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Effects of Crop Types on the Physicochemical and Biological Properties of Agricultural Soils in Semi-Arid Regions (Western Algeria)

Mohamed Zouidi[1]*, Amine Habib Borsali[2], Ayoub Allam[3], Salah Hadjout[1], Imane Hadjadji[2], Djemaa Chikhi[2] and Anne-Marie Farnet Da Silva[4]

[1]Centre de Recherche en Aménagement du Territoire (CRAT), Campus Zouaghi Slimane,
Route de Ain el Bey,25000 Constantine, Algéria
[2]Laboratory "Water Resources and Environment" Dr. Tahar Moulay University, Saida, Algeria
[3]Centre de Recherche en Technologies Agro-Alimentaires (CRTAA),
Campus universitaire Tergua Ouzemour, Bejaia,06000, Alegria
[4]Aix Marseille University, CNRS, IRD, Avignon University, IMBE UMR 7263, Marseille, France

**Correspondence: mohamed.zouidi@crat.dz ; zouidibiologie20@gmail.com*

ABSTRACT

The soil is an element of the biosphere that forms the foundation for agricultural production. Agricultural practices can have a significant impact on the quality of soils, and therefore on the productivity and sustainability of agriculture. Thus, it is crucial to evaluate the impact of different crops on soil fertility and determine the most sustainable agricultural practices to maximize productivity while preserving soil quality. The present work examines the quality variability of agricultural soils due to cultivating different crops in a semi-arid zone in western Algeria. The research aims to compare the impact of three different crops (legumes, cereal and fruit tree cultivation) on the fertility of agricultural soils. To achieve this, we compared the physicochemical and biological properties of 75 soil samples distributed among three types of crops (five sampling stations of 400 m^2 per crop). The results show that agricultural soils in the studied areas are generally characterized by a sandy texture with differences in some physicochemical parameters, notably high moisture content and water retention in arboriculture (7,87%; 53%). Soils in cereal crops are rich in carbon (0,62 g/kg), whereas soils in legumes are rich in nitrogen (0,10 g/kg), which ensures good mineralization of organic matter (C/N: 5,15). Biological property analysis indicates that microbial biomass and its effectiveness are generally homogenous ($p > 0.05$), with a small significant difference in basal respiration ($P < 0.05$). The diversity of microflora (bacteria, fungi, and rhizobium) is influenced by organic matter differentiation caused by the agricultural practices used for each crop and their effects on the physicochemical properties of agricultural soils. In conclusion, this study shows that different types of crops have a significant impact on the quality of agricultural soils in a semi-arid zone in western Algeria. The results highlight the importance of considering the effects of different crops on soil properties to optimize crop yields and ensure the sustainability of agriculture in this region.

Key words: **Soil quality, physicochemical parameters, microbial biomass, microbial diversity, aridity**

INTRODUCTION

Soil represents the support of agricultural production and the interface with other biosphere compartments. It fulfils many essential functions for providing ecosystem services necessary for the well-being of our societies (Bourgeois 2015; Pavan and Ometto 2018). It is also a non-renewable resource as its physicochemical and biological properties have been altered by the development of intensive agriculture (Chabert and Sarthou 2017; Douaer *et al.* 2021). The current awareness of this situation has revealed the need to define new management methods adapted to the preservation and sustainable use of soils. This awareness has marked the entry of agroecology into the agriculture sector which advocates a production model that optimizes the services provided by biodiversity to reduce the use of inputs and energy (INRA 2006; Bourgeois 2015).

The Mediterranean basin is dominated by rain-fed agriculture with a wide cultivation practice of winter cereals such as wheat and barley, rotated with a fallow period lasting from 16 to 18 months (Raymond *et al.* 2018). When moisture permits, cereals are accompanied by olive trees, almond trees, and vines. With irrigation, diversification and intensification are practised, including the cultivation of fruit trees (apple, pear, peach, citrus, olive), vegetables (fava beans, lentils, chickpeas), forage crops (vetch, alfa), potatoes, industrial crops (sunflower, sugar beet, cotton, rapeseed) (Lahmar 2006). On the southern shores of the Mediterranean, especially in arid areas, livestock farming is present in virtually all agroecosystems, with a strong interaction with crops, particularly in cereal-growing regions where it has been and continues to be the main, if not the only, basis for economic activity in these regions (Merdas *et al.* 2021).

Soil is a living environment and constitutes an exceptional reservoir of different microorganisms and genes that determine various activities, which are more or less directly linked to their functioning in general and some of their agronomic properties in particular (Timmis and Ramos 2021). These microorganisms are the foundation of the biosphere and play an important role in biogeochemical cycles, conditioning the efficiency and mechanisms of soil organic matter use (Bowles *et al.* 2014; Dhaliwal *et al.* 2019). These diverse organisms interact with each other and plants and animals in the ecosystem, forming a complex network of biological activities that contribute to a wide range of essential services for the sustainable functioning of all ecosystems. These services are essential for the functioning of natural ecosystems and constitute an important resource for the sustainable management of agricultural systems. The biological activity and composition of the soil can be affected by the spatial variability of agricultural landscapes, including variations in soil physicochemical characteristics and agroecosystem management (Schipanski and Drinkwater 2012; Vasseur *et al.* 2013).

Today, inappropriate types and cultural practices and land over-exploitation that do not correspond to the pedoclimatic evolution of the environment, combined with the conventional tillage technique involving ploughing (cutting and turning over a strip of land), have reached their development limits in arid regions, where tilled lands are directly subject to erosion problems (Abdellaoui *et al.* 2010; Boudiar *et al.* 2022). Comparing agricultural soil to a reference site under a native forest, carbon stocks were 50 to 75% lower in agricultural soils (Spaccini *et al.* 2004; Zouidi *et al.* 2019). Therefore, it is very easy to lose soil organic carbon due to its use and management, but it is very difficult to reach the initial level found in natural forests (Pouya *et al.* 2013; Di Sacco *et al.* 2021). The effects of land use, management practices, and types of agriculture on the physical, chemical, and microbiological properties of soil can provide essential information for assessing sustainability and environmental impact (Swarup *et al.* 2019). It is nevertheless indispensable to stem the degradation of soils, which has continued to increase over the past decades (Zouidi *et al.* 2018; Diop *et al.* 2022).

This work aims to study the effect of crop types based on their rooting and agricultural practice systems of each crop type on the physicochemical and biological quality of agricultural soils in the semi-arid zone. In this study, we focused on studying agricultural soils in the Saida region (western Algeria) of the three most commonly grown crops in this area: cereals, legumes (cultivation of fava beans and peas), and orchards (almond groves).

MATERIALS AND METHODS

Localization and Description of Study Sites

The study area is a ten-hectare agricultural land located 45 km west of Saida upstream of the Youb municipality, in a semi-arid zone (34°57'46.86"N; 0°12'6.71"W; altitude 670 m). The agricultural land contains a one-hectare almond orchard, with the remaining area generally cultivated with cereal crops (wheat and barley) and food legumes (broad beans and cultivated peas) (Figure 1).

