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# Influence of *Olea europea* L. and *Ficus Carrica* L. fine root activity on the K biodisponibility and clay mineralogy of the rhizosphere

**Sophia Mouas-Bourbia [a,*], Pierre Barre [b], Malika Boudiaf-Nait Kaci [a], Malika Mouffok [b], Mohamed Rebbouh [c], Lila Kessouri [c], Hallima Ouahab [c], Arezki Derridj [d], Bruce Velde [d]**

[a] Laboratoire Ressources Naturelles, Faculté des Sciences Biologiques et Agronomiques, UMMTO, Algérie
[b] Laboratoire de Géologie, UMR 8538 CNRS-ENS, 24 Rue Lhomond, 75231 Paris Cedex 05, France
[c] Département des Sciences Agronomiques, Faculté des Sciences Biologiques et Agronomiques, UMMTO, Algérie
[d] Laboratoire de Production, Amélioration & Protection des Végétaux & des Denrées Stockées, Faculté des Sciences Biologiques et Agronomiques, UMMTO, Algérie

## Abstract

The objective of this study was to compare the effect of fine root activity of *Olea europea* L. and *Ficus carrica* L. of soil in its immediate vicinity (in the so-called rhizosphere zone). The study was conducted on two stations in Northern Algeria: Guendoul and Bouira. *Olea europea* L. and *Ficus carrica* L. roots significantly modified some chemical properties of rhizosphere soil. Increases of soil carbon, $KNH_4^+$ and $KHNO_3^-$ were observed in the *Olea europea* L. and *Ficus carrica* L rhizosphere soil at both stations. Bulk and rhizosphere soil clay mineralogy was similar. Interstratified illite-smectite, smectite-illite and illite were predominant in the clay fraction. Chlorite and kaolinite were less represented. The decomposition of XRD diffractograms of two soil clay fractions using the Decomp program revealed that *Olea europea* L. roots promote $nK^+$ storage in interlayer position. Indeed, the lower abscissa position of the gravity center (cg) of the X-ray patterns, the peak displacement of clays populations PCI, I/S, S/I toward illite peak position indicates an increase of "illite-like" layer content in the vicinity of *Olea europea* L. roots. *Olea europea* L. roots appeared to have more influence on the rhizosphere soil than *Ficus carrica* L. roots probably because of its higher root biomass and the greater activity of the tree in winter (contrary to *Ficus Carrica* L., *Olea europea* L. keep their leaves in winter). The two species underground activity seems to be well reflected in their respective rhizosphere..

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## Introduction

*Olea europea* L. and *Ficus Carrica* L. are often grown in Kabylia in North Algeria on soil with a limited fertility. The use of nutrients by plants is highly dependent on the immediate physical, chemical and biological conditions related to the vicinity of the roots (Darrah et al. 2006; Romheld and Neuman, 2006). The magnitude of changes in the rhizosphere depends on the activity of roots and micro-organisms associated with it that appear related to the tree species and soil fertility (Grayston et al. 1996; Chiu et al. 2002; Chen et al. 2006). Studies on the rhizosphere of forest trees or field-grown plants showed a higher concentration of

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[*] Corresponding author.
Laboratoire Ressources Naturelles, Faculté des Sciences Biologiques et Agronomiques, UMMTO, Algérie
Tel.: +21326224538
E-mail address: mouasbsophia@yahoo.fr

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potassium in the vicinity of the roots (Vincenzo et al. 2003; Turpault et al. 2005; Calvaruso et al. 2011). It is well known that the dynamics of potassium in soils is closely related to the amount and type of clay (Goulding, 1987). Processes in the rhizosphere can also affect at relatively short time scales clay mineralogy of the clay fraction (April, and Keller, 1990; Courchesne and Gobran, 1997; Augusto et al. 2001; Turpault et al. 2008) and therefore the bioavailability of potassium (K bioavailability). This capacity of species to modify the nutrient's bioavailability in the rhizosphere can become a major characteristic in the selection of the species to establish on soils deficient in nutriments. An increase of the $KHNO_3$ in the rhizospheric soil of olive groves in North Algeria is confirmed by an increase in the number of illite- like layers in the rhizosphere compared to bulk soil (Mouas Bourbia et al. 2013). Similar to olives, it can be deduced that the roots of the fig tree is likely to affect the chemical and mineralogical properties of the rhizosphere so that it will adapt to even the deficient nutrient soils. To our knowledge, few studies have focused on the impact of the root of the olive and fig trees on soil slightly reworked. The objectives of this study are to determine if there are changes: 1) in properties of potassium in the rhizosphere of olive and fig tree, 2) of the clay mineralogy in the immediate vicinity of the root of olive and fig trees.

