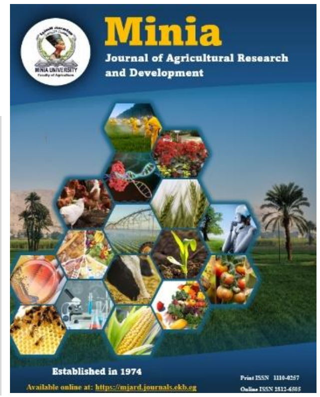
Minia J. of Agric. Res. & Develop., Minia Univ., Vol. 45 (4): 743 - 769, 2025

Minia Journal of Agricultural Research and Development

Journal homepage & Available online at:

https://mjard.journals.ekb.eg



Comprehensive Assessment of Agricultural Land Evaluation in Arid Environments Using Geospatial Tools.

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Received: 6 Oct. 2025 Accepted: 12 Oct. 2025

ABSTRACT

Land evaluation in arid and semi-arid environments is a crucial step toward ensuringg sustainable agricultural development and optimizing resource use. The current study aimed to conduct a comprehensive assessment of land capability and crop suitability using geospatial tools, with a focus on quantifying the physical and chemical limitations that determine soil productivity. A total of 2,118 soil profiles were sampled on a 250 × 250 m grid across 31,000 feddans of newly reclaimed area. Land capability was assessed using the modified Storie Index, and crop suitability was evaluated through the ALESarid-GIS model for some selected field, oil, vegetable, and fruit crops. The findings indicated that land capability results classified 45.64% of the land as Grade 4 and 47.57% as Grade 5, reflecting severe to very severe limitations, while only 0.21% classified as Grade 3. The suitability analysis demonstrated significant variation among crop groups. For the field crops, wheat and barley ranked the highest with 93.20% of the area classified as moderately suitable (S2), while sorghum recorded the lowest with 84.46% in S3. Within the oil crops, sesame showed the best performance with 80.56% in S2, whereas soybean was the least adapted, with only 12.68% marginally suitable (S3) and the majority (80.73%) restricted to conditionally suitable (S4). For the vegetables, onion emerged as the most suitable, achieving 84.13% in S2, while potato showed the lowest adaptability, with 72% confined to marginal suitability (S3). Among the fruit crops, olives proved the most promising, with 57.61% of the area moderately suitable (S2), while peach had the lowest suitability, with only 9.35% in S2 and over 75% restricted to marginal (S3). On the other hand, sensitive crops such as tomato, green pepper, citrus, and mango were largely marginal or unsuitable due to shallow depth, salinity, and alkalinity. In conclusion, the study highlights that although most soils are marginally capable (Grades 4–5), sustainable production is achievable through strategic crop–soil matching, integrated nutrient management, gypsum and organic amendments, and precision irrigation. The findings provide a practical roadmap for prioritizing salt- and drought-tolerant crops (e.g., sugar beet, sorghum, sunflower, alfalfa, wheat, barley, and olive), while discouraging the cultivation of highly sensitive species. This approach promotes efficient resource use, reduces environmental risks, and supports long-term sustainability of agricultural expansion in arid reclamation areas.

Keywords: Geospatial Tools; Land evaluation; ALESarid-GIS; Storie Index; Sustainable agriculture

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1. INTRODUCTION:

Land resources in arid and semi-arid regions represent a cornerstone for achieving food security and sustainable agricultural development, particularly in countries such as Egypt where fertile land in the Nile Valley and Delta is under severe pressure from urban expansion and population growth. Consequently, land reclamation projects in desert fringes have become a strategic priority. However, soils in such environments are often shallow, calcareous, and characterized by low fertility and salinity constraints, which necessitates rigorous scientific evaluation before sustainable agricultural use can be achieved (Yousif et al., 2025). Land evaluation frameworks, most notably those proposed by the Food and Agriculture Organization (FAO, 1976, 1995, 2007), provide systematic approaches to determine land capability and suitability by matching soil, climate, and topographic characteristics with crop requirements. Over the past decades, geospatial technologies such as Geographic Information Systems (GIS) and remote sensing (RS) have enhanced the precision of these evaluations, enabling the production of spatially explicit suitability maps that are vital for agricultural planning (Abdel-Wahab & Ezz, 2025; Burrough et al., 2015; Yousif et al., 2025a). Several studies have applied these approaches in different parts of Egypt. For instance, Khatter et al. (1988) evaluated Wadi El-Rayan soils using parametric indices, while Metwally and Beshay (1997) assessed Baris Oasis soils employing a modified Storie index. More recent efforts integrated GIS with suitability models; Selmy et al. (2024) demonstrated that combining soil properties, water availability, and climatic data provides more reliable zoning for crops in desert reclamation projects. Similarly, Yousif (2019) applied the MicroLEIS model in the north western coast of Egypt, showing that salinity and calcium carbonate were the main limiting factors. Abdullahi et al. (2025b) further highlighted that in western Minya, most soils fall within marginal to moderately suitable classes due to high $CaCO_3$ content, yet cereals and oil crops remain promising options under improved management. Internationally, GIS-based models such as ALES and MicroLEIS have been successfully employed for crop suitability in Mediterranean and arid environments (De la Rosa et al., 2004; Rossiter, 1996). Land suitability programs such as ALESarid-GIS have been successfully employed in evaluating reclaimed desert lands, including the New Valley, the New Delta, and Western El-Minya, showing that cereals (e.g., wheat and barley) and industrial crops (e.g., sugar beet) are often the most suitable options, whereas fruit crops such as citrus and mango face severe limitations (MR Hedia & R Abd Elkawy, 2016; Shokr et al., 2021; Yousif, 2024). These applications highlight the importance of computerized models not only in assessing the potential of new agricultural lands but also in supporting evidence-based planning for sustainable agricultural expansion in arid environments. Despite this progress, significant gaps remain. Many earlier studies either focused on a narrow set of crops or applied a single evaluation framework, potentially overlooking the variability of soil constraints in reclaimed desert lands. Moreover, limited work has systematically integrated both land capability (long-term productivity potential) and land suitability (crop-specific fitness) using modern parametric models and geospatial tools. Addressing this gap is critical for optimizing crop selection, ensuring sustainable resource use, and guiding large-scale reclamation investments in arid regions. Therefore, the present study aims to conduct a comprehensive assessment of land capability and agricultural suitability in arid environments using an integrated approach that combines the Modified Storie Index and ALESarid-GIS model within a GIS framework. This approach provides both a broad evaluation of land productivity potential and a crop-specific suitability analysis, thereby supporting evidence-based agricultural planning and sustainable land management.

2. MATERIALS AND METHODS

2.1. **Study Area**

The study area encompasses approximately 31,704 feddans (≈33,289 acres) in Mallawi District, El-Minya Governorate, Upper Egypt, and extends between longitudes 29°49′–30°04′ E and latitudes 27°51′–28°01′ N along the Cairo–Aswan Western Desert Road as illustrated in Figure 1. It represents one of the most significant reclamation projects in the Western Desert, relying mainly on groundwater resources and modern mechanized farming systems.

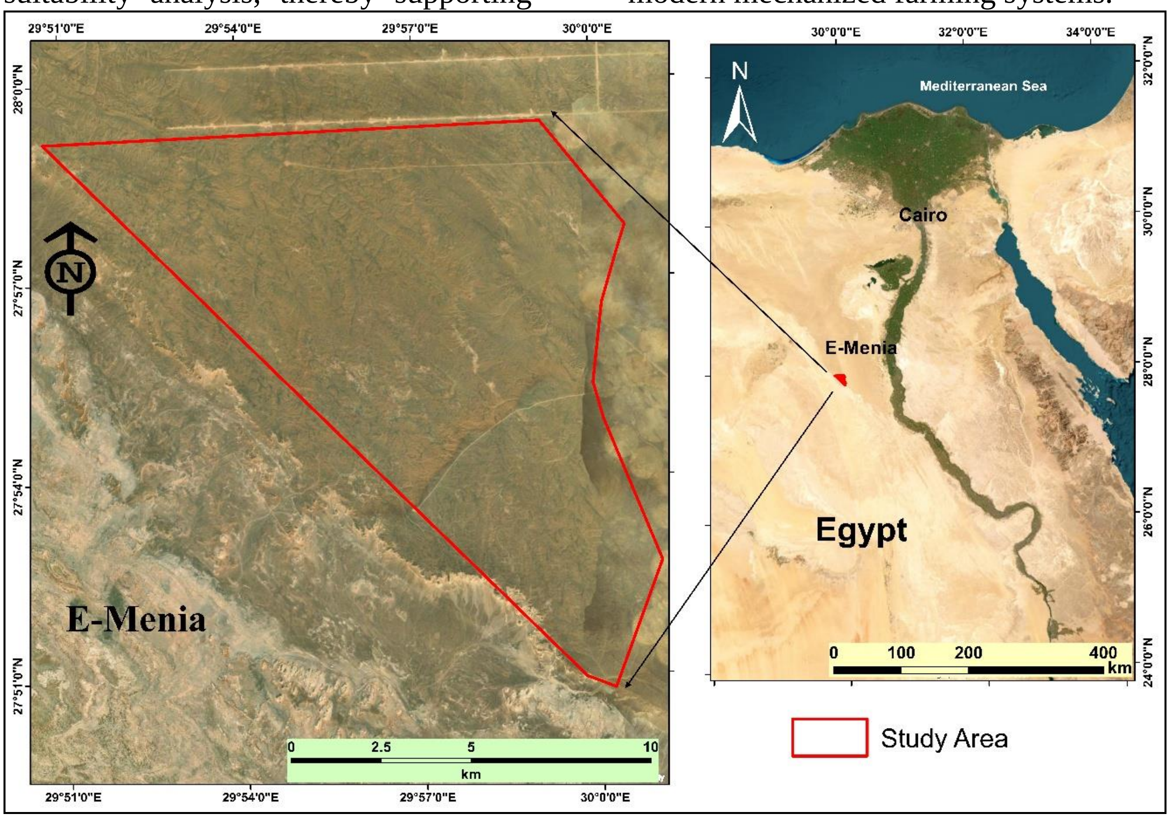

Figure 1. Location map of the study area.

