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Impacts of agroforestry practices on the physico-chemical, water and soil fertility properties in semi-arid environments: The case of Bordjias Plain (Mesra, North-West Algeria)

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Abstract: All problems related to conventional agriculture are a reference to the search for sustainable solutions. In this context, a comparative study between three agroforestry practices (AFP): *Citrus sinensis, Olea europaea, and Punica granatum, each associated with Vicia faba* (Fabaceae), was conducted on Bordjias Plain. In order to study the impacts of each association on the physico-chemical properties and water and soil fertility, the soil samples were taken from two profiles (P1 under the tree and P2 between trees), through three horizons (Sh, Mh and Lh), before and after the establishment of culture. The results of the analyses show that moisture variability appears to be influenced by the type of soil and the woody species. By increasing the organic matter content, these associations improve the structural stability of the soil, accelerating the process of dissolution of calcium carbonate, changing the pH, EC, P2O5, CEC, and ion exchange in soil. The statistical approach (ANOVA) allowed us to bring out the positive impact of agroforestry practices on soil fertility.

Keywords: agroforestry, fertility, soil, environments semi-arid, Bordjias Plain

1. Introduction

Soil, a non-renewable resource with potentially rapid rates of degradation and extremely slow processes of formation and regeneration [1], is subject to

unprecedented natural and anthropogenic pressures and can no longer perform its functions perfectly [9].

The association of trees, crops, and/or sometimes farms on the same plot is assimilated to the notion of agroforestry practices (AFP), which are often very effective both in terms of production and environmental protection [2]. These land-use patterns have existed in Algeria for centuries, where, however, the role of trees in different farming practices has been neglected by farmers. It is in this context that we conducted this study on the impact of AFP on the physico-chemical, water and soil fertility properties in order to determine the changes undergone at the soil level due to the presence of trees (*Citrus sinensis*, *Olea europaea*, and *Punica granatum*) in association with a crop (*Vicia faba*).

