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Original Article

Assessment of Soil Physicochemical Changes Under Contrasting Farming Systems in the Semi-Arid Region of Berkane, Northeastern Morocco

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Abstract: Intensive agricultural practices can accelerate soil degradation in semi-arid Mediterranean regions, yet their effects on soil properties in Clementine orchards of Northeastern Morocco remain poorly documented. To fill this gap, this study investigated how various farming systems influence soil characteristics in the Northeastern region of Morocco. Four farming systems (conventional management, organic management, medium tillage, and no-tillage) were compared in Clementine orchards. In June and July 2024, 60 soil samples (0-15 cm depth) were collected along transects and pooled into three composite samples per system, which were then analyzed for physicochemical properties. Differences were tested by analysis of variance and student–Newman–Keuls, and relationships among variables were assessed using principal component analysis and pearson correlation. Results revealed significant variations in the soil characteristics among the different farming systems. No-till farming exhibited the highest levels of sodium (56.36 mg kg^{-1}), exchangeable potassium (659.74 mg kg^{-1}), available phosphorus (159.87 mg kg^{-1}), and salinity (0.63 g kg^{-1}). Conventional farming practices had the highest calcium carbonate content (8.22%). Organic farming generally recorded lower values for most parameters, including sodium, organic matter, salinity, and calcium carbonate. In contrast, medium-tillage farming showed the highest organic matter content (3.63%). A significant association was found between zero-tillage and elevated levels of sodium, phosphorus, potassium, and electrical conductivity, whereas conventional farming was primarily associated with higher calcium carbonate content. These findings provide baseline information on how unsustainable agricultural practices affect soil physicochemical properties in semi-arid Mediterranean regions and emphasize the importance of adopting sustainable soil management strategies to maintain soil quality and fertility.

1. Introduction

The agricultural sector remains a cornerstone of Morocco's economy, providing employment for nearly 38% of the workforce and contributing 14% to the national gross domestic product [1]. In the

province of Berkane, cultivation of Clementine orchards plays a vital economic role. To improve productivity, farmers frequently use intensive agricultural practices. These include chemical fertilizers, intensive tillage, organic amendments, insecticides, and herbicides. However, these intensive practices can significantly affect key soil parameters, altering soil physicochemical properties and ultimately impacting soil health and agricultural sustainability [2, 3].

Soil quality is a key determinant of agricultural productivity and environmental resilience, particularly in semi-arid regions, where soil erosion, inadequate integrated weed management practices, and excessive fertilizer application can accelerate soil degradation [4, 5]. The effects of different farming systems on soil properties are influenced by several factors, including land use, soil depth, soil type, and management practices [6-10]. Unsustainable land-use management practices are widely recognized as major contributors to soil degradation, leading to the gradual decline of soil quality, fertility, and ecosystem functions [11]. In contrast, several studies have demonstrated that organic farming systems have beneficial effects on soil health and can contribute to sustainable food production by improving soil quality and supporting essential ecosystem processes [12-17]. Additionally, soil fauna play a crucial role in maintaining soil structure, nutrient cycling, and other important edaphic properties [18, 19]. However, agricultural intensification, characterized by excessive land use, nutrient imbalances, and the extensive reliance on phytosanitary products, can disrupt soil ecosystems and adversely affect soil biological communities, structure, fertility, and overall functionality [2, 3, 20].

In the study area, farmers adopt diverse agricultural management practices based on financial constraints, farming expertise, and access to agricultural machinery. Understanding the implications of these varied management approaches on soil properties is essential for promoting sustainable agricultural practices. This paper evaluates the effects of different farming systems on soil physicochemical properties and investigates the relationships among the measured soil characteristics. It was hypothesized that no-till farming systems would maintain higher levels of soil nutrients and organic matter due to reduced soil disturbance and improved soil conservation, whereas conventional farming practices would be associated with lower organic matter content and greater soil degradation due to intensive tillage and frequent chemical inputs. The study also aims to identify the soil properties most strongly associated with different farming systems and to provide a better understanding of their effects on soil quality. The findings are expected to provide valuable insights into the development and optimization of sustainable soil management strategies, supporting the long-term productivity, fertility, and environmental sustainability of agricultural systems in Berkane.

2. Materials and Methods

2.1. Study Site

The study was conducted in the Triffa Plain, located in the Northeast region of Morocco, within the province of Berkane. The study region is characterized by intensive agricultural production and covers approximately 1,985 km² (Figure 1). It experiences a semi-arid Mediterranean climate with hot, dry summers and cold, rainy winters. The mean annual temperature is approximately 20 °C, while average annual precipitation is about 350 mm (Figure 2). These climatic conditions, combined with intensive agricultural activities, make the region particularly relevant for assessing changes in soil physicochemical properties and evaluating sustainable soil management practices.

This study selected four distinct farming systems in Clementine orchards. The first system, conventional management (CM), involves the periodic application of chemical fertilizers (nitrogen (N), phosphorus (P), and potassium (K)), intensive tillage, and agrochemical treatments for disease, weed, and pest control. These practices aim to maximize agricultural productivity. The second system, organic management (OM), relies solely on organic fertilizers to maintain soil fertility and does not use synthetic phytosanitary products. Weed control is managed through sustainable manual weed control methods. The third system, medium tillage (MT), employs less intensive tillage than conventional systems, using tools such as rotary harrows to minimize soil disturbance. The fourth system, no-tillage (NT), involves no application of fertilizers, herbicides, or insecticides.

