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RESEARCH PAPER

Perceptions and attitudes of farmers and landowners on soil salinity management and use of elemental sulphur in Oman

Ahmed Al-Mayahi[1,2] | **Noah Al-Shibli**[1] | **Tarig Gibreel**[3] | **Daniel Blackburn**[1] | **Said Al-Ismaily**[1] | **Caila McHugh**[4]

[1]Department of Soils, Water and Agricultural Engineering, Sultan Qaboos University, Al-Khoud, Oman

[2]Department of Earth Sciences, Utrecht University, Utrecht, The Netherlands

[3]Department of Natural Resource Economics, Sultan Qaboos University, Al-Khoud, Oman

[4]Fulbright Program, Georgetown University, Washington, DC, USA

Correspondence
Said Al-Ismaily, Department of Soils, Water and Agricultural Engineering, Sultan Qaboos University, PO Box 34, Al-Khoud 123, Oman.
Email: esmaily@squ.edu.om

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Abstract

Soil salinity threatens agricultural sustainability globally and is a significant challenge in Oman. Previous studies in Oman focused on examining the causality and spatiotemporal variation of groundwater and soil salinity, neglecting farmers' perceptions and attitudes towards salinity management. Therefore, this study evaluates (i) perceptions and attitudes of landowners and farmers towards soil salinity and its management, and (ii) determinants of willingness to use elemental sulphur to alleviate soil salinity in Oman. A questionnaire survey (122 responses) assessed perceptions, attitudes and knowledge using Likert scales and qualitative questions. Binary Logistic Regression analysed determinants of willingness to use elemental sulphur. Results reveal variations in perceptions, attitudes, knowledge and management practices. Most of the respondents were aware of adequate nutrient and water requirements for crops ($p < .05$). Respondents rely on social media (38.5%), fellow farmers (32.1%) and personal experiences (11.5%) for knowledge acquisition about soil salinity management. Half of the respondents did not monitor soil salinity, while the other half relied primarily on visual observation. A substantial number (62.6%) of the respondents did not implement any techniques to alleviate soil salinity, while among those who acted, a majority preferred cultivating date palms (55%) or fodders (29.4%). Awareness of the national salinity management strategy and commercial products is lacking. However, when introduced to elemental sulphur as a soil amendment for salinity, 74.8% of the respondents demonstrated a willingness to utilize it. Most (82.4%) preferred elemental sulphur products within the lowest price range. Being a full-time farmer, owning a farm, awareness of the national strategy and low-price preferences were positive determinants, while <1 year of farming experience was a negative determinant of willingness to use elemental sulphur. These findings inform future research on socio-economic perceptions of salinity in Oman, the Gulf region and similar arid areas facing food production limitations.

KEYWORDS

arid zone countries, elemental sulphur, Oman, soil amendment, soil salinity, water management

1 | INTRODUCTION

Soil salinity is a significant environmental issue affecting agricultural productivity and sustainability worldwide (Singh, 2022). Soil salinity results from natural factors (e.g. geology, climate, hydrology and coastal influence) and human-induced causes (e.g. improper irrigation, excessive fertilizer use, inadequate drainage and deforestation), which collectively impact salt accumulation and dynamics in soils (Mustafa et al., 2019; Pessarakli & Szabolcs, 2019; Zaman et al., 2018). Globally, soil salinity affects 1128 million hectares of land, of which 60% are classified as saline, 26% as sodic soils and 14% as saline-sodic soils (Wicke et al., 2011). Soil salinity is commonly found in arid and semi-arid regions which are characterized by high evaporation rates, and insufficient rainfall to meet crop water requirements and adequately leach salts from the root zone. Climate change is, however, anticipated to amplify the global soil salinity levels through multiple mechanisms, including rising sea levels, altered precipitation patterns, increased temperature and evaporation rates, modified hydrological cycles and the occurrence of extreme weather events (Corwin, 2021; Eswar et al., 2021; Okur & Örçen, 2020; Shahzad et al., 2021).

Soil salinity exerts profound socio-economic and environmental impacts, affecting agricultural productivity, livelihoods and ecosystems. In terms of socio-economic consequences, reduced crop yields and limited crop options lead to economic losses, posing challenges to farmers and regional economies (Mukhopadhyay et al., 2021). Moreover, soil salinity contributes to land degradation and displacement of agriculturally dependent communities. On the environmental front, disrupted ecosystems and reduced biodiversity result from altered plant composition and habitat suitability (Rengasamy, 2010; Zhang et al., 2019). Soil salinity can also affect water resources by contaminating freshwater supplies, rendering them unsuitable for drinking, irrigation and other uses, while also reducing water availability for plants, humans and organisms because of increased soil salt content. Therefore, addressing these challenges necessitates the implementation of sustainable land management practices and efficient water resource management. Adaptation strategies are vital for mitigating the socio-economic and environmental implications of soil salinity, ensuring the well-being of communities and ecosystems in the long run.

Oman like many other countries faces significant challenges with soil salinity. About 44% of the country's total area is salt-affected, of which agricultural areas are 70% affected (Ahmed et al., 2013; Hussain et al., 2006). The Al-Batinah North and Al-Batinah South governorates are the two most severely affected regions by soil salinity in Oman. However, salinity extends beyond these regions to various agricultural lands throughout the country because of many reasons such as arid climatic conditions, inadequate drainage, saline groundwater and unsustainable agricultural practices. However, it is challenging to provide precise figures on the severity and extent of soil salinity across the country because of the limited availability of data and digital soil salinity maps.

Overall, there are several key factors for the issue of soil salinity in Oman. The arid climate (i.e. limited rainfall and high evaporation rates) produces a high accumulation of salt in its soils (Al-Ajmi et al., 2002). Along with Oman's aridity, rapid population growth and economic development in the region play significant roles. Additionally, the detrimental effects of intensive and unsustainable agricultural practices, coupled with the use of low-quality saline water for irrigation, contribute to the problem. Furthermore, the overpumping of groundwater in coastal areas like Al-Batinah and Salalah leads to seawater intrusion, exacerbating soil salinity levels in Oman (Abdalla et al., 2010; Al-Ajmi et al., 2002; Askri & Ali Al-Shanfari, 2017; Choudri, Baawain, & Ahmed, 2015; Choudri, Baawain, Ahmed, Al-Sidairi, & Al-Nadabi, 2015; Shammas & Jacks, 2007).

Several techniques have been used to determine and map the intensity and extent of the salinity of soil and groundwater in Oman and more specifically, Al-Batinah region. These include the use of remotely sensed satellite images, unmanned aerial vehicles, ground-truthing and the preparation of temporal and spatial variance GIS maps of soil and water salinity (Abulibdeh et al., 2021; Al-Ajmi et al., 2002; Al-Mulla et al., 2010; Al-Rahbi, Al-Mulla, & Jayasuriya, 2019; Al-Rahbi, Al-Mulla, Jayasuriya, & Choudri, 2019). These studies and maps indicating geographical intensity raise several different solutions to salinity problems including:

1. Application of agronomic practices such as microbial nitrogen mineralization, mulching, tillage, effective sowing and nutritional factors of saline settings;
2. Application of biological solutions such as the discovery of salt-tolerant crops (i.e. halophytes) and planting of high-value crop that can tolerate the harsh climate of Oman and soil salinity such as Quinoa (*Chenopodium quinoa* L.) and *Jatropha* alternatives to water-intensive, low-value crops such as Rhodes grass (Al-Aufi et al., 2020; Al-Busaidi & Ahmed, 2020; AlKhamisi et al., 2021);
3. Assessment of the effects of feeding salt-tolerant forage crops to Omani sheep (Al Khalasi et al., 2010);
4. Determination of socio-economic risks and advantages of salinity management activities and incorporation of marginal lands with fish culture in Al-Batinah region;

5. Use of hydroponic and aquaculture systems in severely salt-affected areas (Al-Bakry et al., 2010; Goddard et al., 2010); among others.

Despite the extensive efforts to address soil salinity in Oman, its expansion persists, posing threats to agricultural sustainability and causing significant socio-economic losses in the country. There are several factors that contribute to the continued spread of soil salinity in Oman. Taking Al-Batinah region as an example, Abulibdeh et al. (2021) investigated the spatio-temporal variation of groundwater salinity from 58,000 water wells between 1990 and 2018. They found that groundwater salinity continuously increases over time because of urbanization and overpumping of groundwater. Additionally, many farmers in the salt-affected areas of Al-Batinah region use saline water for agriculture because of their unawareness about the impact of this poor-quality water on soil salinity development, as well as the unavailability of freshwater that can be used for irrigation (Al-Rahbi, Al-Mulla, Jayasuriya, & Choudri, 2019; Hereher & El-Kenawy, 2021). Many farmers also extensively apply chemical fertilizers which ultimately increase the dissolved salt in the soil (Al-Busaidi et al., 2022). Another reason is following the salt-affected lands. Extended periods of leaving the soil uncultivated promote the accumulation of salinity as water movement becomes upward, leading to the build-up of salt. Conversely, maintaining crop cover on the soil proves beneficial as irrigation for crops alters the water cycle, facilitating the downward movement of salt (Hussain et al., 2006). Consequently, effective management of the salinity issue in Oman necessitates stringent policies and regulations to curb excessive groundwater extraction along the coast (e.g. Al-Batinah region and Salalah), enhance soil and water resource management, allocation of a groundwater quota per farm and implement adaptive agronomic practices in salinity-affected areas to optimize yield potential (Abulibdeh et al., 2021; Al-Busaidi & Ahmed, 2020; AlKhamisi et al., 2021; Oukil & Zekri, 2021; Zekri, 2009; Zekri et al., 2017).

Effective long-term reclamation of salt-affected soils, particularly saline-sodic soils, necessitates the removal of salts from the root zone through leaching, using high-quality water and the displacement of Na^+ ions with Ca^{+2} ions (Dagar et al., 2019; Sparks, 2003). Gypsum or lime, serving as chemical amendments, can introduce the needed source of Ca^{+2} ions to the soil. However, this reclamation process is time-consuming, costly and requires substantial volumes of good-quality water (low salinity and low carbonate content), which poses significant challenges in arid regions where water resources are scarce and evaporation rates exceed precipitation.

