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For High-Yield Oasis Agriculture – Case Studies Of Taghit And Tiout (Algeria)

Abdelali Okba Abdelhafid* [1], **Benslimane.Mohammed** [2],**Taibi Warda**[3]
[1]Laboratory of Applied Genetics in Agronomy, Ecology, and Public Health (GenApAgiE), Department of Agronomy, faculty of Natural Sciences and Lif and Earth Sciences the Universe, University of Abou bakr belkaid, Tlemcen, (Algeria).
Email: Abdelaliokba@gmail.com , Orcid: https://orcid.org/0009-0000-7088-9296
[2]Laboratory of Geomatics, Environment mascara, University Mustafa stambouli mascara (Algeria).
Email: m-benslimane@univ-mascara.dz , Orcid: https://orcid.org/0009-0003-4157-0130
[3]Laboratory of Applied Genetics in Agronomy, Ecology, and Public Health (GenApAgiE), Department of Biology, University of Abou bakr belkaid, Tlemcen, (Algeria) .
Email: taibiwarda13@gmail.com , Orcid: https://orcid.org/0000-0001-8529-2812

Abstract

This study aims to assess and compare agricultural yields across two representative oases of the Algerian Sahara–Tiout (Naâma Province) and Taghit (Béchar Province). Both regions, situated in arid to hyper-arid climatic zones, depend entirely on groundwater irrigation. Between 2021 and 2023, field surveys, direct plot sampling, and farmer interviews were carried out to evaluate key crops such as date palms, cereals, and vegetables. In total, 60 plots were monitored and phenologically sampled. Complementary data on agro-climatic parameters, soil profiles, and aquifer characteristics were also collected. Statistical analyses, including Principal Component Analysis (PCA) and Correspondence Analysis (CA), were employed to identify yield structures and regional crop associations.

The results indicated that fruit crops–particularly date palms–achieved the highest yields at both sites. Tiout demonstrated greater crop diversification, especially in vegetables and orchard trees, attributed to relatively higher soil fertility and better water availability. Conversely, Taghit remained dominated by traditional date-palm-based systems, with limited potential for intensification due to elevated soil salinity and pronounced wind erosion. PCA identified three major crop groups accounting for over 76% of total yield variance, while CA revealed strong associations between specific crop types and local agro-ecological conditions.

Overall, the findings emphasize the importance of localized agricultural planning and the sustainable management of groundwater resources in Saharan oases. The insights gained can inform future strategies aimed at enhancing the resilience of oasis farming systems under escalating climate pressures.

Keywords: *oasis agriculture, crop yield, PCA, groundwater, Sahara, Taghit, Tiout*

INTRODUCTION

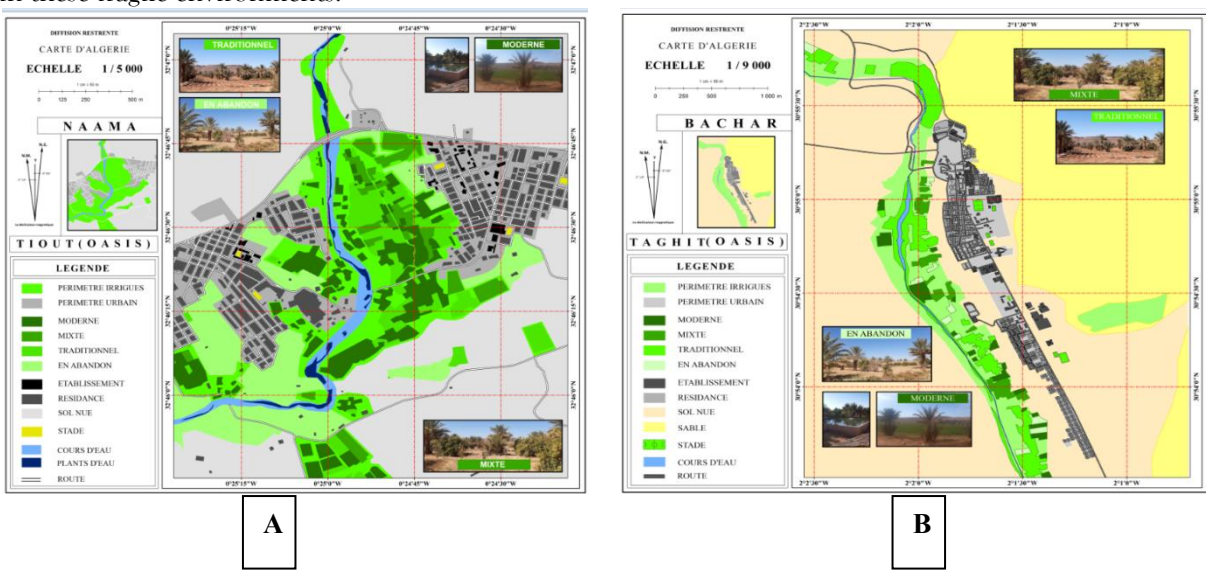
In the Algerian Sahara, oasis ecosystems are characterized by pronounced ecological fragility and ongoing microclimatic degradation. These areas, which encompass a significant portion of Algeria's oasis zones, are highly susceptible to the impacts of climate change, creating major challenges for local populations whose livelihoods depend heavily on climate-sensitive agricultural activities (Addoun & Hadeid, 2022).