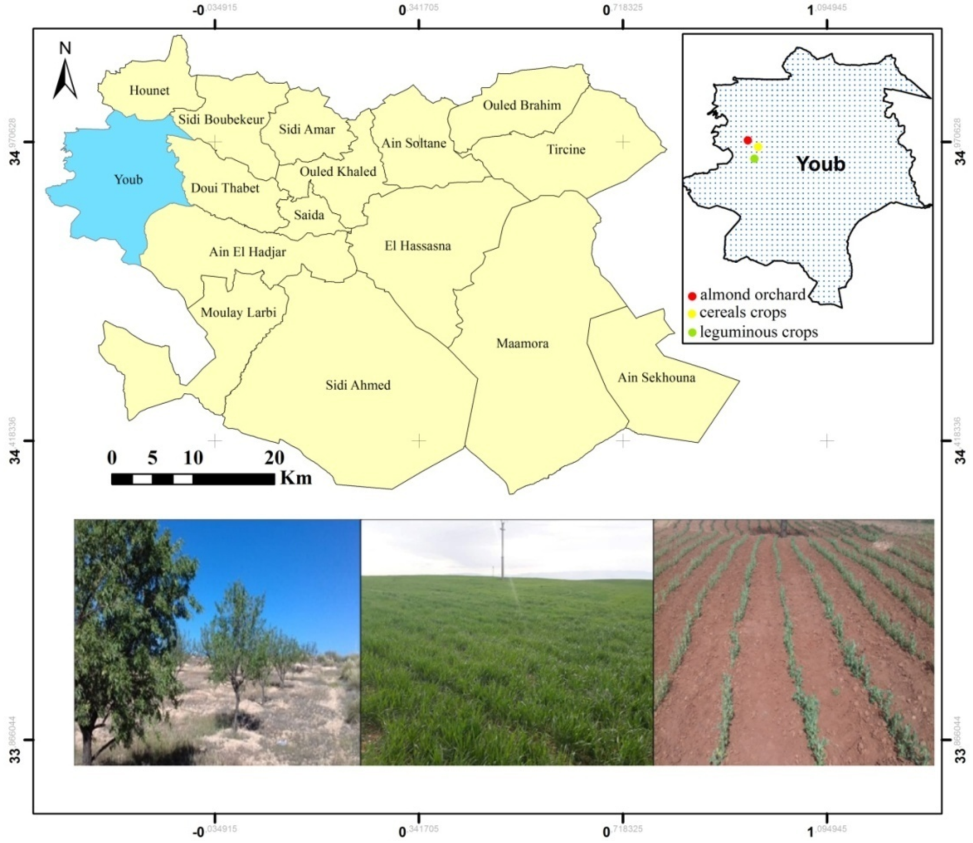

Figure 1. The study area with the different sampling stations (March 2019).

Soil Sampling

Five sampling stations were selected for each type of crop (cereal, legume, almond orchard). At each station with an area of 400 m^2, five soil samples were randomly collected in March 2019, at a depth ranging from 0 to 20 cm corresponding to the organic-mineral surface horizon, resulting in a total of 25 samples for each crop type. The composite soil samples were sieved at 2 mm to perform certain physicochemical analyses, and a portion was kept at 4°C for 15 days pending biological analyses.

Physical Analysis

Field moisture content was measured according to the protocol of (Mathieu and Pieltain 1998). Soil water content was obtained by subtracting the mass of a soil sample after oven-drying (105°C, 24 h) from the mass of the sample before drying. Water content at field capacity was obtained using PVC cylinders according to the protocol described by Saetre (1998). Bulk density (Da) corresponds to the dry weight of a soil volume with an undisturbed structure and is measured by the cylinder method using undisturbed samples, knowing the constant dry weight of the samples at 105 °C and the volume of the cylinder used for sampling (Blake and

Hartge 1986). The measurement of real density (Dr) was determined by the pycnometer method, which consists of determining the volume of benzene displaced by the solid phase of a sample of known mass in a known volume (Petard 1993). Porosity can be determined from real and bulk density. Soil permeability represents the height of water infiltrated per unit of time evaluated by centimeters (Mathieu and Pieltain 1998).

Chemical Analysis

Total organic carbon was determined by the method of oxidation of the cold organic matter by an excess of potassium dichromate ($K_2Cr_2O_7$) in the presence of concentrated sulfuric acid according to the protocol of Anne described by Aubert (1978). Total nitrogen is measured using the Kjeldhal method. Organic matter content is measured by the loss of mass of a dried sample upon calcination at 550°C for 16 h. pH and electrical conductivity are first measured in boiled distilled water on a fine earth suspension (1:2.5) using the electrometric method with a glass electrode (pH meter HI2210; conductimeter HI2300). Total limestone ($CaCO_3$) was estimated using the Bernard calcimeter. This method measures the volume of CO_2 released by the soil samples upon exposure to hydrochloric acid (HCl) (Aubert 1978).

Biological Analysis

Basal respiration: Basal respiration (µg C-CO_2/g dry soil) allows for the evaluation of the physiological state of soil microbial communities. It is measured using the protocol described by Anderson and Domsch (1978) with the help of a gas chromatograph (Chrompack CHROM 3 – CP 9001). The chromatograph was equipped with a TCD detector and a packed column (Porapack) through which helium flowed at a rate of 60 mL/h. The obtained values were adjusted to 22 °C by the ideal gas law with Q10 = 2. Ambient concentrations of CO_2 were subtracted from the concentrations of CO_2 measured after incubation to obtain the amount of CO_2 produced by the heterotrophic microorganisms contained in the sample.

Microbial biomass: The microbial biomass was estimated using the method of induced respiration by adding a mixture of talc and glucose (1,000 µg C g-1 soil) to ten g (dry equivalent) of soil, after incubation to reach a maximal rate of induced respiration (Anderson and Domsch 1978). The CO_2 concentration in the flasks was analyzed by gas chromatography and corrected in the same manner as described previously for basal respiration. The rates of induced respiration were converted to microbial biomass values using the equation given by (Beare *et al.* 1990).

Enumeration of the Microflora

The condition of the soil can be determined by analyzing the state of various groups of microorganisms, including bacteria, actinomycetes, fungi, algae, and rhizobia. The microflora of the soil is characterized by the number of distinct groups within the microbial population of the soil. However, analyzing the state of different microorganisms in the soil is of great importance. Measuring microbial densities using the soil suspension-dilution technique is a good overall indicator.

Bacterial microflora: To obtain bacteria from soil, it is sufficient to suspend a few grams of soil in water. After agitation and settling, we spread a few drops of the supernatant onto a nutrient agar medium with soil extract. This results in separate colonies, each originating from a single bacterium (Davet 1996). The results are read by counting the colonies that appear after incubation for 24 h at 28°C using a colony counter.

Fungi: Fungi are cultivated on a culture medium (PDA) and inoculated with soil suspension dilutions at a rate of 3 drops from each dilution (10^{-1} to 10^{-6}), or 0.2 ml, deposited on each plate and carefully spread over the entire surface. Generally, efforts are made to avoid competitive bacterial growth by acidifying the medium or adding citric acid to a pH of 4 (Davet 1996). The results are read starting from the seventh day of incubation (28°C).

Rhizobia: Inoculation is done with soil suspension dilutions on a sterilized YEM (Yeast, Extract, Mannitol) medium autoclaved at 120°C for 20 min, which particularly favors the growth of rhizobia by inhibiting the growth of other microorganisms. Three dilution plates between 10^{-2} and 10^{-6} are inoculated. Incubation is done for 72 h at 28°C in an inverted position (Vincent 1970).

Statistical Analysis

Statistical analysis of the results was performed using Minitab 17 software to compare the soil results based on the analytical variability of the physicochemical and biological properties among the soils of the study area using one-way analysis of variance (One-Way ANOVA). Then, the homogeneity of the groups was tested using Fisher's test.

RESULTS AND DISCUSSION

The soil is the superficial part that forms the skin of our planet and represents only a thin layer; but farmers or foresters understand its importance well because it forms a non-renewable resource on the scale of human life. Hence, it is of utmost importance to know its characteristics. It is in the soil that seeds germinate and organic matter is recycled (Lal 2015; Girard *et al.* 2011). The physical, chemical, and biological characteristics of the soil condition the functioning of the entire ecosystem, but conversely, climatic factors, type of vegetation, presence or absence of fauna, and nature of the parent rock, also influence the formation and evolution of soils (Bai *et al.* 2018; Kehal *et al.* 2021; Dahmani *et al.* 2023). Fertile soil is fundamental to our ability to achieve food security, but soil degradation problems are exacerbated by poor management. Therefore, it is necessary to better understand management approaches that provide multiple ecosystem services from agricultural lands (Holland *et al.* 2018).

