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Research Article

Agroforestry in crops systems and its influence on the chemical fertility of soils in semi-arid regions: Case of the Dahra foothills (North-West, Algeria)

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Abstract

To guarantee a stable offer and healthy food, the new techniques of maintaining and improving the natural production capacity of agricultural land must take appropriate measures for each environment. However, the identification and the valorization of all local dynamics of production systems must ensure the conservation of agricultural land fertility and butter fertilizer management. This study aims to evaluate the physico-chemical quality of soils in the north-western foothills of Dahra. After a bioclimatic overview of the study area, out of the fourteen studied stations, four of the most practiced farming systems (agroforestry, non-irrigated tree crop cultivation, annual field cropping and fallow cultivation) were compared based on analyses of various indicators related to the physico-chemical properties of soils used in the literature concerning soil chemical fertility. Indeed, the studied soils exhibit a clay-loam and sandy-loam textures, a slightly acidic pH, and an organic matter content that requires improvement for more active biological activity. To optimize soil fertility, the practice of green manures as contributions of major elements (N, P, and K) would be desirable along with studied crop rotations. The results showed that lands in the north-western foothills of Dahra are naturally intended for agriculture and predisposed to promoting agro-ecological practices, particularly agroforestry. This will improve soil health through enhanced biodiversity and efficient resource use. Also, the biological fertility measures offer more opportunities for sustainable agriculture in semi-arid environments where agroforestry practices and green manures effectively contribute to increasing organic matter content, bio-fertility, income diversity, and the standard of living for farmers.

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1. Introduction

The contradiction between the rapid deterioration of soils and the increase in food demand is becoming more and more important. The excessive use of fertilisers as well as other chemical inputs, monotonous crop rotations, conventional land management practices, etc., have resulted in significant soil degradation, the depletion of natural resources and the loss of agricultural sustainability (Rehman & Farooq, 2023). Therefore, the major challenge of modern agriculture is the development of sustainable production systems (Gomez et al., 2020; Kaur & Chauhan, 2023) which ensures food and nutritional security by the increase of agricultural production while preserving soils and water resources (Gomez et al., 2020).

Most soil fertility assessment systems are based on the organic matter content as the main parameter (Hag-Husein et al., 2021). However, the decrease in the concentration of organic matter (MO) in agricultural soils is a serious threat, as it worsens the retention capacity, aggregation, structure, mechanical strength and compaction of the soil while decreasing fertility, which directly affects agricultural productivity (Eden et al., 2017). In view of this identified problem, it is necessary to have effective and sustainable methods to manage the fertility of agricultural soils in order to improve food production.

Soil fertility in semi-arid lands is limited not only by the limited availability of water, but also by low organic matter contents (Hag-Husein et al., 2021) which makes them vulnerable to its structural degradation by erosion (Garcia et al., 2017). Also, the calcareous nature of the soils is characterized by fragile agrosystems with a quick response to environmental variations (Singare et al., 2022). Given the vulnerability of these lands to degradation, the restricted fertility of agricultural soils has emerged for several decades with a strong degradation of its soils thus limiting agricultural production, in particular tillage techniques, monocultures and the abuse of chemical inputs. In addition, unsustainable agricultural land management practices have led to a decrease in soil fertility. In most of the literature, the presence of organic matter and major nutrients for plants (N, P, and K) is used as an indicator of the soil to estimate its fertility (Hag-Husein et al., 2021). Therefore, reclamation and management of these soils are urgently needed to improve soil fertility and crop productivity (Singare et al., 2022). The research on the impact of agroforestry on soil fertility offers a potential solution to modern agriculture. Agroforestry, defined as "agriculture with trees" by the World Agroforestry Centre (2017), is a promising strategy. It plays a crucial role in enhancing food security through its innovative approach.

Agroforestry systems and practices are considered increasingly important to increase food production, combat environmental degradation (Waldron et al., 2017). Also, are widely promoted as a conservation and development tool to sequester carbon, improve soil fertility and conserve biodiversity on agricultural land while generating economic benefits for farmers (Castle et al., 2021). According to the literature, the results of the meta-analysis on the impacts of agroforestry practice interventions for soil fertility replenishment indicated an overall positive effect, including through the incorporation of trees in agricultural fields and improved fallow practices in areas with severe soil fertility issues (Castle et al., 2021).

In this context, the evaluation of the physicochemical properties through peasant fields, and the determination of soil fertility indicators in agroforestry systems compared to other systems as a non agroforestry comparator, such as conventional agriculture systems (Castle et al., 2021) were the subject of our study. This, to determine the modifications undergone at the soil level by the presence of the tree associated with other crops.

2. Materials and methods

2.1 Choice of the study area

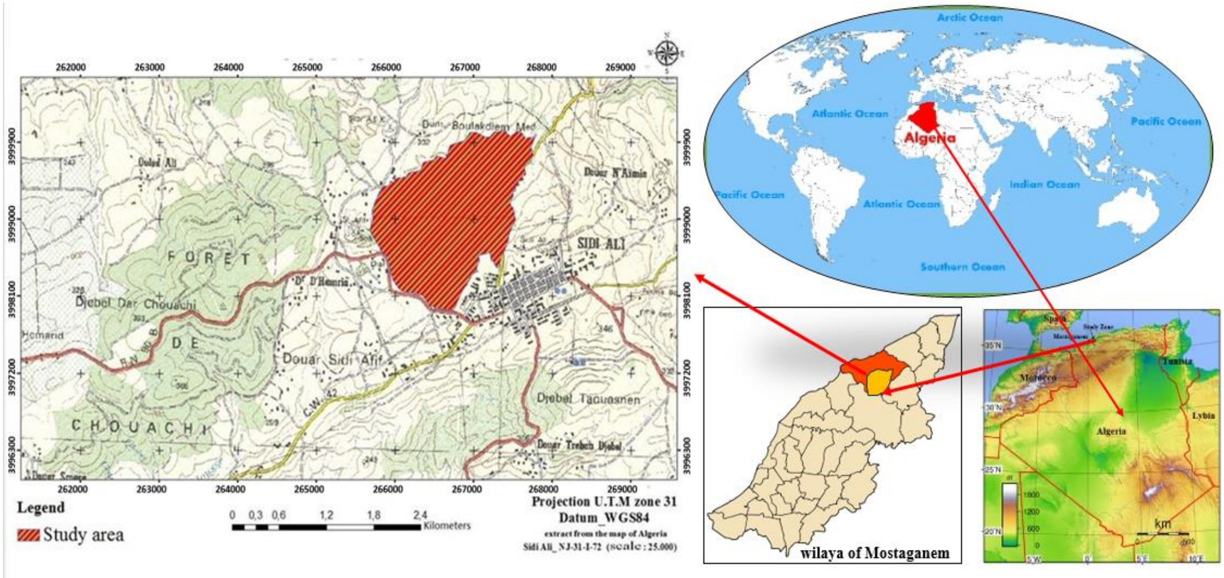

Figure 1. Geographical location of the study area

Located between the localities of Sidi Ali and Hadjadj north of the wilaya of Mostaganem, the study area is an integral part of the foothills of Dahra (Northwest, Algeria) on a latitude of 36 ° 06' N, a longitude of 0 ° 24' E and an altitude ranging from 177 to 338 m. It is constituted by a large majority of agricultural land affected by degradation phenomena (Figure 1).