Although Algerian oases are endowed with extensive palm groves and host diverse ecological systems, vegetation occupies only a limited share of the national territory, constrained by desert expansion and persistent aridity. Despite the growing attention these ecosystems receive within sectoral policies and regional development strategies, the specific roles and coordination of the main institutional and local stakeholders remain insufficiently addressed (Addoun, 2022).

Over the past century, the expansion of agricultural lands in the Saharan regions has been modest, with growth occurring primarily through intensification rather than spatial extension (BRL Engineering, 1999). While successive governmental initiatives have aimed to stimulate agricultural development in the Sahara (Hamamouche et al., 2018), the outcomes of public modernization programs have fallen short of expectations. This shortfall is largely linked to inadequate technical expertise and a limited understanding of the specific environmental and socio-economic realities of local oases (Amrani, 2021).

Accordingly, this study investigates crop yields within the Tiout and Taghit oases as representative models of Algerian oasis ecosystems. Its main objective is to identify the determinants that enhance agricultural

productivity and to analyze crop management practices that could support sustainable and adaptive farming in these fragile environments.



A B

Figure 01 : Cartographie des oasis étudiées dans le sud-ouest du Sahara algérien A - Tiout B - Taghit (Marc côte, 2012 in Boulal, 2017)

Materials and Methods

This study focuses on two distinct oases located in the southwestern Algerian Sahara: Tiout (Naâma Province) and Taghit (Béchar Province). These two sites present contrasting agro-ecological conditions that directly influence local farming systems (Addoun & Hadeid, 2022).

1. Geographic Coordinates

• Tiout Oasis: approximately 33°01'N, 1°07'W; elevation: 1,092–1,115 m.
• Taghit Oasis: approximately 30°55'N, 2°01'W; elevation: 641–647 m.

Both locations lie on gently sloping plains (0–3%), making them suitable for mechanized agriculture and efficient surface drainage (BRL Ingénierie, 1999).

2. Climatic Conditions

• Tiout receives around 202 mm/year of rainfall, mostly during winter and spring; temperatures range from 0 to 36°C, with frequent frost events in winter.
• Taghit receives an average of 108.7 mm/year, mostly in autumn; temperatures are extreme: above 45°C in summer and as low as −4°C in winter.
• Potential evapotranspiration (PET) exceeds 265 mm/month in July in Taghit. Tiout's annual water deficit is estimated at 1,189 mm (ONM, 2022).

3. Soil Characteristics

• Taghit: sandy halomorphic soils with very low fertility (<0.3% organic matter), a pH of around 7.9, and the presence of deep saline crusts.
• Tiout: sandy-loam to loamy soils, 40–70 cm deep, moderately fertile, non-calcareous, and containing approximately 1.2% organic matter (Amrani, 2021).

