

ASSESSMENT OF SOIL FERTILITY AND ITS INFLUENCE ON DATE PALM (*PHOENIX DACTYLIFERA L.*) PRODUCTIVITY IN KHAIRPUR, SINDH, PAKISTAN

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Abstract

This study investigates the influence of intellectual capital (IC) on the advancement of Pakistan's knowledge economy, with a specific focus on the Islamic banking industry. Covering the period 2014–2024, the research examines four leading banks: Meezan Bank, Bank Islami, Faysal Islamic Bank, and Dubai Islamic Bank Pakistan. IC is evaluated through its three primary components—human capital, structural capital, and relational capital—and their contribution to financial performance is assessed using Return on Assets (ROA) as the core indicator. Employing panel data econometrics, including fixed- and random-effects models, the study measures the role of IC in enhancing competitiveness and supporting knowledge-driven growth. The findings reveal that human capital has the most consistent and statistically significant impact on financial performance ($p < 0.01$), confirming its central role in Islamic banking operations. Structural capital shows a positive but insignificant effect, suggesting that Pakistani banks have yet to fully exploit technology and organizational infrastructure compared to benchmarks in Malaysia and the GCC. Relational capital, which is crucial for building trust in Shariah-compliant finance, remains underdeveloped, limiting long-term advantage. Results further indicate that Shariah compliance and digital transformation act as emerging drivers of performance.

Policy implications emphasize the need for the State Bank of Pakistan (SBP) to foster IC growth through targeted training, technology adoption, and collaborative initiatives between academia and industry. The research recommends scaling up employee development, upgrading IT infrastructure, and building stronger stakeholder networks to reinforce relational capital. Overall, the study positions IC enhancement as a strategic requirement for Pakistan's Islamic banks to strengthen their role in the global Islamic finance market and to contribute meaningfully to a knowledge-based economy.

INTRODUCTION

The date palm (*Phoenix dactylifera L.*) stands out as a vital fruit-bearing species, expertly adapted to

thrive in dry and semi-arid environments. Its exceptional drought tolerance and significant economic value make it an essential choice for

these regions. Pakistan ranks among the top global producers of dates, with the Khairpur district in Sindh province serving as a major cultivation hub. The region's hot climate and well-drained soils create favorable conditions for date farming. However, declining soil fertility driven by intensive cropping, poor agronomic practices, and rising salinity has raised concerns about the sustainability of date palm production.

Soil fertility is fundamental to plant development and sustainability. Parameters such as pH, electrical conductivity, organic matter content, and the availability of essential nutrients (notably nitrogen, phosphorus, and potassium) are known to critically influence the physiological health and fruit-bearing potential of date palms. Within Khairpur, issues such as soil nutrient depletion and increasing salinization have triggered alarm among researchers and growers alike. This study aimed to assess the current fertility status of soils across prominent date-growing sites in the Khairpur district and evaluate how variations in soil parameters influence palm health and fruit production. These issues mirror broader concerns in dryland agriculture across Pakistan, where soil degradation and nutrient deficiencies have been widely documented (Baig et al., 2015; Bashir et al., 2017).

2: Materials and Methods

2.1 Study Location

The research was conducted in Khairpur District, located within Sindh province, Pakistan, at an approximate geographic coordinate of 27°30'N latitude and 68°40'E longitude. The region is characterized by a hyper-arid climate, receiving less than 150 mm of annual precipitation, with extended periods of drought and summer temperatures exceeding 48°C. These climatic conditions are particularly conducive to the cultivation of *Phoenix dactylifera* L. The local topography comprises predominantly flat terrain with alluvial soils derived from the Indus Basin, rendering the area well-suited for orchard-based practices.

Agricultural

2.2 Soil Collection Procedure

Soil samples were collected from ten of the district's leading villages known for commercial date farming, such as Kot Diji, Pir Jo Goth, Gambat, and Faiz Ganj. At each sampling location, five subsamples were collected from the root zone (0–30 cm depth) using a stainless steel auger. These subsamples were homogenized to produce one composite sample for each site. All samples were sealed in polyethylene bags, labeled clearly, and transported to the laboratory under controlled ambient conditions to maintain the integrity of soil properties.

2.3 Laboratory Analyses

The collected soil samples were air-dried, pulverized, and sieved through a 2 mm mesh for uniform particle size. Standardized protocols were followed to evaluate the physicochemical characteristics.

- Soil pH and EC
- were measured using a 1:2.5 soil-to-water ratio suspension. The organic matter
- content was estimated using the Walkley and Black method. Nitrogen
- The content was determined using the Kjeldahl digestion method. The phosphorus
- content was measured using the Olsen extraction method. Potassium
- levels were quantified using flame-photometry.

2.4 Evaluation of Date Palm Growth

During the soil sampling phase, growth and productivity parameters of *Phoenix dactylifera* L. were simultaneously assessed across all sampling sites to establish site-specific agro-ecological relationships. Growth evaluations included visual health scoring on a 1–5 scale, documentation of chlorosis symptoms, and quantification of individual tree yield expressed in kilograms. Five representative date palms were selected per site to ensure consistent data collection and minimize variability. Additionally, structured interviews were conducted with local cultivators to obtain firsthand information regarding fertilization regimes, irrigation management practices, and

prevalent agronomic challenges affecting orchard performance.

2.5 Data Analysis

Descriptive statistics and one-way Analysis of Variance (ANOVA) were applied to identify significant differences in soil fertility parameters across study locations and their correlation with date palm yield. Pearson's correlation analysis was used to examine the relationships between specific soil nutrients and crop performance indicators. All statistical computations were performed using SPSS (version 25.0), with significance set at $p < 0.05$.