Relationship Between Physical Quality of Agricultural Soils and Type of Agriculture Practiced

Agricultural soils in our study area for different crop types exhibit significantly different physical properties ($p<0.05$), except for values of bulk density and porosity (Table 1). Based on the average particle size distribution, soils under cereals and legumes have a loamy-sandy texture while soils intended for orchards have a loamy-clay texture. The cereal field has the lowest moisture content (4.68%) compared to other types, which shows homogeneity for moisture content (6.79% - 7.87%). The presence of a proportion of clay in orchard soils significantly increases bulk density (1.67 g/cm^3) and decreases porosity and permeability (45.3% - 37.19 cm/h).

TABLE 1

Physical properties of agricultural soils under the different crop types

Physical properties	Cereals	Legume	Arboriculture	Calculated f value and significance
Texture	loamy-sandy	loamy-sandy	loamy-clay	/
Moisture (%)	4.68±0.88^{b}	6.79± 1.05^{a}	7.87± 1.17^{a}	12.07**
Water retention (%)	46.32± 1.27^{b}	44.46± 1.86^{b}	53.38± 4.21^{a}	14.53**
Apparent density (Da)	1.22± 0.06^{b}	1.34± 0.07^{b}	1.64± 0.33^{a}	5.61*
Real density (Dr)	3.60± 2.33^{a}	3.60± 1.15^{a}	3.07± 1.08^{a}	0.17ns
Porosity (%)	63.99±12.27^{a}	59.84±10.53^{a}	45.3± 22.7^{a}	1.86ns
Permeability (cm/h)	41.65± 1.55^{a}	41.99± 0.85^{a}	37.19± 0.97^{b}	26,14**

Knowledge of soil texture allows for indication of trends in the physical qualities of soil that primarily influence soil water regimes. According to the performed granulometric analysis, the change in soil texture between arboriculture and other crops is the result of tillage that varies according to the different types of crops grown. According to Roger-Estrade *et al.* (2014), tillage technique changes depend on the type of crop practised, which modifies the soil texture, such as the arrangement of voids, aggregates, pore connectivity, and soil aeration (Steponavičienė et *al*. 2022). In our study area, as the same semi-arid climatic conditions prevailed, significant variation in moisture is explained by the type of crop and its rooting in the soil, as well as the effect of agricultural practices, particularly tillage, which can modify soil physical parameters (Boiffin *et al.* 2020). It is therefore essential to take into account the cumulative effects of cropping systems to manage the conditions for tillage intervention. The proportion of sand present in cereal and legume soils prevents them from retaining water, unlike the soil in arboriculture, which contains a higher proportion of clay and promotes water retention. Additionally, vegetation cover plays a role in water retention as protected soil is less susceptible to evaporation. Other scientists explain variations in soil moisture by the effect of variations in precipitation and temperature.

The accumulation of organic matter on the surface layers, particularly depending on the type of crop (cereal and legumes), contributes to improving the physical properties of the soil, particularly its apparent density to provide better porosity (Brewer *et al.* 2014). Several studies, particularly on semi-arid climates in Morocco, have shown that no-till and the passage of agricultural machinery make the soil more compact and less permeable, such as in the case of arboriculture (Mrabet *et al.* 2001). Soils containing more clay have a very compact and dense structure, which decreases their porosity and permeability, making water movement slower.

Chemical Quality Changes of Agricultural Soils Depend on Type of Crop

The determination of carbon and nitrogen levels in the different soils shows a very small variation ($p<0.05$), with the highest carbon level recorded for cereal crops (0.62g/kg), followed by legume soils (0.56g/kg) and orchards (0.53g/kg). In contrast, the highest nitrogen level is found in soils under legumes (0.108g/kg), followed by cereal crops (0.082g/kg). Organic matter levels are correlated with carbon levels. The pH of the studied plots' soils is generally alkaline (pH>8), with a significant difference between agricultural types (p<0.01). The electrical conductivity of soils from different crop type ranges from 0.08 ms to 0.10 ms, and according to Aubert's salinity scale (1978), these are non-saline soils (CE<0.6 mS). Measurements of limestone content show a high level of limestone in orchard soils, which are strongly calcareous (27.53%), while cereal and legume soils are weakly calcareous (between 6.67% and 8.01%). Statistical analysis shows a highly significant difference (p<0.01).

TABLE 2

Chemical properties of agricultural soils under the different crop types

Chemical properties	Cereals	Legume	Arboriculture	Calculated f value and significance
Carbon (C) (g/kg)	0.62±0.14^{a}	0.56 ± 0.18^{ab}	0.53± 0,28^{b}	F=1.78*
Nitrogen (N) (g/kg)	0.08±0.03^{ab}	0.11±0.04^{a}	0.05± 0,01^{b}	F=5.81*
C/N	8.03±1.67^{ab}	5.15±0.95^{b}	11.95±7.91^{a}	F=2.63*
Organic matter (%)	1.07±0,25^{a}	0.97±0,32^{b}	0,92± 0,48^{b}	F=1.18*
pH water	8,17 ± 0,05^{b}	8.20 ± 0.03 ^{b}	8.61± 0,05 ^{a}	F=35.03**
Conductivity (mS)	0.09± 000	0.10± 0.02	0.10± 0.01	F=1.03NS
Total limestone (%)	810 ±3.61^{b}	6.66 ± 1.99 ^{b}	27.53 ± 3.39 ^{a}	F=71.59**

A change or difference in soil management according to the type of agriculture practised can lead to changes in the physical properties of the soil and consequently affect the chemical and biological properties of the soil, and thereforeits function (Chan 2001; Islam and Weil 2000). The evolution of carbon levels in the soil depends on the mechanisms protecting organic matter (OM) from microbial biodegradation, namely: physical protection by trapping OM inside soil aggregates, physicochemical protection by the association of OM with the mineral fraction of the soil, and chemical recalcitrance of OM due to condensation of its chemical structure (Chenu *et al.* 2019). Intensive agricultural practices often cause erosion, leading to soil fertility degradation (García-Ruiz *et al.* 2009; Comino *et al.* 2018). Soil organic carbon (SOC) contributes to maintaining soil health and food security due to its important role in water retention and nutrient supply (Allam *et al.* 2021; Lessmann *et al.* 2022). Legumes, which are an important part of farming systems, have been extensively studied for their significant ecological benefits, particularly in enriching the soil with nitrogen (Aschi *et al.* 2017). During growth, legumes can fix N2 from the atmosphere through symbiotic associations with rhizobia, increasing the nitrogen (N) content of legume biomass (Espinoza *et al.* 2020). The N fixed in the soil by legumes and contained in their residues that enter the soil, increases the availability of N for the benefit of other crops grown in the farming system, thus increasing the supply of C to the agroecosystem (Liu *et al.* 2022). Furthermore, legume residues in the soil with a lower C/N ratio can be effectively utilized by the soil microbiome, thus reducing C losses in the agroecosystem (Cotrufo *et al.* 2013).

In contrast, cereal crops are an excellent source of organic matter for agricultural soils due to their straw, which improves carbon storage (Solberg *et al.* 2019). Land use type strongly affects the control of nitrogen and carbon levels in the soil and allows for control of the C/N ratio (Assemien 2018). According to Baise (2018), the C/N ratio serves to characterize the organic matter under the type of cultivated crop, and in ploughed surfaces, the upper horizon under cultivation with a ratio equal to or greater than 12 indicates that mineralization encounters difficulties such as anaerobic conditions in the presence of clay, as shown in the case of the soil in our orchard. On the other hand, this organic matter decreases due to the sandy structure of the soil, which is too aerated, and thus organic matter decomposes more quickly, which is not the case in clay soils that provide physical protection of organic matter (Karabi 2016).