## Material and Methods

### Site description

The study was conducted on 4 sites in North Kabylia (Algeria), but only the results of two stations are presented in this work. Main characteristics of the sites are presented in table 1. None of the studied sites have been fertilized or irrigated. Guendoul is located north of the Djurdjura Mountains in a sub-humid climatic zone (annual rainfall=826 mm, ETP (Thornwaite) =1072 mm). Bouira is located south of the Djurdjura Mountains which diminish rainfall and consequently give a drier semi-arid zone (annual rainfall= 560 mm, ETP (Thornwaite) =998 mm). The climatic data were measured respectively for the sub-humid and semi-arid zones at the Boukhalfa and Ain-Bessam meteorological stations between 1996 and 2006.

### Soil sampling design

One composite sample of "rhizospheric" and "bulk" soils per site have been collected between December and January 2005. For each site, 10 adjacent diagonally spaced trees have been selected in the middle of the grove in order to avoid possible boundary effects. For each of the 10 selected trees, four soil cores (diameter 7.5 cm; depth 30 cm) positioned at the extremity of a 2.5 x 2.5 m cross centred on the Olive tree and fig tree trunk were excavated. Roots present in the core were shaken freeing large particles and soil particles adhering to the fine roots (less than 2 mm diameter) were collected which were considered to be the "rhizospheric" soil. Rhizospheric soil from the 40 cores (4 cores x 10 trees) were combined, homogenised, air-dried and sieved at 2 mm which constituted the "rhizospheric" sample. In each core, soil that was obviously root-free was collected. Root free soil samples from the 40 cores were combined homogenised and sieved at 2 mm. It constituted the "bulk" soil. The sampling design assured that "bulk" and "rhizospheric" soils were indeed representative of each site. There is no replicate per site which explains why no error bars are associated to the data for each site.

### Root biomass

Three cylinders of volume of 250 ml are introduced into the horizons of the soil of 3 olive trees and 3 fig trees. These depths correspond for both species approximately to the limits of the homogeneous horizons of root prospecting. It is about horizons 0-12cm, 12-30cm and 30-45cm for the olive tree, 0-15cm, 15-25cm and 25-40 cm for the fig tree. The soil and roots contained in cylinders are separated. A composite average sample of the root biomass of 3 trees by station is constituted. Roots having been washed are dried in a steam room at 60 °C. The results are expressed in g of dry matter of roots/ $dm^3$ of soil.

### Soil analyses

### Physico-chemical characteristics of soil samples

Soil characteristics were determined on the composite samples according to standard methods proposed in (Jackson, 1967). Particle size distribution was measured according to the Robinson pipette method (organic matter oxidation by $H_2O_2$, shaking in a sodium hexametaphosphate solution). Soil pH was measured in a 1:5 soil distilled water suspension. $CaCO_3$ was determined only on bulk soil using the HCl 1M volumetric method. Cation exchange capacity was measured according to the ammonium acetate method. Organic C was determined by sulfochromic oxidation. Water extractable Potassium (Kw) was determined as follows. Soil samples were shaken during 45 minutes in deionized water with a 1/10 soil/water ratio. The suspension was then filtrated and $K^+$ concentration in the solution was determined by flame spectrometry. Exchangeable-K was extracted by shaking soil samples in an ammonium acetate 1M solution at pH 7 (soil/solution ratio of 1/10) during 1 h. The suspension was then filtrated and $K^+$ concentration in the solution was determined by flame spectrometry. Slowly-exchangeable K was determined as follow. 25 mL of boiling $HNO_3$ 1M were added to 2.5g of soil. The suspension was boiled during 10 minutes and then filtrated. Potassium concentration in the solution was determined by flame spectrometry. The slowly-exchangeable K corresponded to the $HNO_3$ extracted K minus the $NH_4^+$ extracted K.