Arid and semi-arid soils are calcareous in nature which often exhibit high calcium content because of the presence of gypsum and lime. However, in such environments, calcium frequently remains insoluble owing to the elevated soil pH. A potential solution for increasing calcium solubility is the application of soil-acidifying amendments, such as elemental sulphur (Horneck et al., 2007; Machado & Serralheiro, 2017; Zaman et al., 2018). Upon the addition of elemental sulphur to calcareous soils, soil microorganisms, notably Thiobacillus and certain eubacteria, oxidize it, resulting in the formation of sulphuric acid which decreases soil pH (Horneck et al., 2007; Machado & Serralheiro, 2017). This process leads to the enhancement of numerous physicochemical properties of salt-affected soils, including a reduction in the sodium adsorption ratio, increased soil structure stability and improved soil permeability, facilitating the leaching of water-soluble soil ions (Ahmed et al., 2016; Bole, 1986; López-Aguirre et al., 2007; Mulvany et al., 2019). Elemental sulphur can also be used in combination with gypsum. This integrated application enhances the effectiveness of gypsum in ameliorating saline soils, particularly saline-sodic soils (Bello et al., 2021). A study conducted by de Andrade et al. (2018) illustrated that the simultaneous application of elemental sulphur (at a rate of 1.39 ton/ha) and gypsum (8.49 ton/ha) was effective in reducing both soil pH and salinity. Even when irrigated with saline water, the soil pH decreased by 2.2% (from 8.65 to 8.46), while salinity dropped by a substantial 68.8% (from 27.7 to 8.65 dS/m). Consequently, there were significant improvements in the growth parameters of sweet sorghum (*Sorghum bicolor* L. Moench). Specifically, compared with the control treatment (which did not involve elemental sulphur), plant height, stem diameter, leaf count and dry matter saw marked enhancements of 21.4%, 12.8%, 28.8% and 41%, respectively.

In addition to its use as a soil amendment, elemental sulphur is often utilized as a fertilizer, because of its capacity to restore soil sulphur levels and augment the bioavailability of other key plant macronutrients, including nitrogen and phosphorous (Yasmin et al., 2007). For instance, a study conducted in the United Arab Emirates demonstrated that applying elemental sulphur at rates of 5 and 10 t/ha enhanced nutrient uptake and improved yield and quality of cucumber crops grown in sandy calcareous soil (Motior et al., 2011).

Notably, soil salinity represents a complex, multifaceted issue. Therefore, implementing a one-size-fits-all solution across all sites and soil types is challenging because of the spatiotemporal variations across different environmental and socio-economic contexts (Majeed & Muhammad, 2019; Zaman et al., 2018). To enhance the success of reclamation techniques, an integrated management approach incorporating a combination of physicochemical, hydrological, biological, socio-economic and political solutions is advocated. However, widespread adoption of these strategies requires shifting public behaviours and practices towards sustainable soil management and water conservation. Such a shift necessitates active farmer participation and a deep understanding of their perceptions regarding soil salinity and its management, which are crucial for the initial adoption and subsequent propagation of sustainable practices for managing soil salinity (Giordano et al., 2010; Jumman et al., 2022). Hence, farmers' perceptions about soil salinity and its management are critical to ensure the initial adoption of this technology and the later spread of sustainable practices of soil salinity to other farms. Most previous studies conducted in Oman have primarily focused on examining the causality and spatio-temporal variation of groundwater and soil salinity, rather than assessing farmers' perceptions and attitudes towards soil salinity management. Therefore, this study focuses on understanding farmers' and landowners' attitudes towards soil salinity and their capacity and willingness to adopt new techniques for handling such threats, filling a gap in the existing literature in Oman which currently lacks sociological studies in the agricultural field. Specifically, this study aims to evaluate: (i) the perceptions and attitudes of landowners and farmers towards soil salinity and its management, and (ii) the willingness and determinants of readiness to use elemental sulphur as a soil amendment to alleviate soil salinity in Oman.

In this study, we hypothesize that the variation in the perceptions and attitudes of farmers in relation to their socio-economic status would result in differences in the management of soil salinity in Oman. Moreover, understanding the perceptions and attitudes of farmers towards soil salinity helps develop strategies that align with their needs and preferences. This understanding allows for the design and implementation of targeted interventions, such as education and training programmes, that address specific challenges and promote sustainable practices. Additionally, considering farmers' perceptions and attitudes helps foster ownership and participation, leading to increased adoption of recommended practices and long-term sustainability in managing soil salinity. Moreover, we expect that farmers would be willing to use elemental sulphur to ameliorate soil salinity, especially in areas that are severely degraded and affected by salinity.

2 | METHODOLOGY

2.1 | Study area

Oman is situated on the southeastern coast of the Arabian Peninsula, within the region of Western Asia. As of January 2023, the total population of Oman was ca. 4,962,758, with expatriates accounting for 42.1% (2,089,611) of the population (National Centre for Statistics and Information, 2023). Oman is divided into 11 administrative governorates. Most of the population concentrates in Muscat-the capital city of Oman- (1,408,337), followed by Al Batinah North (877,036), Ad Dakhiliyah (535,804) and then Al Batinah South (520,987) (Table 1). Musandum has the lowest total population in Oman with about 53,320.

Oman is characterized as an arid country with an annual average rainfall of 100 mm and hot summer temperatures ranging between 40 and 45°C. Therefore, most of the country's agriculture depends on irrigation. Although Oman has a vast land with an area of 31.4 M ha, the total arable land only represents 7% (2.2 M ha). However, the actual cultivated lands constitute only about 2.8% (62,000 ha) of the arable lands, which is about 0.2% of the total area of the country (MAF, 2010/11). Despite the harsh climatic nature of the country and the scarcity of water resources, the agricultural sector in Oman plays an important role in the economy and food security. In 2021, the contribution of the agricultural sector to Oman's GDP was 2.1% (World Bank, 2021a, 2021b). Although this contribution may be low, the government of Oman has been developing and implementing programmes to promote sustainable agriculture and improve the productivity and competitiveness of the agricultural sector. According to Oman's Vision 2040, the government is targeting to increase the contribution of the agricultural sector to the national GDP to 3% by 2040 (Government of Oman, 2020). Al Batinah North represents 24% of the total agricultural areas of the country; therefore, it is considered the largest governorate with agricultural lands (35,749.7 ha) and crop production (576,384.0 tons) among the other governorates in Oman (Table 1).

The rapid economic development in Oman over the past century has led to a significant shift of Omanis from agriculture to other industries. As a result of that, the employment rate of Omanis in agriculture has dropped significantly. The reluctance of Omanis to work in the agricultural sector is evident, as reflected in the declining employment rate from 10% to 4% between 1991 and 2021 (World Bank, 2021a, 2021b). A survey conducted by Najat et al. (2016) further supports this trend, revealing that none of the 300 Omani respondents under the age of 30 expressed a preference for a career in agriculture. When asked for their reasons, respondents cited a preference for higher salaries and more challenging and adventurous job opportunities. On the one hand, this transition has led to a lack of sufficient time for Omanis farm owners to properly care for and monitor their farms as they increasingly engage in full-time

TABLE 1 Information about population and agriculture in each governorate in Oman.

Governorate	Population (January 2023)[a]	Agricultural land (ha)[b]	Area of cultivated lands (ha)[c]	Crop production (ton)[c]
Muscat	1,408,337	4853.5	2585.5	33,491.0
Dhofar	491,775	27,686.9	5174.4	93,394.0
Musandum	53,320	1361.6	719.0	9917.0
Al Buraimi	126,579	6771.7	2718.7	50,148.0
Ad Dakhiliyah	535,804	19,207.8	7063.1	143,192.0
Al Batinah North	877,036	35,749.7	25,680.9	576,384.0
Al Batinah South	520,987	20,573.5	10,855.3	305,908.0
Ash Sharqiyah North	303,255	11,559.8	5409.6	101,955.0
Ash Sharqiyah South	351,829	6386.9	2839.6	68,699.0
Adh Dhahirah	234,057	13,983.9	5607.4	114,668.0
Al Wusta	59,779	969.3	209.2	3055.0
Total	4,962,758	149,104.7	68,862.8	1500,811.0

[a]National Centre for Statistics and Information (2023).
[b]MAF (2013).
[c]National Centre for Statistics and Information (2014).

employment outside of the agricultural sector. According to MAF (2017), 93% of farm owners in Oman work part-time in other occupations. This rise in part-time engagement has far-reaching implications for various agricultural activities and decision-making processes, including crop selection, input utilization and considerations regarding sales and storage. On the other hand, the cultivated lands and the production of the farms had dropped leading to a decrease in the income of agricultural households compared with the legislated minimum in the non-agricultural government sector. Therefore, the Omani government has implemented a policy that permits the employment of expatriate labourers per farm area, alongside non-agricultural employment, and temporary labour hiring. This strategy has proven to be instrumental in substantially boosting farm income. Specifically, the existing policy of hiring one expatriate labourer per 2.1 ha, coupled with non-agricultural employment, is deemed optimal in the short term (Kotagama & Al-Farsi, 2018). Consequently, expatriates now manage the majority of farms in Oman.

2.2 | Data collection and analysis

A structured questionnaire was implemented with 122 farm owners and farm workers respondents. We would like to emphasize again here and as mentioned above in Subsection 2.2 that many Omanis are currently part-time farmers since they work in non-agricultural sectors. Therefore, most Omanis hire labourers to work in the farm (Kotagama & Al-Farsi, 2018; MAF, 2017). Additionally, many of these part-time farmers are living away from their farms, sometimes in a different governorate where their job is. Consequently, many of them also rent out their farms to locals or expatriates. Taking into consideration these facts, we therefore limit our study to respondents who own farms or practice farming (full-time or part-time farmers, labour or farm tenants). Respondents who do not have any relation with farming were excluded from this study.

The questionnaire was administered in Arabic and English based on the preference of the respondents. We used face-to-face interviews in case the respondent had little education and for those who were not familiar with the terminologies used in the questionnaire. The questionnaire was distributed to the respondents through different means including direct visits to the farms, social media platforms (i.e. WhatsApp, Twitter, Instagram) and via email of the Sultan Qaboos University. It is worth noting that we distributed the questionnaire to over 1000 respondents; however, we received a response from only 122 participants. This is because the willingness of farmers to participate in research in Oman has been consistently low, a fact that has been highlighted by several previous studies (Al-Mezeini et al., 2020; Kotagama et al., 2014; Zekri et al., 2007). Furthermore, farm visitation allowed direct observation of the farming practices and management (e.g. water use, fertilizers applications and cultivations) and impact of soil salinity. It also allowed informal conversation with the farmers, landowners and the labourers. The questionnaire was designed following the guideline of De Vaus (2013). The questionnaire includes 32 questions (see Section S1) and was divided into four sections as follows:

1. The first section covers the demographic and socio-economic profile of the respondents including gender, age, educational level, place of residence, working status and household monthly income.
2. The second section investigates the perception and attitudes of respondents about soil salinity and its management. This section has questions about farm size, farming experiences, type of cultivated crops, frequency and type of fertilizers use, source of irrigation water, frequency and method of irrigation, causes and effects of soil salinity, monitoring of soil salinity and sources of information about management of soil salinity.
3. The third section addresses the techniques (agronomical and technical methods) used to cope with soil salinity.
4. The fourth section assesses the willingness of the respondents to use elemental sulphur for soil salinity management. This section starts by identifying whether respondents were using any chemical products to control soil salinity (e.g. gypsum). Then, respondents were briefed about the benefits of elemental sulphur. Next, respondents were asked to indicate their willingness to use and pay for elemental sulphur.