Intensive tillage deteriorates soil quality and threatens long-term agricultural production (Lopez-Bellido *et al.* 2013). Fertility, structure, and organic matter (MO) of the soil decrease due to tillage and other practices (grazing, export of straw) that prevent the incorporation of organic material into the soil (Lopez-Bellido *et al.* 2013).

The studied soils are alkaline ($pH>7$). When soils contain a lot of carbonates, oxides, and hydroxides that neutralize $H+$ ions, the pH becomes alkaline (pH 8 and above), therefore there is a close relationship between the limestone content and the degree of soil acidity, which vary inversely (Ramade 2003). Salts are more soluble in water than gypsum. Their overall concentration is generally expressed by electrical conductivity, which actually represents electrolytic conductivity (Halitim 1988). The slightly elevated electrical conductivity in our orchard soils depends on the electrolyte content (SO_4, Cl, K, Na, Mg, Ca) which expresses the salt concentration. According to some authors, the main soil properties determining electrical conductivity are soil depth and clay content (Uribeetxebarria *et al.* 2018). The evolution of limestone is important in soil formation in semi-arid regions, which is mainly due to very abrupt changes in humidity during rain and intense drought for most of the year (Aubert 1951). According to Drouet (2010), $CaCO_3$ content in carbonate soils is extremely variable, ranging from a few per cent to over 70%, and the most abundant carbonate is calcite ($CaCO_3$). Having limestone soil is often considered a calamity by gardeners. A soil is considered limestone when it contains 10 to 30% of lime carbonate which is always associated with clay and which makes the soil rather sticky (Gerbeaud 2018).

Variation of Biomass, Activity, and Microbial Diversity of Agricultural Soils According to Crop Types

Microbial properties of soils under different crops

Regarding microbiological properties, statistical analyses show a weakly significant difference in basal respiration ($p<0.05$) between different soils depending on the type of crop grown. The highest values of microbial activity are recorded for arboriculture soils (0.437 µg CO_2-C/g soil/hour), while the lowest value is recorded for legumes (0.295 µg CO_2-C/g soil/hour).

The microbial biomass of the soils is homogeneous in the different types of crops ($p>0.05$), with averages ranging between 0.069 and 0.085 µg Cmic/g. Microbial biomass varies between 0 and 700 to 800 mg C/kg of soil in agricultural soils.

The metabolic quotient for different types of crops has an average range of between 5.04 and 5.24 µg CO_2-C/g soil/hour. The results show that the efficiency with which microorganisms use the available carbon in the soil for their biosynthesis does not present any significant difference, such as microbial biomass, between the soils.

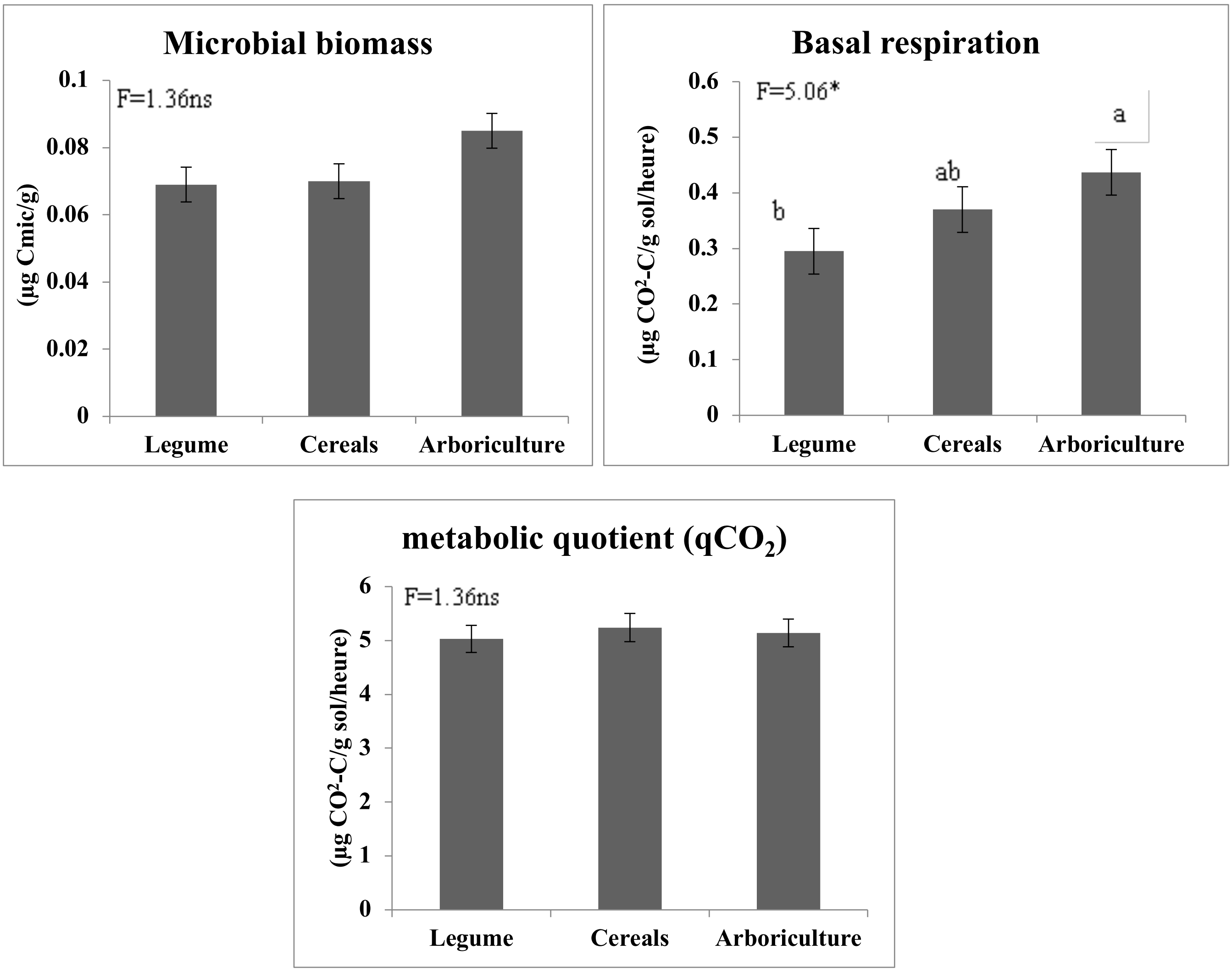

Figure. 2. Microbial properties of agricultural soils

The soil is considered one of the most complex environments in the biosphere and is therefore a major reservoir of microbial diversity. Living organisms in the soil include bacteria, fungi, algae, the underground parts of plants, and a wide variety of animals that play a fundamental role in important processes such as the regulation of biogeochemical cycles (nitrogen, carbon, sulfur) (Dubey *et al.* 2019; Yadav *et al.* 2021). Improving the activity and specific diversity of soil fauna (micro, meso, and macro) is therefore essential for restoring and improving soil quality and reducing the risks of soil degradation (Moreno *et al.* 2008; Borsali *et al.* 2017; Douaer *et al*. 2021).