All these land-use systems have been managed for over 10 years. Table 1 provides a detailed description of each system. Soil sampling was conducted between June and July 2024 from Clementine orchards representing each farming system. Within each system, one site was selected, and internal replication was performed in accordance with international standards to ensure robust data collection.

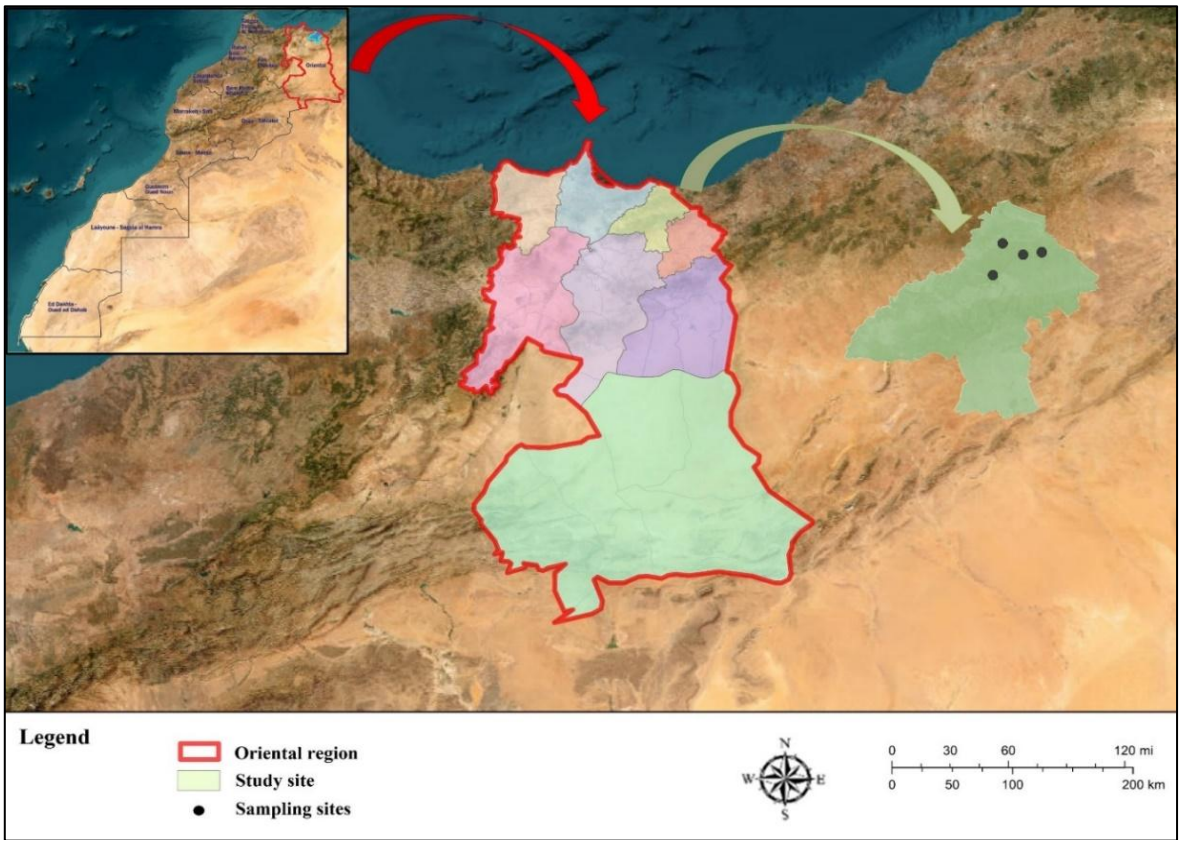


Figure 1: Location map of the study area in Northeastern Morocco. The map shows the study region (outlined in red), the designated study area (shaded in green), and the sampling sites (marked with black dots).