The perception, attitude and knowledge of the respondents about soil salinity and its management were assessed using quantitative (Likert-type scales) and qualitative (open and binary) questions. The collected responses were coded and analysed using descriptive statistics in the Statistical Package for the Social Sciences (SPSS package; SPSS Inc., 2011, Chicago, USA, release 20.0). Pearson's chi-squared test of association was then used to examine associations between two different agronomical practices: the association between the application rate of fertilizer and crop types, and the association between irrigation frequency and seasons for different crop types.

A qualitative Binary Logistic Regression (logit) model was conducted to identify the determinants of individual willingness to use elemental sulphur as an amendment for soil salinity management using the SPSS package. The model was built using backward elimination stepwise regression technique. In this technique, one enters all variables into the model simultaneously. Then, the variables with no significant contribution to the model are removed one at a time until only the significant variables remain. The logit model was selected for this study because of its strength to analyse the impact of independent variables efficiently and powerfully on a binary outcome by quantifying their unique contributions (Hilbe, 2009). This model is also superior to none market-based approach like contingent valuation as it allows for analysing predictor variables and their effects on the probability of a specific outcome (Osborne, 2014; Stoltzfus, 2011; Wilson et al., 2015). Logistic regression, however, requires adherence to key assumptions, including error independence, linearity in the logit for continuous variables, absence of multicollinearity and absence of influential outliers (Hilbe, 2009; Stoltzfus, 2011). All assumptions were satisfied in our logit model. To elaborate, we performed a nonparametric correlations test to confirm that the data was not paired (see Section S2). Outliers were assessed by conducting linear regression with the dependent variable 'willingness to use elemental sulphur' and the independent variables. The Mahalanobis distance was calculated using the formula -1CDF.CHISQ(MAH_1,2) to create the variable 'probability'. This calculation involved into two continuous variables, age and farm size. We also checked for linearity between continuous independent variables and the log odds. Age and farm size were transformed into ln form, and a binary regression was conducted, including interaction variables for Age*ln_Age and Farm_Area*ln_Farm_Area. However, these interactions were found to be insignificant, indicating that the assumption was not violated. In addition, we validated the binary logistic regression model using the holdout method, where 70% of the sample was randomly selected. To determine the significant variables not included in the model, a stepwise linear regression was conducted for the dependent variable 'willingness to use elemental sulphur' (refer to Section S3).

Moreover, the results of the analysis are in the form of an odds ratio as logistic regression calculates the probability of success over the probability of failure. It also determines the impact of multiple independent variables presented simultaneously to predict the membership of one or another of the two dependent variable categories. The expected outcome is represented by 1 and 0 otherwise. In this case, the criterion variable is coded as follows: those who encourage the use of elemental sulphur as 1 and those who do not encourage the use of elemental sulphur as 0.

Logistic regression analysis was also used to determine the reason-result relationship of independent variables, the determinants, with a dependent variable, the willingness to use elemental sulphur as soil amendments for soil salinity. In this analysis, a logistic transformation of the odds, referred to as logit, serves as the dependent variable:

$$\log(\text{odds}) = \text{logit}(P) = \ln(P / 1 - P).$$

If we take the above dependent variable and add a regression equation for the independent variables, we get a logistic regression:

$$\text{logit}(Y=1)=\ln\left(\frac{\text{pr}(Y=1)}{1-\text{pr}(Y=1)}\right)=\ln\left(\text{odds}(Y=1)\right)=b_0+b_1X_1+\ \ldots\ b_1X_k.$$

As in least-squares regression, the relationship between the logit, or P to use elemental sulphur, and X, the independent or exogenous variables, is assumed to be linear (see Table 2).

3 | RESULTS AND DISCUSSION

3.1 | Socio-demographic features of respondents

Socio-demographic characteristics, such as gender, age, education, working status and income, significantly influence farmers' practices, environmental attitudes, technology adoption and sustainable farming (Karami & Keshavarz, 2010; Wordofa et al., 2020). Therefore, collecting this information aids policymakers, researchers and stakeholders in developing effective strategies to enhance agricultural productivity, minimize environmental impacts and promote sustainable agriculture. In this study, these features varied among respondents and are expected to impact farming practices and management. Table 3 displays the socio-demographic characteristics of the respondents. Responses were obtained from all administrative governorates in Oman, except Musandam, where no responses were received. The highest response rates were observed in Muscat (20.5%), Al Batinah North (19.7%), Al Dakhiliya (16.4%), Al Sharqiyah North (13.9%) and Al Batinah South (11.5%), which are most populous and agriculturally important regions in Oman, as shown in Subsection 2.2. It is crucial to highlight that our target was to gather responses from all governorates of Oman, given that salinity can affect farms in any region. About 73.8% of the respondents were men, and 26.2% were women. There was a variation in the age of the respondents, but generally, most were young. About 45.9% were below 25, 23% were between 35 and 44, 16.4% were between 45 and 54, while 13.9% were between 25 and 34, and 0.8% were older than 65. These findings align with previous research, which indicates that young adults in Oman demonstrate a higher propensity to engage in studies related to environmental management and natural resources compared with older individuals (Choudri et al., 2018). Furthermore, young adults were also found to be more likely willing to adopt sustainable agricultural practices than elders (Oyewole & Sennuga, 2020). All respondents were educated to some degree: 24.6% with a secondary school education, 2.5% with a vocational degree, 9.8% with a diploma, 50.8% with a bachelor's degree and 12.3% with a postgraduate degree. Literature indicates that young and highly educated farmers exhibit a greater propensity to adopt new technologies and embrace sustainable agricultural practices (Jumman et al., 2022). Moreover, individuals with higher levels of education are more likely to possess a deeper understanding of soil and water conservation practices, as they have increased access to information and opportunities for training (Njenga et al., 2021). Respondents' working status also varied. About 44.3% were employed, 4.1% were self-employed, 45.9% were unemployed, and the remaining (7.5%) were retired. We would like to clarify here that the term 'unemployed' refers to respondents who practice farming but are not employed in the government or private sector. This distinction arises from the shift many Omanis are making away from agriculture as their primary occupation, as we explained previously. Additionally, concerning the percentage of respondents under 25 years old, it is likely that these individuals completed the questionnaire on behalf of their illiterate family heads. It is important to note that these respondents actively participate in farming as part of their

TABLE 2 Logit regression model variable specification.

Exogenous	Endogenous: Willingness to use elemental sulphur: (1 = yes, 0 = otherwise)
Variable	Variable description
X1	Unemployed (1 = Yes, 0 = Otherwise)
X2	High Income (>1400 Omr)
X3	Hired Labor (1 = Yes, 0 = Otherwise)
X4	Farm Experience (<1 Year of Farming Experience)
X5	Ln (Farm Area) In Feddans
X6	Age In Years
X7	Education Dummy (1 = Undergraduate, 0 = Otherwise)
X8	Female Dummy (1 = Female, 0 = Otherwise)
X9	Awareness About the Oman Salinity Strategy (1 = Yes, 0 = Otherwise)
X10	Willingness to Pay (10–20 OMR For 10 kg Bag)
X11	Government Assistance (1 = Yes, 0 = Otherwise)

TABLE 3 Socio-demographic features of the respondents ($n = 122$).

Variable	No. of respondents	Percentage of respondents
Gender		
Male	90	73.8
Female	32	26.2
Age (in years)		
<25	56	45.9
25–34	17	13.9
35–44	28	23.0
45–54	20	16.4
55–64	0	0.0
>65	1	0.8
Educational level		
Secondary	30	24.6
Vocational	3	2.5
Diploma	12	9.8
Undergraduate	62	50.8
Postgraduate	15	12.3
Governorate of residence		
Al Batina South	14	11.5
Al Batinah North	24	19.7
Al Dakhiliya	20	16.4
Muscat	25	20.5
Al Sharqiyah North	17	13.9
Al Sharqiyah South	6	4.9
Al Dhahirah	12	9.8
Al Buraimi	3	2.5
Dhofar	1	0.8
Working status		
Employed	54	44.3
Self-Employed	5	4.1
Unemployed	56	45.9
Retired	7	5.7
Monthly Household Income (OMR)		
300–500	23	18.9
600–800	21	17.2
900–1100	32	26.2
1200–1400	10	8.2
1500–1700	14	11.5
1800–2000	9	7.4
>2000	13	10.7

family unit, with the entire family collectively owning and working on the farm. Of those employed, monthly income varied with the highest percentage (26.2%) having an income of 900–1100 OMR (equivalent to $2337.56–2857.02).

The study by Al-Mezeini et al. (2020) highlighted that the secondary occupation of farmers or landowners plays a crucial role in determining their knowledge, experience and technology adoption in greenhouse farming in Oman. They found that farmers or landowners with secondary occupations in the government agricultural sector exhibit higher levels of knowledge, experience and technology adoption in greenhouse farming in Oman. This is attributed to the professional networks they establish with agricultural stakeholders, allowing them to stay updated on regulations and technological advancements. Consequently, they gain access to production resources at favourable prices, enhancing their efficiency. On the contrary, farmers or landowners with secondary occupations in none-agricultural sector might be less aware about the technological advancement and sustainable practices in agriculture. Literature shows that the income of farmers or landowners has a substantial positive influence on agricultural practices and sustainability. With higher income levels, farmers can allocate greater financial resources to adopt modern farming techniques, acquire advanced equipment and implement sustainable agricultural practices. These investments play a crucial role in preventing or mitigating salinity and other forms of environmental degradation on farms (Olanipekun et al., 2019).