2.2 Climatic overview of the study area

The study area is characterized by a Mediterranean semi-arid bioclimatic floor, with two seasons (Figure 2), a rainy season in winter and a dry season in summer, belonging to the “Csa” class (“Hot-summer Mediterranean” climate, according to Köppen (Kottek et al., 2006).

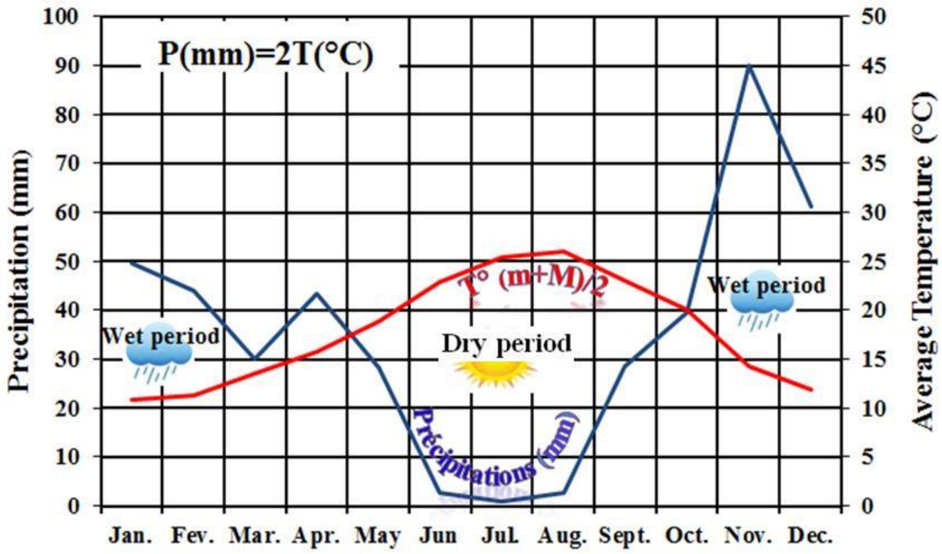

Figure 2. Ombrothermal diagram of Bagnouls and Gaussen (2000-2021; ONM-Mostaganem)

The climate is characterized by irregular rainfall throughout the year, with an annual average of 421mm. The average annual temperature is 18 °C (over a 30 years span). The maximum monthly mean temperature is usually recorded in August (32.3 °C) while the minimum is generally observed in January (6 °C). And an average annual reference evapotranspiration of approximately 1180 mm.

2.3 Physical environment

Geomorphology and lithology

Our area consists of bare marly hills, with rather hilly relief touched by the phenomenon of water erosion and accentuated by the tillage often realized in the direction of the slope, sur les versants dominants, on the dominant slopes.

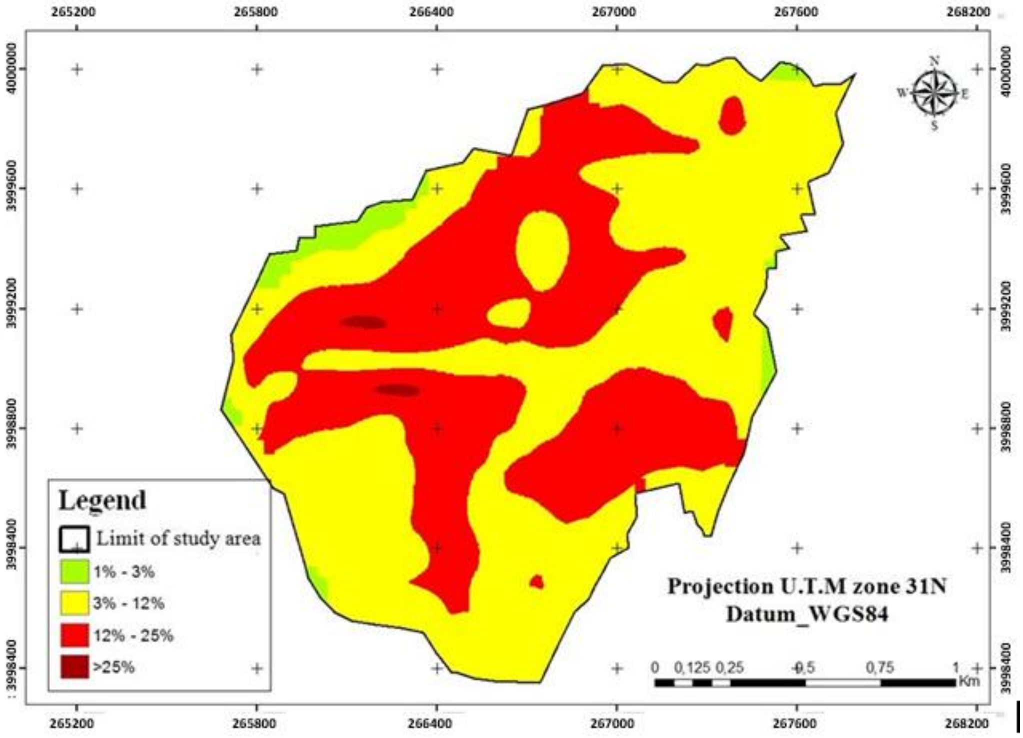

Figure 3. Map of slope

The slopes ranging from 3 to 12% and from 12 to 25% cover the majority of the study area, representing 95.70% of the total surface area (Figure 3). This type of relief promotes soil erosion, which leads to the loss of surface layers rich in nutrients, minerals, and organic matter. As a result, soil fertility decreases, leading to a significant reduction in agricultural productivity (El Mokaddem et al., 2019).

