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Factors influencing the use of rainwater for agricultural irrigation: the case of greenhouse agriculture in southeast Spain

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ABSTRACT

The availability and quality of water resources for agricultural irrigation are being increasingly compromised by different factors. In this context, the installation of rainwater harvesting (RWH) systems for use in agricultural holdings can contribute to mitigating this problem. However, the use of these systems by farmers continues to be very low. This paper analyses the factors that influence a farmer's decision to adopt these systems to take advantage of rainwater. Greenhouse agriculture in southeast Spain is the case studied. For this, a binary logistic regression model based on a survey administered to farmers was used. Among the variables found to be significant, the most important variables are the quantity of water in the pond, the pond capacity and environmental awareness. The variables that least affect the adoption decision are age, education level and income. These results have allowed the development of the main lines of action for policy-makers to intervene in order to promote the adoption of these systems. These measures focus on enhancing the training of farmers, providing them with financial support and boosting their environmental awareness. The results of this study lead to improved research on farmers' behaviour and sustainable management of water resources in agriculture.

Key words: behavioural economics, farmer perception, logistic regression, rainwater harvesting systems, sustainability, water management

HIGHLIGHTS

- Research on factors influences rainwater harvesting (RWH) adoption.
- The most influential variables in adoption are the capacity of the pond and the amount of water at which it is maintained.
- Farmers' environmental awareness is also important in the adoption of RWH.
- Recommendations to promote the adoption of RWH are proposed.
- The results obtained may be useful in agricultural areas with scarce water resources.

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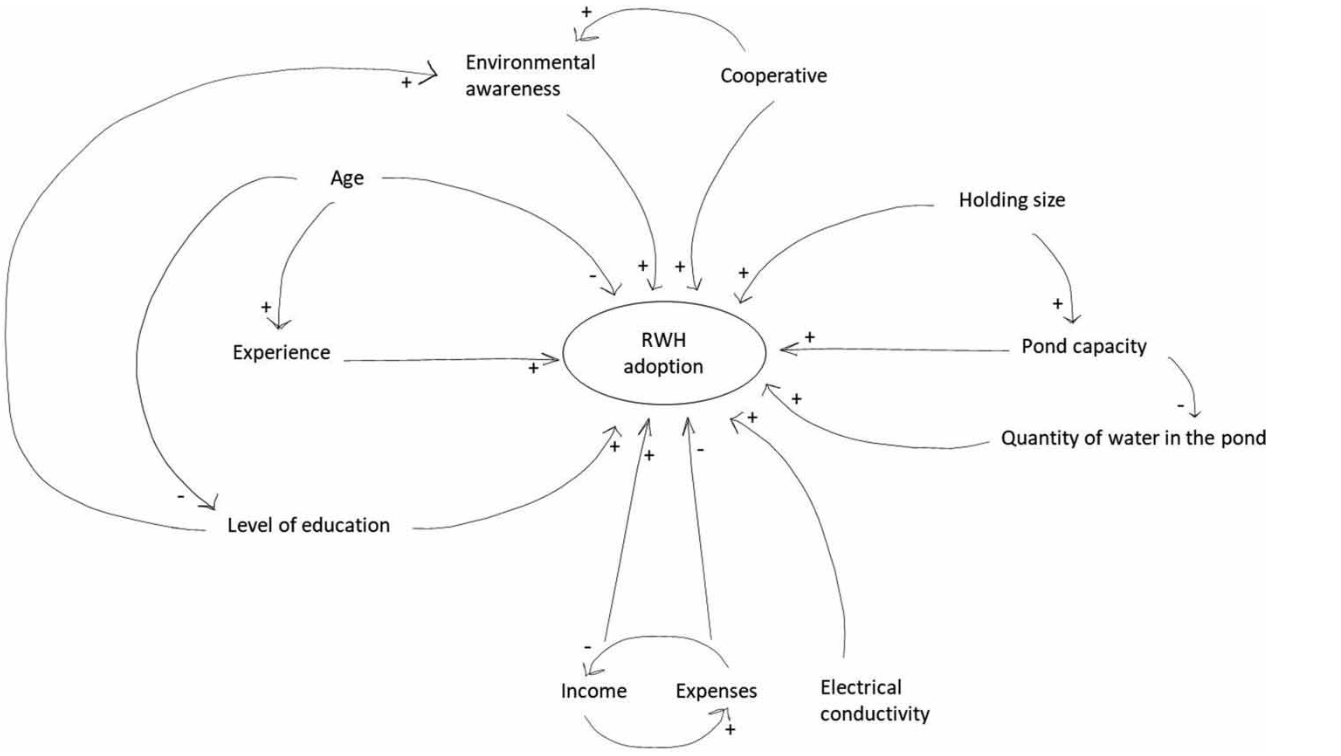
GRAPHICAL ABSTRACT



INTRODUCTION

The availability and quality of water are being compromised as a result of demographic pressure and economic development, which have caused an increase in the demand for water resources worldwide (Balasubramanya & Stifel 2020). This situation is being aggravated by the effects of climate change, which are modifying the rainfall pattern and exacerbating extreme weather phenomena such as droughts and torrential rains (Iglesias & Garrote 2015). As a result, various problems like urban flooding, severe weather, and shortages of water and energy have become increasingly common and severe worldwide (Duan & Gao 2019). One of the regions whose hydrology and water resources will be most affected by climate change is the Mediterranean basin (Ozturk *et al.* 2015; Lionello & Scarascia 2018). It is estimated that temperatures in the Mediterranean regions could increase by 3 °C by 2050 and rainfall could decrease by approximately 30%, which would mean a decrease in water resources by up to 40% (European Environment Agency 2021).