3.2 | Farming characteristics and soil fertility management

The characteristics of farming for respondents are presented in Figure 1a–e. Results showed a variation in farming experience ranging from less than a year to more than 16 years (Figure 1a). The highest percentage of respondents (26.9%) have been farming for more than 16 years. When asked about who takes care of the farm (i.e. irrigation, application of fertilizer, cultivation, harvest of crops and pruning), about half of the respondents indicated that they hire labourers, 42.6% involved family members, and 6.6% rented their farms out (Figure 1b). Based on our field visits and discussions with some of the farmers, we found that most of the farmers who hire labourers granted them full responsibility to manage the farms with minimum supervision. This is because most of the respondents have other occupations aside from farming and may work or live far away from their farms. Therefore, they may tend to be busy during the workweek. These findings are consistent with the studies presented in Subsection 2.2. However, a study conducted by Al-Salmiah (2020) on 188 randomly selected farms across Oman unveiled that 85% of the farm planting decisions were made by the owners, while workers, farm managers and family members accounted for 8%, 5% and 2% of the decisions, respectively. We also

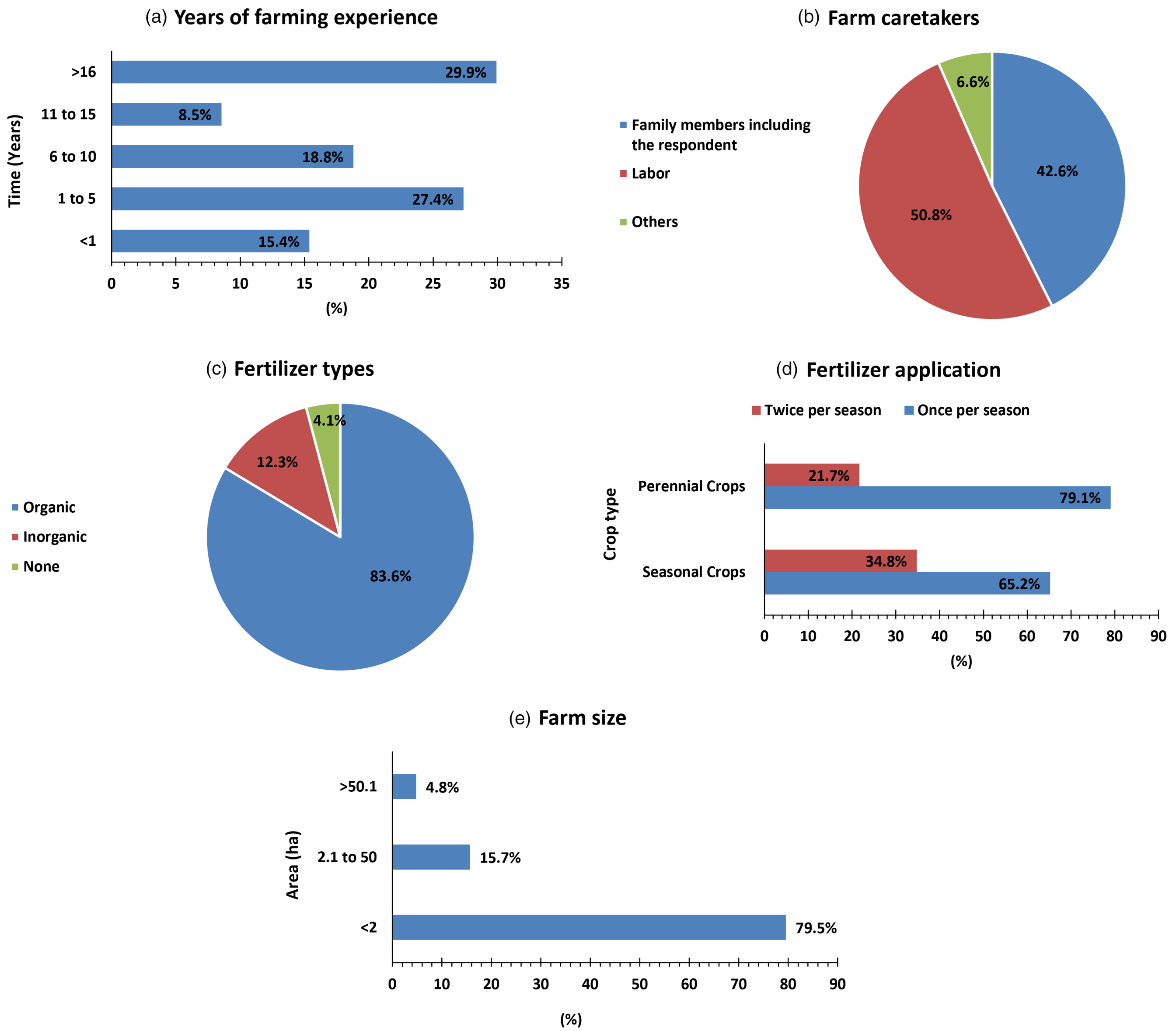

FIGURE 1 Farming characteristics ($n = 122$).

found that some farm owners also rent their farms to local people or their labourers which guarantees the owners a steady income with little effort. We observed that most of the labourers taking care of or renting the farms are primarily foreigners with little education from humid and sub-humid countries. Most of these labourers are from Bangladesh, Pakistan and India (Al-Zadjali et al., 2013). Through our farm visitations and conversations with respondents, it became evident that a significant number of foreign farm tenants prioritize maximizing production and profits above all else. They also manage the farms using indigenous knowledge from their country of origin which may not always apply to Oman's climate. Consequently, there is a tendency to overuse groundwater resources and apply excessive amounts of fertilizer and other agrochemicals—all of which can aggravate the salinity of the groundwater and the soil (Al-Zadjali, 2010). Studies have shown that a considerable proportion of farm workers in the Al Batinah region of Oman exhibit limited awareness and knowledge regarding pesticide application, storage, and disposal and the associated risks to human health (Al-Zadjali et al., 2013; Esechie & Ibitayo, 2011). These studies further uncovered instances where workers continued to use expired pesticides, highlighting the need for improved education and training in this area. Figure 2 shows an example of the impact of excessive use of chemical fertilizers on soil salinity development in one of the farms rented to labourers in Al-Batinah region.

Respondents were also asked about soil fertility management. Surprisingly, a majority of 83.6% of respondents were using organic fertilizers (e.g. goat and cow manures, organic compost and green manure).

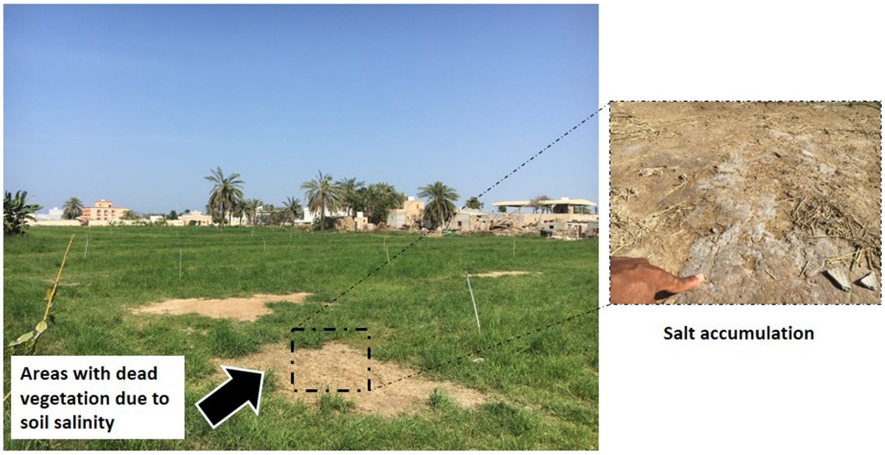

FIGURE 2 Impact of excessive use of fertilizer on salt accumulation in one of the farms rented to labourers in Al Batinah region in Oman.

TABLE 4 Results of chi-squared tests for different agronomical practices.

	df	X^2	*p*-Value
Frequency of fertilizers application vs. crop type	1	4.999	.025*
Frequency of irrigation vs. season (edible perennial plants)	3	14.243	.003*
Frequency of irrigation vs. season (edible seasonal plants)	3	23.128	.000*
Frequency of irrigation vs. season (none-edible plants)	3	15.037	.002*

Abbreviations: df, degree of freedom; X^2, chi-square.

*Indicate significance at $p < .05$.

Conversely, about 12.3% of the respondents were using inorganic fertilizers (e.g. NPK and Urea), and 4.1% were not applying any fertilizer to their farms (Figure 1c). These findings are consistent with the research conducted by Janke et al. (2022). Their review paper revealed that 88% of agricultural lands in Oman received unprocessed manure, while 45% received processed manure or compost. The preference for organic sources of fertilizers is a positive practice that aligns with the global trend towards promoting organic farming, as it is more sustainable in the long term and safer for both the environment and human health. The respondents were also asked about the application rate of fertilizers for different crop types. Our results identified significant differences between the application rate of fertilizers and the crop type (Table 4), meaning the respondents were aware of the differences in nutrient requirements for each specific crop. The largest segment of the respondents applied fertilizers once per season for both the perennial (e.g. date palm, lime and mango) and seasonal (e.g. vegetables and fodder) crops (79.1% and 65.2%, respectively; Figure 1d). Our study also showed that the majority (79.5%) of respondents reported that their farm's size is <2 ha. This finding is consistent with the literature. According to the 2013 Oman Agricultural Census, there were about 166,610 farms in Oman. Of these farms, 90% have an area of less than 2 ha, while the remaining 10% are farms with area larger than 2 ha (Al-Salmi et al., 2020; Al-Zadjali et al., 2013; Jayasuriya et al., 2017; Kotagama et al., 2014). The land in many of these small size farms is intensively used compared with large farms as highlighted by Kotagama (2014). Another study showed that the small size of farms is one of the primary challenges affecting farming efficiency in Oman. The study concluded that enhancing farming efficiency requires increasing the average farm size to 16.85 hectares, a goal that can be achieved through collaborative efforts among agricultural associations and the implementation of shared management practices for small farms. Notably, data from the 2013 Agricultural Census of Oman revealed that 88% of farms are dedicated to family consumption, 9.5% are focused on local market sales, and a mere 0.5% is allocated for export purposes (Al-Salmi et al., 2020; Janke et al., 2022).

3.3 | Irrigation management

Irrigation is one of the most critical factors that determine the success or failure of soil salinity management (Houk et al., 2006; Yaron, 1981). For example, over-irrigation can cause a rise of the water table, especially in areas with shallow groundwater, which can then lead to the accumulation of excess salts in the root zone (Datta & De Jong, 2002). Under-irrigation or use of poor-quality water can also lead to soil salinity. Thus, understanding how people manage irrigation can help develop preventive and corrective measures to control soil salinity. Results on irrigation managements are presented in Figure 3a–e. When asking respondents how they manage irrigation, the majority (69.7%) used groundwater as their main source (Figure 3a). The arid conditions in Oman restrict the presence of surface water, leading to a complete dependence on groundwater and rainfall for irrigation in agriculture (Jayasuriya et al., 2017). A considerable number of the respondents indicated, however, that their groundwater is tainted by salinity. This is either because of the intrusion of seawater into farms located in the coastal areas or the dissolution of minerals from the parent bedrock in areas located in the country's interior (Choudri et al., 2018). As a result, 17.2% were using desalination water supplied by the government, 7.4% were using desalination plants to produce fresh water from the salinized groundwater, and 5.7% used treated wastewater for irrigation (Figure 3a).