The harmful effects of agricultural management on the microbiological quality of soils are a global concern (Bastida *et al*. 2006; Lal 2015). The variation in microbial diversity and their activity is correlated with the presence of organic matter, which forms the energetic state of the soil. According to Delogu (2013), the quantity and quality of crop residues play an important role in soil heterotrophic respiration because residues are directly decomposed by soil microorganisms. The quality of the substrate refers to the biochemical composition of tissues: a highly woody compound will be difficult to decompose, and its residence time in the soil will be very long. The quality of the substrate, which thus influences the rate of decomposition of organic matter, determines the short-term respiration flux of the soil and the long-term storage of carbon in the soil (Fontaine *et al.* 2004; Chirinda *et al.* 2010). These substrate-influenced processes come directly into conflict with climatic or soil texture effects. Soils in orchards are more exposed to the sun compared to other crops that cover it completely, which increases the soil temperature, whereas numerous studies show that soil respiration increases exponentially with temperature (Marino *et al.* 2019). Microbial activity, i.e., the depletion of OM, is stimulated by cultural practices such as fertilization, irrigation, or tillage (Jansa *et al.* 2006). However, intensification of land use could result in a continuous decline in soil organic stock, as in the case of soils on large European plateaus (Van-Camp *et al.* 2004). According to Lechevallier *et al.* (2004), this variation is linked to the crop: biomass (BM) grassland > BM arable crops and orchards > BM market gardening > BM vineyards, and to cultural techniques: BM grassing > BM tillage. The metabolic quotient or specific respiration rate serves as an indicator of the physiological state of soil microorganisms. According to Dilly (2005), qCO_2 in the upper horizons of cultivated soils varies from 0.5 to 10 mg $C\text{-}CO_2$ g/Cmic/hour. High qCO_2 values reflect poor substrate quality and low metabolic efficiency (Fließbach *et al.* 2007).

Microbial density and diversity

In agroecosystems, the soil contains many types of microorganisms - microscopic forms of animal life such as bacteria, actinomycetes, fungi, and algae. Soil microorganisms are important because they affect the physical, chemical, and biological properties of soils. For example, the process of decomposition, breakdown, and disappearance of dead plant and animal matter occurs due to the action of many different types of microorganisms (Wahome *et al*. 2023). There is a group of PGPR strains acting as biocontrol agents in order to suppress the pathogens and thus prevent plants from diseases or infections. The same mode of action is required by the plant to develop resistance against bacterial, fungal, viral phytopthogens, insects and nematodes. The ability of PGPR to produce and discharge metabolites which can ameliorate pathogens' microbial loads and their activities or rhizosphere microflora that are deleterious is another major type of action found in several strains of PGPR (Odelade and Babalola, 2019). Characterization of soil bacterial communities was done using in vitro culture methods on nutrient media, but these did not allow for comprehensive characterization. Among the recognized major groups of bacteria are cellulolytic bacteria which degrade cellulose and pectinolytic bacteria that degrade pectin and its derivatives. The most abundant ones belong to the genus Arthrobacter. Functional groups involved in the nitrogen cycle include ammonifying and nitrifying bacteria, and atmospheric nitrogen fixing bacteria, which transform it into compounds usable by plants (ammonia). These are notably symbiotic bacteria located in the rhizosphere of cultivated plants (Rhizobium in legumes) (Riou and Prevostbourre, 2018).

The bacterial biomass has a slightly higher average in almond orchard soils (53 $x10^6$ CFU/g dry soil) followed by cereal crops (50.75 $x10^6$ CFU/g dry soil) and legumes (49.87 $x10^6$ CFU/g dry soil). The variance analysis shows the homogeneity of microbial biomass between different types of crops ($p>0.05$). It is also noteworthy that legume soils have a higher density of rhizobia (75.6 $x10^4$ CFU/g dry soil) compared to cereal and orchard soils (38.3 $x10^4$ CFU/g dry soil and 32.3 $x10^4$ CFU/g dry soil, respectively). The statistical analysis of these results shows a significant difference ($p<0.05$) among the three sites. The fungal density is low compared to bacterial and rhizobial density. A weakly significant difference in soil fungal density according to the expressed crop type is observed ($p<0.05$) (Table 3).

TABLE 3

Microbial density and diversity under the different crop types

Microbial groups	Cereals	Legume	Arboriculture	Calculated f value and significance
Bacteria (x10^6 CFU. g-1. s. s)	50.75	49.87	53	F=0.02ns
Fungi (x10^3 CFU.g-1 .s.s)	16.66	25.33	11.33	F=2.07*
Rhizobia **(**x10^4 CFU.g-1. s.s)	38.03	75.66	32.33	F=5.51*

Bacteria are both quantitatively and functionally the major group of microorganisms in the soil. For example, it is estimated that 1g of soil contains between 10^6 and 10^9 bacteria (Soltner 2003). They are relatively limited in soils that are insufficient in organic matter and water (Dubey *et al.* 2019). Bacterial densities are generally lower in cultivated soils with tillage, especially in cereal crops, compared to grasslands or forest, or fruit soils (Constancias *et al.* 2014).

Among the soil bacteria there is a unique group called Rhizobia that have beneficial effect on the growth of legumes. Rhizobium is soil-inhabiting bacteria that form the root nodules where symbiotic biological Nitrogen fixation occurs (Howieson and Dilworth 2016). The importance of rhizobial density in legumes is due to the rhizobial symbiosis established with a large number of species in the Fabaceae family (legumes), which is the third largest family after Asteraceae and Orchidaceae. The Rhizobium-legume symbiosis is a mutualistic association with reciprocal benefits between legumes and rhizobium-type bacteria. The latter allows the transfer of nitrogen from the air in a form assimilable by plants. In exchange, the plant provides rhizobia with carbon resulting from its photosynthesis (Haag *et al.* 2013). During symbiosis, a new organ, the nodule, is formed on the roots or more rarely on the stems where atmospheric nitrogen is fixed by the bacteria (Haag *et al*. 2013; Niste *et al.* 2014).

Mabrouk *et al* (2018) suggest that the presence or absence of rhizobia in natural soil depends on their growth, physical properties of the soil, and the host plant. Host specificity is one of the major characteristics of the rhizobium-legume symbiosis. Each bacterial species has a well-defined host spectrum, the amplitude of which is highly variable (Dommergues 2006). Alkalinity is less harmful to the survival of rhizobia. The majority of these bacteria can tolerate pH values up to 9 (Zhang *et al.* 2020).

The results show that fungal density is low compared to bacterial and rhizobial density. Fungi are not the most numerous microorganisms in the soil, but their weight is very important due to their large size, compared to bacteria (Huber and Schaub 2011). The low number of fungi in orchard soils is explained by their texture, which has a high proportion of clay. There is a negative correlation between clay content and fungal biomass, while this correlation is positive with bacterial biomass (Fotio *et al.* 2009). Moreover, fungi predominate in the decomposition of low-quality materials (Senn-Irlet *et al.* 2012). This decrease can be explained by the particularity of fungi with regard to acidity. Indeed, fungi prefer acidic environments where they do not encounter competition from bacteria. The alkaline pH of our soils explains the low density of fungi compared to bacteria, as fungi thrive in a low pH environment (Rousk *et al.* 2009).

CONCLUSION

Cereal cultivation, arboriculture, and legume farming are the main agricultural practices in semi-arid zone. This study aimed to investigate the characterization of agricultural soils based on the type of crops grown. Analysis of physicochemical properties showed that changes in crop types affect the soil water regime by modifying soil texture, density, and permeability. Cereal and legume farming improves chemical fertility more than arboriculture through organic matter and nitrogen amendment.

The microbial properties of the soil showed homogeneous microbial biomass between soils, with little variation in basal respiration represented by CO_2 release. These results were confirmed by the enumeration of microorganisms and their diversity. This bacterial life is linked to soils rich in organic matter, nitrogen, water, and agricultural practice techniques, mainly ploughing, depending on the crop type. Regarding the density of rhizobia in soils, we note that legume soils have a higher density of rhizobia than cereal and orchard soils due to rhizobium-legume symbiosis. Unlike alkaline soils, a low fungal density also characterizes them because fungal development requires an acidic pH. Therefore, agricultural soils in the semi-arid zone are fragile and vulnerable. In this regard, not only do physicochemical and biological corrections need to be considered, but much more attention must be paid to the socio-economic context in which soil protection programs must be successfully carried out, such as cultural practices on land and the use of crop rotation systems.