The way in which water resources are allocated, used and managed will have significant effects on the environment, economy and standard of living (Chen *et al.* 2020). In this context, extensive research has been generated on issues related to the prediction of changes in water availability due to climate change and other factors, the management of droughts and floods or the optimal and sustainable management of the use of available resources. For example, Samareh Hashemi *et al.* (2014) conducted an assessment of floods with the aim of identifying key points for developing policies to cope with this phenomenon. Duan & Gao (2019) develop a systematic analysis framework for designing and assessing the feasibility and hydro-energy capacity in the urban stormwater drainage system by integrating different models. Tansar *et al.* (2022) investigated the optimal spatial location of low-impact development practices (bioretention cell, green roof, permeable pavement and rain garden) within the urban catchment and their impact on the performance of the urban drainage system and concluded that surface runoff, peak runoff and flood volume could be significantly reduced by replacing 25% of the impervious catchment area. Meanwhile, Chen *et al.* (2020) analyse the nexus between water supply, hydropower and environmental variables to assess multiple risks in the water resource system. Wang *et al.* (2022) use multiple extreme learning machines (ELMs) to predict drought, while He *et al.* (2022) use this method to estimate daily evapotranspiration in an agricultural area. Moridi *et al.* (2018) assessed sustainable groundwater management using simulation modelling and found that there is a need to encourage

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the cooperation of groundwater users and to limit and regulate abstractions for sustainable groundwater management. Hatamkhani & Moridi (2021) develop a water allocation model in an integrated framework that includes the interaction of water supply and demand as a function of economic and social factors. Moridi (2019) discusses an approach to resolving disputes over the allocation of river pollutant loadings based on the bankruptcy method.

Water is an essential resource for food production and water scarcity threatens agricultural development in many areas (Chartzoulakis & Bertaki 2015). Therefore, there is an urgent need to use simple and reliable methods to formulate crop water requirements and irrigation schedules to maximize water use efficiency in agriculture (He *et al.* 2022). Furthermore, the adoption of agricultural technologies is an opportunity in a context in which agriculture is being subjected to various changes as a result of the modification of natural conditions, the availability of resources such as water or soil and other socio-cultural issues (Gadanakis *et al.* 2015; Timothy *et al.* 2022). In this sense, it is up to farmers to adopt such technologies, although the benefits generated by their adoption can have a positive impact on society at large. Hjorth & Madani (2013) state that it is necessary to understand the dynamics and interactions that occur in a water resource system, especially in relation to users, in order to achieve sustainable water resource management. Moghimi Benhangi *et al.* (2020) state that the lack of collaboration and trust among farmers negatively impacts optimal water resource management. In addition, it should be noted that the involvement of different decision-makers and stakeholders in water quality management requires the development of new approaches (Moridi 2019; Zolfagharipoor & Ahmadi 2021).

One practice that can contribute to improving the availability of water resources is the installation of rainwater harvesting (RWH) systems. It is an ideal practice for arid and semiarid areas that face water scarcity and are affected by global climate change (Bafdal & Dwiratna 2018; Wang *et al.* 2021). By installing these systems, rainwater from various surfaces, such as the ground or roof of buildings, is collected and stored for later use for agricultural irrigation (Bafdal *et al.* 2017). It is estimated that RWH can help maintain crop production and even increase it between 5 and 100% depending on the characteristics of the area (Piemontese *et al.* 2020). In addition, RWH has other advantages, such as the possibility of self-sufficiently managing water resources, reducing soil salinity, improving the quality of irrigation water or diversifying agricultural production (Jewell 2016; Panagea *et al.* 2016).

In the case of greenhouse agriculture, the installation of RWH systems is especially interesting since the water can be collected directly from the surface of the structure (Panagea *et al.* 2016). Several studies show that the water harvested from the surface of greenhouses can meet between 30 and 60% of the water needs of different crops, such as tomato, cucumber or pepper (Jewell 2016; Boyaci & Kartal 2019; Singh *et al.* 2019). Southeast Spain has the largest concentration of greenhouses in the world, with more than 30,000 ha that provide fruits and vegetables to the European continent throughout the year (Galdeano-Gómez *et al.* 2017). The development of this agricultural model has drawn from the use of groundwater, which has caused its availability and quality to be increasingly compromised. The use of rainwater can be a viable alternative in this area to increase the availability of water resources and minimize the extraction of aquifers (Carvajal *et al.* 2014). Despite all these advantages, the use of rainwater by farmers in this area is limited (García-García *et al.* 2016). Therefore, it is relevant to analyse what economic, social and technical factors are behind the farmer's decision to install RWH systems or not with the aim of assisting policy-makers in developing policies for the sustainable use of water resources. Water resource management policies around the world have gradually incorporated environmental water needs and allocations (Chen *et al.* 2020). However, decision-makers face many challenges in the management of common resources such as water as successful resource planning is necessary to ensure their sustainability (Moridi *et al.* 2018). To this end, it is essential to involve stakeholders in the decision-making process and to know the opinions, beliefs and needs of the affected actors.

Understanding farmers' willingness and opinion on new management practices to improve water use are crucial for developing sustainable water management policies. However, it can be difficult to gain insights into farmers' perceptions and attitudes towards water management for a variety of reasons. According to Liu *et al.* (2018), one of the main challenges is that farmers may have a diverse range of knowledge, skills and resources, which can affect their willingness and ability to adopt new management practices. Additionally, farmers may have different priorities and values, which can influence their perception of water management (Mills *et al.* 2017). Another difficulty is that farmers may have limited access to information and resources related to water management, which can make it harder for them to understand the benefits and drawbacks of different practices (Mango *et al.* 2017). Furthermore, farmers may be hesitant to adopt new management practices if they perceive them to be costly or time-consuming (Gachango *et al.* 2015).

It is important to understand these difficulties in order to develop effective and sustainable water management policies. This requires engaging with farmers, understanding their needs and concerns, and providing them with the necessary

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information and resources to make informed decisions about water management (Velasco-Muñoz *et al.* 2022). In addition, it is essential to involve farmers in the design and implementation of water management policies in order to ensure that they are responsive to their needs and priorities. For this reason, the objective of this work is to analyse what the factors are and what their level of influence is on the farmer's decision to adopt RWH systems for agricultural irrigation in southeast Spain. This study is the first to analyse this issue in the case of greenhouse agriculture, thus contributing to filling the gap in existing research in this field (Velasco-Muñoz *et al.* 2019).

MATERIALS AND METHODS

Study area

This study was carried out in the Campo de Dalías region, located in the province of Almería in southeast Spain, which has a total of 22,054 ha of greenhouses (Figure 1) (Junta de Andalucía 2020). This area is divided into numerous farms, mainly family holdings, where vegetables and fruits are grown (tomato, pepper, eggplant, cucumber, zucchini, green bean, watermelon and melon). The agricultural development of this area has been based on the use of groundwater, given that the available surface water resources are very scarce. Although the study area is characterized by the highly efficient use of water resources, the high demand for irrigation water has led to the overexploitation of aquifers (Caparrós-Martínez *et al.* 2020) reflected in a Horticultural Water Index of 1.1 (Castro *et al.* 2019). Water resources are managed through irrigation communities, which supply water to associated farmers at an average price of €0.30/m^3 (Caparrós-Martínez *et al.* 2020). However, this price is skyrocketing mainly due to the need to extract water from a greater depth and to the rising cost of electricity.