Farmers' use of desalination plants in Oman is one of the adopted technologies for managing saline groundwater and soil salinity (Figure 4a). Our field investigations, however, revealed emerging challenges of how to manage the disposal of brine from the desalination plants. We observed that many of the farmers dispose of the brine ($EC_w = 26$ dS/m) directly to soil pits, old wells on their farms, or empty areas in wadies adjacent to their farms (Figure 4b). Similar occurrences of inappropriate brine disposal have also been reported by Al-Jabri et al. (2015). As more than 50% of the volume of feed water used by desalination units will be returned as brine, farmers using

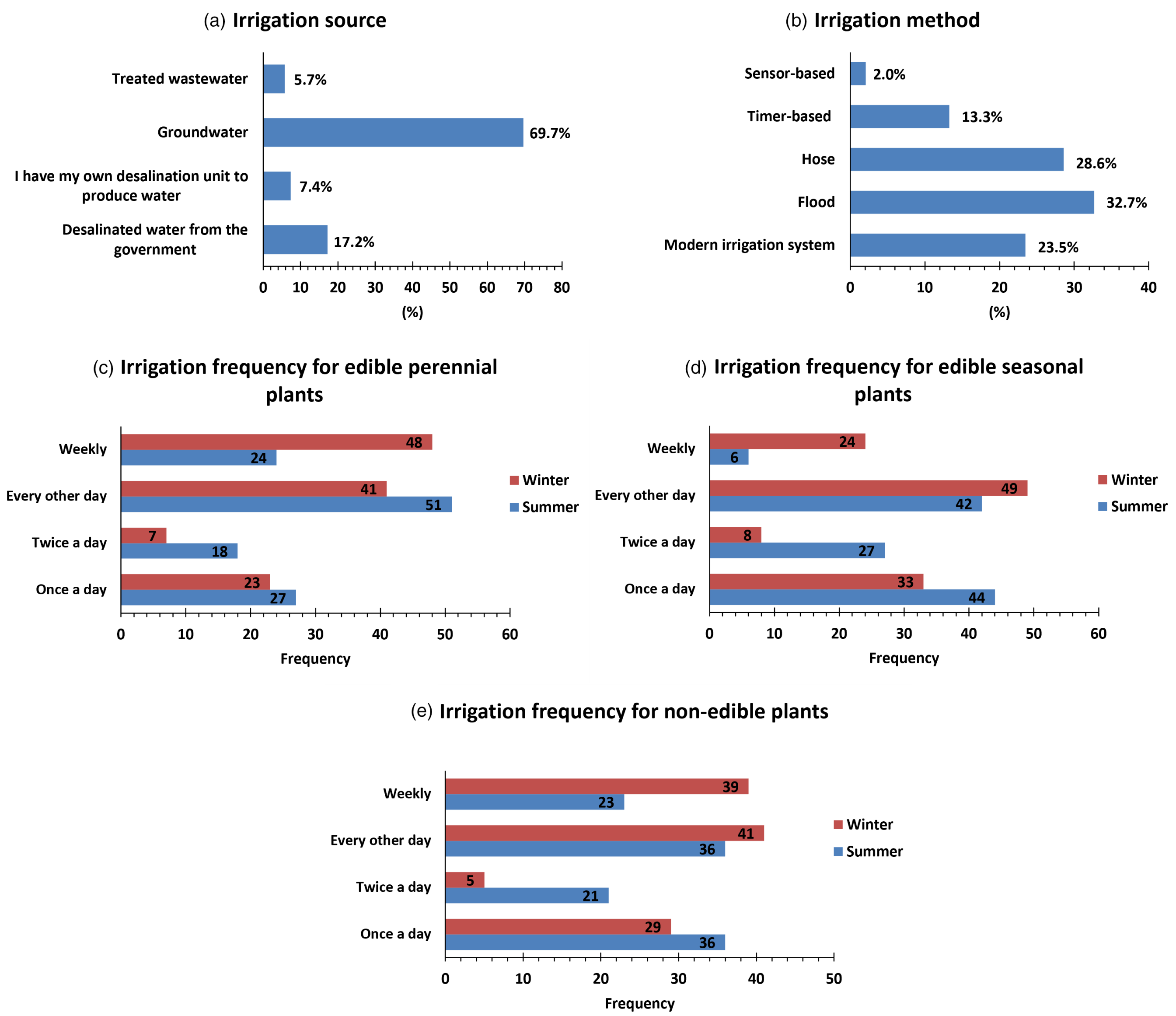

FIGURE 3 Irrigation management ($n = 122$).

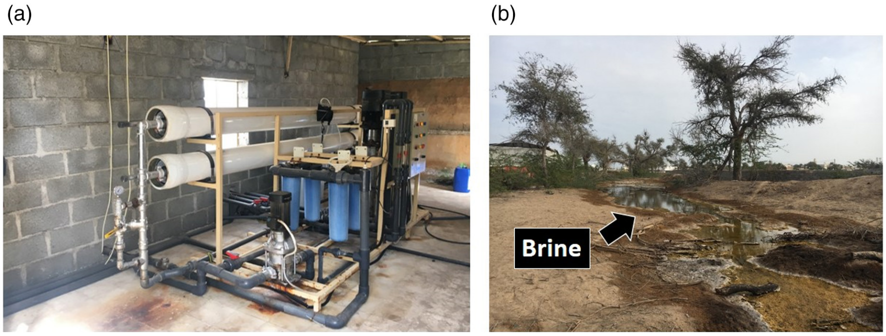

FIGURE 4 Example of desalination plant use in a farm in Barka in Al Batinah North Governorate, in Oman. (a) reverse osmosis (RO) plant, (b) brine disposal in the wadi area adjacent to the farm (Photo courtesy of Ahmed Al Mayahi).

desalination plants produce a large volume of brine daily (Al-Jabri et al., 2015, 2019). If farmers continue to inappropriately dispose of this brine, they will exacerbate the deterioration of soil and groundwater quality at a fast rate. Therefore, more research is needed to identify practical and cost-effective solutions to deal with brine disposal.

Respondents were also asked about the irrigation methods used on their farms. Primarily, respondents used traditional irrigation methods—32.7% used flood irrigation while 28.6% applied hose irrigation (Figure 3b). Both techniques have low irrigation efficiency, and hence, the reliance on them can lead to the exhaustion of limited water resources. Conversely, a significant number of the respondents were using more efficient techniques in comparison to the group using traditional methods. Efficient techniques include the use of modern irrigation systems (e.g. drip, sprinkler, centre pivot, etc.), used by 23.5% of respondents, timer-scheduled irrigation, used by 13.3% of respondents and a sensor-based system used by 2% of respondents (Figure 3b). The study conducted by Janke et al. (2022) revealed varying ratios of traditional flood irrigation (known as Aflaj, see Al-Ghafri et al., 2007; Al-Marshudi, 2001; Wilkinson, 1977; for full details about this system) and modern irrigation methods employed in different regions of Oman. To elaborate, out of the total water used for agriculture in Oman (1546 Mm^3), *ca.* 68.6% (1060 Mm^3) is sourced from pumped groundwater, while 31.4% (846 Mm3) is derived from Aflaj irrigation systems. In governorates such as Al Batinah North, Al Batinah South and Dhofar, where monoculture practices are prevalent in vegetable and fodder production, farmers primarily rely on well water for irrigation, leading to the use of modern irrigation systems. Conversely, in governorates such as Al Dakhiliyah, Al Sharqiyah North and Al Sharqiyah South, where polyculture or mixed cropping is more common, farmers have access to both Aflaj and groundwater irrigation methods. To overcome the limitation of the traditional flood irrigation method, the Ministry of Agriculture has undertaken a project to introduce modern irrigation to Aflaj communities. However, the project faced challenges because of low public acceptance, with farmers expressing concerns about the perceived insufficiency of water supplied by modern irrigation and the cultural significance of preserving Aflaj as a heritage (Al Mamary & Al Kalabani, 2010). Nevertheless, a successful case study in Amla village, Al Dhahira governorate, showcased the transformation of Aflaj into a modern irrigation system, resulting in 90% irrigation efficiency, expanded agricultural areas and significant economic returns (Al Mamary & Al Kalabani, 2010). The economic return of this project from the first year of implementation covered 66% of the overall project costs. This inspiring project highlights the potential for farmers in Oman to adopt modern irrigation methods, enhance water use efficiency and achieve higher farm productivity and profitability. Our study also demonstrates that most respondents were found to be knowledgeable about water requirements for different crops, illustrated by the significant differences between the frequency of irrigation and seasons for various crop types (Table 2). Respondents, therefore, seem to favour giving crops more frequent irrigation (i.e. once a day or twice a day) in the summer rather than in the winter (i.e. every other day or weekly; Figure 3c–e). These findings contradict the findings of Zekri et al. (2017), who reported that despite the adoption of modern irrigation techniques by many farmers in the Al Batinah governorates, they exhibited consistent water usage and irrigation frequencies for their crops throughout the year, regardless of the seasonal variations. This study also highlighted that the implementation of modern irrigation practices led to excessive pumping of groundwater, further exacerbating the problem of soil groundwater salinity in the study area. The findings of this section emphasize that the mere adoption of efficient modern techniques, such as modern irrigation systems, does not guarantee the preservation of natural resources or the achievement of sustainability. It is crucial to ensure that farmers and workers are well-informed about and actively implementing sustainable agricultural practices alongside the use of these modern technologies in order to achieve agricultural sustainability.

3.4 | Perceptions and attitudes about soil salinity

Assessing the levels of knowledge, perceptions and attitudes of farmers is essential in determining the success of the adoption of salinity management practices (Jumman et al., 2022). Our study aimed to evaluate general awareness of the issue by assessing respondents' thoughts on the causes and effects of soil salinity. Respondents were also asked to indicate the sources of information they deem as reliable to alleviate soil salinity in their farms, as displayed in Figure 5a–h. Nearly all the respondents (96.6%) are familiar with soil salinity (Figure 5a). This is because a large portion of the respondents have either faced issues related to soil salinity (29.9%), or have heard about it through social media (29.1%), other farmers (23.1%), family members (12.8%), newspapers (4.3%) or magazines (0.9%) (Figure 5b). Additionally, 74.7% of respondents indicated that salinity in Oman is mainly caused by human activities. Farmers specifically referred to seawater intrusion as a result of overpumping (37%), irrigation with saline water (12.6%), excessive application of fertilizer (10.9%), irregular irrigation patterns (9.2%) and mismanagement by labourers (5%) (Figure 5c). These findings are consistent with the studies of Choudri, Baawain, and Ahmed (2015), Choudri, Baawain, Ahmed, Al-Sidairi, and Al-Nadabi (2015) and Choudri et al. (2018). Moreover, more than half of the respondents indicated that they do not receive any assistance or recommendations on how to alleviate soil salinity (Figure 5d). This indicates that there is a gap between the agricultural extension and the farmers. Therefore, there is a need for more efforts from the government to facilitate extension services and knowledge exchange with the farmers on the preventive and corrective measures of soil salinity management in Oman.