4. Groundwater Resources and Irrigation

• Taghit: Lower Cretaceous (CI), Turonian, and Quaternary aquifers; boreholes range from 70 to 250 m; water flow varies from 20 to 32 l/s; irrigation is carried out through drip and surface methods.
• Tiout: Aptian-Albian aquifers; wells range from 200 to 350 m in depth; flow rates range from 5 to 30 l/s; localized irrigation systems are used (DPNRF, 2021).

5. Environmental Constraints

• Taghit: high salinity, wind erosion, fragile soils, and costly access to water.
• Tiout: exposed to frost and wind and deep aquifers, but benefits from fertile soils and high cropping diversity (Hamamouche et al., 2018).

1. Sampling Design

A stratified random sampling approach was applied in both sites to capture the diversity of crop types and soil conditions:

- **Plot size**: 10 m × 10 m.
- **Plot categories**: date palm, vegetables (tomatoes, onions, potatoes), cereals (durum wheat, oats, barley).
- **Sampling calendar**: three phenological stages — vegetative, flowering, and harvest — sampled per year.
- **Total number of plots**: 60 (30 per site).

This design ensured statistical representativity and comparability across sites and crops.

2. Data Collection Tools

Three categories of data sources were used:

I) Farmer Surveys

- Structured questionnaires administered to 62 farmers (31 per oasis).
- Covered agronomic practices, irrigation, input use, and socio-economic conditions.
- Yield estimations were cross-checked with field records.

II) Field Observations

- Measured variables: plant height, density, visible stress, pest/disease symptoms.
- Soil texture and salinity were assessed using portable EC meters.
- Irrigation system performance and water frequency were recorded.

III) Official and Remote Data

- Meteorological data from ONM (Algerian National Meteorological Office).
- Agricultural records from MADR (Ministry of Agriculture).
- Satellite imagery (Sentinel-2) was used to estimate biomass and NDVI.

3. Statistical Analysis Methodology

The data were processed using multivariate statistical techniques to identify relationships between variables and to cluster cropping systems:

I) Principal Component Analysis (PCA)

- Applied to yield data to reduce dimensionality and detect correlated crop groups.
- Normalization was performed prior to analysis.

II) Correspondence Analysis (CA)

- Used to explore associations between oases and dominant crop types.

III) Software

- All analyses were conducted in **R (version 4.2.1)** using FactoMineR, factoextra, and ggplot2 packages.
- Descriptive statistics and cross-tabulations were confirmed using **SPSS**.

IV) Validation

- Triangulation was performed between farmer reports, field observations, and institutional statistics.
- Yields were expressed in **quintals per hectare (q/ha)**.
- Significance was assessed at $\mathbf{p < 0.05}$ with 95% confidence intervals.

4. RESULTS AND DISCUSSION

The PCA performed on crop yield data across various Algerian wilayas reveals two principal axes explaining 44.47% of the total variance, indicating a moderate but statistically meaningful structure (Figure 02).

Two principal crop groups emerge:

- Group 1: Fodder crops, oats, durum wheat, and olives — positively correlated along Axis 1, often linked to regions with more extensive or mixed farming systems.

- Group 2: Dates, potatoes, tomatoes, and pits — positively correlated along Axis 2, representing intensive oasis-based production systems with greater irrigation dependency.