Water Resources

The study area is devoid of superficial water sources. This explains why the irrigation of tree crops is done with the help of cisterns. From a hydrogeological point of view, the region is characterized by impermeable or low permeable formations, especially marl and clay (Figure 4). Therefore, effective water management practices are crucial for maximizing crop productivity (Ray & Majumder, 2024)

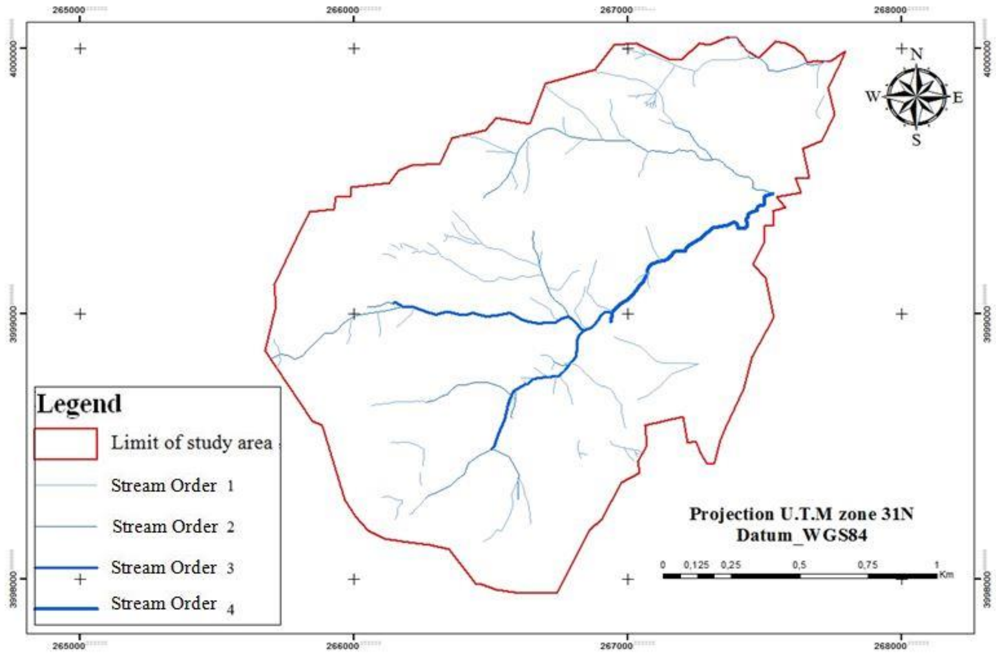

Figure 4. Map of stormwater systems

Soil use

Plant formation is a key element of the physical environment, it reflects both the quality of the soil and the climate (Schulze et al., 2019). Viticulture and fruit arboriculture have taken a great extension on soils of the study area. Some traditional agroforestry practices are already well established in the study area. These methods refer to indigenous peasant experiences in the area like the associated crops to be intercropped between fruit trees. (Figure 5). These intercrops in the vineyards and orchards were practiced in the past, but, a number of prejudices had regressed this practice to avoid water competition.

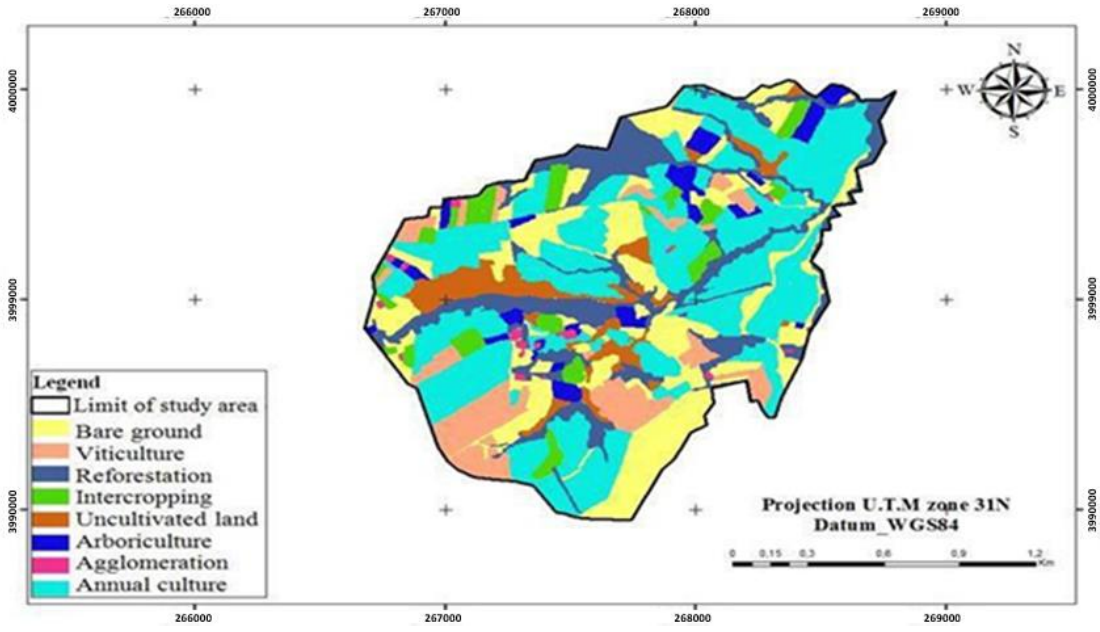

Figure 5. Map of soils use

The farmers have always grown trees on their land, without a doubt that it could have a beneficial effects on soils and crops. Also, the perennial shrub stratum observed in our study area occupies mainly degraded soils, calcareous crust, ravines and thalweg. The most dominant species are lentisque pistachio (*Pistacia lentiscus*), thorny calycotome (*Calicotome spinosa*), wild olive (*Olea europaea*), and lavender (*Lavandula officinalis*), that represents a non-negligible vegetation cover for the protection of the soil against water erosion and also as an organic matter input.

2.3 Methodological approach

Socioeconomic approach

The region is mainly for agriculture and forestry on the one hand because of the weakness of mining resources and industries, on the other hand, because most of the income and the product come from agricultural activities. Considering their ancestral attachment to the earth in general and to the tree in particular, the farmers consider potential revenues growth as the main advantage of mixed farming systems combining trees, crops and livestock.

Experimental design

A visual examination of the soils was conducted at the scale of agricultural plots to assess their condition and potential for use. According to their modes of management (agricultural production system), Table 1 shows the distribution of the characteristics of 14 different plots (agricultural parcel) that were chosen according to the land use and slope. Thus, according to the land use classification of FAO (2006), the cropping systems were identified as follows: mixed farming (M), with four plots belonging to agroforestry system (MF) ; agricultural cropping (A), with the systems classified respectively as follows : four plots with non-irrigated tree crop cultivation (AT1), four plots with annual field cropping (AA), and two plots under fallow system cultivation (AA2).

The study focused on soil samples taken from these different cropping systems chosen for the search for soil fertility indicators through the results of physicochemical analyzes of the studied soils.

Sampling

Field sampling was performed from early April to the mid- May 2018. The surface soil analysis is the most important compared to that of the subsoil, however, is proving to be complementary. So, at each plot, three samples were taken from the topsoil (0-30 cm) according to a strat-ified random sampling design along the slope.

Laboratory analysis

A total of 42 soil samples were taken from the field. The soil samples were air dried, crumbled and passed through a 2 mm sieve and packaged in labeled plastic boxes. Subsequently, they were sent to the laboratory of Soil Erosion Laboratory of the Institute of Sustainable Agriculture of CSIC (Cordoba-Spain) for some physic-chemical analysis. The analysis were mostly focused on organic matter (OM), organic C, total nitrogen (N), extractable phosphorus (P) and exchangeable cations (potassium "K^+", sodium"Na^+", calcium "Ca^{+2}" and magnesium "Mg^{+2}"). Afterwards, we counted the analysis of selected soil properties: clay, sand, silt pH-Water, pH-KCl, Total calcium carbonate "Total $CaCO_3$", Active calcium carbonate "Active $CaCO_3$" and electrical conductivity (EC) at the laboratory of Biodiversity, Soil and Water Conservation of the University of Mostaganem (Algeria). The soil properties selected for our analysis of soil degradation, and methods are described in Table 2.