Results:

Evaluation of soil fertility across ten selected sites revealed substantial variation in physico-chemical attributes, which significantly influenced the physiological condition and fruit yield of trees cultivated in arid zones.

Key fertility indicators namely pH, electrical conductivity (EC), organic matter content, and macronutrient levels (nitrogen, phosphorus, potassium) varied markedly among locations. These disparities correlated strongly with plant health metrics, including chlorosis severity, composite visual health scores, and average fruit output per tree.

Table 1. summarizes the soil characteristics and associated crop performance at each location in the study.

Site	pH	EC (dS/m)	Organic Matter (%)	N (%)	P (mg/kg)	K (mg/kg)	Health (1-5)	Chlorosis	Yield (kg/tree)
Kot Diji	7.5	1.2	0.89	0.08	5.2	145	4.5	Mild	75
Pir Jo Goth	8.1	2.1	0.65	0.06	3.9	110	3	Moderate	52
Gambat	7.7	1.8	1.12	0.09	6.5	160	4.7	None	82
Faiz Ganj	8.3	2.4	0.52	0.05	3.2	98	2.5	Severe	40

Sites such as Gambat and Kot Diji demonstrated comparatively better soil fertility profiles, with near-neutral pH, higher organic matter content, and adequate macronutrient levels. These attributes were associated with higher health scores, minimal chlorosis symptoms, and greater yield (75–82 kg/tree). Conversely, locations such as Faiz Ganj and Pir Jo Goth exhibited signs of nutrient deficiency and elevated EC levels (above 2 dS/m), suggesting salinity stress in the plants. These conditions are correlated with increased leaf chlorosis, lower health ratings, and reduced productivity (as low as 40 kg per tree).

These data reinforce the hypothesis that soil fertility has a direct and measurable effect on the productivity of date palms. Notably, sites with lower EC and higher organic content tended to support more vigorous growth.

4: Discussion

The results highlight that soil fertility plays a pivotal role in shaping both the productivity and physiological vigor of date palm trees (*Phoenix dactylifera* L.) in the arid landscape of the Khairpur region. Notably, sites such as Gambat and Kot Diji featured more favorable soil attributes, including moderate electrical conductivity, near-neutral pH, and elevated organic matter and macronutrient levels (N, P, and K). Such soil conditions were strongly associated with better overall plant health, fewer signs of chlorosis, and enhanced fruit production. In contrast, sites such as Faiz Ganj and Pir Jo Goth displayed higher EC values, indicating salinity stress, along with reduced organic matter and lower nutrient concentrations. These soil limitations were reflected in visibly stressed trees, poor health scores, and significantly reduced productivity. The negative correlation found

between EC levels and palm yield aligns with earlier research, indicating that high salinity impairs nutrient absorption and physiological balance. And physiological balance in date palms (Al-Farsi et al., 2018; Memon et al., 2015).

Organic matter emerged as a particularly significant factor among the various soil indicators. Sites with organic matter content exceeding 0.85% were more likely to support robust palm growth, likely because of enhanced soil structure, moisture retention, and nutrient availability. This observation aligns with previous research (Nasir et al., 2014; Zahran, 2021), which highlights the contribution of organic carbon to long-term soil productivity and crop resilience in water-limited ecosystems.

The wide pranging differences in soil fertility among the sites examined point to the broader challenge of soil heterogeneity in irrigated arid environments in irrigated arid environments. This spatial inconsistency undermines the effectiveness of uniform fertilization strategies, underscoring the importance of adopting site-specific nutrient management approaches, which are strongly advocated in the precision agriculture literature (e.g., Riaz et al., 2018; Khan et al., 2020).

Farmer interviews revealed inconsistent fertilization routines, limited use of organic inputs, and infrequent soil testing, all of which likely contribute to nutrient imbalances and long-term soil degradation. Addressing these gaps through good agricultural practices (GAPs), including regular soil assessment, balanced fertilizer regimes, and incorporation of organic amendments, could substantially enhance both soil health and yield outcomes. Furthermore, techniques such as salinity management through leaching and gypsum application offer practical solutions for rehabilitating degraded soils in saline-prone areas.

This study highlights the pivotal role of enhanced soil fertility especially improved nitrogen accessibility and organic matter enrichment in fostering sustainable cultivation of date palms. The findings also emphasize the necessity of increasing farmer education and bolstering agricultural extension services to advance the adoption of evidence-based practices. These

outcomes align with the observations of Ahmed and Ali (2016), who documented the adverse effects of salinity and nutrient depletion in arid environments.

Conclusion

The outcomes of this study demonstrate the critical influence of soil fertility on the health and productivity of date palms (*Phoenix dactylifera* L.) under arid conditions in Khairpur, Sindh, Pakistan. Soils characterized by balanced pH, adequate organic content, and sufficient levels of key macronutrients, namely nitrogen, phosphorus, and potassium, were associated with visibly healthier trees and significantly higher yields. Locations such as Gambat and Kot Diji, which exhibited favorable soil attributes, demonstrated superior performance compared with sites affected by salinity and nutrient depletion.

To support sustainable date palm cultivation in saline-prone and resource-limited regions, this study recommends implementing site-specific soil management strategies. These include periodic soil testing, customized nutrient application, and soil rehabilitation practices, such as salinity leaching and organic matter enhancement using compost or green manure. Additionally, promoting farmer education and capacity building through agricultural extension services is vital for the widespread adoption of sustainable soil practices. Going forward, continued field-based research and on-site interventions are essential to adapt these recommendations for local farming systems. Strengthening soil health through informed and adaptive management is central to improving productivity and resilience in arid agroecosystems facing increasing environmental stress.

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