Climatology, the climate of the region is classified as arid to semi-arid, with hot summers, mild winters, and almost negligible rainfall (Table 1). Average annual temperature is about 20.3 °C, with maximum values reaching 36.7 °C in June and July, while minimum temperatures drop to 4.0 °C in January. Relative humidity averages 51.2%, fluctuating between 36% in May and 64% in December, whereas mean daily evaporation is about 9.5 mm, peaking at 15.8 mm in June, which imposes considerable evapotranspiration demands and underscores the importance of efficient irrigation scheduling.

Table 1. Meteorological Data of the Study Area (El-Minya Meteorological Station).

Climate Element	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Avg.
Max Temp (°C)	20.4	22.4	25.7	31	34	36.7	36.7	36.2	33.9	31.4	26.2	21.5	29.7
Min Temp (°C)	4	5.3	8.2	12.4	16.6	19.3	21.5	20.4	18.7	15.8	10.9	6.3	13.3
Temp Range (°C)	16.2	17.1	17.5	18.6	18.3	17.4	15.2	15.8	15.2	15.6	15.3	15.2	16.5
Mean Temp (°C)	12.1	13.9	16.9	21.7	25.3	28	29.1	28.3	26.3	23.6	18.6	13.9	20.3
A. P. (b)	1.019	1.017	1.015	1.012	1.011	1.009	1.007	1.008	1.011	1.014	1.017	1.018	1.013
W. S.(km/h)	9.5	10.8	12.8	14.7	15.8	16.7	13.8	11.5	13.2	11.9	10.6	9.1	12.5
Sunshine (hr/day)	8.2	9.1	9.3	10	11.1	12.3	12.5	11.8	10.6	9.9	8.9	7.8	10.1
R. H. (%)	61	55	50	41	36	40	46	51	54	55	61	64	51.2
Eva. (mm)	4.5	5.8	7.8	10.9	14.5	15.8	13.8	11.7	10	8.6	6	4.9	9.5

A. P. =Atmospheric Pressure (b); W. S. = wind speed; R. H. = relative humidity; Eva. = evapotranspiration

Geologically, the area is underlain by the Early Miocene Moghra Formation, composed mainly of sandstone interbedded with clay, shale, and occasional limestone lenses (Said, 1990). This lithology has produced soils that are predominantly sandy to loamy sand, shallow in depth (25–50 cm), strongly calcareous with $CaCO_3$ contents of 10–25%, alkaline in reaction with pH values ranging from 7.9 to 9.0, and generally low in fertility and water-holding capacity.

Geomorphology, the geomorphology reflects a transitional landscape between the fertile Nile Valley floodplain and the arid Western Desert plateau, with Digital Elevation Model (Figure 2) analysis showing that 59.3% of the area is gently sloping (1–5%), 27.6% moderately sloping (5–10%), 11.5% nearly level (0–1%), and only 1.6% strongly sloping (>10%). Such relatively smooth topography is well suited for mechanized agriculture and center-pivot irrigation, although localized depressions may increase risks of salinity and waterlogging.

Hydrologically, the region is characterized by a complex multi-aquifer system, with the fractured Eocene Limestone aquifer (Samalut and El-Minia Formations) serving as the primary groundwater source, exhibiting transmissivity values ranging from less than 100 to more than 20,000 m^2/day (Ghnia, 1997; Hamdan & Sawires, 2013; Rosenthal et al., 1992). Other contributing units include the semi-confining Maghagha Formation, the more saline Oligocene Sand aquifer, localized Quaternary alluvial deposits influenced by Nile levels, and the deeper Nubian Sandstone aquifer, which is rarely exploited.

Groundwater salinity varies widely, with Total Dissolved Solids (TDS) ranging between 560 and 930 mg/L in most wells, but exceeding 2000 mg/L in some locations. From an agricultural perspective, these conditions present both challenges and opportunities: while shallow depth, high calcium carbonate, and salinity pose constraints, the area has considerable potential for strategic crops such as wheat, barley, sugar beet, sunflower, potato, and alfalfa, provided that appropriate soil amendments, fertigation, and irrigation management practices are applied.

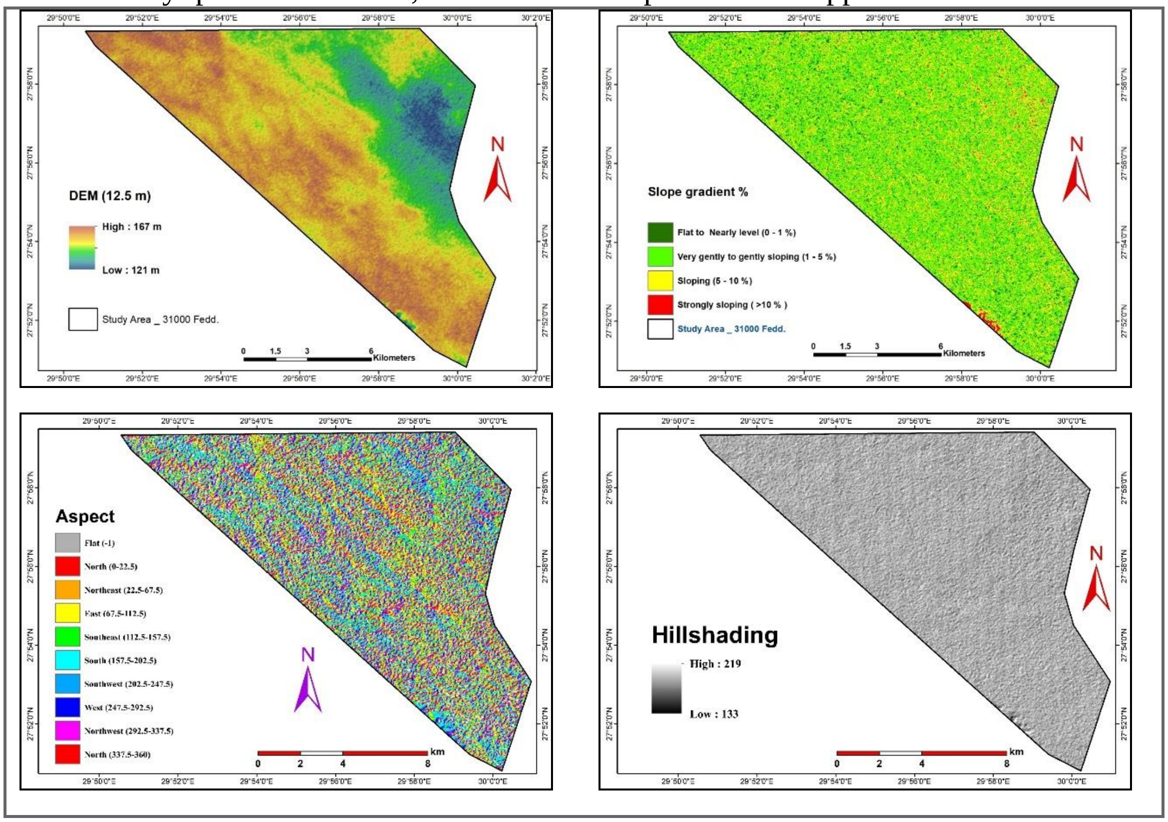

Figure 2. Topographical analysis of the study area

3.2. Field Studies, Soil Sampling, laboratory work.

A detailed soil survey of the study region was conducted through a field trip to conduct field research and gather soil samples. Soil profile sites were selected in the field utilizing a sampling grid of 250 × 250 m, with coordinates collected by a global positioning system device (Garmin GPS). These profile coordinates were projected onto a map to illustrate soil sampling sites across the study area, as shown in Figure 3. As illustrated in Figure 3, a total of 2118 soil profiles were excavated using a sampling grid approach with 250 m spacing. Soil profiles were then morphologically described following the FAO guidelines for soil description (FAO, 2006). Soil samples were collected from profile horizons and transported to the soil science lab, faculty of agriculture, El-Minia university. The collected soil samples were air-dried at room temperature, crushed, and then passed through a 2 mm sieve before being analyzed for physical and chemical parameters. The physical and chemical characteristics of the soil samples were examined following the standards established by the United States Department of Agriculture (USDA, 2014). Consequently, the physical and chemical parameters of the soil were assessed, including EC, pH, sand, silt, clay, CEC, CaCO3, ESP, SAR, and texture.