Table 1. Characteristics of the 14 experimental plots delimited in the study area according to their agricultural management modes

Systems	Plots code	Coordinates			Area (ha)	Exposure	Slope (%)	Crops
		Latitude Nord	Longitude Est	Altitude (m)				
Agroforestry system (MF)	MF.S1	36°06'55.50"	0°24'58.73"	208	01.24	East	9-12	Olive tree. Oat.
	MF.S2	36°06’40.44"	0°24’05.49"	329	00.48	East	1-5	Apricot tree. Fig tree. Chickpea. Plum tree.
	MF.S3	36°06'44.57"	0°24'18.68"	323	01.10	Southeast	12-16	Grape-vine. Peas. Apricot tree. Cypress. Fava bean.
	MF.S4	36°06 :46.61	0°2450.49"	215	00.43	Northeast	5-9	Olive tree. Apricot tree. Fig tree. Pomegranate tree. Oat. Jujube tree.
Non-irrigated tree crop cultivation (AT1)	AT1.S1	36°06'51.97"	0°24'41.61"	241	01.10	Southeast	12-16	Olive tree
	AT1.S2	36°06'33.57"	0°24'42.40"	223	01.21	East	5-9	Apricot tree
	AT1.S3	36°06'39.29"	0°24'12.97"	332	00.28	Southeast	12-16	Apricot tree. Fig tree.
	AT1.S4	36°06'24.50"	0°24'12.77"	289	00.46	Northeast	20-26	Apricot tree
Annual field cropping (AA)	AA.S1	36°06'00.55"	0°24'18.34"	308	02.47	Northeast	1-9	Soft wheat
	AA.S2	36°06'04.52"	0°24'22.68"	284	03.39	Northeast	9-12	Soft wheat
	AA.S3	36°05'58.57"	0°24'25.46"	297	01.24	North	5-9	Soft wheat
	AA.S4	36°06'12.85"	0°24'04.28"	329	07.65	Southeast	1-9	hard wheat
Fallow system cultivation (AA2)	AA2.S1	36°06'16.81"	0°24'48.72"	281	01.55	Northeast	1-9	Unplowed
	AA2.S2	36°05'54.71"	0°24'32.86"	311	04.63	Northwest	1-5	Plowed

Table 2. Methods used in field measurements and laboratory analysis, n means replications

Parameters	Method	Standards	*n*
Laboratory analysis			
Particle size distribution (%)	Robinson’s pipette method	NF X31-107	3
Texture	USDE classification	-	3
pH(H_2O)	1:2.5 suspension in water	NF ISO 10390	3
pH(KCl)	1:2.5 suspension in 1 M KCl solution		3
EC (dS/m)	1:5 suspension in water	ISO 11265	3
Organic C (%)	Anne method	NF ISO 10694	3
Total N (%)	Dumas Method	NF ISO 13878	3
Extractable P ($mg.kg^{-1}$)	Olsen method	NF ISO 11263	3
Exchangeable K^+ ($cmol^+.kg^{-1}$))	Ammonium acetate method	NF X31-108	3
Exchangeable Ca^{+2} ($cmol^+.kg^{-1}$)			3
Exchangeable Na^+ ($cmol^+.kg^{-1}$)			3
Exchangeable Mg^{+2} ($cmol^+.kg^{-1}$)			3
Total $CaCO_3$ (%)	Bernard calcimeter method	NF ISO 10693	3

Parameters	Method	Standards	*n*
Active $CaCO_3$ (%)	Drouineau-Galet method	NF **X 31**-106	3
Parameters calculated from field data			
OM (%)	Calculated from soil organic carbon content	-	3
C/N ratio	Ratio carbon to nitrogen	-	3
Estimate CIC ($cmol^{+}.kg^{-1}$)	Calculated from the sum of exchangeable cations (K^{+}. Ca^{+2}. Na^{+}. and Mg^{+2})	-	3

pH : Hydrogen potential. EC : Electrical conductivity. Organic C : Organic carbon. Total N : Total nitrogen. Extractable P : Extractable phosphorus. Exchangeable K^{+} (mg kg^{-1}) : Exchangeable potassium cation. Exchangeable Ca^{+2} : Exchangeable calcium cation. Exchangeable Na^{+}: Exchangeable sodium cation. Exchangeable Mg^{+2} : Exchangeable magnesium cation. OM : Organic matter. C/N ratio : Carbon nitrogen ratio. Estimate CEC : Estimate cation exchange capacity. $CaCO_3$Total : Total calcium carbonate. Active $CaCO_3$: Active calcium carbonate.

The results make it possible to validate the correspondences between the different cropping systems practiced and the characterization of fertility. The interpretation of the results of soil analyses in relation to the reference standards is essential to evaluate the quality of the soil in the different cultivation systems studied (Table 3).

Table 3. Soil properties evaluated for classes of soil degradation and ranges to be considered degraded

Soil property	Range to be considered degraded	Source
pH(H_2O)	<7.5 or >8.5	Kome et al. (2018)
pH(KCl)	<7or >7.5	Kome et al. (2018)
EC (dS/m)	< 0.2	Rayment & Lyons (2011)
Organic C (%)	0.5 - 1.5	Brady & Weil (2016)
Total N (%)	0.10 - 0.20	Brady & Weil (2016)
Extractable P ($mg.kg^{-1}$)	10 - 20	Marschner (2012)
Exchangeable K^{+} ($cmol^{+}.kg^{-1}$)	0.3 - 0.6	Brady & Weil (2016)
Exchangeable Ca^{+2} ($cmol^{+}.kg^{-1}$)	5.0 - 10.0	Brady & Weil (2016)
Exchangeable Na^{+} ($cmol^{+}.kg^{-1}$)	0.5 - 1.0	Brady & Weil (2016)
Exchangeable Mg^{+2} ($cmol^{+}.kg^{-1}$)	1.0 - 2.0	Brady & Weil (2016)
Total $CaCO_3$ (%)	<5 or >15	Brady & Weil (2016)
Active $CaCO_3$ (%)	<2 or >5	Brady & Weil (2016)
OM (%)	1.5 - 3.0	Carter & Gregorich (2007)
C/N ratio	<10 or >15	Brady & Weil (2016)
Estimate CEC ($cmol^{+}.kg^{-1}$)	<10 or >20	Brady & Weil (2016)

Data analysis

According to Araya et al. (2023), understanding the influence of land use practices on soil quality is crucial for developing appropriate management practices. The analysis, based on variation between and within groups, is often referred to as one-way analysis of variance (or one-way ANOVA) (Gillard, 2020), with significance when $p < 0.05$. This method was chosen to identify the members of the entire dataset (Araya et al., 2023). It can be viewed as a generalization of the t-test for comparing two independent samples to more than two groups (Janczyk & Pfister, 2023).