2. Materials and methods

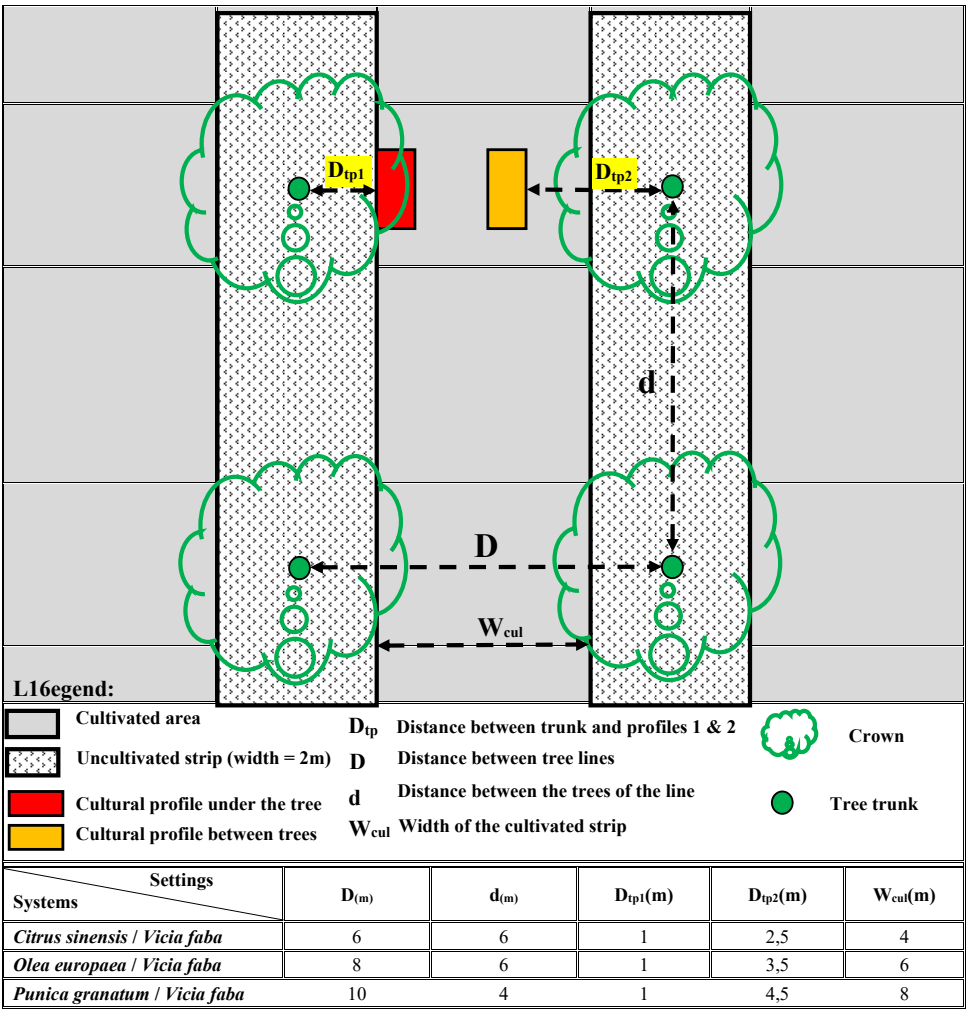
2.1. Presentation of the study area

The study area is part of Bordjias Plain. This plain is located northwest of Algeria. It is bounded on the east by the mountains of Ennaro, Zaimia, and Beiod, on the west by Macta Plain, on the north by Mostaganem Plateau, and on the south by Habra Plain (see *Fig. 1*). The study area is characterized by a semi-arid Mediterranean climate with a long drought period, an annual average reference evapotranspiration of 1,171.32 mm, and an average annual rainfall of 378.13 mm, insufficient to meet the water needs of crops. The land cultivated in this zone occupies a large area of approximately 3,800 ha, i.e. 70% of the total area is market gardening. It is followed by cereal farming (15%), fruit growing (10%), and fodder [3]. Tree-crop associations are becoming more widespread in orchards for economic rather than environmental purposes.

Figure 1. Situation of the study area

2.2. Methodological approach

In this study, we opted for an experimental approach that aims at studying the soil parameters in relation to some AFPs practised in the study area. Cultural profiles (100, 50, and 50 cm) were dug at a distance of 1 m from the trunk of the tree and between the trees (see *Fig. 2*). The soil samples taken from each horizon were subjected to physico-chemical and water analyses, the results of which were statistically processed (ANOVA).



Settings / Systems	$D_{(m)}$	$d_{(m)}$	D_{tp1}(m)	D_{tp2}(m)	W_{cul}(m)
Citrus sinensis / *Vicia faba*	6	6	1	2,5	4
Olea europaea / *Vicia faba*	8	6	1	3,5	6
Punica granatum / *Vicia faba*	10	4	1	4,5	8

Figure 2. Experimental apparatus

3. Results and discussions

3.1. Particle size analyses

Based on the respective values of the clay, silt, and sand fractions projected onto the USDA textural triangle (see *Fig. 3*), the studied soils belong to the sandy loam and sandy-textured textural classes for the first two sites, respectively, and to experimental and silty-sandy loam-clay-sandy for the third site.