Respondents were also asked to indicate which sources they rely on to acquire information about soil salinity management. The top three sources were social media (38.5%), farmers (32.1%) and personal experiences (11.5%), respectively (Figure 5e). Similarly, a study conducted by Choudri et al. (2018) to assess people's perception of land degradation, including salinity, in Oman, revealed that 38.1% of the respondents relied on social media as their primary source of knowledge. These sources can be used as communication channels to further increase farmers' awareness of soil salinity and its management as well as transfer technology and innovations that tackle such issues. The data also indicates that a majority (81.2%) of the respondents are aware of the impact of mismanagement of water resources and land use on soil salinity (Figure 5f) and 95% were specifically aware of its consequences for overall yield and economic return of the farms (Figure 5g). In addition, over half of the respondents have experienced these negative effects—63.8% stated that their farms suffer from salinity problems (Figure 5h). The results presented in this section highlight the importance of enhancing dissemination of knowledge, experiences and technologies through widely used platforms among farmers in Oman, such as social media. Additionally, it emphasizes the need to strengthen the role of agricultural extension services in assisting farmers in mitigating the effects of salinity.

3.5 | Monitoring and management practices

Continuous monitoring of soil parameters can provide early warning about the status of soil salinity in order to take preventive measures against further deterioration of the soil (Allbed & Kumar, 2013; Gorji et al., 2015). To evaluate the implementation of such practices, respondents were asked to indicate how they monitor soil salinity. Results showed that nearly half of the respondents were not monitoring the status of soil salinity in their farms (Figure 6a). Moreover, of the respondents who were monitoring soil salinity, 78.5% were relying on their personal experiences and visible signs of salinity impact on soil and crops (Figure 6b). Only 11.4% of respondents were taking soil samples for laboratory analysis to measure salinity, and 10.1% were directly analysing the collected samples with a portable EC meter. Similarly, farmers in Ethiopia were found to rely on visual observations (e.g. white crust and dark brown colour of the soil) to identify soil salinity in their farms (Qureshi et al., 2019). However, it was reported that farmers who rely on visual observation may fail to identify the status of soil salinity and its impacts on crops and overall yield at early stages (De Bruyn & Abbey, 2003). This is because visible signs of soil salinity impacts (e.g. salt crust, visible salt crystals, stunt plant growth, reduction in yield, etc.) take time to develop and become observable by the farmers.

We then asked respondents about the techniques used to alleviate observed or measured soil salinity in their farms (Figure 6c). As most farmers were aware of the causes and impact of soil salinity and perceived it as a problem, we hypothesized that they would put effort towards the alleviation of soil salinity in their farms. We found, however, that despite their awareness, 62.6% of respondents were not implementing any practices to address soil salinity. The remaining 37.4% managed it by growing crops tolerant to soil salinity (27.4%), controlling fertilizer use (21.9%), using mulch (12.3%), leach the soil by water (5.5%), installing desalination plants (4.1%), employing rhizobacteria promoting plant growth (2.7%), treating with chemical amendments such as gypsum (2.7%) and planting cover crops (1.4%) (Figure 6d). Respondents were

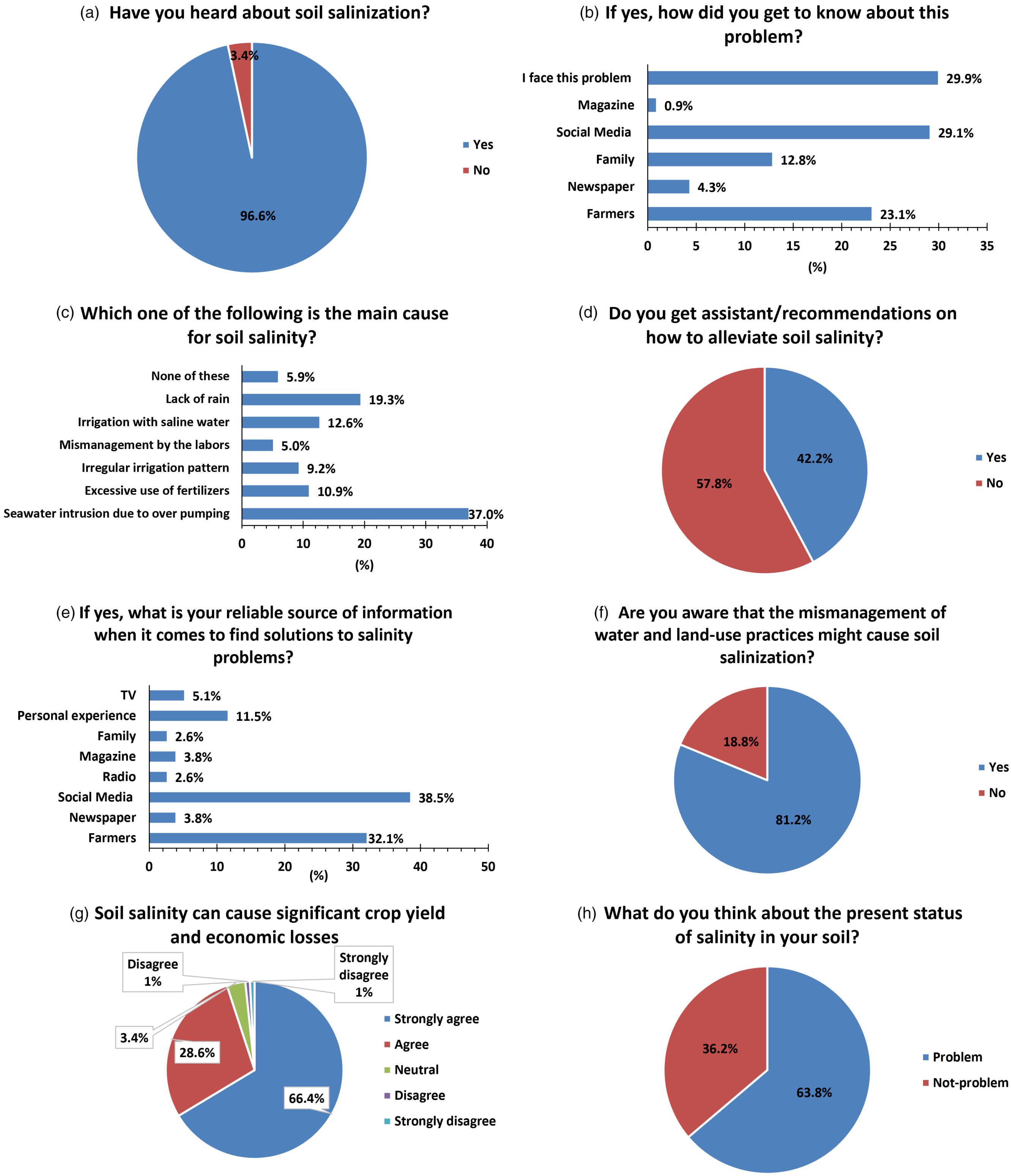

FIGURE 5 Relative distribution of answers to questions regarding the farmer's perception and attitudes about the severity of soil salinity occurrence and source information about related mitigation measures in Oman ($n = 122$).

asked to list the types of crops that they grow under the current salinity status of their farms. About 55% of the respondents cultivated perennial crops like date palm trees, 29.4% grew grasses and fodders, and 15.6% planted seasonal crops like vegetables (Figure 6e). Once again, we reiterate the importance, as highlighted in subsection 3.4, of disseminating knowledge and experience on soil salinity management through social media, considering its

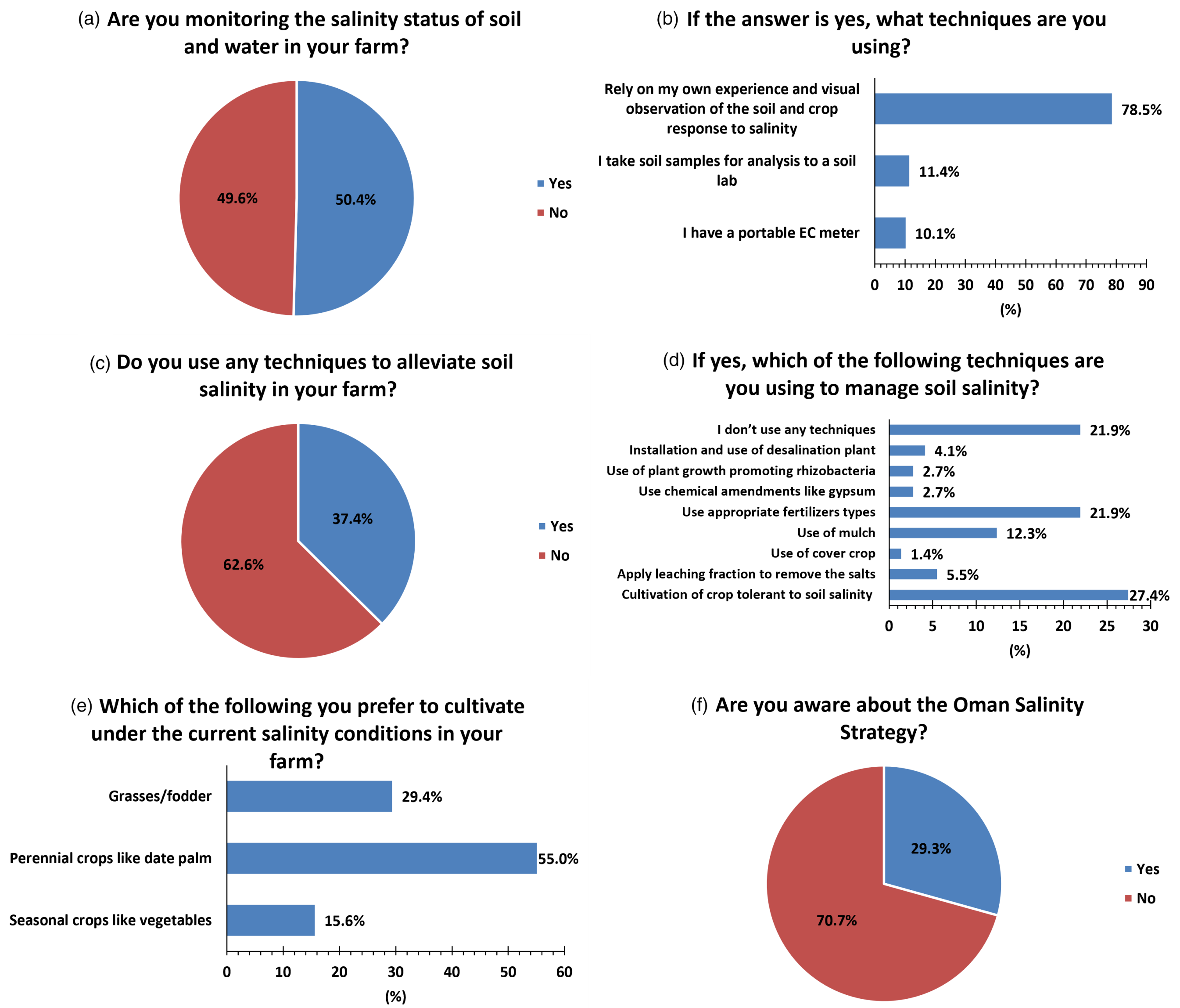

FIGURE 6 Relative distribution of answers to questions regarding the use of monitoring and management techniques to deal with salt-affected soils in Oman ($n = 122$).