The aim was to evaluate the relationship between the cropping systems practiced in the study area and their soil fertility parameters. Therefore, a one-way analysis of variance (ANOVA) and

The Student-Newman-Keuls test (SNK) were carried out. These tests focused on the soil parameters of the different cropping systems.

This statistical method, widely used in agriculture (Bojnec et al., 2024 ; Zenda Za Begani et al., 2024 ; Narmilan et al., 2022 ; Abubakar et al. 2018 ; Diallo et al., 2018 ; Kozak et Piepho, 2018 ; Rezgui et al., 2014) allows to highlight the average comparisons of the physicochemical properties of the studied soils from agricultural plots according to their agricultural management mode (cropping systems). The primary objective is to test if there is a statistically significant difference between these systems practiced in the study area, which allows for distinguishing the systematic influences of agricultural practices on the characteristics of the soil. The results obtained from ANOVA provide valuable insights into the impact of agricultural practices on soil quality. This information is essential for reviewing and optimizing cropping systems, thereby aiming to improve agricultural productivity and promote long-term environmental sustainability.

3. Result and discussion

According to the lithology map established from the granulometric analysis of the collected samples, the soils in the study area are primarily characterized by clay-loam and sandy-loam textures (Figure 6). It has been shown that these physical fractions of aggregates are sensitive to management practices such as tillage and vegetation type (Liu et al., 2021 ; Weidhuner et al., 2021 ; Zhang et al., 2023 ; Steponavičienė et al., 2024).

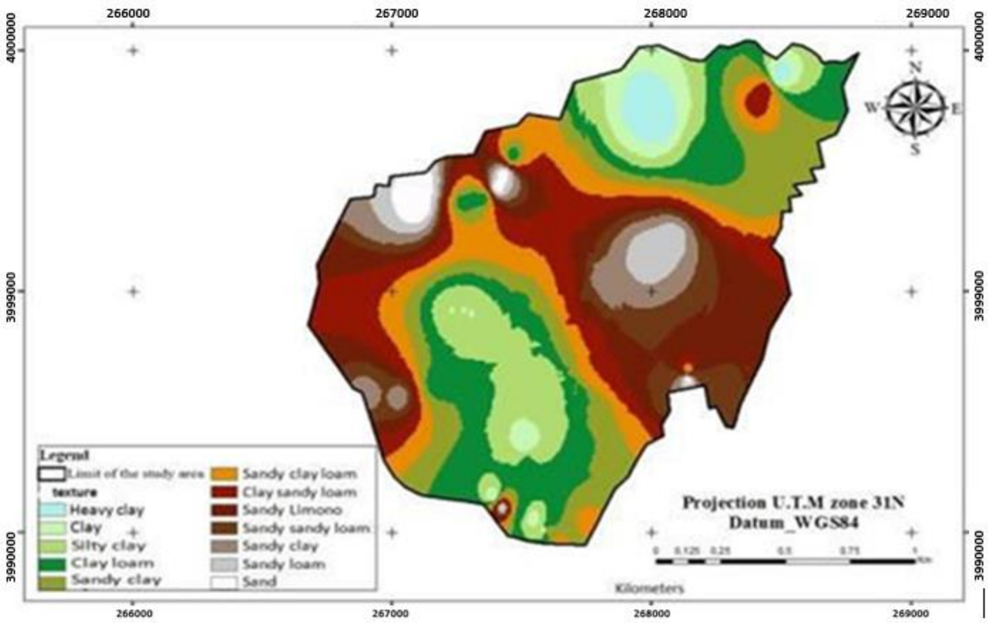

Figure 6. Map of lithology

Table 4 presents the results of the physico-chemical analyses of soil samples. pH, a key parameter for nutrient availability and microbial activity in cultivated soils (Neina, 2019 & Yaulilahua-Huacho et al., 2024), ranges from 7.1 to 8.2, indicating slightly alkaline conditions. According to Table 4, significant differences in pH have been observed between management systems, with the highest pH in the annual cropping soil (AA.S1) at 8.20. The pH values within this group are homogeneous, suggesting a consistent alkalinity, which minimizes the risks of sudden fluctuations affecting plant growth. However, a high pH can reduce the availability of certain micronutrients, such as iron and manganese.

In contrast, the mixed farming systems show lower pH levels (7.10 for MF.S2 and 7.18 for MF.S3), indicating slightly acidic conditions that enhance nutrient availability, but requiring proper management to prevent the leaching of essential elements. Overall, the soils of the western foothills of Dahra Mostaganénois, typical of semi-arid Mediterranean regions, are predominantly calcareous and may show little variation in pH (Singare et al., 2022). Mixed farming systems in this area may contribute to improved soil conditions, enhancing nutrient availability.

The observation of lower pH (KCl) values compared to pH (H2O) is consistent with soil chemistry principles, where the addition of KCl increases the ionic strength of the soil solution. This influences the availability of nutrients and the behavior of soil microorganisms, thereby impacting soil health and crop productivity (Sparks, 2019). So, the statistical analysis of soil pH (KCl) values across different management systems revealed very significant differences, essential for optimizing agricultural practices. The highest pH (KCl) values were 7.82 (AT1.S4), 7.81 (AA.S1), and 7.80 (AA.S3), indicating a more alkaline environment that is beneficial for certain crops. In contrast, mixed crop soils (MF.S3, MF.S2) showed lower pH (KCl) values of 6.79 and 6.89, highlighting the influence of soil management practices or inherent soil properties that may limit alkalinity. Soil pH plays a crucial role in nutrient uptake, as it affects the solubility of various nutrients in the soil solution.

Electrical conductivity (EC) is an indicator of soil salinity, influencing plant growth and soil structure. The study shows a range of EC values from 0.087 dS/m in MF.S3 to 2.040 dS/m in AT1.S1, the latter indicating a much higher salinity level. High salinity can harm crop growth by reducing the ability of plants to absorb water and interfering with nutrient absorption. The significantly higher EC in the non-irrigated tree crop system suggests an increased accumulation of solutes due to limited leaching. Without regular irrigation, salts accumulate in the soil. Effective management of irrigation, especially during dry periods, could mitigate these salinity issues. The total $CaCO_3$ values range from 2.41% to 16.27%. Statistical analysis revealed highly significant differences between soils from different crop management systems.

The results show higher levels of total limestone in soils from fallow system cultivation (AA2.S1 and AA2.S2) with 16.27% and 15.99%, in soils from annual field cropping (AA.S2 and AA.S1) with 15.28% and 14.72%, as well as in some soils from non-irrigated tree crop cultivation (AT1.S4 and AT1.S1) with 15.42% and 15.14%.