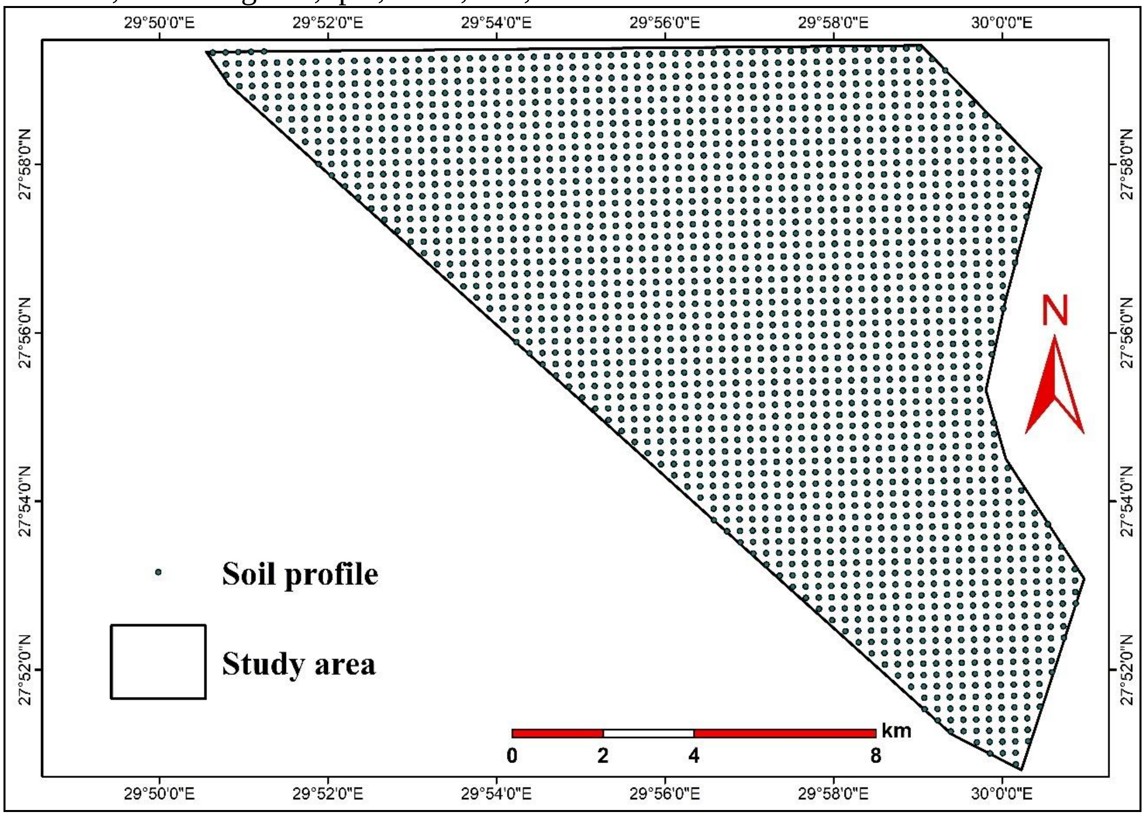

Figure 3. Soil sampling system of the study area.

For each studied soil profile, the weighted mean (WM) values of each soil property dataset were computed as follows:

$$WM = \frac{\sum_{i=1}^{n}(v_i * v_t)}{T} \quad (1)$$

Where WM is the weighted mean value of soil property vi is the soil property value relating to soil horizon i, vt is the soil horizon thickness, n is the number of horizons within a soil profile, and T is the total depth of soil profile. The resulting weighted mean values of soil properties were then utilized in the land evaluation processes.

3.4. Land Evaluation Procedures

3.4.1. Land Capability Assessment

Land capability for productive capacities and potential agricultural uses was assessed using the modified Storie index model (O'geen, 2008). This approach was developed as a parametric approach, the Storie index, and was modified to produce digital ratings by O'geen (2008). The classification of land capability classes was based on inherent soil properties, terrain features, and environmental conditions that permanently limit land use (Ditzler et al., 2017). Furthermore, the modified Storie index model is a land assessment technique that considers soil and landscape attributes that control land productivity and uses. Under the current study, the other soil and landscape properties (Factor X) were represented in coarse fragments, soil pH, soil salinity, and sodium adsorption ratio (SAR). Employing the used model, the rating of each factor was scored according to criteria developed by Storie (O'geen, 2008). A score ranging from 0 to 100% is defined for each factor; the four factors are then multiplied together, with an equal weighting, to calculate the Storie index as shown in Equation (2). The calculation was run and coded using Visual Basic for an application in Microsoft Excel. The final Storie index (SI) rating was computed employing Equation (2). Moreover, land capability categories, grades, and productivity ratings based on the modified Storie index model are shown in Table 2 (O'geen, 2008).

Land capability categories range from excellent class (Grade 1) to non-agricultural class (Grade 5), as shown in Table 2.

$$SI = [(A/100) \times (B/100) \times (C/100) \times (X/100)] \times 100 \qquad (2)$$

where, SI is Storie Index rating, A represents the soil depth, B is the surface texture factor, C is the slope factor, and X represents other soil and landscape parameters such as topography, drainage, fertility, erosion, salinity, alkalinity, etc.

Table 2. Land capability classifications, ratings, and productivity assessments based on the modified Storie index model (O'geen, 2008).

Capability grade	Capability category	Productivity rating (%)	Description
Grade 1	Excellent	80-100	Soils with few or no limitations
Grade 2	Good	60-79	Soils with limitations that reduce the choice of crops or require simple soil conservation practices
Grade 3	Fair	40-59	Soils with severe limitations that reduce the choice of crops and/or require special conservation practices
Grade 4	Poor	20-39	Soils with very severe limitations that restrict the choice of crops and/or require very careful management
Grade 5	Non-agricultural	< 20	Soils with very severe limitations that restrict their use in agriculture

3.4.2. Land Suitability Assessment

In the current study, soils in the study area were evaluated to determine their suitability for growing twenty crops. The seventeen crops assessed were divided into four crop groups:

1. Field crops: (wheat, barley, sugar beet, alfalfa, and sorghum).
2. Oil crops (soybeans, peanuts, sesame, and sunflower).
3. Vegetable crops: (potatoes, tomatoes, onions, and pepper).
4. Fruit trees (peaches, olives, mangoes, and citrus).

This study conducted land suitability evaluations with the ASLEarid-GIS model created by Abd EL-Kawy et al.

(2010). This system was integrated as an embedded model within the Arc-GIS software package to facilitate the calculation of agricultural land suitability indices and classifications for the chosen crops and to generate suitability maps. Table 3 illustrates the ratings utilized by ALESarid-GIS for evaluating crop suitability (Abd EL-Kawy et al., 2010).

Table 3. Land suitability classes, ratings used by ALESarid-GIS.

Class	Definition	Range (%)
S1	Highly suitable	80-100
S2	Moderately suitable	60-80
S3	Marginally suitable	40-60
S4	Conditionally suitable	20-40
NS1	Potentially suitable	10-20
NS2	Actually unsuitable	< 10

3.5. Mapping Soil Properties, Capabilities, and Suitability Classes

Spatial distribution maps of soil attributes, land capability categories, and soil suitability categories were generated in ArcGIS 10.8 software (ESRI Co., Redlands, USA) utilizing the Inverse Distance Weighted (IDW) interpolation method. The IDW is commonly employed in soil research because surface interpolations are easily implemented using it (Aldabaa & Yousif, 2020; Jantaravikorn & Ongsomwang, 2022; Mallah et al., 2022; Saraswat et al., 2023; Shokr et al., 2022).

The IDW approach requires a large number of sampling points (more than 14 points) for representative interpolation outcomes (Yousif et al., 2020). It performs best when sampling points are evenly distributed throughout the study region (Yousif et al., 2020). Therefore, this study employed sufficient sampling points (1934 points) and a systematic grid sampling technique to ensure that all variations in soil properties investigated in the study area were represented. The Inverse Distance Weighting (IDW) technique is commonly employed to create a surface map of a variable affected by its location, based on the assumption that the variable's influence decreases with increasing distance from the sample point. Consequently, the localized impact of the measurement site diminishes with increasing distance, as demonstrated in the subsequent equation:

$$Z_S = \frac{\sum_{i=1}^{n}\left(\frac{z_i}{d_i^p}\right)}{\sum_{i=1}^{n}\left(\frac{1}{d_i^p}\right)} \quad (4)$$

where ZS is the value predicted at site S, zi is the z value at measured site i, di is the distance between site S and site i, and p describes the distance power, that determines the degree to which nearer points are preferred over more distant points.

4. RESULTS AND DISCUSSIONS

4.1. Spatial distribution of different soil characteristics

Soil depth:

The spatial distribution of soil depth in the study area indicates a dominance of shallow soils (25–50 cm), which account for **60.91%** of the total area (19,311.47 feddans). Moderately deep soils (50–100 cm) cover **32.28%**, while very shallow soils (<25 cm) occupy **6.58%**. Deep soils (100–150 cm) are negligible, representing only **0.22%** of the land (Table 4 and Figure 4). The predominance of shallow and moderately deep profiles highlights a significant limitation for crops with extensive root systems, as reduced rooting depth directly restricts soil moisture storage and nutrient availability. This constraint is particularly critical in arid zones where irrigation efficiency and root penetration are important to sustaining yields. These findings are consistent with Mohamed et al. (2023), who reported that most reclaimed lands in West Minya suffer from shallow effective soil depth due to lithic contact and gravel layers. Similar observations were made by Nada et al. (2022), who emphasized that shallow soil depth is a major limiting factor for long-term crop productivity in Upper Egypt. Crops with shallow to moderate rooting systems, such as sugar beet, barley, and sunflower, are thus more suited for such conditions, while deep-rooted crops (e.g., fruit trees) are likely to face severe growth restrictions.

Table 4. Areas of Soil Depth classes in the Study Area.