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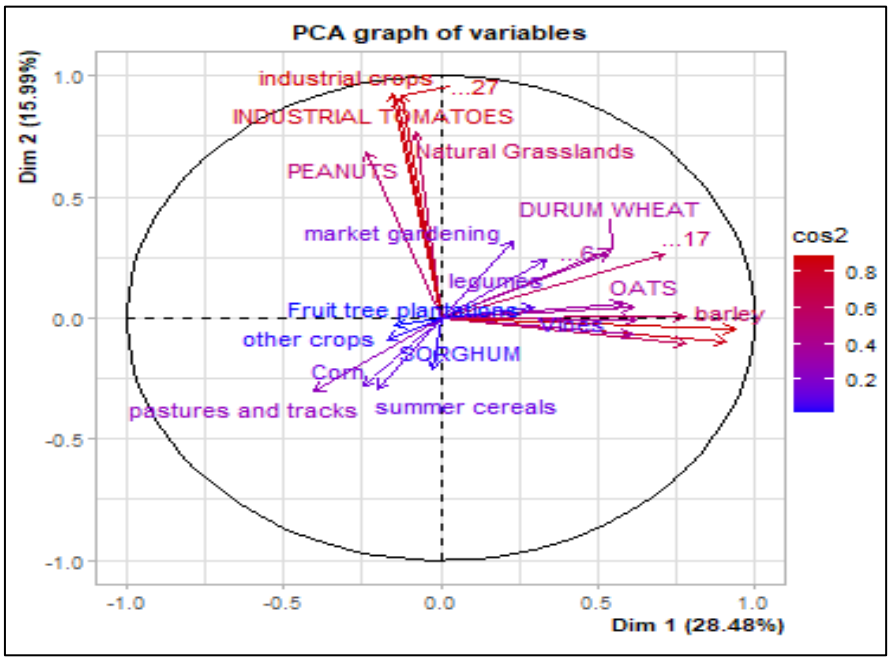

Figure 02: Graphical representation of crop yields using PCA

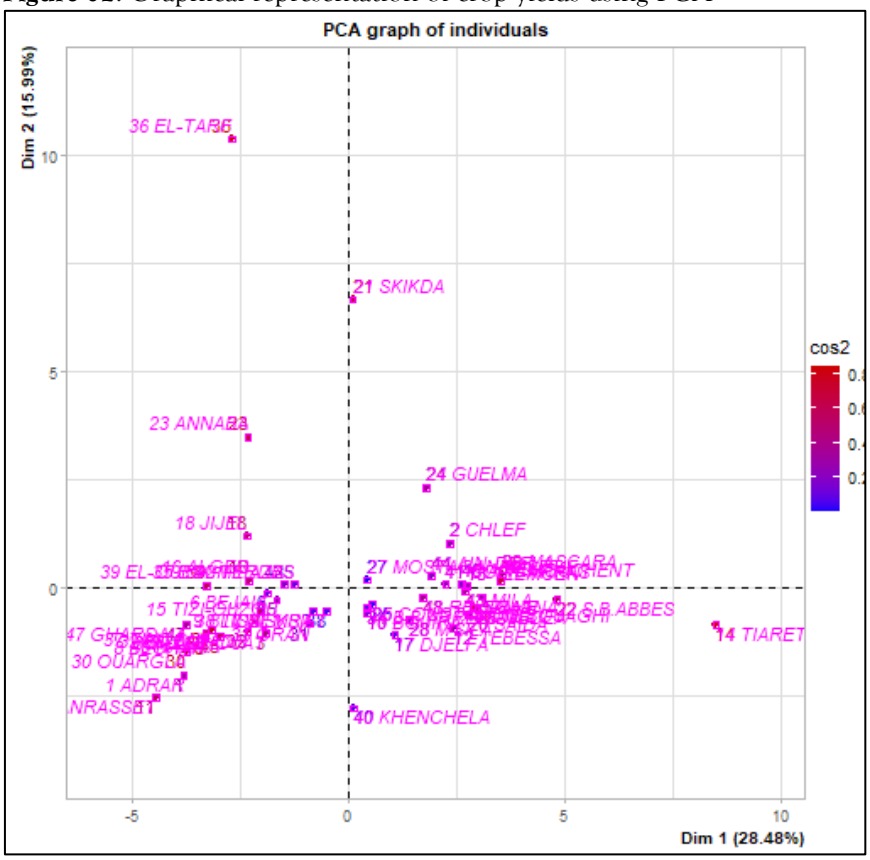

Figure 03: PCA of individuals (Algerian wilayas)

I) PCA of Crop Yields in Tiout and Taghit

I) Principal Component Analysis (PCA) of agricultural yields in Algeria

A focused PCA on the Tiout and Taghit oases displays a clearer separation. The first two axes explain 76.18% of the variance, suggesting a strong structure (Figure 04).