Two main characteristics of agricultural holdings in this area make it ideal for the installation of RWH systems to use this water for agricultural irrigation (Junta de Andalucía 2015). First, most greenhouses are sloping-roof type greenhouses, whose roof is sectioned into variously inclined slopes, which allows rainwater runoff. Second, holdings usually also have a pond to store irrigation water and regulate flow.

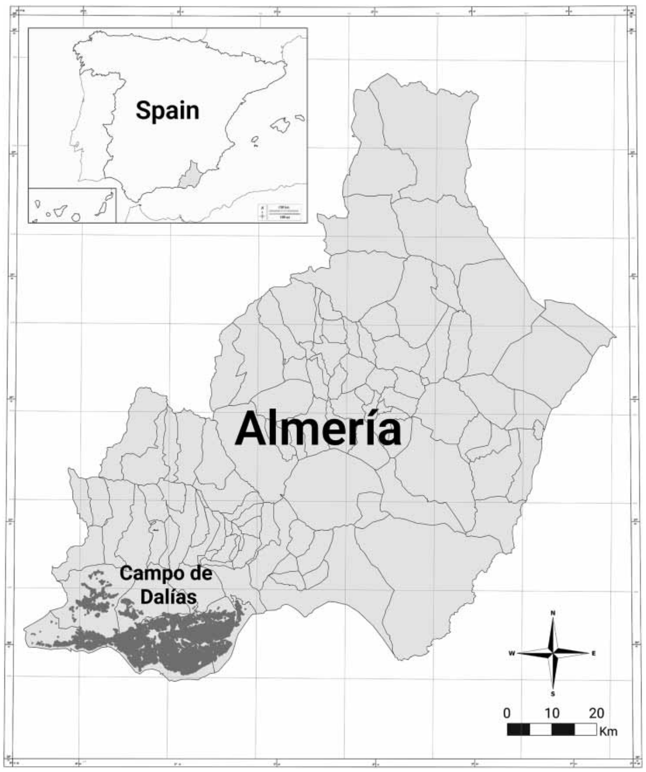

Figure 1 | Location of Campo de Dalías. *Source*: Own elaboration.

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Data source and data collection

For this analysis, primary information from the farmers in the study area was used. The collection of information was carried out through surveys of those responsible for agricultural holdings. For this, a questionnaire was designed using a qualitative methodology, which included interviews with experts and a focus group. The objective was to select relevant variables in relation to the adoption of RWH systems. A group of experts related to agriculture in the study area were interviewed to learn the key aspects regarding the harvesting and use of rainwater. Among the interviewees were the presidents of the main irrigation communities in the area and farmers with extensive experience. Additionally, to validate the questionnaire, a focus group was conducted with a group of 10 farmers, of which five used rainwater and five did not. The questionnaire focused on the socioeconomic characteristics of the farmers (age, experience, level of education, season income, season expenses and cooperative membership), the technical characteristics of the holdings (holding size, pond capacity, quantity of water in the pond and electrical conductivity in irrigation water), the RWH systems and their use of rainwater and farmers' environmental awareness. To measure whether or not farmers were environmentally aware, an index based on the frequency with which they perform environmental behaviours was used following previous studies (Paço & Lavrador 2017; Karasmanaki *et al.* 2021; Musova *et al.* 2021).

Sample size and selection

The determination of the sample size was performed using the following formula:

$$n = \frac{Z_{\alpha}^{2} p(1-p)N}{e_{\alpha}^{2}(N-1) + Z_{\alpha}^{2} p(1-p)} \tag{1}$$

where n is the sample size for finite populations; N is the population size; α is the confidence level; $Z_{\alpha}$is the statistical parameter that depends on the confidence level (e.g., 1.96 for a confidence level of 95%); e_{α} is the maximum accepted estimation error (0.05); p is the probability of occurrence of the event studied (0.5).

Because the exact number of farmers in the study area is unknown, the number of hectares was used to determine the area that was necessary to survey for the sample to be representative. In addition, the probability that farmers would use rainwater for irrigation was also unknown, so it was considered to be 50% (Rogério-Foguesatto & Dessimon-Machado 2022). The study area has an area of 22,054 ha of greenhouses (Junta de Andalucía 2020). Therefore, for a significance level of 95% and a maximum error of 5%, it was necessary to survey a minimum of 378 ha. Finally, a total of 143 farmers who managed 390 ha were surveyed. For the selection of farmers, simple random sampling was used as in other studies (Abu Bakar *et al.* 2021; Adams & Jumpah 2021). To reach the necessary sample, the collaboration of various irrigation communities in the study area was requested. The surveys were conducted between August and November 2021 and lasted approximately 15 min each.

Model specification

The adoption of a practice or technology by farmers can be explained through the theory of utility maximization (He *et al.* 2007; Baiyegunhi 2015; Rogério-Foguesatto & Dessimon-Machado 2022). According to this theory, the farmer will opt for adoption as long as the profit obtained (U_1) is higher than that of non-adoption (U_0), that is, when $U_1 > U_0$. Although the objective of maximizing profit is common to all farmers, the factors that influence profit and the decision to adopt are dissimilar (He *et al.* 2007).

The logistic regression model was used to determine the factors that affect the decision to adopt RWH systems and the use of this water for agricultural irrigation in the study area. This model was selected because it is a standard analysis method when the outcome variable is dichotomous, in addition to being used in similar studies such as those by Baiyegunhi (2015) or Muriu-Ng'ang'a *et al.* (2017). The use of rainwater is measured as a dichotomous response variable that takes values of 0 and 1, where 0 corresponds to 'no use' and 1 to 'use'.

The utility function for the farmer is expressed as:

$$U_i = \beta_0 + \sum_{i=1}^{n} \beta_i X_{ki} \tag{2}$$

where U_i is the indirect utility derived from the decision to use, which is a linear function of k explanatory variables (X); X_i is the set of parameters, including socioeconomic factors and farm characteristics, that influence the ith farmer's decision to use

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rainwater. β_0 is the intercept term; $\beta_1, \beta_2, \beta_3, \ldots, \beta_i$ are the coefficients associated with each explanatory variable $X_1, X_2, X_3, \ldots X_{ki}$.