### Soil clay mineralogy

### Clay fractions recovery procedure and saturation

For each sample, 20 g of soil was dispersed in 100 ml of deionized water using ultrasonic treatment (350J/mL). The suspended matter was left to sediment until only the <2 µm remained in suspension (this procedure had to be repeated several times because of the high calcium content in the samples which caused flocculation of the clays). The supernatant containing the clay fraction was poured in a beaker. The supernatant was divided in two for Sr and K saturation respectively. The Sr saturated clays were prepared as follow: 1) a few millilitres of a 0.5 M strontium chloride solution were added to the supernatant so that the suspension reached a 0.01 M $SrCl_2$ concentration; 2) all clays were flocculated and supernatant was discarded; 3) the flocculated clays were rinsed several times with deionized water until no more $Cl^-$ ions in the supernatant were observed using the $AgNO_3$ test. The K saturated samples were obtained similarly with KCl instead of $SrCl_2$. About three drops of the K or Sr saturated clays were poured on a glass slide for oriented X-ray diffraction.

### X-ray pattern acquisition and calculation of the center of gravity peak position for clay minerals

Air-dried oriented preparations were analysed using a PANalytical Xpert Pro diffractometer (Rigaku). The instrument was set in the θ/θ Bragg-Brentano configuration, with an optical system defined using the following settings and parameters: anti-scatter and diffusion slits respectively 0.25 and 0.5°2θ , Soller slits of 0.04 radians, Ni filter for Cu radiation, and a Xccelerator detector counting simultaneously over an angular range of 2°2θ. The resulting X-ray patterns were then decomposed (after background subtraction and a four point smoothing routine) using the Decomp program (Lanson, 1997). Peak areas were determined as the product of peak height and width at half height. The center of gravity position of the X-Ray patterns in the (001) 2:1 clay area was calculated according to Barré et al. (2007). This indicator gives an insight into the total amount of layers "closed" to 1 nm: the smaller the center of gravity position, the greater the number of 1 nm layers (as discrete illite or in mixed layered minerals).

### Statistical Analyses

The statistical analyses were conducted using the R program. The comparisons of soil characteristics, quantities of K forms and mineralogical data in bulk and rhizospheric soils were conducted using a pairwise t-test.

## Results and Discussion

### Increase in the fine root biomass of the olive tree in the upper layers

The root biomass is highest in the upper layers of soils for the two species**.** It is on average of 12, 5 $g.dm^{-3}$ for the olive-tree (0-12cm), and of 3.94 $g.dm^{-3}$ (0-15cm) for the fig tree. The root biomass falls to $5g.dm^{-3}$ between 10 and 25 cm for the olive-tree and $1.7g.dm^{-3}$ for the fig tree. The *Olea europea* L**.** have the highest root biomass in the two upper layers of root prospecting compared to *Ficus carrica* L.

### Bulk and rhizospheric soil of olive and fig tree

### Properties of bulk soil

The selected physical and chemical properties of the bulk soils are shown in Table 1. Bulk soil of olive and fig tree in the same station presents certain homogeneity. The clay content, the $CaCO_3$, the pH, the organic carbon, the cation exchange capacity (CEC), the $KNH_4^+$ and the $KHNO_3$ does not show important differences. The principal parameters allowing the comparison of the soils are: homogeneity of the soils, parental material, and proximity of the plot, an identical microclimate (temperature, moisture, and precipitations), an exposure and a similar slope (Binkley, 1995). The characteristics of the studied sites (Table 1) allow the comparison of the effect of the root of both species (olive and fig trees) on the same bulk soil. On the other hand, differences in physical and chemical properties of the soil between the sites of Bouira and Guendoul make it possible to compare olive and fig tree roots influence on two contrasted soil. One can quote the clay content and the $KHNO_3$ is higher for Bouira, whereas the soil carbon, the $CaCO_3$, are higher for Guendoul.

Table 1. Main characteristics of the 2 stations

| Station | Coordinates | Specie | Parent material | Slope | Soil type (WRB, 2006) | $CaCO_3$% |
|---|---|---|---|---|---|---|
| Bouira | 36°23'43.19'N | *Olea europea* L. | Old illuvial materials | 0% | Cambisol (calcaric) | 11,8 |
| | 3°53'14.04 '' E | *Ficus carrica* L. | | | | 15,4 |
| Guendoul | 36° 44'20.63"N | *Olea europea* L. | Carbonates | 10% | Cambisol (calcaric) | 25 |
| | 4°13' 05.91'' E | *Ficus carrica* L. | | | | 26,7 |
| | Clay Content (%) | Organic C $g.kg^{-1}$ | pH | CEC $(cmolc,kg^{-1})$ | $KNH_4$ mg/100g | $KHNO_3$ mg/100g |
| Bouira | 23,40 | 7,1 | 7,41 | 10,03 | 21,73 | 97,04 |
| | 26,88 | 8,9 | 7,41 | 11,2 | 27,18 | 73,14 |
| Guendoul | 13,68 | 12,9 | 7,62 | 9,36 | 26,7 | 59,08 |
| | 13,75 | 12,5 | 7,46 | 9,25 | 28,53 | 67,64 |