Three groups are distinguished:

- Group 1: Fodder, oats, durum wheat, and olives — commonly cultivated in both oases but with better performance in Tiout.

- Group 2: Dates, potatoes, tomatoes, and pits — central to Taghit, reflecting its date-oriented systems.
- Group 3: Market gardening crops — mostly associated with Tiout's more diverse systems.

Garlic, onion, and grapes appeared peripheral on the PCA, indicating lower statistical weight in the overall structure.

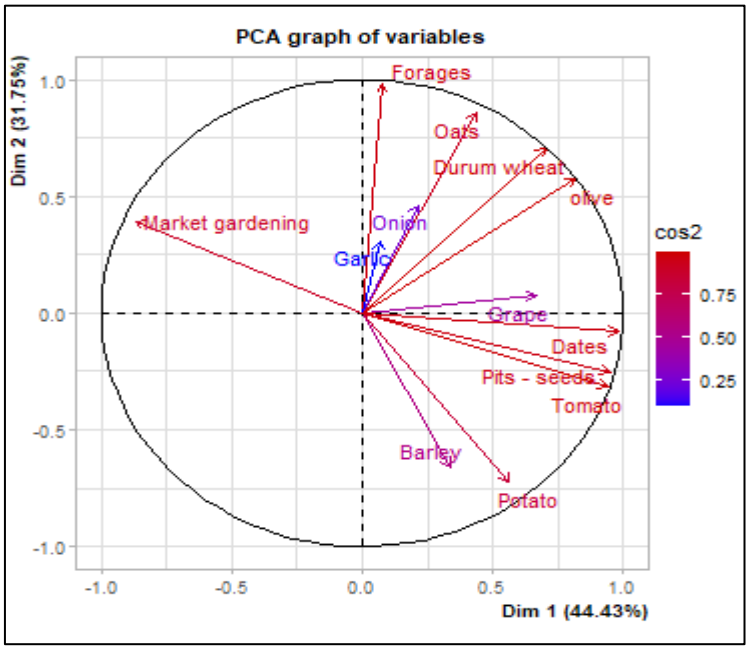

Figure 04: PCA of crop characteristics

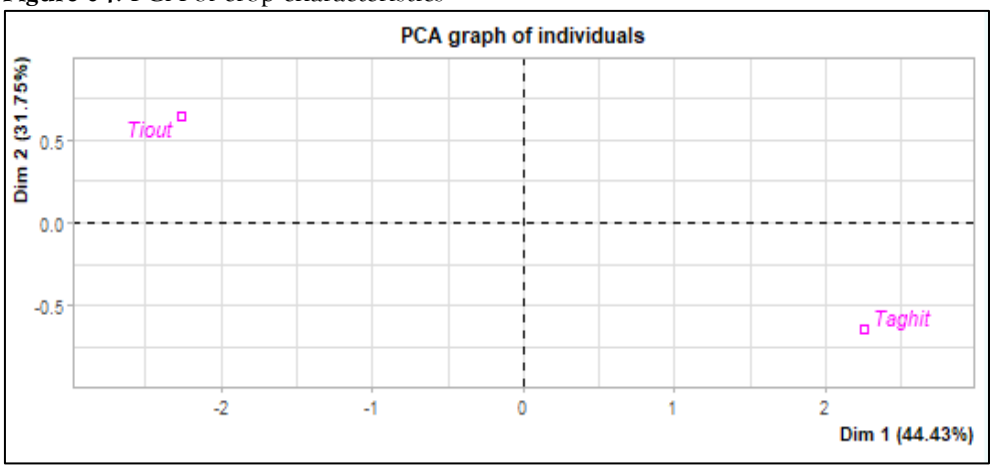

Figure 05. Graphical representation of individuals (Tiout and Taghit)using Principal Component Analysis (PCA).

