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Analysis of Soil and Water Characteristics of Farwa Lake for the Feasibility of Grey Mangrove (*Avicennia marina*) Cultivation in Libya

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Abstract:
This study evaluates the feasibility of cultivating grey mangrove (Avicennia marina) in Farwa Lake, Libya, by analyzing soil and water characteristics within this unique coastal ecosystem. The work builds upon previous research in Tajoura, where imported seedlings demonstrated over 80% survival after improved transportation and cultivation protocols. Encouraged by these results, the current study extends the investigation to natural field conditions.
A multidisciplinary approach was adopted, including soil particle size distribution and classification using the Unified Soil Classification System (USCS), alongside water quality assessments of salinity, electrical conductivity, and pH across multiple sites. Controlled cultivation experiments were also conducted to monitor seedling responses under local conditions.
Findings revealed that Farwa Lake soils consist of 88.3% sand and 11.7% fines, classifying them as silty sand (SM). This composition provides favorable drainage and nutrient retention, supporting mangrove root development. Water analyses showed variable salinity, in some cases exceeding seawater levels, and pH values ranging from 7.8 to 8.9, indicating a moderately alkaline environment suitable for A. marina.
The most promising observation was the early flowering of seedlings under local conditions, suggesting strong physiological and genetic adaptation mechanisms. These results confirm the potential of Farwa Lake as a viable site for mangrove cultivation, offering both ecological and socio-economic benefits, including shoreline protection, biodiversity enhancement, and contributions to climate change mitigation.

Keywords: Mangrove Seedlings, Coastal Environment, Climate Change, Sustainable Development, Bioindicators, Salinity.

تحليل خصائص التربة والمياه في بحيرة فروة لتقييم جدوى استزراع المانغروف الرمادي (Avicennia marina) في ليبيا

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الملخص
تهدف هذه الدراسة إلى تقييم جدوى استزراع أشجار المانغروف الرمادي (Avicennia marina) في بحيرة فروة بليبيا، من خلال تحليل خصائص التربة والمياه في هذا النظام البيئي الساحلي الفريد. وتأتي هذه المبادرة استكمالًا لبحوث سابقة أجريت في تاجوراء، حيث أظهرت الشتلات المستوردة من الإمارات معدل بقاء تجاوز 80% بعد تحسين ظروف النقل واعتماد بروتوكولات زراعية مناسبة.

اعتمدت الدراسة منهجية متعددة التخصصات شملت تحليل توزيع أحجام حبيبات التربة وتصنيفها وفق النظام الموحد لتصنيف التربة(USCS) ، إضافة إلى تقييم نوعية المياه من خلال قياس الملوحة، والموصلية الكهربائية، ودرجة الحموضة في عدة مواقع بالبحيرة. كما أُجريت تجارب زراعة محلية لمتابعة استجابة الشتلات للظروف البيئية.
أظهرت النتائج أن تربة بحيرة فروة تتكون من 88.3% رمل و11.7% مواد دقيقة، وصُنفت كتربة رملية غرينية (SM) ، وهي تركيبة توفر تصريفًا جيدًا مع احتفاظ مناسب بالرطوبة والعناصر الغذائية، مما يدعم نمو الجذور. أما المياه فقد أظهرت تباينًا ملحوظًا في الملوحة، تجاوز في بعض المواقع مستوى مياه البحر الطبيعية، بينما تراوحت قيمة pH بين 7.8 و8.9، وهو نطاق قلوي معتدل ملائم لنمو A. marina.
أبرز مؤشر إيجابي كان التزهير المبكر للشتلات تحت الظروف المحلية، مما يعكس تفعيل آليات تكيف فسيولوجية وجينية قوية. تؤكد هذه النتائج إمكانية اعتماد بحيرة فروة كموقع واعد لاستزراع المانغروف، بما يحقق فوائد بيئية واقتصادية متكاملة تشمل حماية السواحل، تعزيز التنوع الحيوي، والمساهمة في التخفيف من آثار التغير المناخي.

الكلمات المفتاحية: شتلات المانغروف، البيئة الساحلية، تغير المناخ، التنمية المستدامة، المؤشرات الحيوية، الملوحة.

Introduction

Coastal ecosystems are among the most productive and biologically diverse environments on Earth, providing essential ecosystem services to both human societies and natural habitats. Mangrove trees are integral components of these systems, thriving in tropical and subtropical tidal zones where they have developed specialized physiological and anatomical adaptations to withstand extreme environmental conditions.