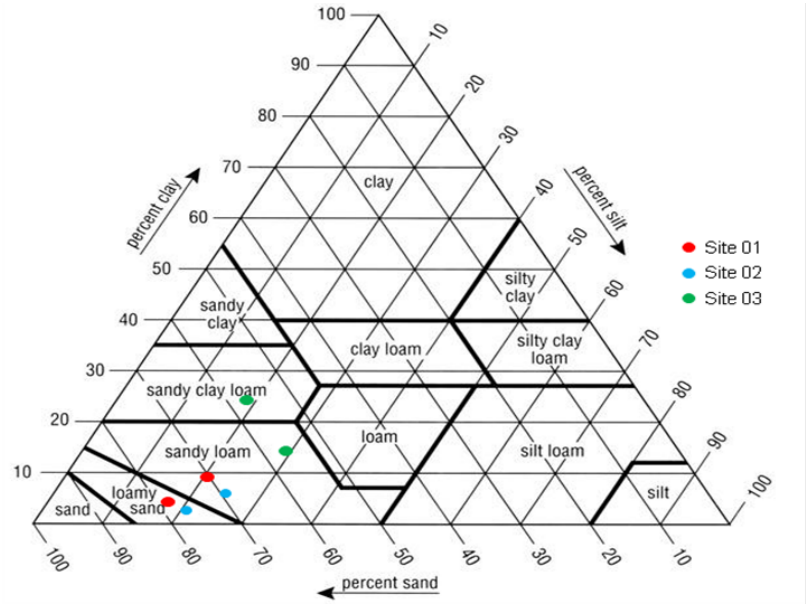


Figure 3. Soil textural triangle

3.2. Statistical data processing (ANOVA)

The interpretation of the results is essentially based on the judgment of the Fisher–Snédécor (F) test, which reflects the global effect of the factor on the different variables characterizing soil fertility and on the Newman–Keuls test, which allows to highlight the place (represented by letters A, AB, B, C, etc.) of each modality of the factor in question relative to another one in the explanation of the overall effect. Three factors (AFP), each with two modalities, were considered in the analysis: the treatment (S1-S2-S3), the plot (P1-P2) with 03, and horizons (Sh-Mh-Lh). The levels of significance achieved are determined from the levels of probabilities, namely:

– Very highly significant (VHS) for a probability level of 0.00001,
– Highly significant (HS) for 0.0001,

– Very significant (VS) for 0.001,
– Significant (S) for 0.05 (critical threshold),
– Not significant (NS) for a level greater than 0.05.

Table 1. Impact of agroforestry practices on the physico-chemical and water properties of soils

Factors	**Agroforestry practices**				**Profiles**			**Horizons**			
Variables	**S_1**	**S_2**	**S_3**	**F**	**P_1**	**P_2**	**F**	**Sh**	**Mh**	**Lh**	**F**
BI	0.00	0.00	0.00	**3.83**	0.00	0.00	**0.13**	0.37	0.50	0.20	**11.08**
	/	/	/	**NS**	/	/	**NS**	**AB**	**A**	**B**	**S**
BD	0.00	0.00	0.00	**2.04**	1.56	1.68	**12.60**	1.52	1.62	1.72	**12.09**
	/	/	/	**NS**	**B**	**A**	**S**	**B**	**AB**	**A**	**S**
EC	0.04	0.04	0.10	**28.64**	0.00	0.00	**0.77**	0.00	0.00	0.00	**0.29**
	B	**B**	**A**	**VS**	/	/	**NS**	/	/	/	**NS**
pH	7.14	7.24	7.68	**22.73**	0.00	0.00	**0.72**	0.00	0.00	0.00	**1.54**
	B	**B**	**A**	**VS**	/	/	**NS**	/	/	/	**NS**
OM	0.00	0.00	0.00	**1.03**	0.00	0.00	**0.03**	0.00	0.00	0.00	**1.15**
	/	/	/	**NS**	/	/	**NS**	/	/	/	**NS**
C/N	0.00	0.00	0.00	**0.84**	0.00	0.00	**1.03**	0.00	0.00	0.00	**0.29**
	/	/	/	**NS**	/	/	**NS**	/	/	/	**NS**
P_2O_5	105.33	63.68	246.47	**93.20**	0.00	0.00	**0.86**	236.13	95.24	84.10	**72.91**
	C	**B**	**A**	**VS**	/	/	**NS**	**A**	**B**	**B**	**VS**
$CaCO_3T$	0.64	0.64	8.99	**207.77**	0.00	0.00	**4.31**	1.77	2.76	5.73	**38.03**
	B	**B**	**A**	**HS**	/	/	**NS**	**B**	**B**	**A**	**VS**
$CaCO_3A$	0.25	0.23	3.13	**16.66**	0.00	0.00	**3.04**	0.00	0.00	0.00	**0.31**
	B	**B**	**A**	**S**	/	/	**NS**	/	/	/	**NS**
CEC	4.25	3.25	10.54	**12.08**	0.00	0.00	**0.01**	0.00	0.00	0.00	**0.16**
	B	**B**	**A**	**S**	/	/	**NS**	/	/	/	**NS**
Exchangeable cations **Ca**	0.00	0.00	0.00	**0.70**	0.00	0.00	**3.47**	0.00	0.00	0.00	**0.34**
	/	/	/	**NS**	/	/	**NS**	/	/	/	**NS**
Mg	0.80	0.47	3.32	**1440.53**	0.00	0.00	**6.74**	0.00	0.00	0.00	**3.45**
	B	**C**	**A**	**HS**	/	/	**NS**	/	/	/	**NS**
K	0.00	0.00	0.00	**1.70**	0.00	0.00	**0.04**	0.00	0.00	0.00	**1.03**
	/	/	/	**NS**	/	/	**NS**	/	/	/	**NS**
Na	0.22	0.13	0.57	**8.01**	0.00	0.00	**1.48**	0.00	0.00	0.00	**1.30**
	B	**B**	**A**	**S**	/	/	**NS**	/	/	/	**NS**
H	1.13	5.24	3.68	**18.71**	1.12	0.61	**7.25**	1.02	1.93	2.57	**11.72**
	C	**A**	**B**	**S**	**A**	**B**	**S**	**C**	**B**	**A**	**S**