active and widespread utilization as a source of knowledge acquisition among farmers in Oman. Government authorities responsible for soil salinity management should provide guidance to farmers regarding the cultivation of profitable and adaptable crops that are suitable for the prevailing salinity conditions. This support will not only enable farmers to cope with soil salinity but also motivate them to sustain agricultural practices in alignment with Oman's 2040 vision of increasing the agricultural sector's contribution to the national GDP and ensuring food self-sufficiency and security.

Figure 6f displays the general level of awareness of Oman's national strategy to address soil salinity. A majority of 70.7% of the respondents were not aware of the national strategy. These data illustrate a need to spread awareness among farmers about the importance of soil monitoring and salinity management practices, as well as increase familiarity with the national and international strategies to combat soil salinity in order to achieve agricultural sustainability. Again, one method to achieve this in Oman is continuous communication with people through primary sources of information acquisition identified in this study such as social media and farmer-to-farmer interactions (see Section 3.4).

3.6 | Farmers' willingness to use elemental sulphur for soil salinity management

Elemental sulphur was used as an example of a locally tested effective amendment to manage soil salinity during the survey. Nevertheless, before mentioning the use of elemental sulphur, the respondents were asked to indicate their knowledge of existing commercial products to combat soil salinity in Oman. Contrary to our hypothesis, the majority of the respondents (74.4%) were unaware of such products (Figure 7a). Based on this survey, we then asked whether farmers were willing to use elemental sulphur to manage salinity to which most responded positively. Although most of the respondents expressed their willingness to use soil amendments, however, they rose concerns about the price point (Figure 7b). When asked to attribute a financial value to the application of elemental sulphur, a majority of 82.4% of respondents chose the lowest price range (Figure 7c). This, however, contrasts 82.4% of respondents' indication of willingness to purchase effective amendments despite the potential high costs (Figure 7d). Based on the responses to these two questions, it is evident that most participants' true willingness lies within the lower price range for the elemental sulphur product. Consumer behavioural studies reveal that individuals have different perceptions of value. Some prioritize quality and long-term benefits when making purchasing decisions, while others prioritize immediate cost savings. The latter group tends to opt for the lowest-priced product, often disregarding its long-term environmental benefits (Solomon et al., 2012). To encourage more sustainable consumption behaviours, it is crucial to educate and guide farmers and landowners, towards products that offer long-term benefits and align with sustainable practices.

3.7 | Determinants of willingness to use elemental sulphur for soil salinity management

To evaluate the overall goodness of fit of our logistic regression model, we employed the Omnibus test of model coefficients. This test assesses whether our model significantly outperforms a null model, with a p-value <.05 indicating a good fit to the data. Our Omnibus test results indicated a significantly better fit of our model compared with the null model ($\chi^2(13) = 37.494$, $p < .001$), confirming its statistical significance and good fit (Table 5). However, it is important to note that the Omnibus test provides an assessment of the overall model fit and does not identify specific areas where the model may be lacking. To obtain further information about the fit of our model, we conducted the Hosmer–Lemeshow test. This test evaluates the agreement between the observed and predicted values of the model. A close correspondence between the predicted and observed values indicates a good fit, while significant differences suggest potential issues with model fit. Our Hosmer–Lemeshow test yielded non-significant results ($\chi^2(8) = 2.887$, $p = .941$) (Table 5). Additionally, the

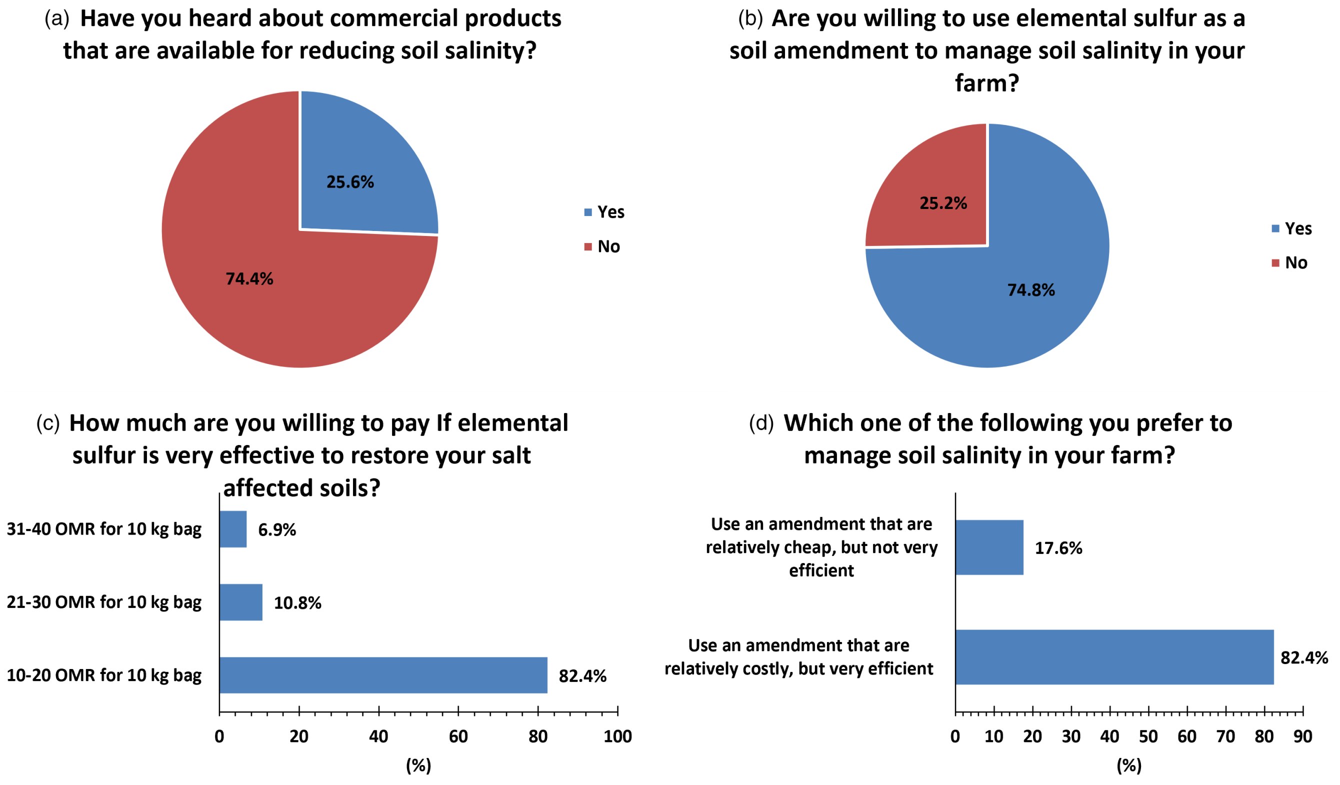

FIGURE 7 Farmers' willingness to manage salt-affected soils using elemental sulphur ($n = 122$).

contingency table for the Hosmer–Lemeshow test demonstrated a strong match between the predicted and observed values, supporting the conclusion that our model exhibited a good fit to the data (Table 6).

Comprehensive model fit is also often assessed using 'Pseudo-R-Squared' indices which evaluates the degree to which the model is able to classify individuals into groups based on the dependent variable (Smith & McKenna, 2013). In this case, the data suggest that a 49.6% change in the criterion variable (willingness to use elemental sulphur) can be attributed to the exogenous variables in the model (Table 5).

The classification table serves as an alternative approach to evaluate the predictive accuracy of the logistic regression model. It provides detailed information about the correct and incorrect classifications of the dependent variable, along with the corresponding percentage of accurately classified cases. Upon analysing the classification table, it becomes evident that the regression model demonstrates high accuracy in predicting cases where the observed willingness to use elemental sulphur is 'No', with a correct classification rate of 95.5%. However, its performance is comparatively less accurate when predicting cases where the observed willingness is 'Yes', yielding a correct classification rate of 50%. Considering the overall dataset, the classification table reveals an average accuracy level of 87.9%. This indicates a moderate level of accuracy for the entire dataset, considering both the correctly and incorrectly classified cases (Table 7).

Table 8 presents logistic regression estimations, which include the unstandardized regression slopes and associated significance tests, odds ratios and confidence intervals. The odds ratio of probability signifies the probability of willingness to use elemental sulphur over the probability of willingness not to use elemental sulphur. This illustrates the relationship between the exogenous variables and willingness to use the elemental sulphur. The coefficient B (Beta) is the estimated change in Log Odds, meaning that for every 1 unit change in an exogenous variable, there is an Exp(B) change in the probability of the willingness to use elemental sulphur.

TABLE 5 Omnibus tests of model coefficients and the Hosmer and Lemeshow test.

Omnibus tests of model coefficients			
	Chi-square	**df**	**Sig.**
Step	37.494	13	0.000
Block	37.494	13	0.000
Model	37.494	13	0.000
Hosmer and Lemeshow test			
Chi-square		**df**	**Sig.**
2.887		8	0.941
Psuedo R-Square (Nagelkerke's R^2)		49.6%	

TABLE 7 Classification results.

	Predicted		
	Willingness to use elemental sulphur		
Observed	**No**	**Yes**	**Percentage correct**
Willingness to use elemental sulphur			
No	85	4	95.5
Yes	9	9	50.0
Overall percentage			87.9

TABLE 6 Contingency table for the Hosmer and Lemeshow test.