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REFERENCES

Abdellaoui, Z., H. Tissekrat, A. Belhadj and O, Zaghouane. 2010. Etude comparative de l'effet du travail conventionnel, semi direct et travail minimum sur le comportement du blé dur. In acte des 4èmes rencontres méditerranéennes du semis direct. Sétif, du 3 au 5 mai 2010. *Recherche Agronomique* INRAA : 68–82.

Allam, A., A.H. Borsali, A. Kefifa, M. Zouidi, A.M.F. Da Silva and C. RéBufa, 2021. Impact of water erosion on the properties of forest soils. *Notulae Scientia Biologicae* 13(2): 10921–10921. https://doi.org/10.15835/nsb13210921

Anderson, J.P.E. and K.H. Domsch. 1978. A physiological method for the quantitative measurement of microbial biomass in soils. *Soil Biology and Biochemistry* 10(3): 215-221. https://doi.org/10.1016/0038-0717(78)90099-8

Aschi, A., M. Aubert, W. Riah-Anglet, S. Nélieu, C. Dubois, M. Akpa-Vinceslas and I. Trinsoutrot-Gattin. 2017. Introduction of Faba bean in crop rotation: Impacts on soil chemical and biological characteristics. *Applied Soil Ecology* 120 : 219–228. 10.1016/j.apsoil.2017.08.003

Assemien, E. F. L. 2018. Impact de pratiques agricoles conventionnelles et innovantes sur la fertilité des sols et les acteurs microbiens impliqués dans la zone de savanes humides de Côte d'Ivoire. Doctoral dissertation, Université de Lyon. 205p. https://theses.hal.science/tel-01896147/document

Aubert, G. 1951. Les sols des régions semi-arides d'Afrique et leur mise en valeur. Paris : Secrétariat Général de l'UISB, 1951, p. 11-25

Aubert, G. 1978. Méthodes d'analyses des sols. Edit.C.R.D.P. Marseille.189p

Bai, Z., T. Caspari, M.R. Gonzalez, N.H. Batjes, P,Mäder, E.K.Bünemann and Z. Tóth. 2018. Effects of agricultural management practices on soil quality: A review of long-term experiments for Europe and China. *Agriculture, Ecosystems & Environment* 265:1–7. https://doi.org/10.1016/j.agee.2018.05.028

Baise, D. 2018. Guide des analyses pédologie ; 3 eme édition revue et augmentée ; edition Quae Versailles Cedex 326p.

Bastida, F., J.L. Moreno, T. Hernández and C. García. 2006. Microbiological degradation index of soils in a semiarid climate. *Soil Biology and Biochemistry* 38(12): 3463–3473.

Beare M.H., C.L. Neely, D.C. Coleman and W.L. Hargrove.1990. Substrate induced respiration (SIR) method for measurement of fungal and bacterial biomass on plant residues. *Soil Biology and Biochemistry* 22: 585–594. https://doi.org/10.1016/0038-0717(90)90002-H

Blake, G. and K. Hartge.1986. Methods of Soil Analysis: Part 1—Physical and Mineralogical Methods. Madison, WI: Soil Science Society of America, American Society of Agronomy

Boiffin, J., F. Laurent and G. Richard. 2020. Réussir l'implantation des cultures ; Enjeux agroécologiques, itinéraires techniques. 1ère Éditions Quae, 440p.

Borsali, A.H., M. Zouidi, K. Hachem, R. Gros and T. Hagenimana. 2017. Catabolic profiles of cultivable microbial communities in forest soils of western Algeria along a latitudinal gradient. *Advanced Studies in Biology* 9(4):157-169. https://doi.org/10.12988/asb.2017.749

Boudiar, R., K.S. Alshallash, K. Alharbi, S.A. Okasha, M. Fenni, A. Mekhlouf and M. Mekhlouf. 2022. Influence of tillage and cropping systems on soil properties and crop performance under semi-arid conditions. *Sustainability* 14(18): 11651. https://doi.org/10.3390/su141811651

Bourgeois, E 2015. Contribution au développement de bioindicateurs microbiens pour l'évaluation de l'impact de pratiques agricoles sur les sols. Thèse de Doctorat. Université de Bourgogne. 188p

Bowles, T. M., V. Acosta-Martínez, F. Calderón, and L.E. Jackson. 2014. Soil enzyme activities, microbial communities, and carbon and nitrogen availability in organic agroecosystems across an intensively-managed agricultural landscape. *Soil Biology and Biochemistry* 68: 252-262. https://doi.org/10.1016/j.soilbio.2013.10.004

Brewer, C. E., V.J. Chuang, C.A. Masiello, H. Gonnermann, X. Gao, B.Dugan and .C.A. Davies. 2014. New approaches to measuring biochar density and porosity. *Biomass and Bioenergy* 66: 176-185. https://doi.org/10.1016/j.biombioe.2014.03.059

Chabert, A. and J. P. Sarthou. 2017. Agriculture de conservation des sols et services écosystémiques. *Droit et ville* 84(2) : 135-169. https://doi.org/10.3917/dv.084.0135

Chan, K. Y. 2001. Soil particulate organic carbon under different land use and management. *Soil Use and Management* 17(4): 217-221. https://doi.org/10.1111/j.1475-2743.2001.tb00030.x

Chenu, C., D.A. Angers, P. Barré, D. Derrien, D. Arrouays and J. Balesdent. 2019. Increasing organic stocks in agricultural soils: Knowledge gaps and potential innovations. *Soil and Tillage Research* 188: 41-52. https://doi.org/10.1016/j.still.2018.04.011

Chirinda, N.J.E. Olesen, J.R.Porter and P. Schjønning. 2010. Soil properties, crop production and greenhouse gas emissions from organic and inorganic fertilizer-based arable cropping systems. Agriculture, *Ecosystems & Environment* 139: 584-594.

Comino-Rodrigo, J., C. Martinez-Hernandez, T. Iserloh and A. Cerda. 2018. Contrasted impact of land abandonment on soil erosion in Mediterranean agriculture fields. *Pedosphere* 28(4): 617-631.

Constancias, F., N. C. Prévost-Bouré, S.Terrat, S. Aussems, V. Nowak, J.P. Guillemin, ... and L. Ranjard. 2014. Microscale evidence for a high decrease of soil bacterial density and diversity by cropping. *Agronomy for Sustainable Development* 34: 831-840.

Cotrufo, M. F., M.D.Wallenstein, C.M. Boot, K. Denef and E.Paul. 2013. The microbial efficiency-matrix stabilization (MEMS) framework integrates plant litter decomposition with soil organic matter stabilization: do labile plant inputs form stable soil organic matter? *GlobalChange Biology* 19(4): 988-995. https://doi.org/10.1111/gcb.12113

Dahmani, R., A.H. Borsali, A. Merzouk., M. Zouidi, S.A. Aouadj and H. Khatir. 2023. The effect of beneficial autochthonous microorganisms (BAMs) on the chemical quality of agricultural soils and olive production in the province of Tlemcen (Western of Algeria). *Advanced Research in Life Sciences*. 7: 1-9 https://doi.org/10.2478/arls-2023-0001

Davet, P. 1996. Vie microbienne du sol et production végétale. Editions Quae.

Delogu, E. 2013. Modélisation de la respiration du sol dans les agro-écosystèmes. These de Doctorat, Université Paul Sabatier-Toulouse III. 240p.

Dhaliwal, S.S., R.K.Naresh, A. Mandal, R. Singh and M.K. Dhaliwal. 2019. Dynamics and transformations of micronutrients in agricultural soils as influenced by organic matter build-up: A review. *Environmental and Sustainability Indicators* 1: 100007.