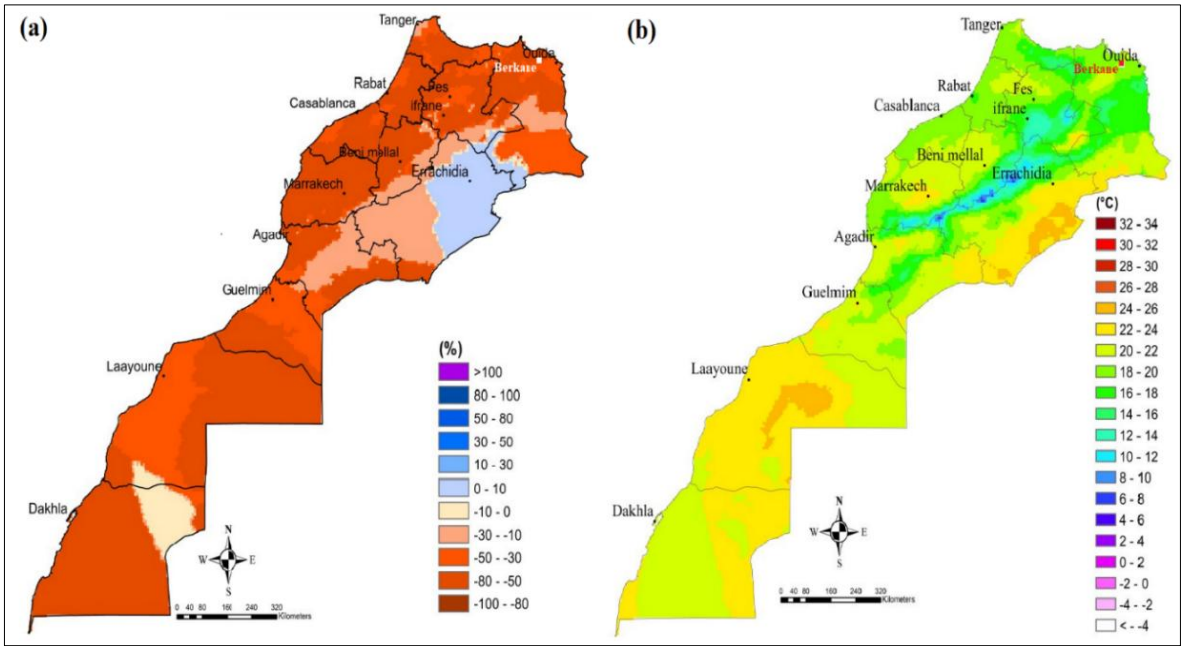


Figure 2: Climate characteristics of Morocco in 2024. (a) Represents the annual average rainfall, and (b) shows the annual average temperature. Source: General Directorate of Meteorology, Ministry of Equipment and Water (www.marocmeteo.ma).

Table 1 : Description of the farming systems selected for the study.

Farming type	Longitude	Latitude	Elevation (m)	Soil texture
CM	35°01'03''N	2°12'49''W	104	Silt loam
OM	35°00'11''N	2°14'23''W	103	Sandy loam
MT	35°00'05''N	2°14'15''W	104	Silt loam
NT	35°00'16''N	2°11'35''W	115	Silt loam

CM = Conventional management; OM = Organic management; MT = Medium tillage; NT = No-tillage.

2.2. Soil Sampling and Analysis

At each farming system site, 15 soil monoliths were collected from a depth of 15 cm along three transects spaced 20 m apart (Figure 3). Five sampling points were established at 10 m intervals along each transect, ensuring a representative spatial distribution of sampling locations within each site. The collected soil samples were thoroughly mixed to obtain representative composite samples, then were oven-dried at 40 °C for 48 h and passed through a 2 mm sieve to remove stones, roots, and other coarse materials. Following this procedure, three composite soil samples were obtained for each farming system and subsequently used to determine the selected physicochemical properties.

Soil physicochemical properties were analyzed at the Laboratory of Soil Sciences Agropolis of Berkane, using standard soil analytical methods. Soil pH was measured using a pH meter (1/2.5) ratio, while salinity was determined with an electrical conductivity meter. Sodium concentrations were assessed using a flame photometer (Sherwood® Flame Photometer). Available phosphorus was quantified via the Olsen method [21]. Exchangeable potassium was extracted with neutral ammonium acetate and measured using a Sherwood® flame photometer [22]. Calcium carbonate levels were measured with a Bernard calcimeter, after treatment with 6N hydrogen chloride. Organic matter was determined using the Walkley-Black method [23].