3.2.1. Effect of AFPs on soil properties

AFPs do not have an overall effect on the following physico-chemical parameters (see *Tab. 1*): BI, BD, OM, and C / N. However, these practices have a significant effect on the BI at different horizons of the soil. The increase in the rate of organic matter in the soil explains the decrease in the soil fertility index.

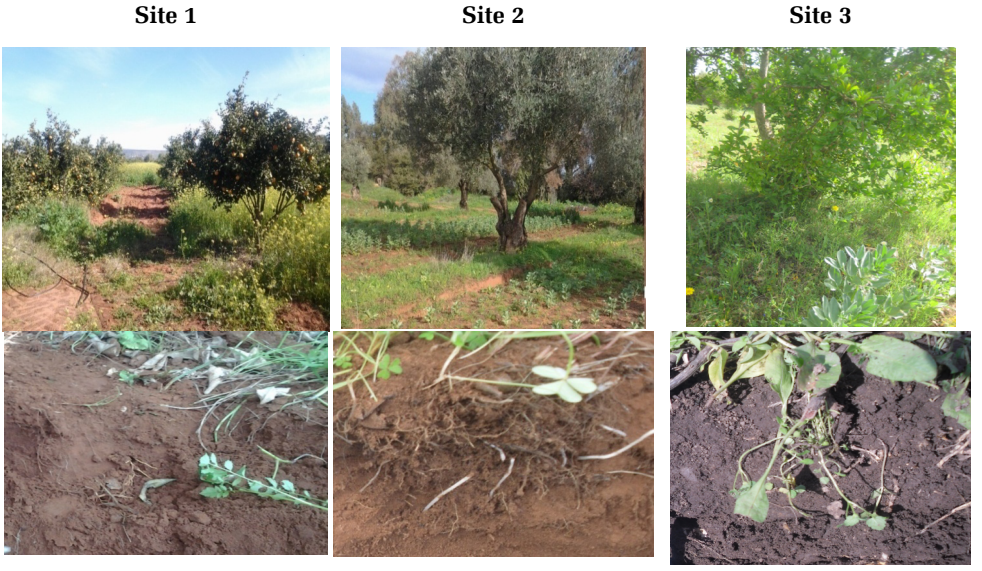
The position of the profile and the change of the soil horizon seem to have a significant effect on bulk density. Variations in bulk density with different horizons of the profiles appear to be strongly influenced by the position of the profile at the tree trunk. It is observed that the further away one gets from the tree, the more the soil becomes compact. The settlement occurs between the tree lines due to the passage of farmers, animals, and gear. The area of influence of the tree is about 3 to 5 m in diameter.

– AFPs have a very significant effect on EC and soil pH. Thus, the system characterizing the woody species *Punica granatum* has a greater overall effect compared to other woody species (*Citrus sinensis* and *Olea europaea*). Maintaining the pH of the soil between some limits close to neutrality (6 to 7) is necessary for the nutrients of the soil to be well assimilated by the roots of the plants. pH is a parameter that plant roots can directly alter through multiple processes, mainly including root respiration and excretion of root substances from trees and crops [6]. Pousset [7] shows that the biological activity always tends to bring the pH towards neutrality, in the neighbourhood of 7. EC reveals nothing of the nutritive elements that are present, nor of their quantity, but it gives an overall idea of the nutritional value of the solution. Generally, crops and trees have an influence on EC in poor soils (sandy soils) as nutrients [4].

– AFPs have a very significant overall effect on P_2O_5 in different horizons of the soil. Also, the system characterizing the species *Punica granatum* has a greater effect compared to other woody species. In the presence of calcium in the soil, iron, aluminium, etc., phosphorus combines to form phosphates, insoluble compounds. Phosphorus is no longer available for the plant; it is no longer assimilable [5]. Thus, these practices have a significant to highly significant effect on total limestone. The variability of limestone seems to be much more influenced by the system characterizing the species *Punica granatum* and by the horizon of the soil. The limestone content varies from one soil to another because this parameter (limestone) characterizing each horizon behaves differently depending on the nature of the parent material and the root and the biological activity of each experimental site applied to it (see *Fig. 4*).