Di Sacco, A., K.A.Hardwick, D. Blakesley, P.H. Brancalion, E. Breman, L.Cecilio Rebola... and A. Antonelli. 2021. Ten golden rules for reforestation to optimize carbon sequestration, biodiversity recovery and livelihood benefits. *Global Change Biology* 27(7): 1328-1348. https://doi.org/10.1111/gcb.15498

Diop, M., N. Chirinda, A. Beniaich, M. El Gharous and K. El Mejahed, 2022. Soil and water conservation in Africa: state of play and potential role in tackling soil degradation and building soil health in agricultural lands. *Sustainability* 14(20): 13425. https://doi.org/10.3390/su142013425

Dommergues. O. 2006. Diversité des *rhizobia* associés à ononis repens : une légumineuse adaptée aux milieux méditerranéens. L'École Pratique des Hautes Études, 33p.

Douaer, N., A. Douaoui, M. Mehaiguene, M. Zouidi and W.Hamza. 2021. The effect of municipal sewage sludge on properties physicochemical and microbial agricultural soil. *Notulae Scientia Biologicae* 13(1) : 10804-10804. https://doi.org/10.15835/nsb13110804

Drouet, T. 2010. Pédologie. BING-F-302 Edition. Lagev. 140 p. http://www.geologues-prospecteurs.fr/cours/pedologie/pe-dologie-1.pdf

Dubey, A., M.A. Malla, F. Khan, K.Chowdhary, KS.Yadav, A. Kumar and M. L.Khan. 2019. Soil microbiome: a key player for conservation of soil health under changing climate. *Biodiversity and Conservation* 28: 2405-2429.

Espinoza, S., C. Ovalle and A. del Pozo. 2020. The contribution of nitrogen fixed by annual legume pastures to the productivity of wheat in two contrasting Mediterranean environments in Central Chile. *Field Crops Research* 249: 107709.

Fließbach, A., H.R.Oberholzer, L. Gunst and P. Mäder. 2007. Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming. *Agriculture, Ecosystems & Environment* 118(1-4): 273-284. https://doi.org/10.1016/j.agee.2006.05.022

Fontaine, S. B., G.R. Bardoux, L. Abbadie and A. Mariotti. 2004. Carbon input to soil may decrease soil carbon content. *Ecology Letters* 7: 314-320.

Fotio, D., S. Simon, R. Njomgang, J. Nguefack, M. Ngueguim, J.S.N. Maniepi and Y. Clarice. 2009. Impacts de la gestion du sol sur la biomasse microbienne et le statut organique deu sol de la zone ouest du Cameroun. 13p.

García-Ruiz, R., V. Ochoa, B. Vinegla, M.B. Hinojosa, R. Pena-Santiago, G. Liébanas... and J.A. Carreira. 2009. Soil enzymes, nematode community and selected physico-chemical properties as soil quality indicators in organic and conventional olive oil farming: Influence of seasonality and site features. *Applied Soil Ecology* 41(3): 305-314. https://doi.org/10.1016/j.apsoil.2008.12.004

Gerbeaud X. 2018. Connaitre son sol : Calcaire.: https://www.gerbeaud.com/jardin/fiches/fp_sol_calcaire.php3

Girard, M. C., C. Walter, J.C. Rémy, J. Berthelin and J.L. Morel. 2011. Sols et environnement-2e édition-Cours, exercices et études de cas-Livre+ compléments en ligne : Cours, exercices corrigés et études de cas. Dunod.

Haag, A. F., M.F. Arnold. K.K. Myka, B. Kerscher, S. Dall'Angelo, M. Zanda... and G.P. Ferguson. 2013. Molecular insights into bacteroid development during Rhizobium–legume symbiosis. *FEMS Microbiology Reviews* 37(3): 364-383.

Halitim, A. 1988. Sols des régions arides d'Algérie. OPU, Alger, 384 p

Holland, J. E., A.E. Bennett, A.C. Newton, P.J. White, B.M. McKenzie, T.S. George and R.C. Hayes. 2018. Liming impacts on soils, crops and biodiversity in the UK: A review. *Science of the Total Environmen*t 610: 316-332. https://doi.org/10.1016/j.scitotenv.2017.08.020

Howieson, J. G. and M.J. Dilworth. 2016. Working with rhizobia. Canberra: Australian Centre for International Agricultural Research, 314p.

Huber, G. and C. Schaub. 2011. La fertilité des sols : L'importance de la matière organique. Chambre d'agriculture du Bas-Rhin. 46p.

INRA. 2006. Rapport national sur l'état des ressources phytogénétiques pour l'alimentation et l'agriculture, (Deuxième rapport national- Algérie), 68p.

Islam, K. and R. R. Weil. 2000. Soil quality indicator properties in mid-Atlantic soils as influenced by conservation management. *Journal of Soil and Water Conservation* 55(1): 69-78.

Jansa, J., A. Wiemken and E. Frossard.2006. The effects of agricultural practices on arbuscular mycorrhizal fungi. *Geological Society, Special Publications* 266(1) : 89-115.

Karabi, M. 2016. Fonctionnement microbiologique des sols oasiens. Cas de quelques sols de la regionde Ouargla. These de Doctorat, Université de Ouargla

Kehal, L., M. Zouidi, D. Keddari, S. Hadjout and A.H.Borsali. 2021. Comparative analysis of forest soil properties from sub-humid and semi-arid areas of Djebel El Ouahch biological reserve in Algeria. *South Asian Journal of Experimental Biology* 12(3) : 349-356.

Lahmar, R. 2006. Opportunités et limites de l'agriculture de conservation en Méditerranée. Les enseignements du projet KASSA. CIHEAM-IAMZ, Zaragoza, 69 : 11-18.

Lal, R. 2015. Restoring soil quality to mitigate soil degradation. *Sustainability* 7(5) : 5875-5895. https://doi.org/10.3390/su7055875

Lechevallier, C., B. Planques and X. Salducci. 2004. Évaluer la dynamique biologique des sols: Des analyses de la fertilité biologique, élément bénéfique aux plantes. *Phytoma, la défense des végétaux* (568) : 41-43.

Lessmann, M., G.H. Ros, M.D. Young and W.de Vries. 2022. Global variation in soil carbon sequestration potential through improved cropland management. *Global Change Biology* 28(3): 1162-1177. https://doi.org/10.1111/gcb.15954

Liu, L., X. Wang and C. Chang. 2022. Toward a smart skin: Harnessing cuticle biosynthesis for crop adaptation to drought, salinity, temperature, and ultraviolet stress. *Frontiers in Plant Science* 13:961829.

Lopez-Bellido, L., V. Muñoz-Romero and R.J. López-Bellido. 2013. Nitrate accumulation in the soil profile: long-term effects of tillage, rotation and N rate in a Mediterranean Vertisol. *Soil and Tillage Research* 130: 18-23. https://doi.org/10.1016/j.still.2013.02.002

Mabrouk, Y., I. Hemissi, I.B. Salem, S. Mejri, M. Saidi and O. Belhadj. 2018. Potential of rhizobia in improving nitrogen fixation and yields of legumes. *Symbiosis* 107(73495): 1-16.

Marino, G., D. Zaccaria, R.L. Snyder, O.Lagos, B.D. Lampinen, L.Ferguson and B.L.Sanden. 2019. Actual evapotranspiration and tree performance of mature micro-irrigated pistachio orchards grown on saline-sodic soils in the San Joaquin Valley of California. *Agriculture* 9(4): 76. https://doi.org/10.3390/agriculture9040076

Mathieu, C. and F. Pieltain.1998. Analyse physique des sols. Paris, 275p.