Soils from mixed farming agroforestry systems (MF.S1, MF.S3) belongs to the "ab" group, show a moderate difference in $CaCO_3$ compared to other agricultural systems in terms of soil management. However, an excess of calcium carbonate can reduce nutrient availability, especially at high pH, and affect soil structure by altering its texture and porosity (Umer et al., 2020). Active $CaCO_3$ levels also varied significantly, with a maximum of 6.75% in AT1.S1, indicating good potential for buffering pH. In contrast, the soils of agroforestry systems MF.S3 (0.21%) and MF.S2 (0.17%) exhibit significantly lower $CaCO_3$ levels, suggesting a low limestone content, probably due to mixed cultivation practices.

Generally, in a semi-arid region, calcareous soils are prevalent, typically containing over 15% $CaCO_3$ (Bolan et al., 2023 ; FAO, 2016). These soils have a $CaCO_3$ content ranging from 3% to over 25% by weight and pH values between 7.6 and 8.3 (Singare et al., 2022). They significantly influence soil properties that affect plant growth, including physical aspects like soil-water interactions and crust formation, as well as chemical properties affecting nutrient availability (Taalab et al., 2019).

The study reveals significant differences in soil management types regarding pH, EC, and $CaCO_3$ content. Annual and fallow cropping systems exhibit higher pH and $CaCO_3$ values, while mixed cropping systems show lower levels, particularly in limestone-related parameters. Calcareous soils can be productive when managed appropriately, highlighting the importance of tailored agricultural practices to optimize soil health. Understanding the relationships between pH, salinity, and $CaCO_3$ content can help farmers enhance crop productivity and sustainability. Future research should focus on long-term monitoring of these parameters to understand their dynamics better.

Additionally, soil organic carbon (SOC) and total N are key indicators of a soil's ability to recycle nutrients, retain water, and support biodiversity (Bünemann et al., 2018 ; Lal, 2016 ; Wiesmeier et al., 2019).

The P-values from the ANOVA suggest that there are highly significant differences among the soil management practices in terms of Organic C, Total N, OM, and Extractable P (Table 5), suggesting that these systems have a considerable impact on soil characteristics. The groups marked with different letters (abcde) indicate significant differences among the management systems. Non-irrigated tree crop cultivation (AT1.S1 to AT1.S4) and annual field cropping (AA.S1 to AA.S4) exhibit varying organic C values, with AT1.S4 showing a very highly significant difference (1.97 ± 0.06%). Additionally, MF.S4 (1.62 ± 0.20%) differs very significantly from MF.S3 (0.78 ± 0.13%), and the mixed culture systems (MF.S1 to MF.S4) also show notable variations. The soils studied showed a limitations in terms of total organic carbon content, quite the contrary, the levels obtained (1.97%) are lower the normative value range (5% - 15%). A similar result was also observed for organic matter, where the highest percentages were recorded in the cropping systems AT1.S4 and AA2, with respective values of 3.4 ± 0.1 % and 3.4 ± 0.4 %, indicating better soil quality.This good OM content could be explained by the long period of set-aside of the plots in the area, which favored significant organic inputs. Generally, the soil fertility is closely related OM content (Abdelsalam et al, 2017). The lack of soil fertility due to low OM content in semi-arid soils it may be resolved to the quality soil amelioration in these areas. No doubt that OM improves the physical condition like cohesion, structure, porosity, water retention or storage, as well as its decomposition increases the N content in the soil (Hag-Husein et al., 2021).

According to Diallo et al. (2019), the use of litter stimulates the activity and development of soil microorganisms, through the direct input of C-substrates into soil-vegetation systems. Thus, the integration of OM, such as litter from trees or shrubs into tree crop and agroforestry systems, plays a crucial role in soil conservation. It mainly contributes to improving soil structure by reducing erosion, while feeding plants through increased CEC and nutrient availability (Hatfield et al., 2017). Moreover, it has beneficial effects on biological activity, water retention, drainage, and the reservoir of nutrients (Diaité et al., 2020).

The total N values follow a similar trend, with AT1.S4 (0.18 ± 0.02 %) showing the highest concentration. The other systems, such as MF.S2 (0.04 ± 0.01 %), exhibit much lower values. Generally in alkaline soils (pH > 7), N is lost from soil by ammonia volatilization process, this is further exacerbated in presence $CaCO_3$ in calcareous soil (Samal & Kumar, 2020).

The C/N ratio varies significantly between plots. The soil at the MF.S2 site has the highest C/N ratio (25.9 ± 6.5), indicating slower OM decomposition due to the relative abundance of C compared to N. In contrast, the soil at the AA.S1 site, with a lower C/N ratio (10.2 ± 1), suggests faster decomposition, likely due to a higher availability of N relative to C. Except for MF.S2. The cropping systems that tend to perform the best, showing the highest levels of C, N, and OM, are typically those that incorporate agroforestry or mixed practices. This suggests that such methods are advantageous for soil health. The plot MF.S4 stands out with the highest levels of organic C and total N, suggesting superior soil fertility. The plot MF.S1 shows a balance between organic C and total N, with a low C/N ratio, indicating efficient nutrient cycling and good nutrient availability. For the plot MF.S3, with slightly higher N levels, also has a lower C/N ratio, suggesting better nutrient availability.

For extractable P, a high values was recorded in the soil of the AA.S1 (8.37 ± 4.02 $mg.kg^{-1}$) followed by AT1.S4 (6.83 ± 2.04 $mg.kg^{-1}$), while other systems have much lower values. The phosphorus availability levels measured across all systems in the study area are below the critical threshold, which ranges by 20 $mg\ kg^{-1}$. Phosphorus is generally lower in calcareous soils (Singare et al., 2022). Additionally, inappropriate agricultural practices in the region have contributed to soil depletion, resulting in common deficiencies of P, K, and N (Diallo et al., 2018). Consequently, the limited availability of P in these soils acts as a major constraint on plant growth (Alori et al, 2017 ; Bindraban et al, 2020 ; El Attar et al, 2022).

Increased organic C and N levels are associated with better soil quality across various farming systems, with fallow and mixed farming systems showing particularly positive results, which are generally beneficial for soil fertility and health. The statistical results emphasize the crucial role that soil management practices play in determining soil quality and fertility. Practices that boost C, N, and OM content are particularly beneficial for improving soil health and enhancing agricultural yields. The results from the analysis of soil nutrients and CEC provide valuable insights into the effects of different agricultural management practices (Table 6).

Significant differences were found in the levels of Ca^{2+}, Mg^{2+}, K^+, Na^+, and overall CEC ($P < 0.05$), emphasizing the influence of management systems on these nutrients. The considerable variation in nutrient concentrations (Ca^{2+}, Mg^{2+}, K^+, Na^+) across different systems indicates that management practices play a crucial role in shaping soil chemistry. The average sodium content recorded in the studied soils is considered normal because the values obtained are less than 1.0 Cmol/kg (threshold value). This indicates that the soils present low risks of salinity for plants and are therefore favorable for agriculture.