## Change of the chemical properties of the rhizosphere

The selected physical and chemical properties of the bulk and rhizospheric soils are shown in Table 2. A significant decrease ($p \leq 0.05$) of rhizospheric pH is observed for the two species, at the two studied stations. Several authors (Hinsinger et al. 2003; Augusto et al. 2002; Ma et al. 2009; Dinesh et al. 2010) measured a decrease of pH in the rhizosphere of various species of trees. In our case, the decrease of rhizospheric pH remains limited because of the buffering capacity of calcium carbonates. However, this light acidification can improve the assimilability of nutrients, such as phosphorus and iron. Rhizospheric organic carbon increases significantly ($p \leq 0.05$) for the two species at the two stations. This is likely due to the rhizodeposition, and to the many residues colonized by the rhizospheric microorganisms (Bonkowski et al. 2000).

The rhizospheric soil of the two species and for the two stations was significantly richer ($p \leq 0.05$) in Kw and $KHNO_{3^-}$ The increase in the $KNH_4^+$ was significant ($p \leq 0.05$) only in the rhizosphere of the fig tree. This accumulation of K in the vicinity of roots is explained by the mass flow, the exudation of K by the roots (Smith, 1976), and the release of K by weathering of minerals in the rhizosphere (Turpault et al. 2009). The accumulation of potassium in the rhizosphere was caused by the prevalence of the release of potassium in the rhizosphere in the K absorption by roots (Zhu et al. 2006). In a general way, this improvement of the soil fertility in the vicinity of roots by the rhizospheric processes could explain, partly, the capacity of adaptation of these two species to nutrient deficient soils. Indeed, 15 showed that this enrichment in K of the rhizospheric soil of the olive-tree made it possible to mitigate the deficiency of potassium of the bulk soil of olive orchards. We did not determine a significant difference between the rhizospheric effects of each species on the bulk soil of each station. Although the roots effect of the two species is similar, because its root biomass is more important, the olive-tree would impact a higher volume of soil at the agro-system level.

Table 2. Some properties of bulk and rhizospheric soil of olive and fig tree of 2 stations

| Station | Specie | Soil | pH | Organic carbon $(g.kg^{-1})$ | CEC $(cmol^+.kg^{-1})$ | Kw (mg/100g) | $KNH_4^+$ (mg/100g) | $KHNO_3^-$ (mg/100g) |
|---|---|---|---|---|---|---|---|---|
| Bouira | Olive tree | B | 7,4 | 7,13 | 10,03 | 2,27 | 21,73 | 97 |
| | | Rh | 7,3 | 13,27 | 11,28 | 2,46 | 27,18 | 123 |
| | Fig tree | B | 7,4 | 7,93 | 11,20 | 2,43 | 21,67 | 73,14 |
| | | Rh | 7,3 | 15,50 | 11,30 | 3,37 | 28,07 | 77,30 |
| Guendoul | Olive tree | B | 7,6 | 13,00 | 9,36 | 3,75 | 26,83 | 59,1 |
| | | Rh | 7,5 | 16,35 | 10,54 | 3,93 | 28,53 | 62,7 |
| | Fig tree | B | 7,4 | 10,86 | 9,25 | 1,72 | 29,16 | 67,6 |
| | | Rh | 7,4 | 14,76 | 11,50 | 2,62 | 32,14 | 76,26 |

## Does clay soils are modified in vicinity of the root?

The use of the center of gravity position (cg) allowed us to compare numerically X- ray patterns of clays recovered in bulk and rhizosphere soils of *Olea europea* L. and *Ficus carrica* L. Lower cg in the rhizophere of the olive tree at the two stations which has been studied (Table 3), the shift of peaks of PCI, I/S and S/I in the rhizosphere of the olive tree of Guendoul toward illite peak position indicate an increase in the content of 'illite-like layers' in the vicinity of roots (Figure 2). For Bouira, increase of relative PCI peaks area in the rhizopheric clays (Table 3) comparatively to clays recovered from the bulk soil of the olive tree confirms an increase of 'illite-like layers' content in the soil root zone. Vermiculite clays present in the bulk soil of the olive tree of Bouira fixed potassium, which led to the formation of 'illite-like layer' and the increase in PCI and I/S contents in the rhizosphere. These results are in agreement with those of 12 which showed a significant decrease in the amount of vermiculite in the rhizosphere of forest trees.