Soil depth class	Area	
	Feddan	%
Deep soil (100-150 cm)	70.32	0.22
Moderately deep soil (50-100 cm)	10235.35	32.28
Shallow soil (25-50 cm)	19311.47	60.91
Very Shallow soil (<25 cm)	2086.83	6.58

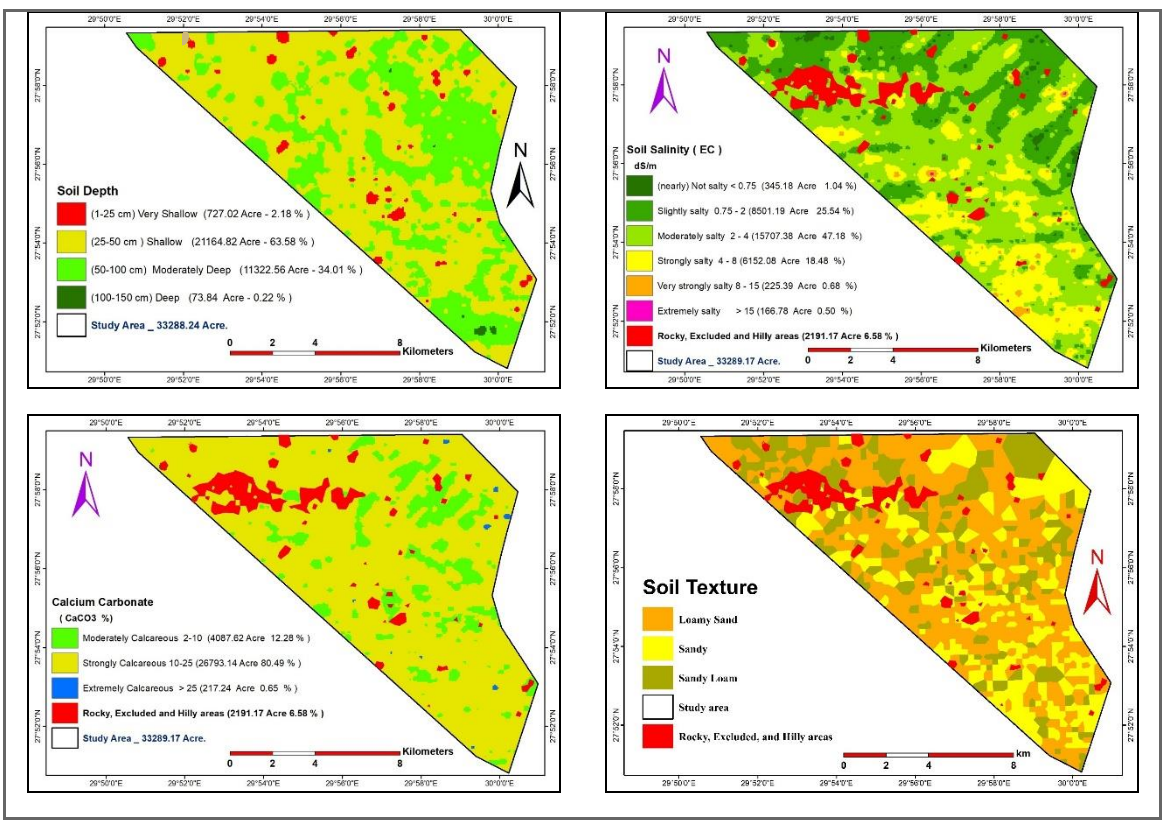

Figure 4. Spatial distribution of some soil properties.

Soil EC:

Soil salinity emerged as one of the most critical constraints in the study area. Nearly half of the soils (47.18%) fall into the moderately saline category (2–4 dS/m), while 18.48% are strongly saline (4–8 dS/m). Slightly saline soils (0.75–2 dS/m) cover 25.54%, whereas non-saline soils (>0.75 dS/m) constitute only 1.04%. Very strongly saline (8–15 dS/m) and extremely saline (>15 dS/m) soils together represent just over 1% (Table 5 and Figure 4). Soil salinity, soil depth, and texture are the most critical significant factors of agricultural priorities. The results of this investigation indicated that soil salinity varies across the study area. Salinity is the most critical element in desert areas and in the research area due to groundwater constraint and the forced use of contemporary irrigation systems. High salinity levels reduce osmotic potential, impair seed germination, and restrict the uptake of essential nutrients, thereby decreasing crop productivity. Sensitive crops such as tomato, green pepper, and citrus are unlikely to perform well under such conditions, while moderately tolerant crops (e.g., sugar beet, barley, sorghum) are better adapted. These findings are consistent with (Selmy et al., 2024), who found that secondary salinization is a widespread issue in reclaimed lands of the Western Desert, primarily caused by limited leaching and irrigation with moderately saline groundwater. Gabr (2023) also stressed that salinity management is a key challenge for sustainable agriculture in Egypt's desert reclamation projects. The findings highlight the urgent need for improved irrigation practices, leaching requirements, and the incorporation of salt-tolerant crops into cropping systems.

Table 5. Salinity degrees in the study area.

Salinity Class	Area	
	Feddan	**%**
(Nearly) Not salty (<0.75 dS/m)	328.74	1.04
Slightly saline (0.75 – 2 dS/m)	8096.37	25.54
Moderately saline (2 – 4 dS/m)	14959.41	47.18
Strongly saline (4 – 8 dS/m)	5859.13	18.48
Very strongly saline (8 – 15 dS/m)	214.65	0.68
Extremely saline (> 15 dS/m)	158.84	0.50

Calcium carbonate:

The soils of the study area are predominantly strongly calcareous (10–25% $CaCO_3$), representing about 80.49% of the land. Moderately calcareous soils (2–10%) cover 12.28%, while extremely calcareous soils (>25%) are rare, occupying only 0.65% of the total area (Table 6 and Figure 4). High calcium carbonate levels are a defining feature of desert soils in Upper Egypt and have important agronomic implications. Excessive $CaCO_3$ reduces soil fertility by fixing phosphorus, limiting micronutrient availability (e.g., Fe, Zn, Mn), and increasing alkalinity. This creates nutritional imbalances that can affect both crop yield and quality. Abdullahi et al. (2025a) reported similar results in West Minya, emphasizing that strongly calcareous soils require careful nutrient management. Abdullahi et al. (2025b) further observed that crops grown under high $CaCO_3$ conditions often exhibit micronutrient deficiencies unless supplemented with foliar applications or chelated fertilizers. Therefore, while sugar beet and barley can tolerate calcareous conditions, sensitive crops may require intensive soil amendments to perform effectively. In the investigated area, addressing calcareous constraints is therefore a prerequisite for improving crop yields.

Table 6: Calcium carbonate contents of the study area.

Class	Area	
	Feddan	%
Moderately calcareous (2-10 %)	3892.98	12.28
Strongly calcareous (10-25 %)	25517.27	80.49
Extremely calcareous (>25 %)	206.90	0.65

Soil texture:

The dominant texture in the study area is loamy sand, covering 43.91% of the total area. Sandy soils constitute 24.72%, while sandy loam accounts for 24.43% (Table 7 and Figure 4). Coarse-textured soils such as these are generally well-drained and suitable for mechanized farming. However, they have low water-holding capacity and poor nutrient retention, which can limit productivity under insufficient fertilization and irrigation. These results are in line with Yousif and Ahmed (2024), who observed that most reclaimed soils in West Minya are sandy in nature, requiring frequent irrigation and fertilization to sustain productivity. Zakarya et al. (2021) also noted that sandy and loamy sand textures in Upper Egypt facilitate the adoption of center-pivot irrigation but necessitate careful management to prevent nutrient leaching. Comparable results were obtained by Yousif et al. (2020 a), who found that sandy-textured soils in Egypt's northwestern coast required frequent irrigation to sustain crop yields. Mohamed et al. (2023) similarly concluded that sandy loam soils in arid Egypt, although suitable for cereals under modern irrigation, demand significant soil amendments and precise water management to ensure sustainability. In the study area, the preponderance of sandy textures emphasizes the significance of using organic amendments, crop residues, and soil conditioners to improve soil structure and fertility.

Table 7. Soil texture of the study area.

Texture class	Area	
	Feddan	%
Loamy Sand	13920.13	43.91
Sand	7838.01	24.72
Sandy Loam	7745.87	24.43

4.2. Land Capability Evaluation

The land capability assessment of the study area was carried out using the modified Storie Index (Aldbaa, 2012; O'geen, 2008). As shown in Table 7 and Figure 5, the findings revealed that the study area is dominated by low to grade 4, reflecting the combined effects of soil depth, salinity, calcareousness, and texture limitations.

Land capability assessment represents a cornerstone in evaluating the potential of soils for agricultural use. It classifies land units into different grades based on their ability to support sustained agricultural production under current conditions. This evaluation is essential in arid regions, where soils are characterized by multiple limitations, including shallow depth, salinity, alkalinity, and coarse texture. According to FAO guidelines (FAO, 1976), land capability is determined by integrating physical, chemical, and climatic factors to highlight both opportunities and constraints for agricultural development.