II) Agricultural Yield Trends in Tiout and Taghit (2021–2023)

Three-year yield data (Figure 05) were grouped into three crop types:

- Fruit crops: Dates, olives, stone fruits, grapes
- Vegetables: Tomatoes, onions, potatoes, fodder
- Cereals: Oats, barley, durum wheat

Key observations:

- In 2023, dates reached their highest yield (~60 qx/ha), matching economic threshold values from previous models.
- Grapes also showed upward trends in Tiout, likely due to favorable microclimates.
- Tomatoes and potatoes performed well, particularly in Tiout, thanks to diversified practices and water management.
- Durum wheat outperformed other cereals, though overall cereal contribution remained limited compared to fruit crops.

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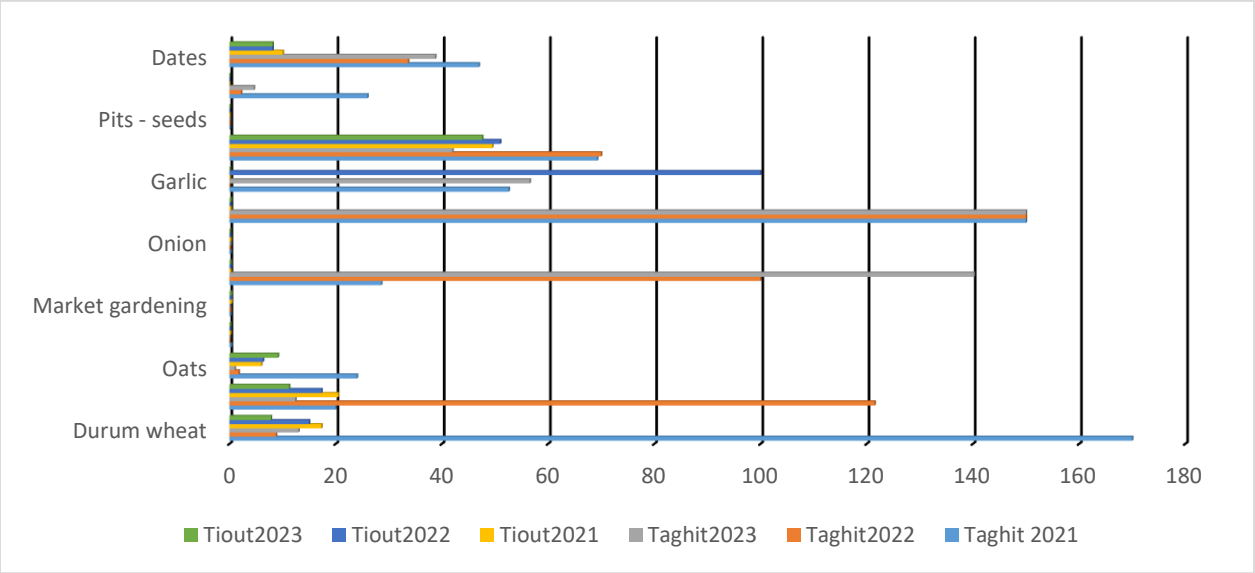

Figure 06: Crop yield trends by type (2021–2023)

III) Correspondence Analysis (CA)

Correspondence analysis further confirmed site-specific associations:

- Ain Témouchent (reference wilaya) was strongly associated with high yields of dates, barley, tomatoes, and fruit trees.
- Tiout was closely linked to vegetables and grape production, reflecting better soil fertility and diversified cropping.
- Taghit remained centered around date palms, with minor diversification due to constraints such as salinity and limited water retention capacity.