Table 3. Relative peak areas of illite peaks, center of gravity position and center of gravity modification following K saturation (ΔCg=100*(CgSr−CgK)/CgSr).

| Stations | Species | Soil | Relative PCI peak area (%) Sr saturated | Relative Illite peak area (%) Sr saturated | Cg position (nm) Sr saturated | Cg position (°2ɵ ) Sr saturated | Cg position (nm) K saturated | Cg position (°2ɵ ) K saturated | ΔCg % |
|---|---|---|---|---|---|---|---|---|---|
| Guendoul | Olive tree | B | 6.9 | 8.3 | 1,26 | 7,01 | 1,13 | 7,77 | 9.8 |
| | | Rh | 7.0 | 8.5 | 1,25 | 7,16 | 1,15 | 7,68 | 6.7 |
| | Fig tree | B | 7,9 | 13,1 | 1,26 | 7,03 | 1,16 | 7,62 | 7,4 |
| | | Rh | 5,6 | 8,5 | 1,26 | 7,03 | 1,15 | 7,71 | 8,8 |
| Bouira | Olive tree | B | 15.2 | 20 | 1,21 | 7,3 | 1,15 | 7,68 | 4.9 |
| | | Rh | 22 | 27.5 | 1,14 | 7,68 | 1 ,12 | 7,9 | 2.8 |
| | Fig tree | B | 20,7 | 34,2 | 1,16 | 7,65 | 1,13 | 7,84 | 2,4 |
| | | Rh | 17,6 | 31,5 | 1,18 | 7,49 | 1,12 | 7,92 | 5,4 |