The classification results can be presented as follows:

- Only a negligible fraction of the study area, about 66.94 feddans (0.21%), was classified as Grade 3 (Table 7 and Figure 5). These soils are relatively more favorable than the rest, with moderately deep profiles, acceptable salinity levels, and suitable textures that allow for the cultivation of a wider range of crops under proper management. Although their extent is limited, these lands represent valuable opportunities for cultivating high-value crops such as wheat, onion, or even selected vegetables with careful soil amendments.
- Soils classified as Grade 4 occupies about 14,469.41 feddans (45.64%) of the study area. These soils are characterized by shallow to moderately deep profiles, moderate salinity, and alkaline conditions. While their limitations are significant, they can still support the production of moderately tolerant crops such as sugar beet, sorghum, and sunflower, provided that soil and water management practices are implemented.
- The largest portion of the study area, about 15,080.79 feddans (47.57%), falls under Grade 5, making it the dominant class. These soils are characterized by severe limitations, including very shallow depth, high salinity, and strong alkalinity. Their productivity potential is considered poor, and only highly tolerant crops can be cultivated with moderate success.
- Excluded Lands: Approximately 2,086.83 feddans (6.58%) of the total area were classified as excluded lands, unsuitable for cultivation. These areas are mainly characterized by rocky areas, extremely shallow soil depth (<25 cm) and excessive salinity, making them inappropriate even for tolerant crops. Their agricultural use would not be economically viable without major land reclamation interventions, such as deep ripping, leveling, and intensive soil amendments.

The dominance of Grade 4 and 5 soils highlight the need for site-specific management interventions, including:

- Application of organic amendments and gypsum to improve soil structure and reduce sodicity.
- Adoption of precision irrigation (e.g., center-pivot with leaching requirements) to manage soil salinity.
- Prioritization of salt- and drought-tolerant crops in the cropping plan.

Table 7. Land capability grades of the study area.

Capability Grade	Area	
	Feddan	%
Grade 3	66.94	0.21
Grad 4	14469.41	45.64
Grade 5	15080.79	47.57
Excluded	2086.83	6.58

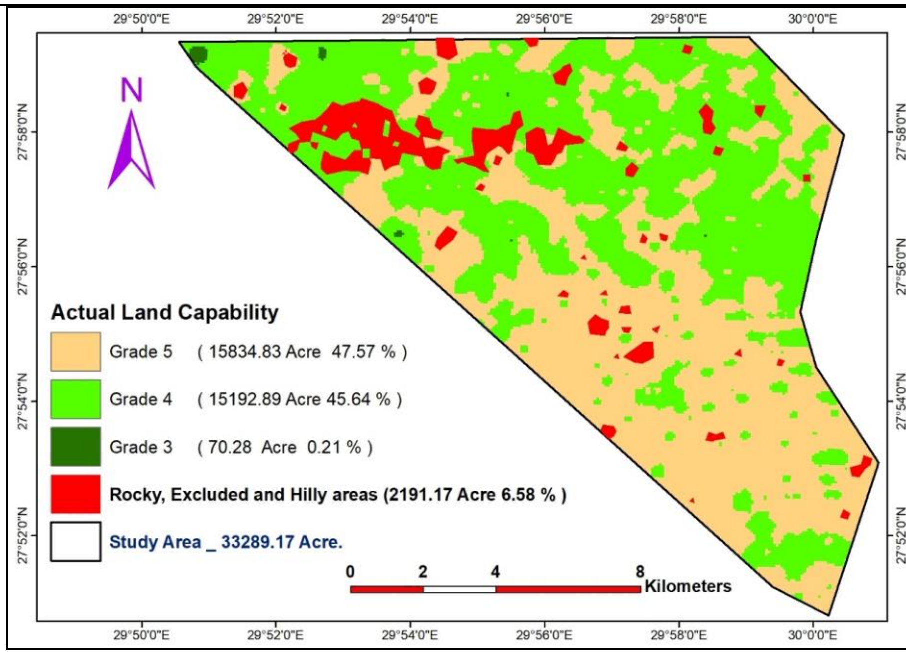

Figure 5. Land Capability map of the study area.

Finally, the land capability evaluation indicates that, while the study region has agricultural potential, it must be developed using the idea of "management for sustainability rather than maximization of yields." This is consistent with recent comments by Gabr (2023), who suggested that long-term success in Egypt's desert reclamation initiatives is dependent on sustainable management rather than short-term productivity improvements.

These results are consistent with other studies in Egypt’s Western Desert. Abdullahi et al. (2025a) found that more than 70% of desert reclamation areas in western El-Minya fall within grade 4 due to salinity and calcium carbonate content. The capability classification in West Minya underscores the need for zoning-based land use planning, where highly capable soils are targeted for immediate cultivation, marginal lands are subjected to phased reclamation, and unsuitable lands are reserved for non-agricultural uses. Land capability classification in the study area emphasizes the importance of zoning-based land use planning, in which highly capable soils are prioritized for immediate agriculture expansion, marginal lands are gradually reclaimed, and unsuitable lands are reserved for non-agricultural uses.

4.3. Land Suitability Evaluation

Field crops:

The evaluation of land suitability for field crops in the 31,000-feddan study area revealed marked variations in the adaptability of different species, reflecting the combined influence of soil depth, salinity, alkalinity, calcium carbonate accumulation, and coarse textures (Table 8 and Figure 6). Among the examined crops, sugar beet stands out as the strategic focal crop of the study area to its industrial importance and moderate tolerance to the prevailing soil constraints. Although highly suitable (S1) areas were not abundant, sugar beet proved viable in the extensive Grade 4 soils, which dominate the landscape. Its ability to tolerate salinity levels up to 7–8 dS/m and grow under moderately shallow rooting depth makes it particularly adapted to the West El-Minya environment, where more than 47% of the land is moderately saline and about 61% is shallow in depth. Sorghum demonstrated the highest overall adaptability among the evaluated field crops. The results indicated that approximately 26,777.46 feddans (84.46%) of the land fell under the moderately suitable class (S2), with an additional 2,839.68 feddans (8.96%) classified as marginally suitable (S3). This distribution highlights sorghum's strong resilience to the prevailing limitations, particularly salinity, shallow rooting depth, and coarse soil textures. Its deep rooting system and inherent drought tolerance allow it to exploit subsurface moisture more effectively than most cereals, making it a reliable summer crop for the region. Abdullahi et al. (2025a) reached similar conclusions in their evaluation of Western El-Minya, identifying sorghum as a promising grain and fodder crop under constrained soil conditions. Consequently, sorghum provides an excellent option for diversifying the cropping system and ensuring feed security in the newly reclaimed lands. Alfalfa also showed notable adaptability, with 20,021.31 feddans (88.38%) classified as moderately suitable (S2) and 2,086.83 feddans (6.58%) as marginally suitable (S3). As a perennial forage crop, alfalfa is moderately tolerant to alkalinity and calcareous soils but somewhat sensitive to high salinity, which restricts its distribution in the more degraded areas. Its inclusion in the cropping system is particularly advantageous because it enriches soil organic matter and fixes atmospheric nitrogen, thereby improving soil fertility and reducing the need for synthetic fertilizers. Zakarya et al. (2021) highlighted alfalfa's role in enhancing soil productivity in West Minya, while Selmy et al. (2024) emphasized the importance of forage crops in sustaining livestock production in arid environments. Thus, alfalfa serves both as a productive forage option and a soil-improving crop, fitting well into the sustainability objectives of the development. Sugar beet, the cornerstone crop of the project, achieved its highest coverage in the moderately suitable (S2) class, representing 29,262.84 feddans (92.30%), with an additional 354.30 feddans (1.12%) in the marginally suitable (S3) class. This distribution reflects the crop's tolerance to moderate salinity and alkaline soils, which are widespread in the study area. Its industrial importance, combined with moderate environmental adaptability, ensures its prioritization in the winter cropping system. These findings are consistent with Said et al. (2020) and Yousif and Ahmed (2024), who confirmed sugar beet's suitability under saline groundwater irrigation in West El-Minya, noting its superior water-use efficiency compared to sugarcane. The results reinforce sugar beet's role as the leading agro-industrial crop, even though its distribution is confined to moderate rather than high suitability classes. Wheat and barley also performed well in the evaluation, with 5.70 feddans (0.02%) identified as highly suitable (S1), 29,548.16 feddans (93.20%) as moderately suitable (S2), and 63.28 feddans (0.20%) as marginally suitable (S3). Their dominance in the S2 class underscores their moderate tolerance to salinity (up to 6 dS/m) and adaptability to shallow soils. Both crops remain essential components of the cropping system due to their dual importance for food and feed. Abdullahi et al. (2025b) identified wheat and barley as key cereals for desert reclamation projects in Upper Egypt, while Yossif and Taher (2020) noted that barley often surpasses wheat under more saline conditions, making it an essential fallback crop in marginal zones.

Table 8. Land suitability classes of some field crops.