Merdas, S., Y. Kouba, T. Mostephaoui, Y. Farhi and H. Chenchouni.2021. Livestock grazing-induced large-scale biotic homogenization in arid Mediterranean steppe rangelands. *Land Degradation & Development* 32(17): 5099-5107. https://doi.org/10.1002/ldr.4095

Moreno, J. L., F. Bastida, T. Hernández and C. García.2008. Relationship between the agricultural management of a semi-arid soil and microbiological quality. *Communications in Soil Science and Plant Analysis* 39(3-4): 421-439. https://doi.org/10.1080/00103620701826548

Mrabet R., N, Saber, S.El-Brahli, S. Lahlou and F. Bessam. 2001.Total organic matter and structural stability of a calcixeroll soil under different wheat rotations and tillage systems in a semi-arid area of Morocco. *Soil and Tillage Research* 57: 225-235

Niste, M., R. Vidican, I.Rotar, V.Stoian, R. Pop and R.Miclea. 2014. Plant nutrition affected by soil salinity and response of rhizobium regarding the nutrient accumulation. *ProEnvironment Promediu* 7(18) :71-75. https://journals.usamvcluj.ro/ index.php/ promediu/article/view/10178

Pavan, A. L. R. and A.R. Ometto. 2018. Ecosystem services in life cycle assessment: A novel conceptual framework for soil. *Science of the Total Environment* 643: 1337-1347. https://doi.org/10.1016/j.scitotenv.2018.06.191

Odelade, K. A. and O.O. Babalola.2019. Bacteria, fungi and archaea domains in rhizospheric soil and their effects in enhancing agricultural productivity. *International Journal of Environmental Research and Public Health* 16(20): 3873. https://doi.org/10.3390/ijerph16203873

Petard, J. 1993. Les méthodes d'analyse. Analyse de sols.

Pouya, M. B., M. Bonzi, Z. Gnankambary, K. Traoré, J.S. Ouédraogo, A.N.Somé, and M.P. Sédogo. 2013. Pratiques actuelles de gestion de la fertilité des sols et leurs effets sur la production du cotonnier et sur le sol dans les exploitations cotonnières du Centre et de l'Ouest du Burkina Faso. *Cahiers Agricultures* 22(4) : 282–292 https://doi.org/10.1684/agr.2013.0643

Ramade F. 2003. Eléments d'écologie, Ecologie fondamentale. 3ème édition. Paris, p 690.

Raymond, F., A. Ullmann and P. Camberlin. 2018. Très longs épisodes secs hivernaux dans le bassin méditerranéen: variabilité spatio-temporelle et impact sur la production céréalière en Espagne. Cybergeo: *European Journal of Geography*. N:858 Environnement, Nature, Paysage | 2018 https://doi.org/10.4000/cybergeo.29156

Riou, V., Prevostbourre, N.C. 2018. Les bactéries du sol. Bulletin Sol et Agronomie des Chambres d'agriculture des Pays de la Loire. SOLAG ; N°3 du 3/04/2018

Roger-Estrade, J., J. Labreuche and H. Boizard. 2014. Importance du travail du sol : typologie des modes de mise en œuvre et effet sur le rendement des cultures. https://hal.inrae.fr/hal-02798149/document

Rousk, J., P.C. Brookes and E. Bååth. 2009. Contrasting soil pH effects on fungal and bacterial growth suggest functional redundancy in carbon mineralization. *Applied and Environmental Microbiology* 75(6): 1589-1596.

Saetre, P. 1998. Decomposition, microbial community structure, and earthworm effects along a birch–spruce soil gradient. *Ecology* 79(3): 834-846. https://doi.org/10.1890/0012-9658(1998)079[0834:DMCSAE]2.0.CO;2

Schipanski, M. E. and L.E. Drinkwater. 2012. Nitrogen fixation in annual and perennial legume-grass mixtures across a fertility gradient. *Plant and Soil* 357(1): 147-159.

Senn-Irlet, B., Mürner, R., Martini, E., Küffer, N., de Marchi and Bieri, G. (2012). Saprobic fungi on wood and litter of Alnus alnobetula in the Swiss Alps. Mycotaxon, 120(506), 1-34.

Solberg, E.D., M. Nyborg, R.C. Izaurralde, S.S. Malhi, H.H. Janzen and M. Molina-Ayala. 2019. Stockage du carbone dans les sols en culture céréalière continue : engrais azoté et paille. Dans Gestion de la séquestration du carbone dans le sol (pp. 235-254). Presse CRC.

Soltner, D. 2003. The basis of plant production. Tome I: Soil and its improvement (23rd ed.) pp. 97-327.

Spaccini, R., J.S.C. Mbagwu, C.A. Igwe, P. Conte and A. Piccolo. 2004. Carbohydrates and aggregation in lowland soils of Nigeria as influenced by organic inputs. *Soil and Tillage Research* 75(2): 161-172. https://doi.org/10.1016/S0167-1987(03)00158-2

Steponavičienė, V., V. Bogužas, A. Sinkevičienė, L. Skinulienė, R. Vaisvalavičius and A. Sinkevičius. 2022. Soil water capacity, pore size distribution, and CO_2 emission in different soil tillage systems and straw retention. *Plants* 11(5): 614. https://doi.org/10.3390/plants11050614

Swarup, A., M.C. Manna and G.B. Singh. 2019. Impact of land use and management practices on organic carbon dynamics in soils of India. *Global Climate Change and Tropical Ecosystems*. Book chapter pp 261-281, CRC Press USA.

Timmis, K. and J.L. Ramos. 2021. The soil crisis: the need to treat as a global health problem and the pivotal role of microbes in prophylaxis and therapy. *Microbial Biotechnology* 14(3): 769-797. https://doi.org/10.1111/1751-7915.13771

Uribeetxebarria, A., J. Arnó, A. Escolà and J.A. Martínez-Casasnovas. 2018. Apparent electrical conductivity and multivariate analysis of soil properties to assess soil constraints in orchards affected by previous parcelling. *Geoderma* 319: 185-193. https://doi.org/10.1016/ j.geoderma.2018.01.008

Van-Camp, L., B. Bujarrabal, A.R. Gentile, R.J. Jones, L. Montanarella, C. Olazabal, and S.K. Selvaradjou. 2004. Technical working groups established under the thematic strategy for soil protection.

Vasseur, C., A. Joannon, S. Aviron, F. Burel, J.M. Meynard and J. Baudry. 2013. The cropping systems mosaic: how does the hidden heterogeneity of agricultural landscapes drive arthropod populations?. *Agriculture, Ecosystems & Environment* 166: 3-14. https://doi.org/10.1016/ j.agee.2012.08.013

Vincent, J. M. 1970. A manual for the practical study of root-nodule bacteria. International Biological Programme handbook no. 15. Blackwell Scientific Publications, Ltd., Oxford.

Wahome, C. N., J.M. Maingi, O. Ombori, E.M. Njeru, M. Muthini and J. Kimiti. 2023. Diversity and abundance of bacterial and fungal communities in rhizospheric soil from smallholder banana producing agroecosystems in Kenya. *Frontiers in Horticulture* 2:1061456 https://doi.org/10.3389/fhort.2023.1061456

Yadav, A.N., D. Kour, T. Kaur, R, Devi, A. Yadav, M. Dikilitas and A.K. Saxena. 2021. Biodiversity, and biotechnological contribution of beneficial soil microbiomes for nutrient cycling, plant growth improvement and nutrient uptake. *Biocatalysis and Agricultural Biotechnology*,33: 102009. https://doi.org/10.1016/j.bcab.2021.102009

Zhang, J., D. Singh, C. Guo, Y. Shang and S. Peng. 2020. Rhizobia at extremes of acidity, alkalinity, salinity, and temperature. *Microbial Versatility in Varied Environments: Microbes in Sensitive Environments*: Book chapter pp51-65. https://doi.org/10.1007/978-981-15-3028-9_4

Zouidi, M., A.H. Borsali, A. Allam and R.Gros. 2018. Characterization of coniferous forest soils in the arid zone. *Forestry Studies* 68(1): 64-74. https://doi.org/10.2478/fsmu-2018-0006

Zouidi, M., A.H. Borsali, A. Allam and R. Gros. 2019. Quality estimation of the western Algeria forest soils. *Malaysian Journal of Soil Science* 23: 87-98. https://www.msss.com.my/ mjss/ Full%20Text/ vol23/V23_07.pdf