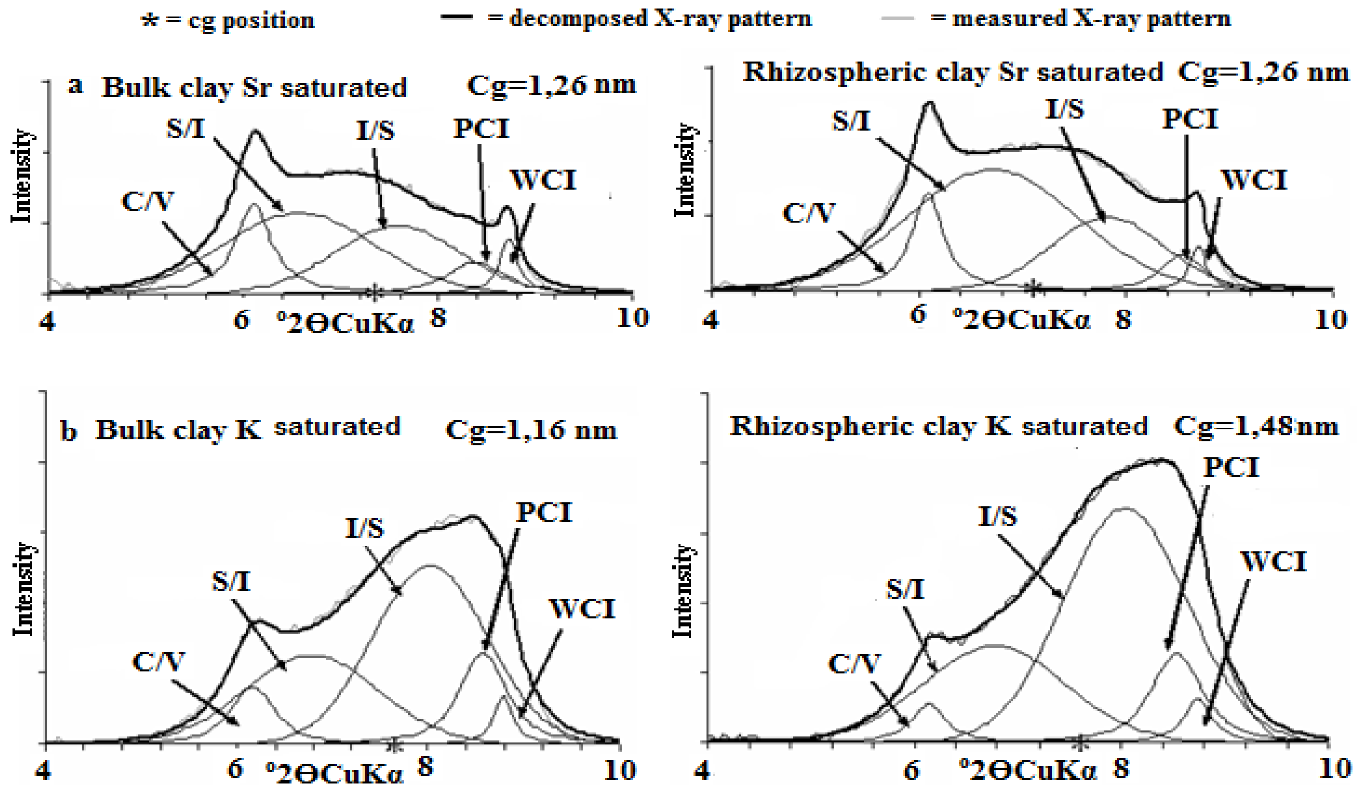

Figure1. X-ray patterns, Sr and K saturated, of clay samples recovered from rhizospheric and bulk soils of olive orchard of Guendoul. C/V, S/I, I/S, PCI and WCI refer to interstratified chlorite/vermiculite, interstratified smectite/illite, interstratified illite/smectite, poorly crystallized illite and well crystallized illite respectively.

The X-Rays decomposed patterns Sr-saturated clay fraction of rhizospheric soil of the fig tree, showed a lack of shift toward illite for Guendoul station (Table 3). For Bouira station (Figure 3), a limited shift of cg, I/S and S/I toward smectite is observed. KCl saturation of clays induced a decrease (in nm) in cg position for the two fractions of soil and for both species (Table 3) and an increase in PCI, I/S. Δcg is lower for the rhizosphere soil of olive tree compared to bulk soil. This lower increase in 'illite-like layer' in the rhizosphere of the olive tree suggests that clay near the roots were already enriched in illite.

Rhizosphere and bulk soil clays showed an opposite behavior. The rhizosphere clays fixed more potassium than bulk clays. This is confirmed by the value of Δcg of the rhizospheric soil of the fig tree (Table 3). This different effect of the two species on the clay fraction revealed a significant ($p \leq 0.04$) difference in the soil-specie interaction. The impact of the two species on the clay mineralogy of the rhizosphere would be related to the root system of the two species.