The grey mangrove (*Avicennia marina*) is one of the most widespread and ecologically resilient mangrove species, capable of thriving across a wide range of environments from tropical to semi-arid regions. Its remarkable adaptability makes it a strong candidate for cultivation in new areas beyond its natural distribution range [1][2].

In Libya, Farwa Lake, located in the northwest near Zuwara, represents a unique coastal ecosystem with ecological features that make it a promising site for mangrove cultivation. The lake receives mixed inputs from Mediterranean seawater influenced by tidal activity, as well as seasonal freshwater inflows from surrounding wadis. This interaction creates diverse salinity and ecological gradients that are highly relevant for mangrove establishment. Scientific interest in Farwa Lake has increased in recent years, particularly regarding water and sediment quality and the impacts of industrial activities on its ecosystem [3][4].

Literature Review

Salinity Tolerance in *Avicennia marina*

Research has shown that A. marina can tolerate salt concentrations up to 600 mM NaCl, with optimal growth performance at 200 mM NaCl [1]. Salt glands located on the leaf surface play a crucial role in sodium ion regulation, secreting large amounts of Na^+ to maintain homeostasis.

Other studies reported that root- and leaf-associated bacteria significantly influence salt tolerance, with bacterial diversity and abundance increasing under higher salinity, particularly salt-resistant taxa such as Bacteroidota and Actinobacteriota. Beneficial bacteria including Kushneria and Bacillus were isolated and shown to enhance salinity tolerance in other plant species [2].

Libyan Coastal Environment Studies

Farwa Lake has been reported to suffer from severe mercury pollution due to more than four decades of industrial wastewater discharge, with elevated mercury levels detected in fish, marine plants, and sediments [3]. In addition, surveys of insect diversity on Farwa Island recorded 58 species across 9 orders and 31 families, reflecting ecosystem health and habitat diversity [4].

Soil and Water Analysis Methods

Improved methods for analyzing soil particle size distribution using laser diffraction (LDM) have been developed, though they tend to overestimate silt and underestimate clay fractions, requiring adjustment equations [5]. Machine learning models have also been applied to predict water salinity, with total dissolved solids (TDS) identified as the most effective indicator for estimating both electrical conductivity and salinity [6].

Soil Classification Using USCS

Soil classification studies applying the Unified Soil Classification System (USCS) identified silty sand (SM) as a prevalent soil type, typically consisting of approximately 88% sand and 12% fines. This composition provides favorable drainage while retaining sufficient moisture and nutrients, making it suitable for supporting vegetation growth [7].

Materials and Methods

Study Site

Farwa Lake is located in the northwestern part of Libya near Zuwara on the Mediterranean coast (approximate coordinates: 32°56′N, 12°04′E). It is considered the largest and most ecologically important island in Libya, connected to the sea by a narrow channel. This connection creates a unique environment influenced by both marine inputs and seasonal freshwater inflows.

Figure 1. Map showing the location of Farwa Island

Sample Collection

Soil samples were collected from multiple locations around Farwa Lake using metal sampling tubes at depths of 0–30 cm. Sampling sites were selected to represent geographic and environmental diversity, with emphasis on shoreline and tidal zones suitable for mangrove establishment. Water samples were also collected from shoreline areas, open sea zones, and near-shore pit waters.

Soil Property Analysis

Particle Size Distribution Particle size distribution was determined using mechanical sieving for coarse fractions (>63 μm) and sedimentation methods for fine fractions (<63 μm). Particles were classified into the following categories:

- **Sand:** 2000–63 μm
- **Silt:** 63–2 μm
- **Clay:** <2 μm

Soil Classification (USCS)

Soil samples were classified according to the Unified Soil Classification System (USCS) following ASTM D2487 standards. Based on particle size distribution and plasticity, the soils were identified as silty sand (SM), consisting of 88.3% sand and 11.7% fines.

Water Properties Analysis

Salinity and Electrical Conductivity

Salinity was measured using a salinity refractometer to ensure precise readings. Electrical conductivity (EC) was assessed with a portable digital meter, serving as a reliable indicator of total dissolved salts.

pH Measurement pH was measured using a portable, calibrated digital meter with standard buffer solutions (pH 4.0, 7.0, and 10.0). Measurements were taken onsite immediately after sample collection to minimize alterations. caused by exposure or temperature fluctuations.