– AFPs have a significant overall to highly significant influence on CEC and exchangeable cations (Mg, Na). The system characterizing the woody species *Punica granatum* has a greater effect compared to other woody species. The variability of moisture seems to be strongly influenced by the type of the woody

species (*Punica granatum*, *Citrus sinensis*, or *Olea europaea*) and by the position of the profile with respect to the trees for the three horizons of the profiles (Sh, Mh, Lh). It is better felt in the second site than in the first and third ones. The low water content at the surface horizon (Sh) appears to be related to soil texture and evaporation.



Photos by D. Fettouch, 2015

Figure 4. Effects of AFP on the root activity of each experimental site

Impact of AFP on soil ion balance

AFPs have a significant overall to very significant influence on the ionic balance of profiles (see *Tab. 2*). The system characterizing the woody species *Punica granatum* has a greater overall effect on the ionic balance and much more on the bicarbonates compared to other woody species because soluble calcium in the form of calcium bicarbonate Ca $(HCO_3)_2$ is more important, as the level of active limestone is high in the soil [5]. [8] shows a large variation in the composition of mineral exudates released by trees according to the species; these results show that apart from Na^+, it is K^+ and Ca^{2+} that are released in greater quantities and dominate the cationic moiety, while the anionic moiety is predominantly Cl^- and SO_4^{2-}.

Table 2. Impacts of agroforestry practices on soil ion balance

Factors	Agroforestry practices				Profiles			Horizons			
Variables	S_1	S_2	S_3	F	P_1	P_2	F	Sh	Mh	Lh	F
Cl^-	1.74	1.16	1.08	**19.62**	1.66	0.99	**51.69**	0.00	0.00	0.00	**0.68**
	A	**B**	**B**	**S**	**A**	**B**	**VS**	/	/	/	**NS**
HCO_3^-	0.70	0.75	1.51	**83.61**	0.00	0.00	**0.24**	0.00	0.00	0.00	**1.25**
	B	**B**	**A**	**VS**	/	/	**NS**	/	/	/	**NS**
SO_4^{2-}	0.00	0.00	0.00	**1.51**	0.00	0.00	**0.45**	0.00	0.00	0.00	**0.20**
	/	/	/	**NS**	/	/	**NS**	/	/	/	**NS**
Ca^{2+}	1.09	1.17	1.66	**10.87**	0.00	0.00	**0.87**	1.61	1.18	1.13	**7.70**
	B	**B**	**A**	**S**	/	/	**NS**	**A**	**B**	**B**	**S**
Mg^{2+}	0.79	0.54	1.18	**20.04**	0.00	0.00	**0.67**	0.00	0.00	0.00	**6.52**
	B	**B**	**A**	**S**	/	/	**NS**	/	/	/	**NS**
Na^+	1.34	0.90	2.40	**12.66**	0.00	0.00	**0.35**	0.00	0.00	0.00	**0.56**
	B	**B**	**A**	**S**	/	/	**NS**	/	/	/	**NS**
K^+	0.00	0.00	0.00	**5.16**	0.00	0.00	**1.26**	0.00	0.00	0.00	**0.58**
	/	/	/	**NS**	/	/	**NS**	/	/	/	**NS**

Conclusions

As a result of this study, it appears that variations in moisture and bulk density are influenced by soil type and woody species. Variations in bulk density appear to be strongly influenced by distances to the tree where the soil becomes compact as one moves farther away. pH is a parameter that tree roots and crops can alter directly. This effect on pH varies with species and soil type. AFPs have an influence on EC in soils that are poor in nutrients (sandy soils). This influence may be due to the phenomenon of macro-element rooting. Thus, these practices have an effect on the beating index by increasing the rate of organic matter in the soil horizons. Limestone is much more influenced by the nature of the parent material of each site.

AFPs have an influence on CEC, exchangeable cations, and soluble ions in the soil solution due to rooting phenomena. The study showed that a significant increase in CEC is observed near trees. From these results, we consider that the effect of these practices on soil properties is not negligible in our study area. The introduction of trees in cultivated plots gradually and durably modifies the agricultural landscape. Therefore, the return of trees to agricultural communities is an essential concern in order to ensure the sustainable rural management of soil fertility.

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