency and profitability. These findings align with research indicating the economic advantages of sprinkler irrigation for improving groundnut productivity(41, 46).

Beyond financial support, awareness and capacity-building initiatives were crucial in promoting adoption. The findings highlighted the need for targeted interventions, such as enhancing credit access and promoting education, to encourage sustainable groundnut cultivation adoption of sprinkler irrigation (water-efficient technologies) (40). Training programs and extension services could effectively demonstrate the long-term benefits of sprinkler irrigation, emphasizing its impact on yield, income and water efficiency. Encouraging progressive farmers to adopt and showcase the systems' advantages could further drive interest among their peers. Cooperative models and group-based investments also provided a viable alternative, allowing small and marginal farmers to share the cost of installing sprinkler systems. Farmer Producer Organizations (FPOs) and community irrigation models facilitated collective investment, reducing the financial burden on individual farmers. Government policies supporting micro-irrigation adoption could further strengthen this transition. Incentivizing precision farming techniques alongside sprinkler irrigation could enhance operational efficiency and reduce long-term costs.

Conclusion

Sprinkler irrigation was highly efficient for groundnut cultivation in arid regions, reducing water usage by 37.11 % while increasing yield by 7.98 % compared to canal irrigation. Despite its economic and agronomic advantages, adoption was influenced by education, access to credit and farm size. However, the high initial investment required for irrigation setup and the additional costs incurred due to excessive seed rates remained significant barriers. Farmers using sprinkler irrigation invested Rs. 105356.07 per hectare, higher than Rs. 93958.49 per hectare under canal irrigation, partly due to unnecessary seed costs. The seed rate exceeded the recommended 110-125 kg/ha, reaching 202.86 kg/ha under sprinkler irrigation and 160.00 kg/ha under canal irrigation, leading to increased expenses. This highlighted the need for farmer education on optimal seed usage and spacing. To address these challenges, targeted policy interventions, including improved credit access, flexible loan schemes and awareness of subsidies like PMKSY (₹ 25000/- per ha for installing Sprinkler / Drip Micro Irrigation Systems) were essential. Promoting sprinkler irrigation through these measures would have enhanced groundnut production, improved irrigation water productivity and ensured sustainable agricultural practices in arid regions. Several research studies (40-45) have highlighted the potential of sprinkler irrigation systems and their suitability for water-scarce areas. However, this study revealed that, despite the efficiency of sprinkler irrigation in groundnut cultivation, its adoption among farmers remains limited due to high initial costs, increased seed rate requirements, farmers' education levels and access to credit. This study provided new insights into the need for targeted farmer education, emphasizing these critical factors to enhance adoption for sustainable groundnut cultivation in western dry region of India.

Authors' contributions

VK[1] helped in conceptualization, project administration, writing original draft, writing, review and editing and validation. VY helped in conceptualization and formal analysis. RK helped in data curation, resources and supervision. AS[1] helped in writing, review and editing. AS[2] helped in methodology, formal analysis, data curation and writing original draft. VK[2] helped in writing, review and editing. [VK[1] Stands for Vandana Kumari; VK[2] stands for Vijay Khanna; AS[1] Stands for Ashok Kumar Sharma and AS[2] stands for Aravindh Kumar S].

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While preparing this work, the author(s) used Rytr (blog/content writing AI software) to reframe some sentences to have proper research terms for some parts alone. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the publication's content.

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