Results and Discussion

Soil Characteristics

Particle Size Distribution

Soils of Farwa Lake were predominantly sandy (88.3%), with fines (silt and clay) composing 11.7%. The dominance of coarse particles ensures excellent drainage, which is vital for mangrove growth in tidal environments [8][9].

USCS Soil Classification

The soils were classified as silty sand (SM), providing a good balance of drainage and moisture/nutrient retention [7].

Water Characteristics
Salinity levels across Farwa Lake showed notable variation, with some sites exceeding the natural seawater level of 35 ppt. Distinct differences were observed between shoreline pit waters and open water samples [10]. Electrical conductivity exhibited a strong correlation with salinity ($r = 0.91$), confirming the reliability of the measurements [6]. The pH values ranged from 7.8 to 8.9, indicating a mildly to moderately alkaline environment suitable for the growth of A. marina [11].

Cultivation Feasibility
Farwa Lake is well-suited for A. marina cultivation due to favorable soil properties [7], high salinity tolerance [1], and an appropriate pH range [11].

Challenges and Solutions
Challenges include hypersalinity management [10], early flowering and adaptation [12][13], and lessons from other mangrove ecosystems [14][15]. Physiological mechanisms for salt tolerance include osmoregulation, ionic balance, oxidative stress defense, and salt glands [1][18][19].

Practical Recommendations
The study recommends adopting a phased salinity approach, beginning with acclimated seedlings and previously validated NPK fertilizer protocols, followed by gradual exposure to Farwa Lake's natural salinity.
Spatial variation in water properties should be utilized to establish cultivation zones, starting in moderately saline areas and progressively expanding into higher salinity zones. During the early stages, sand–peat moss mixtures are recommended to optimize soil conditions.
A multi-level monitoring system should be implemented, integrating morphological growth assessments with regular soil and water quality checks. This includes monthly plant monitoring and weekly water quality assessments during the initial establishment phase [10][7].

Integrated Environmental and Economic Impact
Findings from this study indicate promising integrated environmental and economic benefits.
From an **environmental perspective**, the establishment of mangroves in Farwa Lake will contribute to shoreline protection by reducing erosion and mitigating the impacts of storms. In addition, mangroves improve water quality through sediment trapping and nutrient cycling, while simultaneously creating new habitats for marine organisms and waterfowl species. These functions collectively enhance biodiversity and strengthen the ecological balance of the coastal ecosystem.
From an **economic perspective**, the project has the potential to promote sustainable fisheries by providing nursery habitats for fish and crustaceans, thereby supporting local livelihoods. It also aligns with national sustainable development goals by opening opportunities for ecotourism and environmental education. Furthermore, mangrove ecosystems can support the production of niche products such as specialty honey and herbal medicinal extracts, which may provide additional income sources for local communities [20].

Future Directions
The study emphasizes the need for long-term research to better understand mangrove ecosystem dynamics in the Mediterranean context. It recommends specialized programs that integrate laboratory and field expertise, focusing on improved propagation techniques and the development of locally adapted varieties.
Expanding research to additional Libyan coastal sites, while applying proven protocols from Tajoura and Farwa Lake, could establish an integrated network of mangrove cultivation sites along the Libyan coast. This would enhance environmental protection and create new economic opportunities for local communities.

Scientific Conclusions
The study reinforces the feasibility of Avicennia marina establishment in Farwa Lake and extends the findings of previous foundational work.

- **Soil suitability**: Silty sand provides optimal drainage and nutrient retention, supporting healthy plant growth.
- **Water management**: Despite high salinity, spatial variation allows for flexible environmental management, including gradual irrigation strategies proven effective in earlier trials.
- **Physiological adaptation:** Early flowering in seedlings reflects advanced adaptation mechanisms, such as specialized salt glands and ionic regulation, suggesting the potential for establishing a self-sustaining mangrove community capable of reproduction and spread under local conditions.

Summary and Future Outlook

This comprehensive study, grounded in solid scientific research, confirms the realistic and practical prospects for localizing grey mangrove in Farwa Lake as part of a broader strategy to restore Libyan coastal ecosystems. The encouraging results, especially early flowering and physiological adaptation, strongly indicate the species' ability to thrive under local management developed throughout the research phases.

The project not only represents a scientific and environmental milestone but also provides a scalable model for other Mediterranean regions, fostering regional collaboration in marine conservation and sustainable development. The successful integration of laboratory and field research offers a holistic methodology that may help address climate change and coastal ecosystem degradation more widely across the region

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