The decision to use rainwater or the probability that the ith farmer uses it due to these factors X_i will be given by:

$$P_i = \frac{e^{U_i}}{1 + e^{U_i}} \tag{3}$$

where P_I is the probability that the decision of the i^{th} farmer is 1 and $(1 - P_i)$ that is 0.

The odds that rainwater will be used can be defined as the relationship between the probability that a farmer uses rainwater P_I and the probability that they do not use it $(1 - P_i)$, that is,

$$\text{odds} = \frac{P_i}{1 - P_i}.$$

Taking into account the natural log, we can obtain the prediction equation of an individual farmer:

$$ln = \frac{P_i}{1 - P_i} = \ln \text{odds} = \beta_0 + \sum_{i=1}^{n} X_{ki} = U_i \tag{4}$$

where U_i is also called the log of the odds ratio in favour of use.

Data analysis

The explanatory variables analysed are shown in Table 1. In addition, Figure 2 shows the causal loop diagram of the variables analysed. The data were organised and studied using the Statistical Package for Social Sciences (SPSS version 28). First, descriptive statistics were extracted and checked for significant differences between adopters and non-adopters for the variables analysed. For dichotomous variables, the chi-square test was used, and for continuous variables, the t-test was used. Before performing binary logistic regression, the variables were subjected to a multicollinearity test by calculating the correlation matrix. Values greater than 0.7 are considered critical values for multicollinearity (Rogério-Foguesatto & Dessimon-Machado 2022). To corroborate the viability of the regression, several statistics of the model were used for verification. To determine if the model fits the data correctly, the Hosmer and Lemeshow fit test was used. According to this test, the

Table 1 | Description of the variables used in the logistic regression model

Variable	Description	Expected sign
Dependent variables		
Use of rainwater	Dummy (1 if yes, 0 if no)	
Explanatory variables		
Age	Numeric (years)	–
Experience	Numeric (years)	+
Level of education	Number of years of formal education	+
Holding size	Numeric (hectares)	+
Pond capacity	Numeric (m^3)	+
Quantity of water in the pond	Dummy (1 more than 75%, 0 less than 75%)	–
Electrical conductivity in irrigation water	Numeric (dS/m)	+
Cooperative membership	Dummy (1 if yes, 0 if no)	+
Season income	Numeric (€/m^2)	+
Season expenses	Numeric (€/m^2)	–
Environmental awareness	Dummy (1 if yes, 0 if no)	+

Source: Own elaboration.

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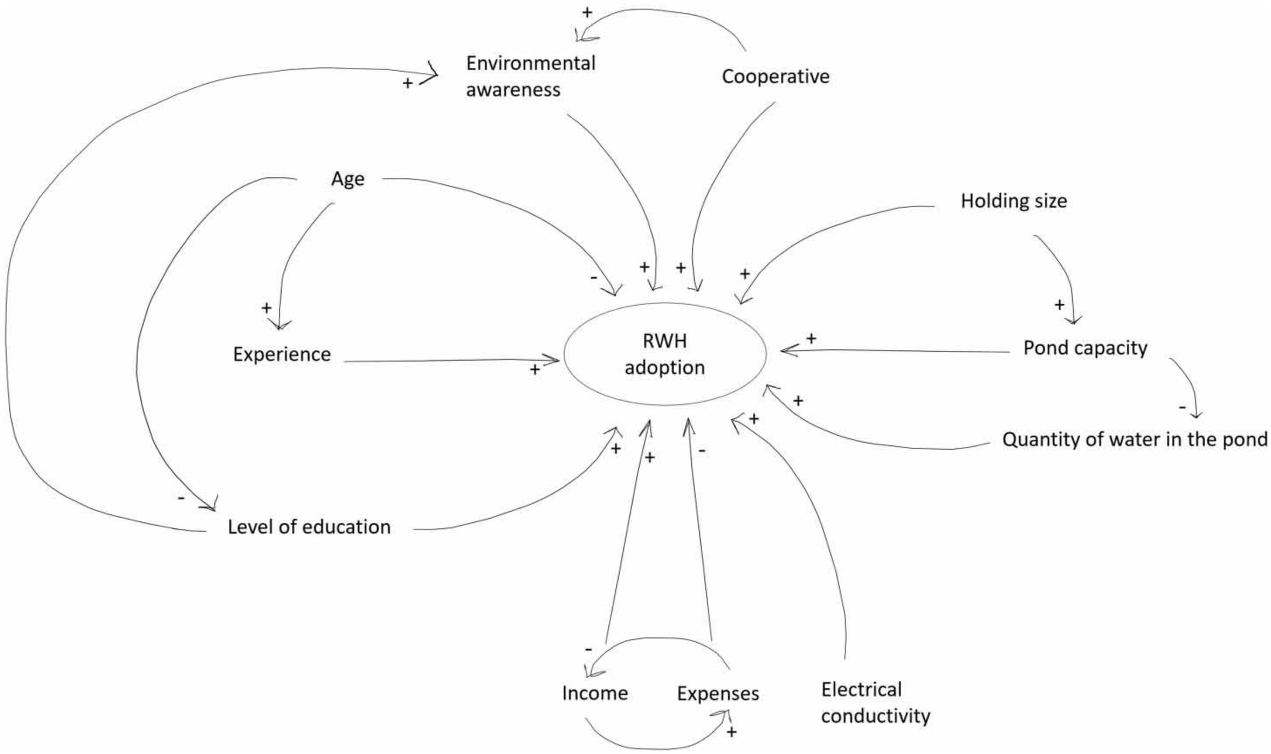

Figure 2 | Causal loop diagram of the variables analysed. *Source*: Own elaboration.

significance must be greater than 0.05, indicating that there are differences between the observed and expected values, so that the model fits the data well. Nagelkerke's R^2 is an estimated coefficient of determination for models with categorical response variables. This coefficient can range between 0 and 1, indicating the amount of variance explained by the model (Aydogdu 2016). The overall percentage of cases that were correctly classified was also taken into account, with values greater than 60% being considered adequate (Muriu-Ng'ang'a *et al.* 2017).