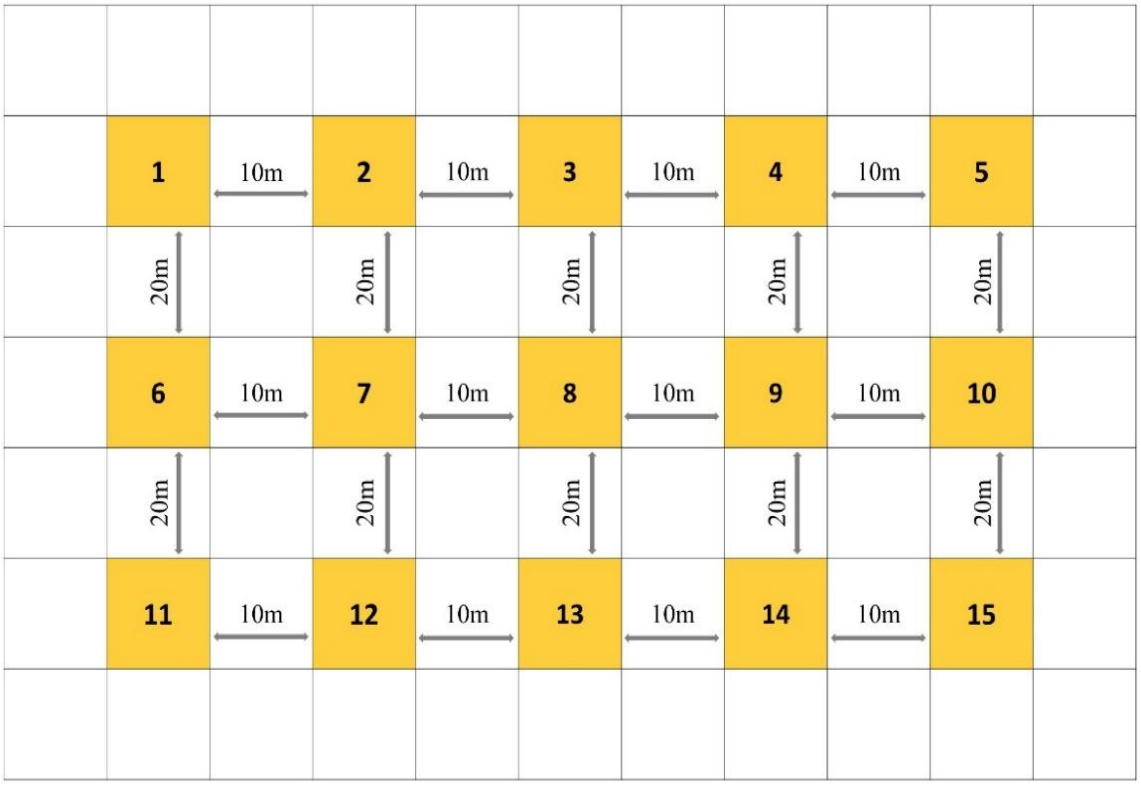


Figure 3: Sampling scheme for soil properties in each farming system within the province of Berkane, Morocco. A soil monolith was placed within a 1 m2 area (indicated in yellow) at 10 m intervals. The distance between the three transects was 20 m.

2.3. Statistical Analysis

Prior to analysis, the normality of residuals was assessed using the Shapiro-Wilk test and the homogeneity of variances using Levene's test. When these assumptions were not met, data were log-

transformed before analysis. To assess differences in soil physicochemical properties among the different farming systems, a one-way analysis of variance was performed, followed by the Student–Newman–Keuls (SNK) test for multiple comparisons. Principal component analysis was subsequently conducted to evaluate the overall influence of farming management practices on soil physicochemical properties and to identify the variables contributing most strongly to the observed variation. In addition, Pearson's correlation analysis was performed to determine the strength and direction of relationships among soil properties across the different land-use systems. Statistical differences were considered significant only when $p<0.05$ and all statistical analyses were conducted using R software, version 4.4.1.

3. Results

3.1. Effects of Farming System on Soil Physicochemical Properties

The soil phosphorus content ranged from 26.66 to 159.87 (mg kg-1) across the different farming systems (Figure 4), with the NT system having the highest and the MT system the lowest. The results showed that phosphorus differed significantly ($p \leq 0.05$) between the CM and NT systems.

The sodium in all land uses ranged from 6.31 to 56.36 (mg kg-1), following the trend OM < CM < MT < NT, with mean values of 6.31, 17.37, 25, and 56.36 (mg kg-1), respectively. The results showed that sodium varied significantly ($p \leq 0.05$) between OM and NT farming systems (Figure 5). The soil organic matter for all the farm types ranged from a minimum in OM (1.74%), followed by CM (3.25%), NT plantation (3.55%), to a maximum in MT (3.63%). With the exception of OM, no significant difference was observed among the farming system (Figure 6). Salinity and electrical conductivity at 25°C were significantly higher in the no-till system than in the other farming systems (Figure 7). Conversely, soil parameters such as pH levels, potassium, and calcium carbonate content were unaffected, and no significant impact ($p > 0.05$) of the practices was observed. NT soils had a higher potassium content (659.74 mg kg-1) than OM soils (607.40 mg kg-1), followed by CM (472.31 mg kg-1) and MT (469.17 mg kg^{-1}). With regard to calcium carbonate content, CM soil had the highest (8.22%), followed by MT soils (6.47%) and NT systems (5.40%), whereas OM soils had the lowest (4.5%).

The first two principal components accounted for 68.5% of the total variance in soil parameters (Figure 8). The first axis showed a strong correlation between elevated levels of sodium, phosphorus, potassium, and electrical conductivity and the NT system. Conversely, the second axis highlighted the link between conventional system type and higher calcium carbonate.