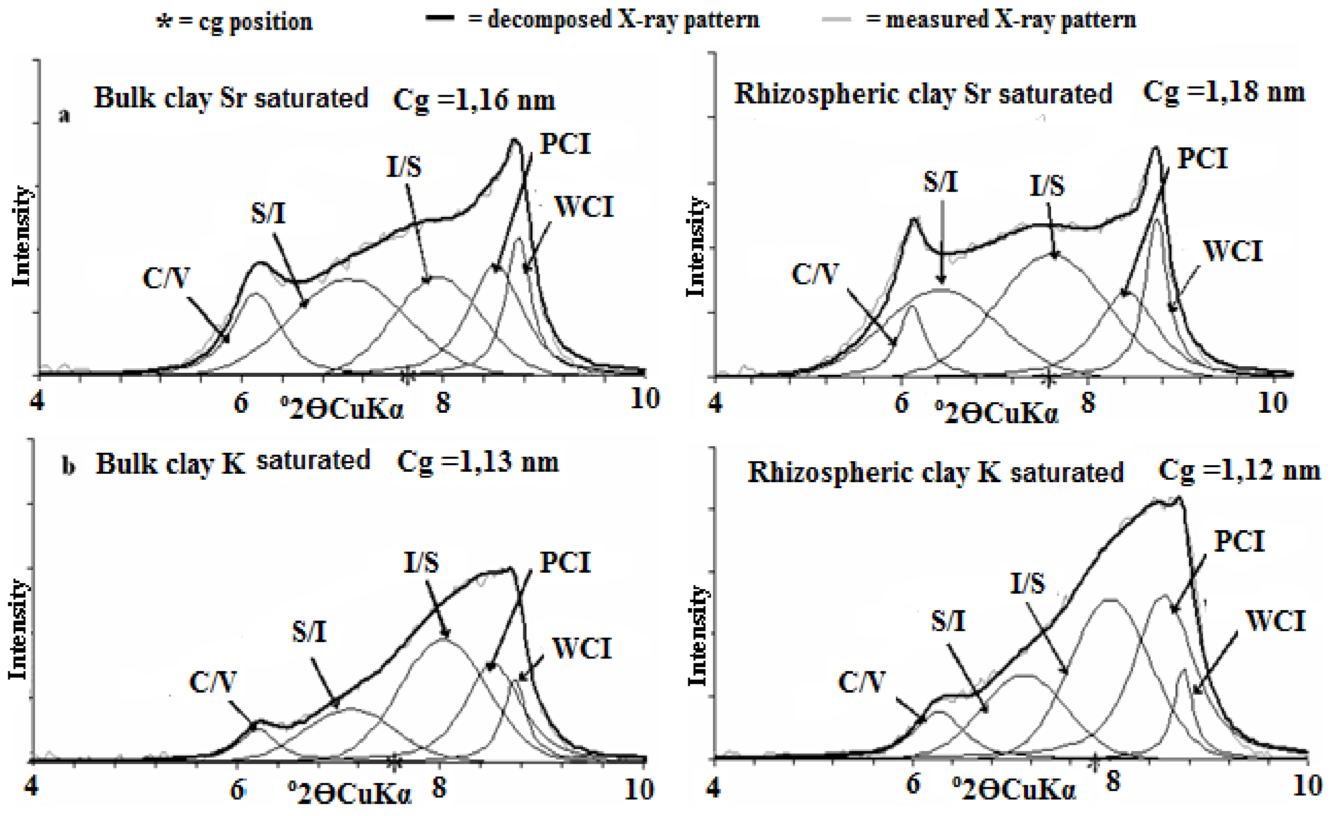

Figure2. X-ray patterns, Sr and K saturated, of clay samples recovered from rhizospheric and bulk soils of fig orchard of Bouira. C/V, S/I, I/S, PCI and WCI refer to interstratified chlorite/vermiculite, interstratified smectite/illite, interstratified illite/smectite, poorly crystallized illite and well crystallized illite respectively.

## Conclusion

*Olea europea* L. and *Ficus carrica L.* have, in similar way, modified certain properties of their rhizosphere. An increase in the soil carbon content, Kw and $KHNO_3$ were measured in the rhizosphere of the two species. However, we did not observe a significantly different rhizospheric between the two tree species. In spite of that, the olive tree seems to have a more intense root activity than the fig tree. It is probably due to its higher root biomass. These results suggest that at the level of the agro-system, olive trees impact a larger volume of soil than fig trees. The results concerning the impact of the root of these two species on the mineralogy of the clay fraction show that the activity of the root of the olive tree enhance the storage of potassium in clays of the rhizosphere compared to that of the fig tree.

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# References

April, R., Keller, D., 1990. Mineralogy of the rhizosphere in forest soils of the eastern United States. *Biogeochemistry* 9: 1–18.

Augusto, L., Ranger, J., Binkley, D., Rothe, A., 2002. Impact of several common tree species of European temperate forests on soil fertility. *Annals of Forest Science* 59(3): 233-253.

Augusto, L., Ranger, J., Turpault, M.P., Bonnaud, P., 2001. Experimental in situ transformation of vermiculites to study the weathering impact of tree species on the soil. *European Journal of Soil Science* 52: 81-92.

Barré, P., Velde, B., Catel, N., Abbadie, L., 2007. Soil-plant potassium transfer: impact of plant activity on clay minerals as seen from X-ray diffraction. *Plant and Soil* 292: 137-146.

Binkley, D., 1995. The influence of tree species on forest soils: Process and Patterns. In: Mead DJ, Cornforth IS (eds) Proceeding of the trees and soil workshop. Agronomy Society of New Zealand Special Publication, Lincoln University, Canterbury, 1–33.

Bonkowski, M., Cheng, W., Griffiths, B.S., Alpha, J., Scheu, S., 2000. Microbial-faunal interactions in the rhizosphere and effects on plant growth. *European Journal of Soil Biology* 36: 135-147.