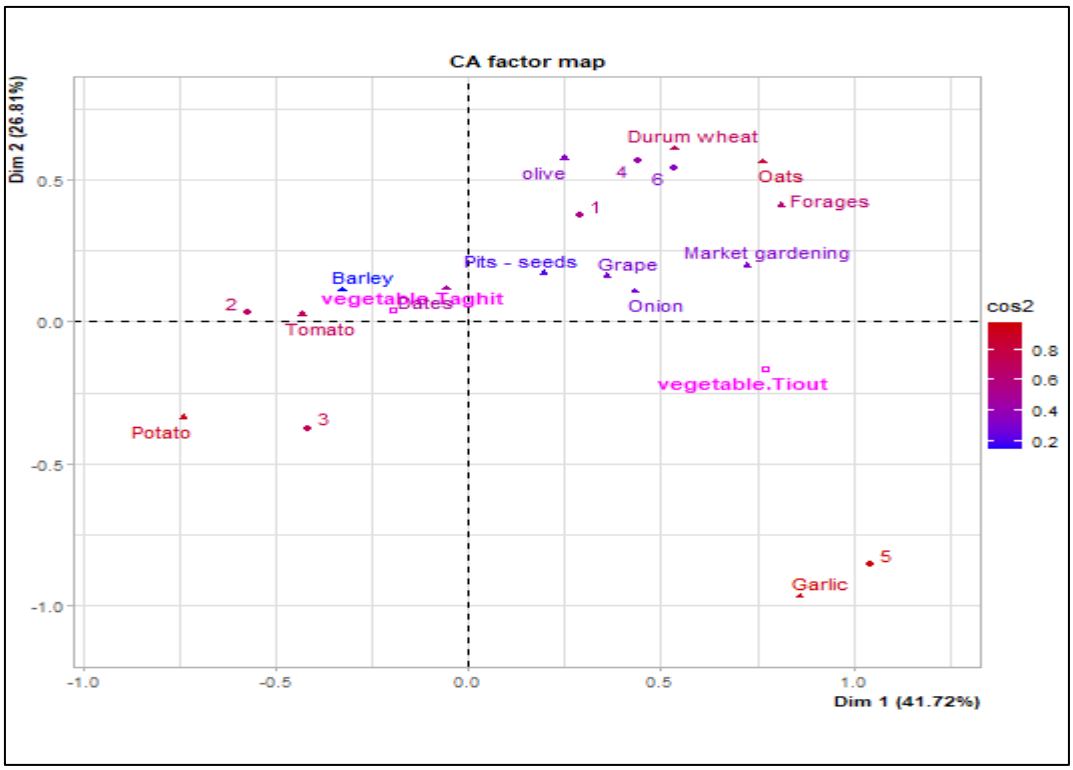

Figure 07: Correspondence Analysis (CA) of oasis crop associations

DISCUSSION

The oasis agricultural systems of Tiout and Taghit exhibit distinct structural and performance characteristics. Tiout's agricultural profile is marked by greater diversity and productivity, driven by improved irrigation infrastructure (49% localized systems), shallower aquifers, and comparatively more fertile soils. In contrast, Taghit faces significant agronomic constraints—high soil salinity, deep boreholes, and recurrent wind erosion—all of which hinder crop diversification and limit productivity.

Although both oases maintain favorable conditions for date palm cultivation, vegetable and fruit crops demonstrate higher productivity and economic returns in Tiout. Economic assessments reveal that onions and dates yield the highest net value added per hectare, accounting for 456% and 288% of operational costs, respectively. These findings highlight the necessity for targeted agricultural planning that:

- Aligns crop selection with local agro-pedoclimatic constraints and market opportunities.
- Expands the use of drip irrigation and organic amendments to mitigate salinity and enhance long-term sustainability.
- Utilizes PCA and CA as analytical tools for optimizing crop planning in data-limited oasis environments.

The results reaffirm the structural imbalance of oasis agriculture in the Algerian Sahara, particularly in Tiout and Taghit. Despite moderate diversification, agricultural production remains overwhelmingly dominated by date palms and, to a lesser degree, grapes. This crop concentration reflects both cultural preferences and structural constraints—especially those related to water access, soil quality, and limited agronomic knowledge dissemination.

Principal Component Analysis (PCA) results indicated that over 76% of the variance was captured by the first two components, underscoring a statistically significant differentiation among productivity clusters. These clusters mirror the underlying agroecological and technical determinants shaping local production systems. Tiout's closer association with vegetable crops can be attributed to its adoption of localized irrigation and small-scale market gardening, while Taghit remains dependent on traditional date palm monoculture, increasing its vulnerability to productivity decline under intensifying climatic stress.

These observations are consistent with the findings of Hamamouche et al. (2018), who argued that the "mosaic continuity" between traditional and newly extended oases remains insufficient to achieve structural balance in production systems. Likewise, Addoun and Hadeid (2022) emphasized that, without targeted reforms, oasis agriculture risks perpetuating existing inequalities in land use and yield performance.