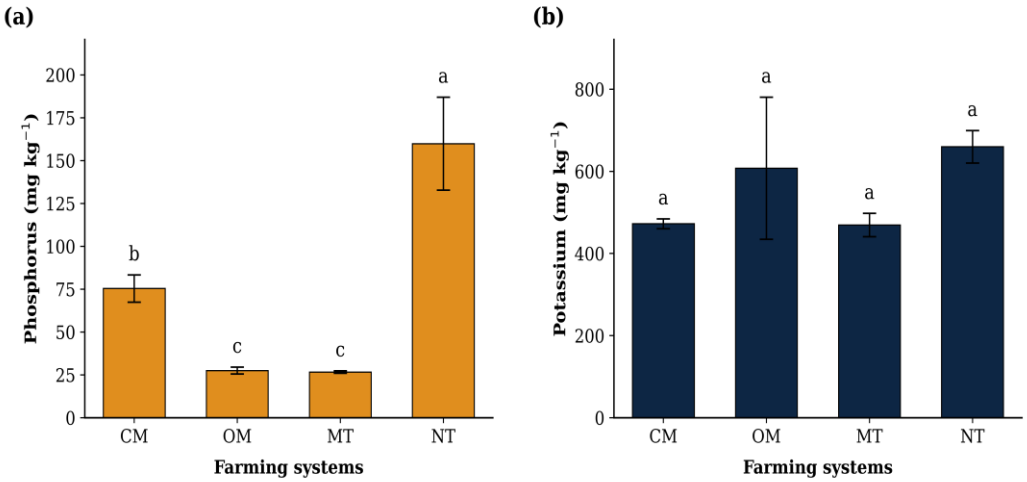


Figure 4: Phosphorus (a) and potassium (b) levels across different farming systems in the province of Berkane, Morocco. Data are presented as the mean ± standard deviation of three composite soil samples. Bars sharing different letters indicate significant difference based on the SNK test at $p \leq 0.05$. Farming systems include: CM (conventional management), OM (organic management), MT (medium tillage), and NT (no tillage).

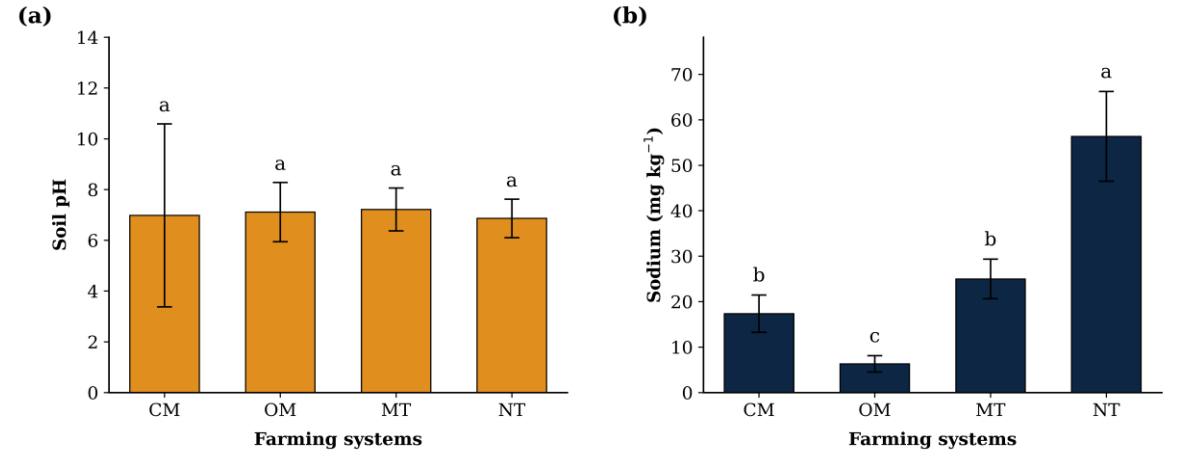


Figure 5: pH (a) and sodium (b) levels across different farming systems in the province of Berkane, Morocco. Data are presented as the mean ± standard deviation of three composite soil samples**.** Bars sharing different letters indicate a significant difference based on the SNK test at $p \leq 0.05$. Farming systems include: CM (conventional management), OM (organic management), MT (medium tillage), and NT (no tillage).

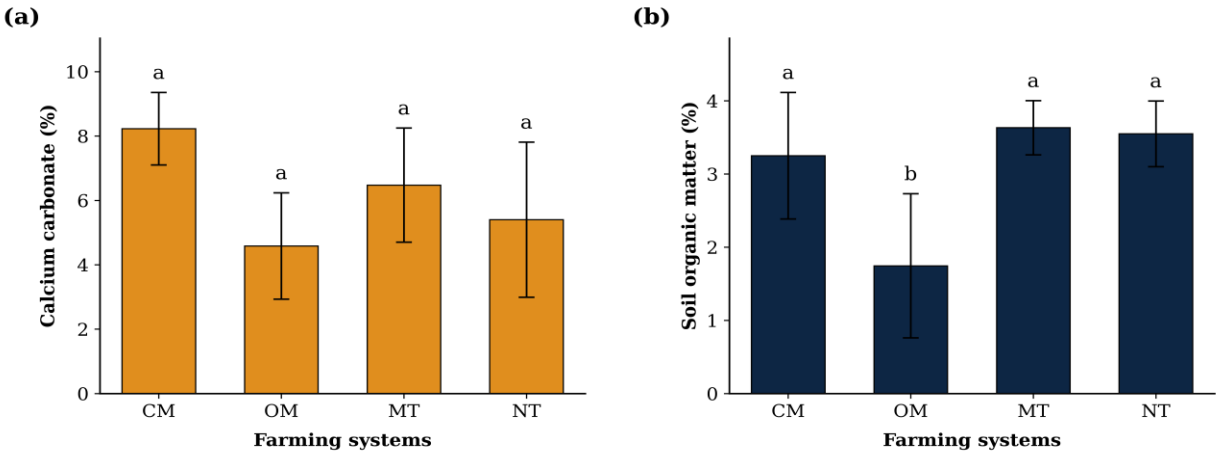


Figure 6: Calcium carbonate (a) and organic matter (b) levels across different farming systems in the province of Berkane, Morocco. Data are presented as the mean ± standard deviation of three composite soil samples**.** Bars sharing different letters indicate significant difference based on the SNK test at $p \leq 0.05$. Farming systems include: CM (conventional management), OM (organic management), MT (medium tillage), and NT (no tillage).