Crop	Land suitability classes							
	S1		S2		S3		S4	
	Feddan	%	Feddan	%	Feddan	%	Feddan	%
Suagrbeet			29262.84	92.30	354.30	1.12		
Sorghum					26777.46	84.46	2839.68	8.96
Alfalfa	2086.83	6.58	28021.31	88.38	50.19	0.16	--	--
Wheat & Barley	5.70	0.02	29548.16	93.20	63.28	0.20	--	--

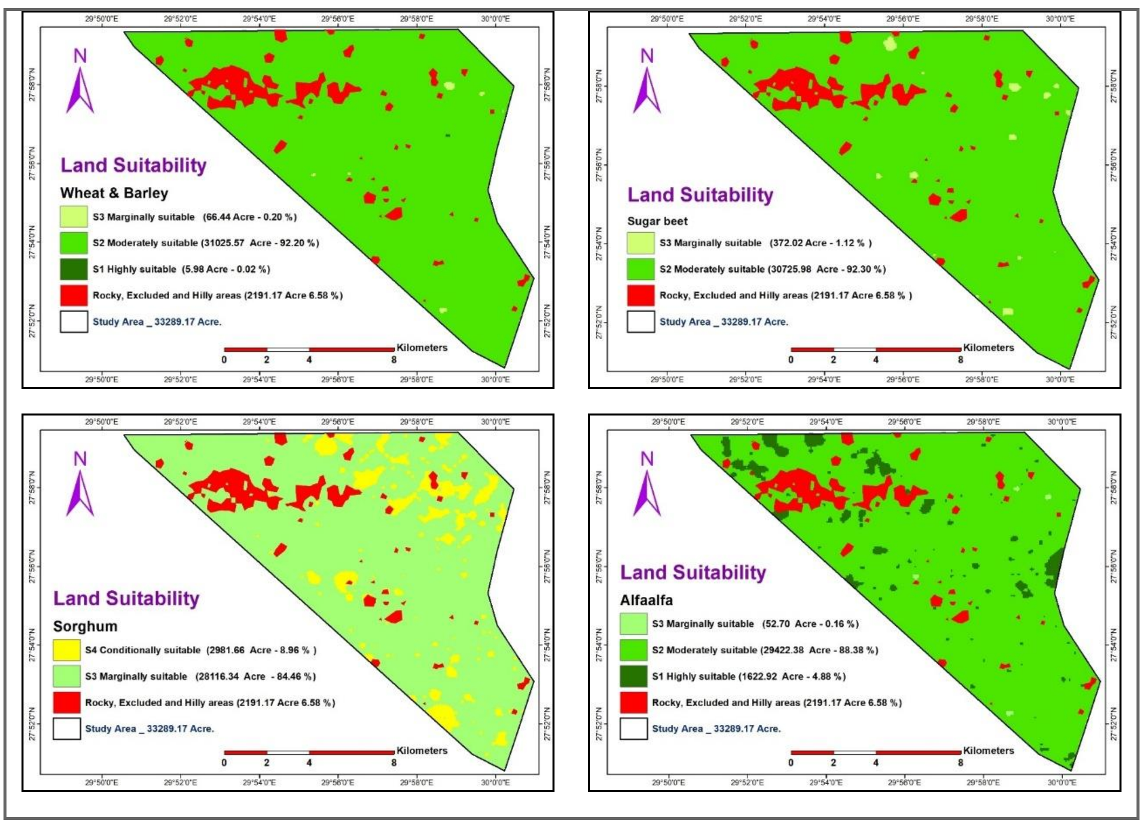

Figure 6. Land suitability classes for some field crops.

Oil crops.

The land evaluation for oil crops in the research area, as represented in Table 9 and Figure 7, revealed that while certain crops show promise adaptability, most are limited by salinity, soil depth, calcareous and sandy texture. Sesame emerged as the most promising oil crop, with approximately 80.56% of the total area classified as moderately suitable (S2). The crop's sensitivity to osmotic stress and its relatively shallow rooting system limit its adaptability to saline and alkaline soils. Zakarya et al. (2021) emphasized that sesame suffers significant yield reductions even under moderate salinity levels, making it less viable for large-scale cultivation in reclaimed desert lands. Nevertheless, small-scale cultivation could still be feasible in localized areas with better soil conditions, especially where sandy loam textures prevail, and where improved irrigation methods can mitigate salinity stress. Also, sunflower emerged as a promising oil crop, with approximately 93.02% of the total area classified as marginally suitable (S3). Despite the absence of highly suitable (S1) areas, the extensive coverage of S3 indicates that sunflower can be cultivated successfully in most parts of the study area, provided that adequate fertilization and irrigation practices are adopted. Its physiological resilience to salinity and drought, as well as its relatively short growing cycle, make it a favorable option for desert agriculture. Yousif and Ahmed (2024) confirmed sunflower's strong adaptability in Upper Egypt, noting its superior performance compared to other oil crops under salinity stress. Furthermore, Abdullahi et al. (2025b) emphasized that sunflower's deep rooting system allows it to get moisture in moderately shallow soils, supporting its position as a priority crop for oil production in reclaimed lands. Groundnut also showed a reasonable level of adaptability, with 74.91% of the area falling under the marginally suitable (S3) class. Although groundnut requires higher soil fertility and is sensitive to extreme salinity, its performance in sandy soils can be enhanced through integrated management practices, including the addition of organic matter and gypsum, as well as precise irrigation scheduling. Metwally et al. (2018) highlighted that groundnut cultivation in sandy soils had acceptable results under sandy loam soils when supported with modern irrigation and fertilization regimes. Its inclusion in the cropping system could diversify farm income and contribute to export-oriented oil production, although its management demands are higher compared to sunflowers. In contrast, soybean was the least adapted crop in the study area, with the majority of soils classified as marginal (S3) or conditionally suitable (S4) classes. This poor performance is primarily linked to the combined effects of soil salinity and alkalinity, which severely restrict soybean growth. Mohamed (2021) reported similar results, noting that soybean is highly sensitive to the high calcium carbonate and pH levels typical of desert soils, leading to nutrient imbalances and low yields. While soybean remains a crop of high nutritional and economic importance, its cultivation in the study area would be limited to small patches of relatively better soils and would require substantial inputs, such as foliar micronutrients and frequent irrigation. Taken together, the results suggest that oil crop production in the study area should focus primarily on sesame and sunflower as the leading option, given its adaptability and resilience, followed by groundnut, which can perform satisfactorily under improved management. Soybean, while important from a nutritional and economic perspective, remain less suitable for large-scale cultivation in West El-Minya under current soil conditions. These findings align with recent regional studies (Metwaly et al., 2021; Abdallah et al., 2023; Selmy et al., 2024; Abdullahi et al., 2025), which consistently recommend prioritizing salt- and drought-tolerant oil crops in Egypt's reclamation projects.

Table 9. Land suitability classes of some oil crops.

Crop	Land suitability classes					
	S2		S3		S4	
	Feddan	%	Feddan	%	Feddan	%
Soya bean	--	--	4021.1	12.68	25596.04	80.73
sesame	25446.56	80.56	4052.47	12.83	--	--
Sunflower	--	--	29492.56	93.02	124.58	0.39
Groundnuts	--	--	23748.42	74.91	5868.73	18.51

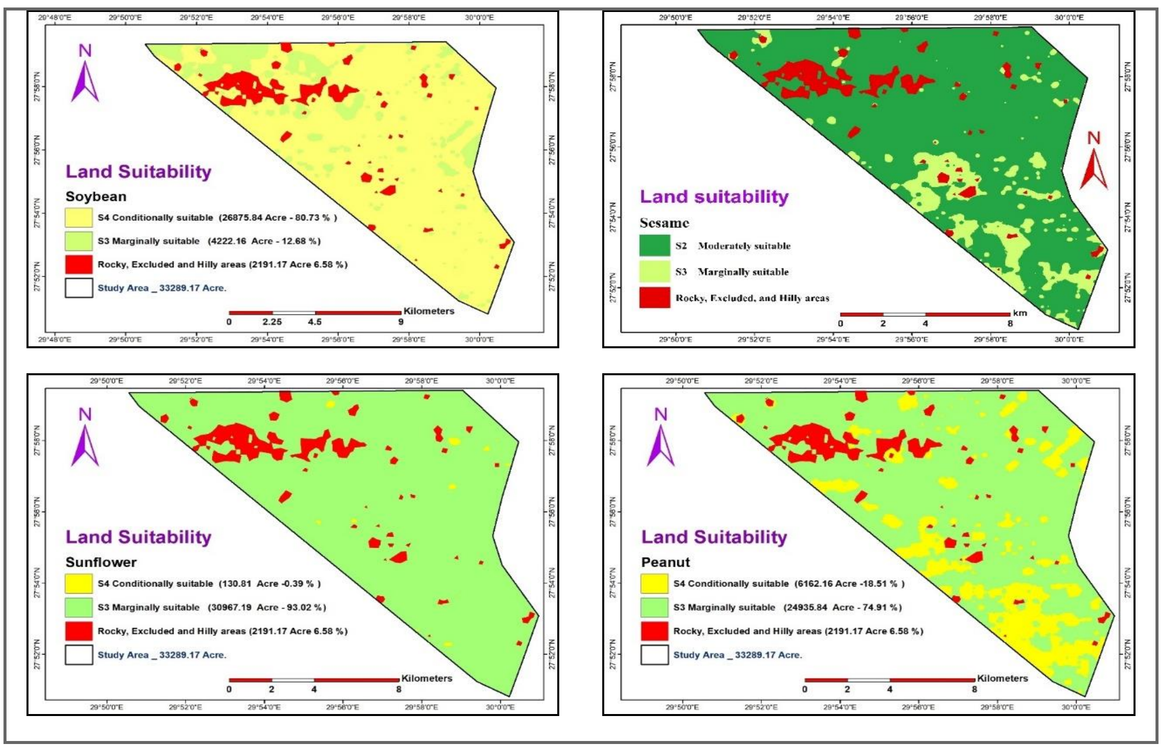

Figure 7. Land suitability classes for some oil crops.

The inclusion of sunflower and groundnut into the cropping plan would not only diversify the production base but also enhance the resilience and profitability of the farming system in the study area. This ranking aligns with broader regional findings (Selmy et al., 2024; Yousif et al., 2024), which emphasized sunflower and sesame as strategic oil crops for Egypt's arid reclamation areas.

Vegetables crops.