To determine the validity of the model, two dimensions must be analysed: calibration and discrimination (Hosmer *et al.* 2013; Harrell 2015). Calibration indicates the degree of agreement between model predictions and observed results. A commonly used test to assess calibration is the Hosmer and Lemeshow test, where observed and expected values are compared in different previously established categories, usually at each value of the variable that provides the probability of the event predicted by the model or at each decile of that variable (Hilbe 2009). If the fit is good, one would expect a good match between what is observed and what is predicted by the model. For its part, discrimination assesses the model's ability to differentiate between individuals in whom the event is present and those in whom it is not. The common measure of discrimination is the area under the receiver operating characteristic (ROC) curve, which reflects the proportion of times the model correctly identifies the individual with the event of interest among all possible pairs consisting of an individual with the event and an individual without the event (Hosmer *et al.* 2013). An area of 0.7 or higher on the ROC curve indicates acceptable discrimination of the model (Javid & Nejat 2017).

RESULTS

Characteristics of farmers and their holdings

Table 2 shows the descriptive statistics of the variables included in the analysis. Rainwater is used in 57% of the holdings in the sample. The average age of the farmers is 45 years, ranging from 27 years for the youngest respondent to 68 years for the oldest. More than 70% of the respondents are over 40 years of age. The average experience as a farmer is 24 years, with a minimum of 3 years and a maximum of 49. In general, the sample has a high level of experience in the sector because

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Table 2 | Descriptive statistics

Variable	Minimum	Maximum	Mean	SD
Dependent variables				
Rainwater use	0.00	1.00	0.57	0.50
Explanatory variables				
Age	27.00	68.00	45.45	8.98
Experience	3.00	49.00	23.59	9.32
Level of education	1.00	18.00	11.38	3.04
Holding size	0.75	11.00	2.72	1.93
Pond capacity	70.00	20,000.00	1,440.44	2,495.91
Quantity of water in the pond	0.00	1.00	0.70	0.46
Electrical conductivity in irrigation water	0.53	2.00	1.16	0.30
Cooperative membership	0.00	1.00	0.61	0.49
Season income	5.00	13.00	8.27	1.39
Season expenses	2.50	8.00	4.71	1.13
Environmental awareness	0.00	1.00	0.53	0.50

Source: Own elaboration.

57% of the farmers have been involved in this activity for at least 20 years. The farmers surveyed have been in school for an average of 11 years, which is a basic level of academic training.

The average area of the holdings is 2.72 ha, the smallest being 0.75 ha and the largest 11 ha. The average capacity of the holdings is 1,440 m^3, although there is a large difference between the smallest (70 m^3) and the largest (20,000 m^3). In most cases (70%), the pond level is usually maintained above 75% of its water capacity. The average conductivity of the irrigation water is 1.16 dS/m. The majority of farmers (61%) belong to a cooperative to sell their harvest. The average income of the holdings is 8.27 €/m^2, while that of expenses is 4.71 €/m^2. Finally, 53% of farmers show behaviours associated with a medium-high level of environmental awareness.

Table 3 shows the differences in mean values between adopters and non-adopters. In the case of age, the results indicate that adopters are significantly younger than non-adopters at a 1% significance level. This implies that in the study region, younger farmers are more likely to collect rainwater in the fields compared to older farmers. In relation to education,

Table 3 | Differences in mean values between adopters and non-adopters

	Adopters		Non-adopters		
	Mean	Standard deviation	Mean	Standard deviation	*p*-value
Age	43.52	8.209	48.03	9.388	0.005***
Level of education	12.32	2.775	10.13	2.941	<0.001***
Holding size	2.96	2.242	2.41	1.367	0.083*
Pond capacity	1,656.02	2,558.42	1,150.66	2,399.58	0.001***
Quantity of water in the pond	0.56	(*)	0.89	(*)	<0.001***
Electrical conductivity in irrigation water	1.20	0.307	1.11	0.283	0.067*
Cooperative membership	0.67	(*)	0.52	(*)	0.696
Season income	8.61	1.305	7.80	1.385	0.003***
Season expenses	4.67	1.043	4.77	1.236	0.876
Environmental awareness	0.62	(*)	0.41	(*)	0.074*

Notes: (*) No data on Standard Deviation is given for categorical variables.
*significant at 10%, **significant at 5%, ***significant at 1%.

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there are also significant differences between the two groups at a significance level of 1%. Adopters have studied for more years (12) than non-adopters (10).

Holding size is significantly larger for adopters (2.96 ha) than for non-adopters (2.41 ha) at a 10% significance level. Pond capacity is significantly higher for adopters than for non-adopters. Specifically, adopters have ponds with an average capacity of 1,656.02 m^3, while for non-adopters it is 1,150.66 m^3. Regarding the level of electrical conductivity of irrigation water, adopters have higher levels (1.20 dS/m) than non-adopters (1.11 dS/m) with a significance level of 1%. There are no significant differences between the means of the two groups in relation to cooperative membership. In the case of income, the groups have significant differences at 1%. Adopters earn an average of 8.61 €/m^2, while non-adopters earn 7.80 €/m^2. On the other hand, average expenses do not show significant differences between groups. Finally, the means obtained for environmental awareness are significantly different at a significance level of 10%. Sixty-two percent of adopters have medium-high levels of awareness, while for non-adopters this value is 41%.

Model validation

The experience variable was finally not included in the analysis when presenting multicollinearity with the age variable (coefficient = 0.725 with a significance of 0.01). A significance of 0.679 was obtained for the Hosmer–Lemeshow test, which confirms that the model fits the data adequately. As shown in Table 4, the observed and expected values for each of the deciles are approximately equal, so there is no difference between the observed and predicted values in the model. This allows us to conclude that the model fits the data correctly. In addition, according to Nagelkerke's R^2, the response variable defines 55.5% of the variance of the explanatory variables.

Table 5 shows an indication of the model's ability to predict the correct category once predictors have been added to the study. The percentages in the first two rows indicate the specificity and sensitivity of the model (Hosmer *et al.* 2013). Specificity is the ability of the model to correctly classify subjects without an event, which in this case is 72.1%. Sensitivity is the ability of the model to correctly identify subjects with the studied event, which amounts to 79.3% in our study. Overall, the correct prediction rate was good at 76.2%.