Non-irrigated tree crop cultivation (AT1.S1) showed the highest concentrations of Ca^{2+}, Mg^{2+}, and Na^+. In contrast, the agroforestry systems (MF.S2 and MF.S3) exhibited significantly lower nutrient levels. For the Ca^{2+}, the values are higher than the standard range (5.0 to 10.0 cmol/kg). This can hinder the absorption of other essential nutrients like K^+ and resulting in deficiencies, as observed in the case of (MF.S2) where the average level is 0.29 cmol/kg. While limestone soils typically have adequate potassium, the elevated calcium concentration can interfere with the absorption of K^+ ions (Singare et al., 2022).

The climatic conditions of the study area form significant challenges for the availability of nutrients and soil fertility, which are major limiting factors for agricultural production. The soils in this region are usually alkaline and accumulate minerals such as K^+, $Na^+$and Ca^{2+}at levels that can adversely affect plant growth (Hag-Husein, 2021). This accumulation occurs mainly due to the lack of water, which inhibits the dissolution of CO_3, in the form of C bonds with O_2 to form carbonates under dry conditions (Hag-Husein, 2021).

The CEC is a crucial factor for soil fertility, as it measures nutrient retention. The AT1.S1 and AA2.S2 systems show high CEC values due to better OM, while agroforestry systems (MF.S2 and MF.S3) display low values, indicating poor nutrient management and a risk of loss during heavy rains. Strategies like cover cropping could improve the situation. This suggests that agroforestry practices enhance soil nutrient availability through OM from trees, improved root structures, and reduced erosion. The ability of these systems to retain nutrients is essential for agricultural production and soil health. The study highlights the importance of management practices in nutrient dynamics and CEC.

The classification of the chemical fertility of the studied ecosystems is based on specific indicators such as the pH, the levels of exchangeable cations, the available P content or the C/N ratio, may fluctuate depending on the indicator chosen. Therefore, the observed differences in nutrient levels and CEC underline the importance of long-term management of soil health. To maintain agricultural productivity in the study area, it is essential to adopt nutrient management strategies that increase organic matter and stimulate biological activity in the soil. These approaches can improve nutrient levels in underperforming systems. The results support agroecological practices, such as agroforestry, which enhance soil health, improve nutrient cycling, pest control, and resilience to climate change.

Table 4. Physico-chemical analyses (pH, EC and $CaCO_3$) results of cultivated soils in the study area

Factor	Management		Parameters				
			pH(H_2O)	pH(KCl)	EC (dS/m)	Total $CaCO_3$ (%)	Active $CaCO_3$ (%)
Mixed farming	Agroforestry system soil	MF.S1	7.79 ± 0.09 b	7.58 ± 0.07 ab	0.250 ± 0.017 b	14.15 ± 1.37 ab	4.71 ± 0.69 c
		MF.S2	7.1 ± 0.17 c	6.89 ± 0.19 c	0.207 ± 0.159 b	3.26 ± 1.07 d	0.17 ± 0.07 e
		MF.S3	7.18 ± 0.27 c	6.79 ± 0.26 c	0.087 ± 0.012 b	2.41 ± 0.67 d	0.21 ± 0.07 e
		MF.S4	7.86 ± 0.03 ab	7.62 ± 0.02 ab	0.240 ± 0.036 b	10.61 ± 5.00 ab	5.25 ± 0.33 bc
Agricultural cropping	Non-irrigated tree crop cultivation soil	AT1.S1	7.90 ± 0.20 ab	7.64 ± 0.19 ab	2.040 ± 0.485 a	15.14 ± 0.65 a	6.75 ± 0.57 a
		AT1.S2	7.91 ± 0.04 ab	7.72 ± 0.03 ab	0.170 ± 0.026 b	4.15 ± 1.68 d	1.13 ± 0.55 e
		AT1.S3	7.99 ± 0.13 ab	7.72 ± 0.19 ab	0.217 ± 0.074 b	6.08 ± 0.89 cd	0.25 ± 0.12 e
		AT1.S4	8.05 ± 0.01 ab	7.82 ± 0.02 a	0.247 ± 0.038 b	15.42 ± 0.89 a	6.42 ± 0.75 ab
	Annual field cropping soil	AA.S1	8.20 ± 0.13 a	7.81 ± 0.23 a	0.247 ± 0.081 b	14.72 ± 1.49 a	6.38 ± 0.45 ab
		AA.S2	8.17± 0.03 a	7.76 ± 0.02 ab	0.370 ± 0.295 b	15.28 ± 1.47 a	4.71 ± 0.63 c
		AA.S3	8.15 ± 0.12 a	7.80 ± 0.12 ab	0.313 ± 0.179 b	13.87 ± 4.29 ab	5.38 ± 0.76 bc
		AA.S4	8.16 ± 0.03 a	7.73 ± 0.13 ab	0.193 ± 0.040 b	9.62 ± 0.88 bc	2.88 ± 0.57 d
	Fallow system cultivation soil	AA2.S1	7.94 ± 0.05 ab	7.42 ± 0.04 b	0.267 ± 0.057 b	16.27 ± 1.91 a	4.79 ± 0.89 c
		AA2.S2	8.18 ± 0.03 a	7.75 ± 0.04 ab	0.167 ± 0.025 b	15.99 ± 1.61 a	6.21 ± 0.31 ab
	ANOVA P-value		***	***	***	***	***

MF.S : Soil samples collected under agroforestry system. AT1.S : Soil samples collected under non-irrigated tree crop cultivation. AA.S : Soil samples collected under annual field cropping. AA2.S : Soil samples collected under fallow system cultivation.

NS = Not significant. * = Significant. ** = Highly significant. *** = Very highly significant at the probability level 5%. 1% and 1 ‰ respectively.

Different letters indicate significant differences using the Student-Newman-Keuls test. P value ≤0.05

Table 5. Results of OM rate and total elements of cultivated soils in the study area