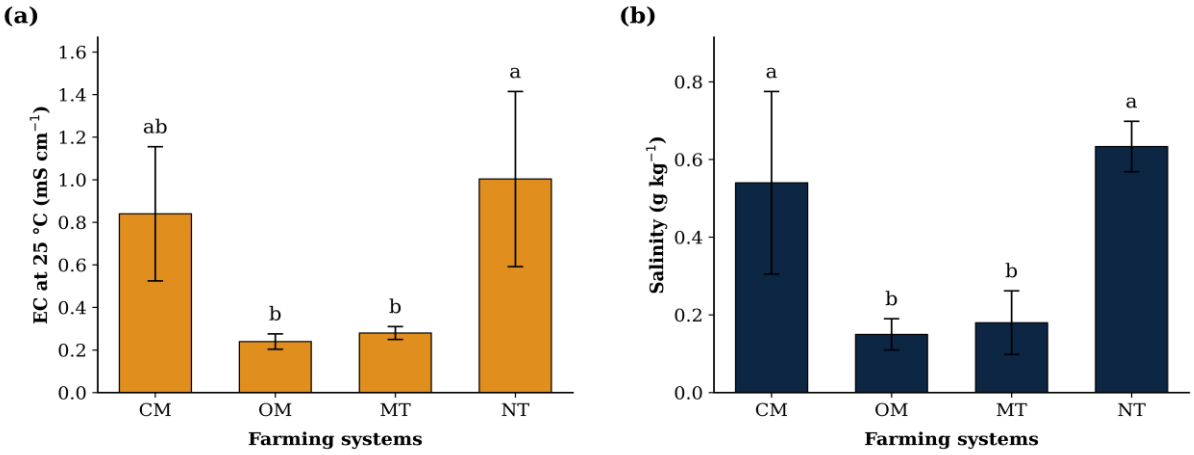


Figure 7: Conductivity (a) at 25 °C and salinity levels (b) across different farming systems in the province of Berkane, Morocco. Data are presented as the mean ± standard deviation of three composite soil samples**.** Bars sharing different letters indicate significant difference based on the SNK test at p ≤ 0.05. Farming systems include: CM (conventional management), OM (organic management), MT (medium tillage), and NT (no tillage).

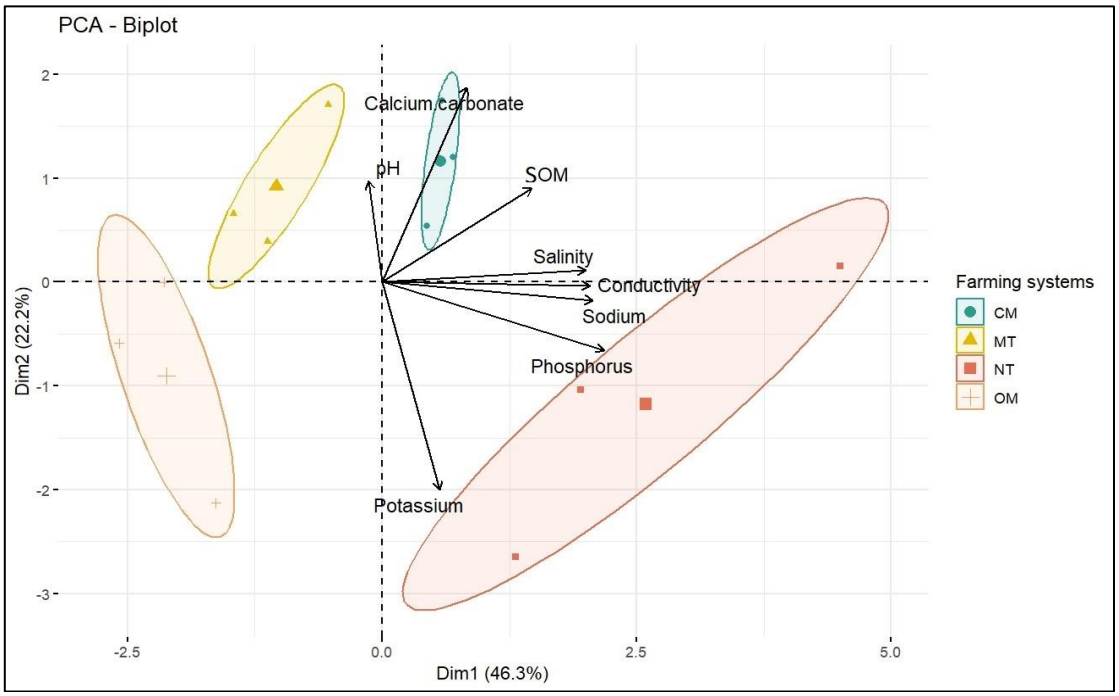


Figure 8: Principal component analysis plot showing the impacts of farming systems on the soil characteristics in the province of Berkane, Morocco. pH: potential of hydrogen; SOM: soil organic matter. Farming systems include: CM (conventional management), OM (organic management), MT (medium tillage), and NT (no tillage).