Table 4 | Contingency table for the Hosmer and Lemeshow test

	No RWH		RWH		
Deciles	**Observed**	**Expected**	**Observed**	**Expected**	**Total**
1	14	13.250	0	0.750	14
2	11	12.064	3	1.936	14
3	12	10.730	2	3.270	14
4	7	8.621	7	5.379	14
5	6	6.413	8	7.587	14
6	4	4.363	10	9.637	14
7	5	2.989	9	11.011	14
8	2	1.683	12	12.317	14
9	0	0.725	14	13.275	14
10	0	0.162	17	16.838	17

Table 5 | Classification of the observations

	No RWH	RWH	Percentage Correct
No RWH	44	17	72.1
RWH	17	65	79.3
Overall percentage			76.2

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The ROC curve represents sensitivity on the *Y*-axis and the complementary of specificity, i.e., 1 − specificity, on the *X*-axis (Figure 3). The discriminatory power of a model is quantified by the area under the ROC curve (AUC) (Hosmer *et al.* 2013). In our study, we obtained an area under the curve (AUC) of 0.883, so we conclude that the discriminatory power of the model is 88.3%.

Factors that influence the use of rainwater

Table 6 summarizes the main results of the logistic regression. There is a statistically significant negative relationship between age and rainwater use ($\beta = -0.113$, sig. = 0.001). The Wald statistic (11.781) also reflects its significant relationship. The negative sign indicates that as farmer age increases, the use of rainwater decreases. The odds ratio for age shows that for every 1 year increase in the farmer's age, the probability of using rainwater decreased by a factor of 0.893. The educational level of farmers is positively correlated with the use of rainwater at a significance level of 1% ($\beta = 0.325$, sig. = 0.000). The Wald statistic (13,822) also confirms the significant association between both variables. This indicates that farmers with more years of education are more likely to use rainwater. The odds ratio indicates that every additional year of education increases the probability of using rainwater by a factor of 1.384. The size of the holding shows a positive relationship with the use of rainwater, significant at 10% ($\beta = 0.537$, sig. = 0.062), an aspect also confirmed by the Wald statistic (3.476). Farmers who have larger holdings are more likely to use rainwater. According to the odds ratio, an increase in the size of the farm by one hectare increases the possibility of using rainwater by a factor of 1.712. The capacity of the pond is positively related and at a significance level of 1% with the use of rainwater ($\beta = 1.066$, sig. = 0.001). The Wald statistic confirms this relationship (10.667). Therefore, it is more likely that farmers use rainwater if they have higher-capacity ponds. The odds ratio for this variable reveals that an increase of 1 m^3 in the capacity of the pond increases the probability of using rainwater by a factor of 2.903. The volume of water to which the pond is maintained is negatively correlated with the use of rainwater at a significance level of 1% ($\beta = -2.124$, sig. = 0.001). The Wald statistic (11.164) confirms this significant relationship. Therefore, it is less likely that rainwater is used in holdings which keep their ponds at a high volume of water. The odds ratio reveals that farmers

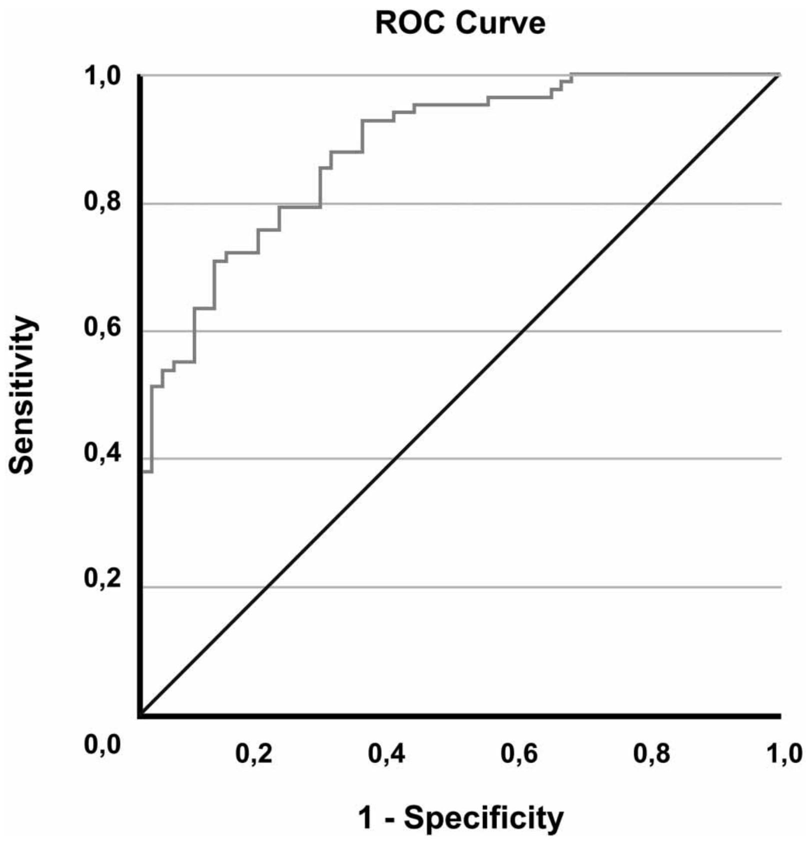

Figure 3 | ROC curve.

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Table 6 | Results of the binary logistic regression

Variable	β	Standard error	Wald	Significance	Exp. (β)
Age	−0.113	0.033	11.781	–0.001***	0.893
Level of education	0.325	0.087	13.822	–0.000***	1.384
Holding size	0.537	0.288	3.476	–0.062*	1.712
Pond capacity	1.066	0.326	10.667	–0.001***	2.903
Quantity of water in the pond	−2.124	0.636	11.164	–0.001***	0.120
Electrical conductivity in irrigation water	0.791	0.853	0.860	–0.354	2.206
Cooperative membership	0.638	0.493	1.673	–0.196	1.892
Season income	0.451	0.258	3.057	–0.080*	1.569
Season expenses	−0.351	0.241	2.116	–0.146	0.704
Environmental awareness	1.069	0.490	4.762	–0.029**	2.914
Constant	−0.353	2.633	0.018	–0.893	0.703

Number of observations: 143; Hosmer and Lemeshow test: Chi-square = 5.718; df = 8; sig. = 0.679; Nagelkerke R^2 = 0.555; percent correct prediction = 76.2%.
*significant at 10%, ** significant at 5%, *** significant at 1%.
Source: Own elaboration.

who maintain their ponds at a volume lower than 75% of their capacity use rainwater 0.12 times more than those who maintain it beyond 75% of their capacity. The electrical conductivity of irrigation water has a nonsignificant positive impact on the use of rainwater ($\beta = 0.791$, sig. = 0.354). The positive sign indicates that the greater the electrical conductivity of the irrigation water is, the greater the probability of using rainwater.