Government programs intended to modernize Saharan agriculture have largely underperformed (Amrani, 2021). The disconnect between national agricultural frameworks and the specific environmental and social realities of oasis regions has resulted in resource misallocation and weak implementation of sustainable practices. This study reinforces that critique: the persistently low yields of cereals and forage crops in both Tiout and Taghit demonstrate that diversification strategies have yet to take effect in practice.

Water resource management emerges as a critical challenge. Oasis ecosystems are inherently vulnerable to hydrological disequilibrium, and excessive groundwater extraction threatens their long-term viability. High-yield fruit crops, particularly date palms, impose heavy water demands, accelerating aquifer depletion. Although water-saving technologies such as drip irrigation are promoted, their adoption remains limited due to high initial costs and insufficient technical support.

Soil degradation and salinization—common in arid and semi-arid contexts—further constrain productivity, particularly for cereals and certain vegetables. The limited use of organic amendments and inadequate crop rotation practices compound these issues, undermining the ecological sustainability of oasis agriculture.

Socioeconomic dynamics also shape cropping patterns. Farmers in both oases tend to prioritize market-oriented, high-value crops such as dates and tomatoes, favoring immediate income generation over long-term food security. While this strategy enhances profitability, it simultaneously heightens dependence on external food sources and exposes farmers to market volatility and climatic shocks.

The comparatively stronger vegetable performance in Tiout suggests that localized innovations—possibly driven by informal farmer networks or regional extension activities—can foster diversification and resilience. However, such practices remain fragmented and insufficiently documented. Institutional intervention is therefore essential to amplify these successes and embed them within coherent regional development strategies.

In synthesis, this study underscores the urgency of adopting an integrated development framework that reconciles ecological resilience, economic efficiency, and sociocultural compatibility. Policy priorities should include:

- Strengthening local agricultural extension and research services.
- Expanding access to climate-resilient crop varieties.
- Scaling up efficient irrigation systems adapted to arid contexts.
- Enhancing farmer capacity through training in sustainable agroecological management.

Only through such an integrated approach can oasis agriculture transition from a survival-based paradigm toward a model of sustainable intensification attuned to the environmental realities of the Algerian Sahara.

CONCLUSION

This study presents a comparative evaluation of crop yields and production systems in two representative oases of the Algerian Sahara—Tiout and Taghit. Although both sites share a harsh arid climate and depend primarily on deep groundwater irrigation, they exhibit distinct agro-ecological behaviors and levels of agricultural performance.

Findings derived from field surveys, phenological observations, and multivariate analyses (Principal Component Analysis – PCA, and Correspondence Analysis – CA) confirm that fruit crops, particularly date palms, constitute the structural foundation of oasis agriculture in both regions. Nonetheless, Tiout displays a higher degree of crop diversification and superior yields—especially for vegetables and grapes—owing to more favorable soil characteristics, shallower groundwater reserves, and the widespread use of localized irrigation systems. In contrast, Taghit remains heavily dependent on traditional date palm monoculture, facing persistent constraints linked to soil salinity, wind erosion, and deeper aquifers.

The statistical patterns identified through PCA and CA emphasize the necessity of adopting site-specific agricultural strategies rather than uniform national approaches. Complementary economic analysis further reveals the significant profitability of selected crops—most notably onions and dates—when cultivated under optimized agronomic and resource management conditions.

Amid escalating pressures from climate change, water scarcity, and land degradation, the study calls for a shift toward resilient, diversified, and resource-efficient oasis farming systems. Achieving this transition requires reinforcing farmer technical capacities, expanding access to efficient irrigation technologies, and integrating indigenous ecological knowledge into modern agricultural planning. Such measures are essential to sustain food production, protect water resources, and safeguard the cultural and environmental heritage of Algerian oases.

Future research should focus on monitoring long-term yield dynamics under projected climate scenarios and analyzing the socio-economic trade-offs associated with various intensification and adaptation models within fragile desert ecosystems.

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