3.2. Relationships between Soil Physicochemical Parameters

The relationships among the measured soil physicochemical variables are presented in figure 9. Pearson's correlation analysis revealed several significant associations among soil characteristics across the different land-use systems. Phosphorus showed strong and significant positive correlations with sodium ($r = 0.82$, $p = 0.001$), electrical conductivity ($r = 0.82$, $p = 0.001$), and salinity ($r = 0.83$, $p = 0.001$), indicating a close association between nutrient availability and soil salt-related properties. Salinity was also positively correlated with sodium ($r = 0.65$, $p = 0.021$) and electrical conductivity ($r = 0.66$, $p = 0.019$). Moderate but non-significant positive relationships were observed between sodium and electrical conductivity ($r = 0.52$, $p = 0.080$) and between sodium and soil organic matter ($r = 0.52$, $p = 0.083$), while potassium tended to be negatively correlated with calcium carbonate ($r = -0.57$, $p = 0.053$). In contrast, soil pH showed weak and non-significant correlations with all measured variables ($r \leq 0.19$, $p > 0.05$).

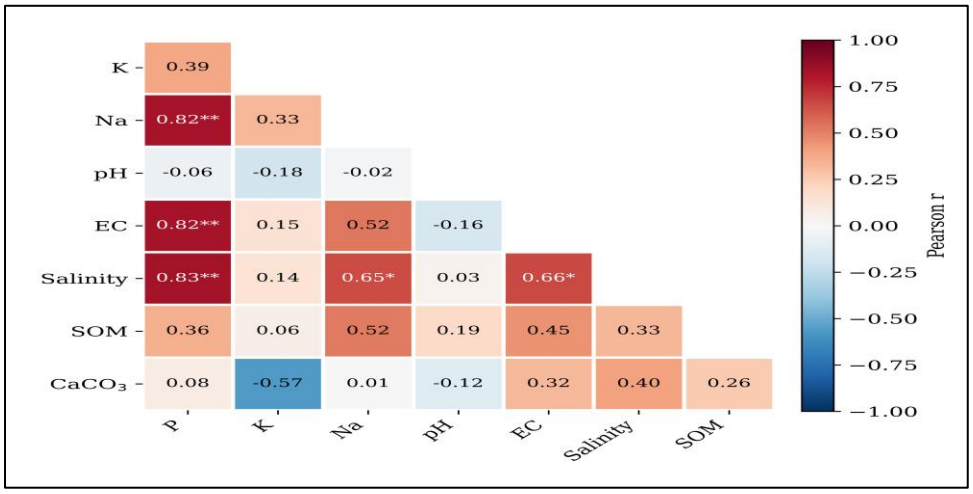


Figure 9: Pearson correlation matrix between soil physicochemical properties across farming systems in the province of Berkane, Northeastern Morocco. Values indicate Pearson correlation coefficients (r); * $p < 0.05$, ** $p < 0.01$. pH: potential of hydrogen; EC: electrical conductivity; SOM: soil organic matter.

4. Discussion

This study provides novel insights into how different land-use practices influence soil physicochemical properties in Mediterranean agroecosystems, revealing substantial variations in key soil parameters among farming systems. The significantly higher phosphorus levels observed in NT systems (Figure 4) can be attributed to reduced soil disturbance, which minimizes organic matter mineralization and erosion, thereby preserving P near the soil surface [24]. Additionally, NT practices are known to foster microbial activity and mycorrhizal associations, which facilitate organic phosphorus mineralization [25]. This aligns with findings from [26], where reduced tillage enhanced phosphorus availability through microbial-mediated processes. However, the absence of a significant difference in phosphorus levels between NT and CM suggests that chemical fertilization in CM may compensate for phosphorus losses due to intensive tillage [27]. Similar observations were reported by Hobbs *et al.* [28], where conventional farming maintained elevated phosphorus levels through fertilizer inputs despite continuous soil disturbance. In contrast, the lower P content in OM likely reflects the slower mineralization rates of organic fertilizers compared to synthetic inputs [29]. These findings underscore the potential of NT practices to enhance phosphorus retention, which could be particularly beneficial in Mediterranean agro ecosystems where nutrient depletion is a recurring challenge.

The elevated sodium levels observed under NT management may reflect reduced leaching associated with minimal soil disturbance, which limits vertical salt redistribution. Under semi-arid conditions, restricted soil mixing combined with high evapotranspiration can promote salt accumulation in the surface layers. Similar findings have been reported in Mediterranean no-till systems, where reduced leaching efficiency and capillary rise of groundwater salts contribute to salinity accumulation [30]. In contrast, the lower sodium concentrations observed in organic systems may be linked to improved soil aeration and enhanced drainage associated with manual weeding and reduced compaction. Increased porosity can facilitate salt leaching, thereby limiting sodium accumulation. These findings are consistent with previous reports indicating lower salinity levels in organically managed soils due to improved structural stability and water movement [31]. Furthermore, NT systems were characterized by elevated salinity and electrical conductivity, likely due to limited soil disturbance, which restricts vertical redistribution of soluble salts and reduces leaching efficiency. Reduced mechanical mixing may promote the accumulation of salts in upper soil horizons, particularly under semi-arid conditions. In contrast, systems involving greater soil disturbance exhibited comparatively lower salinity levels, potentially due to enhanced soil porosity and improved infiltration capacity, which facilitate the leaching and vertical translocation of soluble salts within the soil profile [32]. These findings highlight the need for adaptive salinity management in NT systems to mitigate potential long-term soil degradation.