Willingness to use soil amendments = No		**Willingness to use soil amendments = yes**		
Observed	**Expected**	**Observed**	**Expected**	**Total**
11	10.988	0	0.012	11
11	10.944	0	0.056	11
11	10.892	0	0.108	11
11	10.807	0	0.193	11
11	10.555	0	0.445	11
9	10.057	2	0.943	11
9	9.312	2	1.688	11
9	7.940	2	3.060	11
5	5.664	6	5.336	11
2	1.841	6	6.159	8

TABLE 8 Logistic regression estimation results.

Exogenous variables	B	SE	Wald	df	Sig.	Exp(B)	95% CI for EXP(B) Lower	Upper
Constant	−6.735	1.907	12.475	1	0.000	0.001		
X1	2.760	1.288	4.591	1	0.032	15.795	1.265	197.182
X2	1.192	0.790	2.277	1	0.131	3.293	0.700	15.483
X3	0.941	0.837	1.266	1	0.261	2.563	0.497	13.213
X4	−3.071	1.435	4.581	1	0.032	0.046	0.003	0.772
X5	0.311	0.117	7.016	1	0.008	1.364	1.084	1.717
X6	−0.210	1.350	0.024	1	0.877	0.811	0.058	11.419
X7	0.689	0.779	0.782	1	0.376	1.992	0.433	9.165
X8	2.183	0.877	6.204	1	0.013	8.876	1.592	49.473
X9	2.084	1.197	3.029	1	0.082	8.037	0.769	84.008
X10	1.801	1.011	3.177	1	0.075	6.057	0.836	43.894
X11	0.453	0.846	0.286	1	0.592	1.573	0.299	8.266

Note: Endogenous: (willingness to use elemental sulphur): (1 = Yes, 0 = Otherwise), X1 = UNEMPLOYED (1 = Yes, 0 = Otherwise), X2 = HIGH INCOME (>1400 OMR), X3 = HIRED LABOR (1 = Yes, 0 = Otherwise), X4 = FARM EXPERIENCE(<1 Year of Farming Experience), X5 = LN(FARM AREA) In Feddans, X6 = AGE (In years), X7 = EDUCATION DUMMY (1 = Undergraduate, 0 = Otherwise), X8 = FEMALE DUMMY (1 = Female, 0 = Otherwise), X9 = AWARENESS ABOUT THE OMAN SALINITY STRATEGY (1 = Yes, 0 = Otherwise), X10 = WILLINGNESS TO PAY (10–20 OMR for 10 kg bag), X11 = GOVERNMENT ASSISTANCE (1 = Yes, 0 = Otherwise).

According to the results, the positive and significant estimators of the probability of an individual willing to use elemental sulphur are as follows: being unemployed, in another word being a full-time farmer (B = 2.760, SE = 1.288, Wald $\chi^2(1) = 4.591$, $p = .032$), having a farm (B = 0.311, SE = 0.117, Wald $\chi^2(1) = 7.016$, $p = .008$), being a female (B = 2.183, SE = 0.877, Wald $\chi^2(1) = 6.204$, $p = .013$), being aware of the Oman salinity strategy (B = 2.760, SE = 1.288, Wald $\chi^2(1) = 4.591$, $p = .032$) and being willing to pay between 10 and 20 OMR for 10 kg of the elemental sulphur amendment (B = 1.801, SE = 1.011, Wald $\chi^2(1) = 3.177$, $p = .075$). Conversely, an individual with less than 1 year of farming experience (B = -3.071, SE = 1.435, Wald $\chi^2(1) = 4.581$, $p = .032$) is a negative and significant estimator of the probability of an individual willing to use elemental sulphur.

The Exp(B) column in Table 8 contains odds ratios indicating the multiplicative change in odds of a case in the willingness to elemental sulphur equalling 1, per unit increase on a given estimator, controlling for the other factors in the model. If an Exp(B) value is greater than 1, it indicates that the odds associated with target group membership increase as the predictor increases. It reasons that the probability of willingness to elemental sulphur is greater at higher levels of the exogenous variable. Therefore, a consideration of whether individuals are unemployed (being a full-time farmer), have access to land, or are female; an increase in individual awareness about salinity strategies; and the determination of pricing of elemental sulphur in the range of 10–20 OMR ($26–$52) per 10 kg would increase the probability to adopt and use elemental sulphur to manage soil salinity.

When exploring the likelihood of adopting elemental sulphur as a potential solution to soil salinity, five characteristics were deemed positive determinants among respondents. These categories include: (a) unemployed individuals (being a full-time farmer), (b) farm owners, (c) females, (d) those aware of Oman's national salinity strategy and (e) availability of a product priced between 10 and 20 OMR ($26–$52).

Although unemployed respondents only consisted of 1% more than those who were employed, they indicated a higher willingness to implement the use of elemental sulphur versus those who were employed, self-employed or retired. Employment status most directly correlates with time availability, and therefore the ability to embark on potentially time-consuming new practices. With more time to focus on their farms, unemployed individuals were able to consider the use of new technologies and address challenges to their farms more thoroughly than those with alternate commitments. However, a study conducted in the Jianghan Plain region of China involving 433 farmers indicated that engaging in part-time farming had a significant and positive influence on the likelihood of adopting sustainable agricultural practices such as conservation agriculture. The reason behind this relationship is that being a part-time farmer while also being employed in non-agricultural sectors contributes to higher family income. As a result, part-time farmers are more inclined to invest in conservation agriculture technologies compared with full-time farmers (Yang & Sang, 2020). While part-time farmers tend to allocate more resources towards capital and materials for farming, their limited time spent in agricultural activities has certain implications. Consequently, the farming practices on their lands are typically carried out by elderly individuals, females and labourers with relatively lower levels of education (Haiguang et al., 2013).

Farm owners were also among the positive determinants in favour of a more permanent solution to soil salinity issues as opposed to those temporarily renting out farmland. The reason behind this disparity is that farm owners tend to prioritize the long-term benefits of practices and technologies that promote agricultural sustainability and safeguard the land from degradation. They possess a forward-thinking mindset focused on maintaining the productivity and sustainability of their farms for future generations. In contrast, farm tenants often place greater emphasis on maximizing immediate productivity and profitability from the land. Their shorter-term tenure and lack of ownership may limit their inclination to invest in long-term solutions for soil salinity and other sustainability issues. Likewise, a study conducted by Yang et al. (2022) showcased that both farm ownership and land tenure stability have a significant positive influence on the adoption of sustainable agricultural practices within the Chinese banana industry. This, in turn, contributes to the promotion of cleaner production methods.

Although females only composed 26.2% of respondents, they were more likely to display a willingness to amend the soil to manage salinity. The implications of this require further gender analysis but indicate differences in agricultural experience and role.

Respondents who were aware of Oman's national salinity strategy similarly were more willing to adopt solutions, indicating an increased understanding of the gravity of salinity to overall soil health. Furthermore, when soil amendments with elemental sulphur were priced between 10 to 20 OMR, this increased economic accessibility to a solution and therefore was a positive determinant to adoption. As highlighted in subsection 3.6, consumer behaviours vary based on individuals' perceptions of a product's value. Some individuals prioritize long-term benefits, while others focus on cost savings and always choose the lowest-priced option (Solomon et al., 2012). Consequently, it becomes imperative for government sectors, such as the Ministry of Agriculture, Fisheries and Water Resources, to raise awareness among farmers about the long-term advantages of adopting sustainable practices and implementing effective soil and water resource management. By doing so, agriculture can be sustained, and the detrimental impact of soil salinity can be minimized. This can be achieved by increasing the active involvement of extension services, agricultural corporations and leveraging social media platforms to disseminate information and educate farmers.

In comparison, the only category negatively affecting the use of elemental sulphur was 'farmers with less than one year of experience', which was expected because of their lack of exposure to such issues. This, however, emphasizes the need to spread awareness of soil salinity issues on a wider scale so as to produce action and solutions from both new and experienced farmers.

4 | CONCLUSIONS

This questionnaire study filled a research gap by evaluating the perceptions and attitudes of 122 farmers in Oman regarding soil salinity and its management. The study employed Likert scales and qualitative questions to assess farmers' perception and attitude, and utilized Binary Logistic Regression to identify the determinants of their willingness to use elemental sulphur as a method to alleviate soil salinity. Key findings showed adequate awareness of crop nutrient and water requirements among respondents. However, knowledge gaps were observed in soil salinity monitoring, management techniques and awareness of a national salinity strategy. Social media, fellow farmers and personal experiences emerged as primary knowledge sources for soil salinity management, presenting potential channels for knowledge sharing, increasing awareness and transferring technology. Most respondents expressed willingness to use elemental sulphur for soil salinity improvement upon learning about its benefits. Positive determinants included being a full-time farmer, owning a farm, awareness of the national strategy and preference for low-priced elemental sulphur. Less than 1 year of farming experience was a negative determinant. Our study brings two main recommendations which are to both increase awareness of the severity of soil salinity issues to Omani agriculture and increase the ease of solution implementation, such as the application of elemental sulphur. To increase awareness of soil salinity issues, one possible solution is to emphasize and spread the solutions listed in Oman's national salinity strategy and the new technologies through the main sources of knowledge acquisition identified in this study. Awareness of Oman's national strategy plays two roles: (a) increasing awareness of soil salinity as a national issue and (b) provides a framework to combat the challenge on a national scale, therefore providing ideas to mitigate salinity, a detailed plan and potential future support for farmers. Once more, farmers are aware of the severity of soil salinity, whether by means of national channels or farmer-to-farmer communication, solutions and technologies addressing this issue must be accessible and feasible to implement. This then influences the general perception of handling soil salinity issues and increases the likelihood of the adoption of products seen as both effective and efficient. Perceived heightened capability compounded with low prices ultimately determines the accessibility of amendment products such as elemental sulphur. Therefore, with increased issue awareness and accessible solutions, both inexperienced and experienced farmers across a range of socio-economic and demographic backgrounds can deem soil salinity as a critical problem in Oman and quickly adopt solutions to prevent its negative effects. The study results emphasize the significance of integrating farmers' perceptions and attitudes with the adoption of technology and best management practices to achieve sustainable soil salinity management in agriculture. Furthermore, this work establishes a precedent for similar evaluations in other Gulf Cooperation Council (GCC) countries and other regions worldwide grappling with soil salinity challenges. It underscores the need to evaluate the social feasibility of adopting technically suitable management practices to address this crucial constraint in food production within arid and semi-arid agroecosystems.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

ORCID

Said Al-Ismaily https://orcid.org/0000-0001-8708-0231

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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