Belonging to a cooperative is not significantly but is positively correlated with the use of rainwater ($\beta = 0.638$, sig. = 0.196). Therefore, the probability of using rainwater is greater if the farmer belongs to a cooperative which markets their production. Income is positively and significantly related to the use of rainwater at a significance level of 1% ($\beta = 0.451$, sig. = 0.080). The Wald statistic (3.057) also confirms the significant association between both variables. This indicates that farmers with higher incomes are more likely to use rainwater. According to the odds ratio, an increase in income by €/m^2 increases the probability of using rainwater by a factor of 1.569. The expenses present a nonsignificant and negative relationship with the use of rainwater ($\beta = -0.351$, sig. = 0.146). In other words, the probability of using rainwater decreases as expenses increase. Environmental awareness is positively related and at a significance level of 5% to the use of rainwater ($\beta = 1.069$, sig. = 0.029). The significance is also confirmed by the Wald statistic (4.762). As such, it is more likely that those farmers who have more environmental awareness choose to use rainwater. According to the odds ratio, environmentally aware farmers use rainwater 2.914 times more than those who are not.

DISCUSSION

Older farmers are often reluctant to change their usual way of managing the farm when they feel that they are doing well, in addition to the fact that at an older age, learning and implementing new techniques and practices are more challenging. In this sense, He *et al.* (2007) and Mango *et al.* (2017) obtained similar results in previous studies, concluding that the age of farmers has a negative impact on the adoption of RWH systems. Asfaw & Neka (2017) note that young farmers are more willing to adopt new technologies and sustainable practices. Cristea *et al.* (2019) also indicate that young farmers are interested in the advantages that new technologies can bring them to maintain agricultural activity, while Giannakis & Bruggeman (2015) demonstrate that young farmers have a greater aptitude to innovate, intercept financing opportunities and adopt a new technological framework. According to different studies (Baiyegunhi 2015; Mango *et al.* 2017; Muriu-Ng'ang'a *et al.* 2017), education helps the farmers cope with introducing new practices and technologies that involve adapting and making changes in their holdings. RWH involves carrying out a more exhaustive control of the water parameters to maintain them at the appropriate levels for agricultural irrigation (Jewell 2016; Panagea *et al.* 2016). For that reason, higher levels of education can facilitate the adoption of this practice.

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As rainwater is collected from the surface of the greenhouse, the larger the greenhouse, the greater the volume of water that can be collected and therefore the more profitable the investment will be. Liang & van Dijk (2015) conclude that it is only feasible to incorporate RWH systems in large holdings. Mango *et al.* (2017) determined that having a larger surface area of land increases the availability of capital and, therefore, profits from investing in practices of this type. Liu *et al.* (2018) claim that farmers with larger holdings are more likely to adopt better management practices in the agricultural field because they are more environmentally aware and have more resources to invest in these practices. The holdings in the study area usually have an irrigation pond that stores water from different sources, such as desalinated or underground water, and for regulating flow (Junta de Andalucía 2015). Therefore, the greater the storage capacity of the pond is, the greater the probability that harvesting systems will be installed and that this alternative water source will be used. This is even more relevant if it is taken into account that in the study area, the episodes of rain are few but usually very intense, so to be able to use the water, it is necessary to have sufficient storage capacity. In this sense, as established by Londra *et al.* (2021), the appropriate size of the irrigation ponds should be determined considering the specific characteristics of the area, especially rainfall and water demand, to meet the water needs of the crops. Based on the characteristics of the study area, harvesting the rainwater that falls on greenhouse roofs could reduce water needs by up to 53% (Carvajal *et al.* 2014; Mendoza-Fernández *et al.* 2021). Although the farmers in the study area have a stable water supply, they usually keep their irrigation ponds at a volume of more than 75% of their capacity as a precaution against the possibility of malfunctions or supply problems. Taking this into account, it is observed that the farmers of the study area show some aversion to risk and, therefore, opt to keep the ponds with a high volume, which reduces the amount of rainwater that can be collected. In this sense, Liu *et al.* (2018) indicate that the risk of crop yield loss is one of the most important barriers to adopting better management practices in the agricultural field. During the collection of primary information, some farmers commented that they try to reduce the volume of water in the pond when heavy rains are expected. However, in many cases, the rain forecast is imprecise or is not known well in advance, which limits the possibility of farmers preparing the pond to store the water.

One of the factors that most affects water quality is salinity, which is measured by electrical conductivity. Crop yield can be affected by irrigation with water that has high levels of conductivity (Ourimbah *et al.* 2011). The conductivity of rain is practically zero, so its mixture with water from other sources of supply can reduce the final electrical conductivity (Zdeb *et al.* 2020). Redwood *et al.* (2014) and Phogat *et al.* (2020) established that the use of rainwater is a good option in areas where salinity is a problem. In addition, Aznar-Sánchez *et al.* (2019) determined that the high conductivity water from the aquifer is one of the variables that influences the use of desalinated water for agricultural irrigation. Although in recent years the overexploitation of aquifers has increased the conductivity level of the water in the study area, it still remains below 2 dS/m, which is the maximum acceptable value for cultivating fruit and vegetable products without affecting their yield and quality. This may be the reason why this variable is not significant in regard to using rainwater.

As in this work, studies of Baiyegunhi (2015) and Jha *et al.* (2019) also indicate a positive relationship between membership in farmers' associations and the adoption of water conservation practices. These authors conclude that belonging to this type of association strengthens social relations and facilitates the passing of information and experiences, giving confidence to farmers who are interested in implementing new technologies. In addition, farmers' associations play a fundamental role in the adoption of technologies by farmers because they offer them financial support (Piedra-Muñoz *et al.* 2017). The lack of significance of this variable can be attributed to the fact that the majority of farmers in the area are members of a cooperative. Several studies indicate that higher levels of income improve the adoption of practices and technologies by farmers (Baiyegunhi 2015; Arunrat *et al.* 2017; Mangisoni *et al.* 2019). These studies show that by earning more, farmers can make greater investments, in addition to being able to assume the risk that adopting new practices and technologies may entail. This is even more relevant if one considers that there is a high initial investment which can limit the installation of water conservation technologies (Liu *et al.* 2018; Bogdan & Kulshreshtha 2021). Higher expenses for developing agricultural activity can negatively impact the decision to make new investments due to the risk that these pose and the possibility of not being able to make the payments. In addition, farmers are unaware of the savings that using rainwater can generate due to the uncertainty about when and how much it will rain. This aspect has also been highlighted in other studies as a barrier to adopting RWH systems (Gadanakis *et al.* 2015; Willy & Kuhn 2016). The lack of significance of this variable may be because it refers to the overall expenses of the holding and not specifically to those related to the use of rainwater.