Potassium (K^+) concentrations varied among the different soil management systems, with NT soils exhibiting the highest K^+ levels. This pattern may be attributed to reduced soil disturbance under NT, which can limit potassium redistribution and minimize potential losses through erosion and leaching. Previous study has similarly reported greater exchangeable K^+ availability under conservation-based management systems than under conventional tillage [33]. In contrast, the comparatively lower K^+ concentrations observed in CM and MT systems may be associated with greater nutrient removal via crop uptake and enhanced redistribution due to mechanical soil disturbance. Intensive tillage can modify soil structural stability and influence cation mobility, thereby affecting K^+ dynamics and availability [34]. The relatively high K^+ concentrations observed under the OM system, despite the absence of synthetic fertilizers, may be explained by the gradual release of nutrients from organic amendments and an enhanced cation exchange capacity associated with higher organic matter levels [35]. Overall, these results indicate that NT and OM management practices may help conserve and maintain soil potassium, an essential nutrient that sustains soil fertility and supports long-term agricultural productivity.

Soil organic matter content was comparatively higher under NT and MT systems, likely reflecting reduced mechanical disturbance and enhanced residue retention. Limited soil inversion can reduce mineralization rates and promote the physical protection of organic carbon within soil aggregates, thereby favoring the stabilization of soil organic matter. Conservation-oriented management

practices have been widely reported to enhance soil carbon storage relative to intensive tillage systems [18, 36-38]. Additionally, reduced agricultural intensification, sustainable land use management, and decreased application of phytosanitary products may indirectly support biological activity and improve soil structural stability, further contributing to organic matter retention [20, 39-43].

Regarding soil pH, the absence of significant differences among the farming systems suggests that, under the conditions and sampling period of this study, tillage intensity and OM had limited effects on soil acidity. The near-neutral pH values observed across all treatments may be attributed to the continuous incorporation of crop residues and the application of organic amendments, which can provide a buffering effect and reduce rapid fluctuations in soil pH [11, 44-46]. Soil pH stability may also be influenced by microbial decomposition processes, during which the production of organic acids and the release of protons (H^+) into the soil solution can counteract alkalization and help maintain relatively stable pH conditions [47]. Compared with other farming systems, soils under the OM and MT systems exhibited slightly higher pH values, consistent with previous findings that less intensive cropping practices may increase soil pH [48]. Nevertheless, the relatively short sampling period and the absence of seasonal replication represent important limitations of the present study. Long-term monitoring across different seasons and years is therefore recommended to better evaluate the temporal dynamics of soil pH and the long-term effects of farming practices, particularly under changing climatic conditions in Mediterranean environments. Overall, the findings have important implications for sustainable soil management, highlighting the potential of NT and OM systems to support soil fertility while reducing the risk of adverse processes such as salinity accumulation.

5. Conclusions

The results showed clear differences in soil characteristics among the farming systems. The NT system exhibited elevated levels of sodium, phosphorus, potassium, and salinity due to minimal soil disturbance. On the other hand, CM had higher calcium carbonate levels due to fertilizer inputs. Organic farming produced a distinct soil environment characterized by comparatively lower levels of several nutrients, whereas MT resulted in the highest organic matter content, suggesting greater potential for soil carbon storage and sequestration. These findings demonstrate that each farming system has specific advantages and limitations in maintaining and improving soil quality. From a practical perspective, balanced soil management strategies that combine reduced soil disturbance with appropriate organic amendments could help enhance soil fertility, maintain soil organic matter, and minimize the risk of salinity accumulation in semi-arid environments. Such integrated approaches should be adapted to local soil conditions, climatic constraints, and agricultural production requirements to sustain long-term productivity and ecosystem functions. Tailored management strategies are therefore essential for maintaining soil health and improving the resilience of agricultural systems under increasing environmental pressures. Future research should incorporate biological and microbial indicators, together with long-term and seasonal monitoring, to better understand soil–microbiome dynamics and evaluate how management practices influence soil functioning over time. This integrated approach could provide a stronger scientific basis for optimizing sustainable agricultural practices and supporting resilient soil management in semi-arid regions.

Author Contributions: Mourad Bendada: Conceptualization, Investigation, Methodology, Formal analysis, Resources, Writing - original draft, Writing - review & editing. **Muhammad Farooq:** Writing – review & editing, Validation. **Mohammad Abdul Momin Siddique:** Writing – review & editing. **Abderrahmane Hadini:** Conceptualization, Investigation, Resources, Formal analysis. **Khalid El Bekkaye:** Methodology, Supervision, Validation. **Khalid Chaabane:** Supervision, Validation.

Data availability: Data will be available upon reasonable request by authors.

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