Calvaruso, C., N'Dira, V., Turpault, M.P., 2011. Impact of common European tree species and Douglas-fir (*Pseudotsuga menziesii* [Mirb. ]Franco) on the physicochemical properties of the rhizosphere. *Plant and Soil* 342 (1-2): 469-480.

Chen, Y.M., Wang, M.K., Zhuang, S.Y., Chiang, P.N., 2006. Chemical and physical properties of rhizosphere and bulk soils of three tea plants cultivated in Ultisols. *Geoderma* 136: 378-387.

Chiu, C.Y., Wang, M.K., Hwong, J.L., King, H.B., 2002. Physical and chemical properties in rhizosphere and bulk soils of Tsuga and Yushania in a temperate rain forest. *Communications in Soil Science and Plant Analysis* 33: 1723-1735.

Courchesne, F., Gobran, G.R., 1997. Mineralogical variation of bulk and rhizosphere soils from a Norway spruce stand. *Soil Science Society America Journal* 61: 1245-1249.

Darrah, P.R., Jones, D.L., Kirk, G.J.D., Roose, T., 2006. Modelling the rhizosphere: a review of methods for up scaling to the whole-plant scale. *European Journal of Soil Science* 57: 13-25.

Dinesh, R., Srinivasan, V., Hamza, S.V.A., Parthasarathy, V.A., Aipe, K.C., 2010. Physico-chemical, biochemical and microbial properties of the rhizospheric soils of tree species used as supports for black pepper cultivation in the humid tropics. *Geoderma* 158: 252-258.

Goulding, K.W.T., 1987. Potassium fixation and release in: Methodology in soil potassium research. 20th colloque of I.P.I., 125-141.

Grayston, S.J., Vaughan, D., Jones, D., 1996. Rhizosphere carbon flow in trees, in comparison with annual plant: the importance of root exudation and its impact on microbial activity and nutrient availability. *Applied Soil Ecology* 5: 29-56.

Hinsinger, P., Plassard, C., Tang, C., Jaillard, B., 2003. Origins of root-mediated pH changes in the rhizosphere and their response to environmental constraints. *Plant and Soil* 248: 43-59.

Jackson, M.L., 1967. Soil Chemical Analysis. Asia publishing House, Bombay, India.

Lanson, B., 1997. Decomposition of experimental X-ray diffraction patterns (profile fitting): A convenient way to study clays. *Clays and Clay Minerals* 45: 132-146.

Ma, B., Zhou, Z.Y., Zhang, C.P., Zhang, G., Hu, Y.J., 2009. Inorganic phosphorus fractions in the rhizosphere of xerophytic shrubs in the Alxa Desert. *Journal of Arid Environments* 73(1): 55-61.

Mouas Bourbia, S., Barré, P., Boudiaf Naït Kaci, M., Derridj, A., Velde, B., 2013. Potassium status in bulk and rhizospheric soils of olive groves in North Algeria. *Geoderma* 197-198: 161–168.

Romheld, V., Neuman, G., 2006. The rhizosphere: Contributions of the Soil-Root interface to sustainable soil systems in Biological Approach, to sustainable soil systems. Ed. CRC Taylor and Francis Group, 91-103.

Smith, W.H., 1976. Character and significance of forest tree root exudates. *Ecology* 57: 324-331.

Turpault, M.P., Nys, C., Calvaruso, C., 2009. Rhizosphere impact on the dissolution of test minerals in a forest ecosystem. *Geoderma* 153: 147-154.

Turpault, M.P., Righi, D., Utérano, C., 2008. Clay minerals: Precise markers of the spatial and temporal variability of the biogeochemical soil environment. *Geoderma* 147: 108-115.

Turpault, M.P., Uterano, C., Boudot, J.P., Ranger, J., 2005. Influence of mature Douglas fir roots on the solid soil phase of rhizosphere and soil solution chemistry. *Plant and Soil* 275: 327-336.

Vincenzo, D.M., Arienzo, M., Adamo, P., Violante, P., 2003. Availability of Potassium, Calcium, Magnesium, and Sodium in "Bulk" and "Rhizosphere" Soil of Field-Grown Corn Determined by Electro-ultrafiltration. *Journal of Plant Nutrition* 26(6): 1149-1168.

Zhu, H., Liu, Z., Wang, C., Zhong, Z., 2006. Effects of intercropping with persimmon on the rhizosphere environment of tea. *Frontiers of Biology in China* 4: 407-410.