Several studies reveal that the environmental awareness of farmers has a positive effect on implementing sustainable practices (Liu *et al.* 2018). Prokopy *et al.* (2019) state that having general knowledge about the environmental impacts of agriculture is essential for farmers in deciding to implement practices aimed at addressing these impacts. Velasco-Muñoz

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et al. (2022) suggest that one of the main lines of action to improve the adoption of sustainable practices is through the awareness of farmers, for which it is necessary to strengthen the channels of communication with them. One of the main environmental benefits that can occur in the study area derived from the harvesting and use of rainwater is the recovery and conservation of underground water bodies (Aznar-Sánchez *et al.* 2019). Therefore, it would be important to convey to farmers the benefits that this practice can have to guarantee water supply in the long term and contribute to the conservation of aquifers.

Taking into account the results of this work, the following recommendations are proposed for policy-makers to intervene and improve the adoption of RWH systems by farmers. Firstly, there is a need to strengthen the training of older and less educated farmers. Older farmers are more reluctant to change the way they manage their farms, while less educated farmers have less capacity, resources and information to adopt change. Training programmes must therefore be tailored to the specific needs and circumstances of farmers. In this sense, demonstration days in which, in addition to technicians and advisors, other farmers who have been successful in implementing technologies and practices participate are one of the most effective instruments as they allow the exchange of experiences among the farmers themselves (Velasco-Muñoz *et al.* 2022). In the specific case of RWH systems, it is necessary to organize workshops to show how the system works, the technical and economic viability of its implementation, as well as the benefits that it can generate both on the farm and at the social level in the area.

Secondly, economic instruments should be designed to facilitate the installation of these systems for farmers. This is especially necessary among farmers with smaller farms because they may have more difficulties in recovering the investment needed to adopt RWH systems due to their smaller water catchment and storage area. Therefore, different types of economic incentives such as tax exemptions or cost-sharing schemes should be considered (Piñeiro *et al.* 2020). In addition, subsidies aimed at covering the cost of installing these systems should also be taken into account to make them more accessible to farmers.

Finally, the level of environmental awareness of farmers needs to be improved. Environmentally conscious farmers are more likely to understand the benefits of RWH, such as conserving water resources and reducing reliance on groundwater. They are also more likely to see the long-term benefits of such systems, such as improved crop yields and reduced irrigation costs. Different instruments can be used to raise farmers' awareness of these aspects, such as educational programmes (workshops, seminars and training sessions), publicity campaigns or field demonstrations (Ardoin *et al.* 2020; Ingram *et al.* 2022). In addition, work can also be done to improve the general public's awareness of the benefits of RWH, so that farmers can gain commercial advantages from the use of environmentally friendly techniques.

Furthermore, taking into account that the level of associationism among farmers in the area is very high, it is necessary to work with these associations to incorporate the proposed instruments as it can be a simple and effective way to reach farmers. In this regard, Moghimi Benhangi *et al.* (2020) state that collaboration and trust among farmers should be fostered to improve the optimal management of water resources.

CONCLUSIONS

The objective of this work was to analyse the factors that condition and their level of influence on the adoption of RWH systems for irrigation in greenhouse agriculture in southeast Spain. Knowing this information is relevant because the planning and sustainable management of water resources has become a challenge for policy-makers due to the context of water scarcity and increased competitiveness of different sectors for its use. It is therefore essential to know farmers' opinions on practices that can contribute to a more sustainable use of water resources, as well as the factors that influence their adoption. To obtain this information, logistic regression was carried out to analyse the influence of the following variables on the farmers' decision to adopt RWH systems: age, educational level, holding size, pond capacity and volume of water at which the irrigation pond is maintained, the electrical conductivity of the water, belonging to a cooperative, income, expenses and level of environmental awareness. Of these variables, the electrical conductivity of the water, belonging to a cooperative, and expenses were not significant for explaining the adoption of RWH systems and the use of this water for agricultural irrigation by farmers, contrary to what was initially expected. Among the variables found to be significant, the most important is the quantity of water in the pond. This is followed by pond capacity and environmental awareness. Age, education level and income are the variables that least affect this decision.

These results are relevant for policy-makers when establishing measures to expand the use of rainwater since they show which are the key areas of action in which they can intervene. First, it is necessary to reinforce the training of older and

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less educated farmers to demonstrate the benefits that using rainwater can generate and thus help in overcoming their resistance. Second, it would be advisable to financially support farmers who have small holdings since they cannot harvest as much rainwater and, therefore, take longer to recover the investment represented by the installation. Third, the environmental awareness outreach could boost its implementation, given that environmentally aware farmers are the most willing to use rainwater. Since most farmers are part of some type of association, either for irrigation or harvest management, these institutions would be a very appropriate channel.

Future lines of research include the study of farmers' willingness to pay for RWH systems using choice experiments or the contingent valuation method, the study of the existing types of farmers in relation to their adoption in order to develop instruments to boost personalized adoption using cluster analysis, and further information on how environmental awareness and social learning affect adoption through the application of the Theory of Planned Behaviour.

It is important to note that the findings of this study are limited in their applicability to other regions or agricultural systems. The study specifically focused on the most significant variables in the context of intensive agriculture in southeastern Spain. Additionally, the attitudes and perceptions of farmers may have been influenced by the unique characteristics of the study area. Therefore, it would be interesting to work on the replicability of this study in other geographical areas, to consider the inclusion of other variables that may affect the adoption of these systems by farmers, as well as to develop analyses showing the effect of the measures proposed to promote the adoption of this practice. However, from this case study, lessons can be drawn on how to promote the use of rainwater in other greenhouse agriculture areas in which water availability is acting as a limiting factor of their present and/or future development.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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