The evaluation of land suitability for vegetable crops in the area revealed a clear gradient in adaptability among the tested crops, potato, onion, tomato, and green pepper, reflecting their differential sensitivity to the prevailing soil and environmental constraints (Table 10 and Figure 8). Vegetables are particularly important for both domestic consumption and export markets; however, their productivity is highly sensitive to salinity, alkalinity, and shallow rooting depth. The results demonstrate that while some vegetable crops, notably onion and potato, show promising adaptability under the current conditions, others such as tomato and green pepper are significantly more constrained. Onion found to be the most adaptable vegetable crop, with 84.13% of the area classified as moderately suitable (S2) and an additional fraction in marginally suitable (S3). This widespread suitability reflects onion's moderate tolerance to salinity and its ability to perform reasonably well in sandy loam and loamy sand soils, which dominate the area. These findings are consistent with Fadl and Sayed (2020), who reported that onion cultivation in Upper Egypt achieved acceptable yields under moderate salinity levels when supported by center-pivot irrigation and balanced fertilization. The relatively high suitability of onion makes it a strong candidate for inclusion in the cropping system, particularly as an export crop with significant economic returns. Potato also showed promising results, with approximately 72.1% of the area classified as marginally suitable (S3). While potato is more sensitive to salinity than onion, its performance can still be optimized in soils with moderate salinity and relatively deeper profiles. Zakarya et al. (2021) observed similar trends in West El-Minya, where potato cultivation was feasible but required frequent irrigation and careful nutrient management to counteract the effects of salinity and low water-holding capacity in sandy soils. Although potato's adaptability is more restricted compared to onion, it remains a viable option in localized patches of more favorable soils and contributes significantly to dietary diversity and market demand. In contrast, tomato was classified largely under the marginally suitable (S3) class, with no significant areas reaching S2 or S1 levels. Tomato's sensitivity to both salinity and alkalinity, combined with its relatively high nutrient demand, restricts its potential in the study area. Alsafadi et al. (2022) emphasized that tomato yields in desert reclamation projects decline sharply at high salinity levels, which corresponds closely with the prevailing soil conditions of the study area. While tomato remains a valuable cash crop, its cultivation here would require intensive management inputs, including the use of drip irrigation, frequent fertilization, and foliar applications of micronutrients. Consequently, tomato is better suited as a secondary crop in the project's cropping system rather than a primary component. Green pepper displayed the lowest adaptability, with most of the area falling into the marginal suitable (S3) and conditionally suitable (S4) classes. The crop's shallow rooting system and high sensitivity to both salinity and high pH make it particularly vulnerable to the constraints of West El-Minya soils. These findings are consistent with Massimi and Radocz (2021), who highlighted that pepper cultivation in calcareous desert soils often suffers from nutrient deficiencies, especially of iron and zinc, leading to stunted growth and poor yields. While small-scale cultivation in localized favorable soils may be possible for market diversification, large-scale pepper production is unlikely to be economically viable under current conditions.

Table 10. Land suitability classes of some vegetable crops.

Crop	Land suitability classes					
	S2		S3		S4	
	Feddan	%	Feddan	%	Feddan	%
Green pepper	--	--	28574.94	90.13	1042.2	3.29
Tomato	--	--	29526.52	93.13	90.63	0.29
Potato	--	--	22858.72	72.1	6758.42	21.32
Onion	26673.33	84.13	2943.81	9.29	--	--

Overall, the vegetable crop evaluation highlights onion and potato as the most promising options for the study area, capable of contributing to both domestic consumption and export markets, while tomato and green pepper remain highly constrained and should only be considered under intensive management in selected zones. These results align with recent research in arid regions of Egypt (Alsafadi et al., 2022; Yousif & Ahmed, 2024; Zakarya et al., 2021), which consistently demonstrate that while vegetables can play an important role in desert reclamation projects, their successful integration depends on careful crop selection matched to soil constraints. For the study area, prioritizing onion and potato as key vegetable crops offers the best balance between agronomic feasibility and economic return, while minimizing the risks associated with cultivating highly sensitive species such as tomato and green pepper.

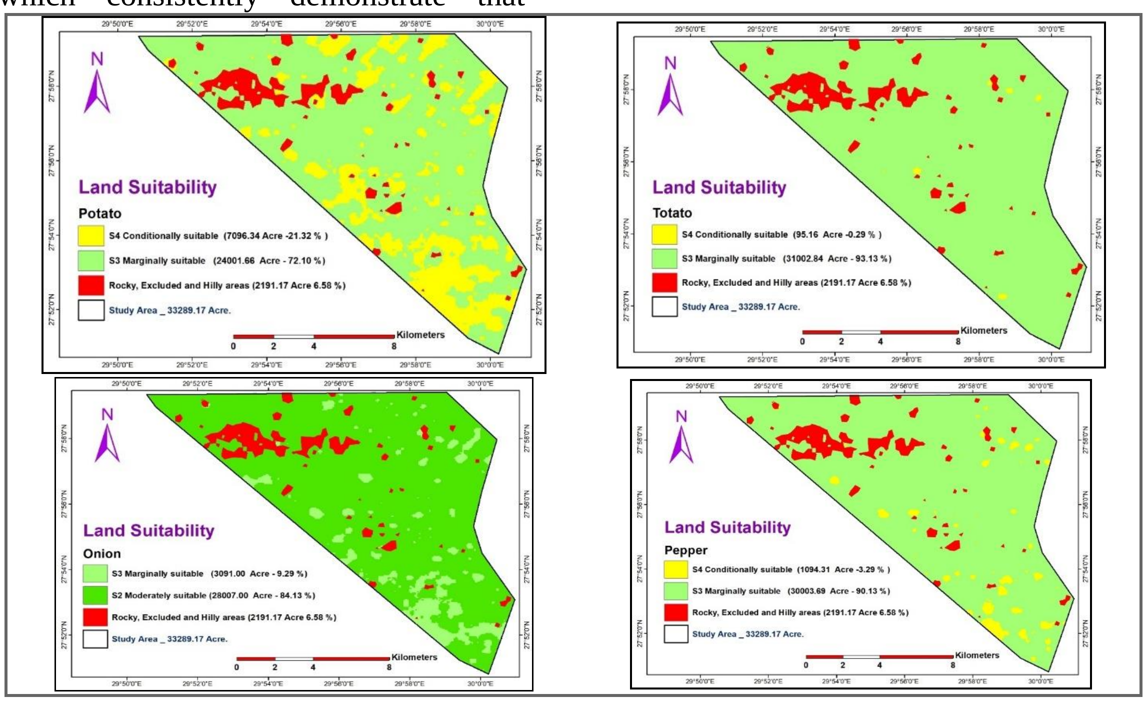

Figure 8. Land suitability classes for some vegetable crops.

Fruit crops.

The assessment of land suitability for fruit crops in the study area revealed marked differences among the tested trees, olive, citrus, mango, and peach, reflecting their varying tolerance to soil salinity, alkalinity, depth, and calcium carbonate content (Table 11 and Figure 9). Fruit trees are particularly important for long-term agricultural development, as they not only diversify production but also increase land value and provide perennial cover that contributes to sustainability. However, the results demonstrated that much of the area falls within the moderately suitable (S2) and marginally suitable (S3) classes, with very limited areas identified as highly suitable (S1), emphasizing the importance of careful crop selection and management. Olive emerged as the most promising fruit crop, with approximately 57.61% of the land classified as moderately suitable (S2). This strong adaptability is attributed to olive's tolerance of salinity, drought, and shallow soils, making it particularly well-suited to the constraints of West Ei-Minya. Selmy et al. (2024) reported similar findings, identifying olive as one of the most sustainable fruit trees for reclaimed desert lands due to its resilience and relatively low water requirements. The findings of this study reinforce olive's role as the leading perennial option in the sustainable cropping plan, offering both economic value and ecological stability. Citrus, by contrast, displayed more restricted suitability, with most of the evaluated soils falling into the marginal (S3) category. Citrus trees are highly sensitive to salinity and shallow soils, both of which dominate the study area. Alsafadi et al. (2022) highlighted that citrus yields in desert reclamation projects decline sharply when salinity exceeds 3 dS/m, a threshold surpassed in much of the study area. Although citrus remains a valuable fruit crop for both domestic consumption and export, its successful cultivation in West El-Minya would require intensive management, including frequent irrigation, soil amendments, and careful site selection in the relatively better soils. Mango also showed low adaptability, with most of the soils classified as marginally suitable (S3). The crop's sensitivity to shallow soil depth and high calcium carbonate content limits its long-term performance in reclaimed desert lands. Sethy (2021) noted that mango suffers from severe micronutrient deficiencies in calcareous soils, especially of iron and zinc, which restrict growth and productivity. In the current study area, mango could only be recommended in localized zones where soils are moderately deep and salinity is lower, but it is not suitable for large-scale cultivation under existing conditions. Peach exhibited similar limitations to mango, with suitability also confined largely to S3. Like other stone fruits, peach is particularly sensitive to salinity and alkalinity, and its shallow rooting system further reduces its adaptability in the study area. Fadl and Sayed (2020) confirmed that peaches in Egypt often fail to achieve economic yields without intensive soil amelioration and irrigation management. Given these constraints, peach should be considered only for small-scale trials in favorable patches rather than as a core component of the cropping system. Finally, the results demonstrate that Olive is the most promising perennial crop, benefiting from its high adaptability and long-term sustainability. While Citrus and mango are feasible but restricted to zones with lower salinity and deeper soils, requiring advanced management (fertigation, salt-tolerant varieties). Peach is unsuitable for large-scale cultivation due to its extreme sensitivity, making it a low-priority option. This prioritization reflects broader findings in Egypt's desert reclamation projects (Selmy et al., 2024; Yousif & Ahmed, 2024), which consistently recommend olives as the backbone of perennial cropping systems, with citrus and mango limited to carefully selected niches.