Factor	Management		Parameters				
			Organic C (%)	Total N (%)	OM (%)	C/N ratio	Extractable P (mg.kg^{-1})
Mixed farming	Agroforestry system soil	MF.S1	1.00 ± 0.20 de	0.10 ± 0.01 bc	1.7 ± 0.3 cd	10.8 ± 1.9 c	2.17 ± 0,38 ab
		MF.S2	0.84 ± 0.09 e	0.04 ± 0.01 d	1.4 ± 0.2 d	25.9 ± 6.5 a	2.15 ± 1.51 ab
		MF.S3	0.78 ± 0.13 e	0.05 ± 0.01 cd	1.3 ± 0.2 d	13.8 ± 0.9 bc	2.80 ± 0.71 ab
		MF.S4	1.62 ± 0.20 abc	0.13 ± 0.02 b	2.8 ± 0.3 ab	12.3 ± 1.2 bc	4.13 ± 0.52 ab
Agricultural cropping	Non-irrigated tree crop cultivation soil	AT1.S1	0.98 ± 0.22 de	0.09 ± 0.03 bc	1.7 ± 0.4 cd	12.2 ± 2.8 bc	2.13 ± 0.61 ab
		AT1.S2	1.11 ± 0.16 de	0.06 ± 0.01 cd	1.9 ± 0.3 cd	20.3 ± 5.9 b	1.81 ± 0.27 b
		AT1.S3	1.25 ± 0.04 cde	0.08 ± 0.03 bc	2.2 ± 0.1 cd	15.6 ± 0.4 bc	4.01 ± 2.76 ab
		AT1.S4	1.97 ± 0.06 a	0.18 ± 0.02 a	3.4 ± 0.1 a	11.0 ± 1.1 c	6.83 ± 2.04 ab
	Annual field cropping soil	AA.S1	1.08 ± 0.29 de	0.08 ± 0.03 bc	1.5 ± 0.3 d	10.2 ± 1.0 c	8.37 ± 4.02 a
		AA.S2	1.17 ± 0.12 de	0.09 ± 0.01 bc	2.0 ± 0.2 cd	13.5 ± 0.7 bc	3.64 ± 0.42 ab
		AA.S3	1.21 ± 0.09 cde	0.10 ± 0.01 bc	2.1 ± 0.2 cd	11.7 ± 0.6 bc	4.92 ± 2.27 ab
		AA.S4	1.37 ± 0.34 bcd	0.11 ± 0.02 b	2.4 ± 0.6 bc	12.1 ± 0.3 bc	4.94 ± 1.59 ab
	Fallow system cultivation soil	AA2.S1	1.72 ± 0.16 ab	0.12 ± 0.03 b	3.0 ± 0.3 ab	14.9 ± 2.9 bc	7.42 ± 4.88 ab
		AA2.S2	1.95 ± 0.26 a	0.13 ± 0.03 b	3.4 ± 0.4 a	15.7 ± 5.3 bc	3.35 ± 0.45 ab
	ANOVA P-value		***	***	***	***	***

MF.S : Soil samples collected under agroforestry system. AT1.S : Soil samples collected under non-irrigated tree crop cultivation. AA.S : Soil samples collected under annual field cropping. AA2.S : Soil samples collected under fallow system cultivation.
NS = Not significant. * = Significant. ** = Highly significant. *** = Very highly significant at the probability level 5%. 1% and 1 ‰ respectively.
Different letters indicate significant differences using the Student-Newman-Keuls test. P value ≤0.05

Table 6. Results of exchangeable cations and Estimate CEC of cultivated soils in the study area

Factor	Management		Nutriments (cmol⁺.kg⁻¹)				Estimate CEC (cmol⁺.kg⁻¹)
			Ca^{2+}	Mg^{2+}	K^+	Na^+	
Mixed farming	Agroforestry system soil	MF.S1	32.68 ± 1.41 ab	2.46 ± 1.36 bc	0.92 ± 0.17 abc	0.19 ± 0.18 b	36.25 ± 2.65 bc
		MF.S2	3.18 ± 0.29 d	0.37 ± 0.04 c	0.29 ± 0.11 c	0.04 ± 0.01 b	3.88 ± 0.32 e
		MF.S3	7.43 ± 3.87 d	1.42 ± 1.26 bc	0.57 ± 0.24 bc	0.15 ± 0.14 b	9.57 ± 5.50 e
		MF.S4	32.86 ± 5.43 ab	1.53 ± 0.42 bc	0.81 ± 0.34 abc	0.12 ± 0.03 b	35.33 ± 5.22 bc
Agricultural cropping	Non-irrigated tree crop cultivation soil	AT1.S1	43.46 ± 4.05 a	4.52 ± 0.24 a	0.81 ± 0.05 abc	1.43 ± 0.82 a	50.22 ± 4.84 a
		AT1.S2	27.09 ± 2.42 bc	0.77 ± 0.18 bc	0.50 ± 0.09 bc	0.06 ± 0.01 b	28.42 ± 2.53 cd
		AT1.S3	21.32 ± 7.40 c	1.89 ± 0.32 bc	0.99 ± 0.09 ab	0.30 ± 0.07 b	24.50 ± 7.78 d
		AT1.S4	38.87 ± 2.32 a	2.65 ± 0.37 b	0.91 ± 0.23 abc	0.14 ± 0.01 b	42.57 ± 0.51 ab
	Annual field cropping soil	AA.S1	34.96 ± 0.30 ab	1.40 ± 0.50 bc	0.69 ± 0.23 bc	0.19 ± 0.12 b	37.24 ± 2.24 bc
		AA.S2	39.97 ±2.07 a	1.33 ± 0.21 bc	0.68 ± 0.05 bc	0.10 ± 0.01 b	42.08 ± 6.92 ab
		AA.S3	38.08 ± 7.87 ab	2.13 ± 1.63 bc	0.71 ± 0.26 abc	0.58 ± 0.83 b	41.50 ± 6.92 ab
		AA.S4	38.06 ± 4.46 ab	1.65 ± 0.56 bc	1.32 ± 0.58 a	0.15 ± 0.07 b	41.19 ± 5.16 ab
	Fallow system cultivation soil	AA2.S1	36.54 ± 5.20 ab	1.95 ± 0.51 bc	0.45 ± 0.13 bc	0.23 ± 0.07 b	39.18 ± 5.23 abc
		AA2.S2	41.95±5.00 a	2.21 ± 0.65 bc	0.50 ± 0.11 bc	0.48 ± 0.53 b	45.13 ± 5.22 ab
	ANOVA P-value		***	***	**	**	***

MF.S : Soil samples collected under agroforestry system. AT1.S : Soil samples collected under non-irrigated tree crop cultivation. AA.S : Soil samples collected under annual field cropping. AA2.S : Soil samples collected under fallow system cultivation.
NS = Not significant. * = Significant. ** = Highly significant. *** = Very highly significant at the probability level 5%. 1% and 1 ‰ respectively.
Different letters indicate significant differences using the Student-Newman-Keuls test. P value ≤0.05

Conclusion

Fertilization remains a key ancestral practice in the management of agricultural lands. It influences the diversity and composition of soil microbiomes, with significant repercussions on their physicochemical properties and resource availability as well as on their productivity. In practicing rainfed agriculture, little attention has been given to assessing and improving fertility status in the semi-arid areas of the Dahra foothills. However, with limited fertility, a low OM content, low water retention capacity, and other constraints such as alkalinity, the productivity of agricultural soils in the study area is significantly restricted by the farming systems practiced. In this context, agroforestry systems can be a promising solution. Thus, agroforestry represents an effective means of restoring the physicochemical and biological balances of degraded soils, leading to improved productivity of agricultural lands in the study area. Even though they are as old as they are, agroforestry practices are not always well understood by farmers in the study area. There is a need for awareness-raising and dissemination to facilitate their adoption. The study could recommend implementing a monitoring and evaluation system for agroforestry practices to ensure sustainable soil fertility improvement. To achieve this, in-depth research on the physico-chemical and biological properties of soils will be necessary. This would allow for tracking soil fertility over the long term and more accurately assessing the effectiveness of agroforestry systems.

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Author's declaration

We have no conflict of interest to declare

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