Table 11. Land suitability classes of some fruit crops.

Crop	Land suitability classes					
	S2		S3		N	
	Feddan	%	Feddan	%	Feddan	%
Peach	2952.345	9.35	23816.39	75.46	2707.924	8.58
Mango	4596.09	14.50	22888.28	72.19	2132.77	6.73
Citrus	6039.94	19.05	21051.53	66.4	2525.68	7.97
Olive	18265.4	57.61	11351.74	35.81	--	--

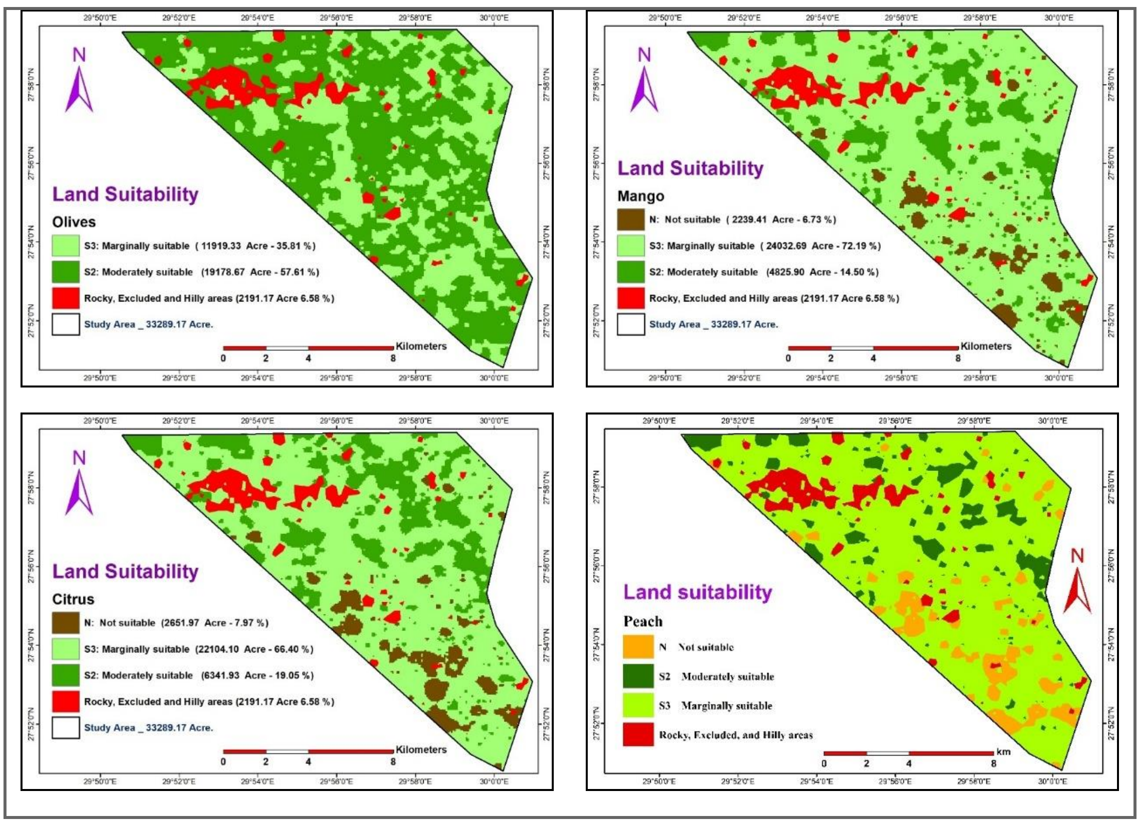

Figure 9. Land suitability classes for some fruit crops.

5. CONCLUSION

The evaluation of land resources in arid and semi-arid regions is fundamental to achieving sustainable agricultural development, particularly in reclamation projects where soils are shallow, calcareous, and often affected by salinity. This study was designed to provide a comprehensive assessment of land capability and crop suitability in an area of approximately 31,704 feddans in West El-Minya, Egypt, through the application of the Modified Storie Index and the ALESarid-GIS model, both integrated within a GIS framework. The physical and chemical characterization of soils revealed that 60.9% of the area is shallow (25–50 cm depth), 32.3% moderately deep (50-100 cm), and 6.6% very shallow (<25 cm). Soil texture was predominantly sandy to loamy sand, with $CaCO_3$ contents of 10–25%, alkaline pH values ranging from 7.9 to 9.0, and electrical conductivity values between 1.2 and 4.8 dS/m, indicating moderate salinity limitations. According to the modified Storie Index, 12% of the soils were classified as good capability (Grade 3), 45% as moderate (Grade 4), 47% as unsuitable or poor (Grade 5), demonstrating that while the area is constrained by soil depth and salinity, it retains potential for agricultural exploitation under proper management. Crop suitability assessment provided more detailed insights. Cereal crops showed the highest potential: wheat and barley were classified as highly to moderately suitable (S1–S2) across more than 93% of the area, reflecting their tolerance to moderate salinity and shallow rooting depths. Sugar beet also achieved favorable results, with over 92% of the land classified as moderately suitable (S2), confirming its adaptability to calcareous and moderately saline soils. Oilseed crops presented more variable performance: sunflower and sesame were moderately suitable (S2–S3) in about 80–93% of the studied soils, indicating potential but with lower expected yields unless soil amendments are applied. Vegetable crops showed mixed results: onion was moderately suitable (S2) in about 84% of the studied soils, while potato and tomato were marginally suitable (S3) in approximately 90% of the area, though yield performance would be highly dependent on efficient irrigation and fertigation practices. In contrast, fruit crops faced severe limitations: olives were moderately suitable (S2) in about 73% of the studied soils, but citrus were found to be moderately suitable (S2) in more than 66% of the area, mainly due to shallow depth, salinity, and high $CaCO_3$ content. These results demonstrate that the recently reclaimed soils in West El-Minya may sustain a strategic agricultural system that is focused on cereals, sugar beet, and specific oilseed and vegetable crops. Fruit cultivation should be restricted to species that resist drought and salt. To maximize productivity, management interventions are necessary, including the application of organic and mineral amendments to improve soil fertility, precision irrigation to minimize salinity buildup, and careful crop selection based on land suitability classes. In conclusion, a strong foundation for agricultural planning in reclaimed desert environments is provided by the combination of crop suitability assessment and land capability. By combining quantitative indices with geospatial modeling, this study demonstrated the potential of West El-Minya soils for sustainable agricultural expansion. Future research should include long-term monitoring of salinity dynamics, water-use efficiency models, and socioeconomic assessments to create more comprehensive land-use planning strategies that guarantee productivity, profitability, and environmental sustainability in dry environments.

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الملخص العربي

التقييم الشامل للأراضي الزراعية في البيئات القاحلة باستخدام الأدوات الجغرافية المكانية

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تهدف هذه الدراسة إلى تقييم نحو ٣١ ألف فدان غرب المنيا باستخدام تقنيات الاستشعار عن بعد ونظم المعلومات الجغرافية لتحديد القدرة الإنتاجية للأراضي ومدى ملاءمتها لمجموعة من المحاصيل الحقلية، الزيتية، الخضرية والفاكهة.

أظهرت النتائج أن غالبية الأراضي تعاني من قيود حادة مثل: ضحالة التربة (أكثر من ٦٧% بعمق أقل من ٥٠ سم)، القوام الرملي والرملي الطميي (حوالي ٩٣%)، ارتفاع كربونات الكالسيوم (٨٠%)، الملوحة المتوسطة إلى العالية (أكثر من ٦٥%)، والقلوية (pH حتى ٩.٠). هذه القيود جعلت معظم الأراضي في الدرجة الرابعة (٤٥.٦%) والخامسة (٤٧.٦%) من حيث القدرة الإنتاجية، مع استبعاد ٦.٦% لعدم صلاحيتها الزراعية.

من ناحية ملاءمة المحاصيل، وُجد أن:

لمحاصيل الحقلية: القمح والشعير أظهرا أعلى ملاءمة (٩٣% متوسطة S2)، يليه البرسيم (٨٨% S2)، بينما الذرة الرفيعة كانت حدية الملاءمة (S3).

المحاصيل الزيتية: السمسم وعباد الشمس أفضل من الفول السوداني وفول الصويا الذي كان الأقل ملاءمة.

الخضر: البصل كان الأكثر نجاحًا (٨٤% S2)، البطاطس متوسطة (٧٢% S3)، بينما الطماطم والفلفل محدودة جدًا بسبب حساسيتها للملوحة.

الفاكهة: الزيتون كان الأكثر ملاءمة (٥٧% S2)، في حين أن الموالح والمانجو والخوخ كانت حدية الملاءمة (S3).

توصي الدراسة بالتركيز على المحاصيل الاستراتيجية المتحملة للظروف القاسية مثل: بنجر السكر، القمح، الشعير، البصل، السمسم، عباد الشمس، الزيتون، مع استبعاد المحاصيل الحساسة. كما شددت على ضرورة استخدام تقنيات الإدارة الحديثة مثل: الغسيل الدوري للأملاح، شبكات الصرف، إضافة الجبس والمادة العضوية، واعتماد الري الحديث (التنقيط والرش).

ختامًا، ترى الدراسة أن التنمية الزراعية في هذه المنطقة ممكنة إذا تم اختيار المحاصيل الملائمة وتطبيق ممارسات إدارة دقيقة توازن بين الإنتاجية والحفاظ على الموارد.