Agronomy Research **17**(6), 2158–2171, 2019
https://doi.org/10.15159/AR.19.212

Use of olive pomace as an amendment to improve physico-chemical parameters of soil fertility

H. Ameziane[1,*], A. Nounah[1], M. Khamar[1] and A. Zouahri[2]

[1]Mohammed V University, High School of Technology, Civil Engineering and Environment Laboratory (LGCE), Materials Water and Environment team, MA11060 Sale, Morocco
[2]INRA, Regional Center for Agricultural Research in Rabat, Research unit on Environment and Conservation of Natural Resources, MA10112 Rabat, Morocco
[*]Correspondence: amezianehalima@gmail.com

Abstract. Given their richness in nutritive elements, the majority of agricultural waste is used as soil amendments, including olive oil waste. The purpose of this study is to determine the effects of the use of olive pomace from three extraction systems on the physico-chemical fertility of the soil, after their use as an amendment for faba bean cultivation. The experiment is carried out at the Civil Engineering and Environment Laboratory in the EST of Salé, in pots where the olive pomace has been mixed with the soil, respecting the percentages studied. Several relative physico-chemical parameters of soil fertility were determined at the end of the experiment, namely pH, electrical conductivity (EC), total kjeldhal nitrogen (NTK) content, organic carbon and exchangeable bases concentration and soil cation exchange capacity (CEC) determination. Different percentages of pomace from the three extraction systems were applied (control, 10%, 15%, 25%, 50%, 75% and 100%) for four months of bean germination test. The application of the pomace reduced soil pH, and increased soil organic matter and organic carbon content in proportion to the added percentage of pomace. The available phosphorus and exchangeable potassium content increased significantly ($p < 0.05$) in pots containing different percentages of pomace compared to their concentrations in the soil (control). The total nitrogen content has not increased sufficiently but remains significantly different from the control, especially for the percentages of 25%, 50% and 75%. For its part, the cation exchange capacity (CEC) is important and will allow a good retention of nutrients for all percentages.

Key words: olive pomace, physico-chemical fertility, soil amendment.

INTRODUCTION

The waste management from olive crushing plays a key role in the sustainable production of olive oil and is a major environmental problem, particularly in Mediterranean countries, which produce more than 95% of olive oil worldwide (Roig et al., 2006). The extraction of olive oil can be carried out by several processes, including the three extraction systems mentioned in this study: the traditional pressing system based on manual pressing of olives and natural separation of oil from olive mill wastewater by simple settling, the continuous system based on the use of a centrifuge to ensure the separation of oil from the paste resulting from the crushing of olives. The paste is separated into two phases (olive oil and wet pomace) in the case of a continuous two-phase system and into three phases (olives mill wastewater, pomace and olive oil) in the case of the continuous three-phase system Fig. 1.

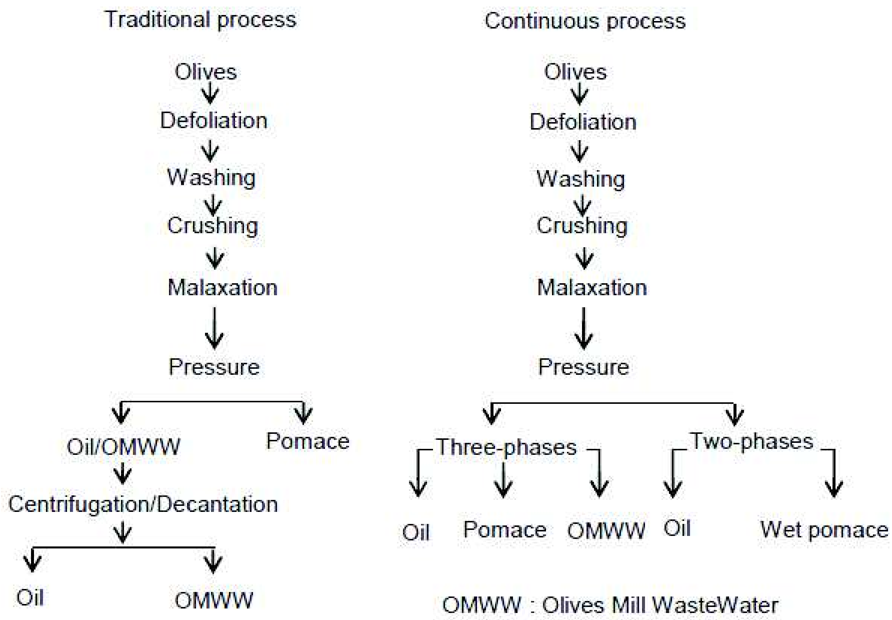

Figure 1. Extraction processes of olive oil.

Pomace and olive mill wastewater together represent potential threats to the environment due to the large amount produced over a short period of time on the one hand, and their high organic load on the other (Morillo et al., 2009). Several recovery methods have been proposed to reduce the residual impact of this waste on the environment. Indeed, the pomace has been used as fuel, adsorbent, livestock feed, thermal insulation and fertilizer (Federici et al., 2009; Morillo et al., 2009).

Direct application of pomace to agricultural land appears to be operationally simple and economically achievable. In addition, in some European countries, national legislation allows the application of specific quantities of pomace on cultivated land. In Italy for example, the spreading of olive pomace on agricultural land can be done in accordance with Law No. 574 of 1996.

The application of raw or composted pomace on agricultural land has been the subject of several in-depth studies (Di Serio et al., 2008; Mechri et al., 2009; Chartzoulakis et al., 2010).

As a result, the olive pomace can be considered a good fertilizer because of its high levels of nutrients needed for plant growth and development, namely potassium (K), nitrogen (N), phosphorus (P), magnesium (Mg), and organic matter (Niaounakis et al., 2006; Lozano-García et al., 2011). In addition, the incorporation of these wastes into the soil is an interesting contribution to carbon sequestration, the reduction of runoff and soil loss through erosion (Mondini & Sequi, 2008; Lozano-García et al., 2011), without negatively affecting the soil microbial community (Proietti et al., 2015), which plays a significant role in the assimilation of certain nutritive elements necessary for plants.

The olive pomace use as a soil amendment has given satisfactory results in terms of yield and crop production (Lopez-Pineiro et al., 2006) due to its high content of macro and microelements (Ameziane et al., 2018). Therefore, the study of the effect of pomace on the physico–chemical fertility of the soil is necessary to ensure sustainable olive growing that respects the environment without negative effects on the soil. The objective of this work is to study the effect of the use of olive pomace at different percentages as soil amendment on the physico-chemical characteristics of Moroccan sandy soil, in order to improve the fertility parameters of these soils, for a better agricultural exploitation of the latter.

MATERIALS AND METHODS

Materials

The olive pomace was collected from three oil mills in the city of Tahla (Tahla, Morocco, latitude 34°02'58" North, longitude 4°25'17" West, altitude above sea level: 606 m). The first oil mill operates on a two–phase continuous system, the second on a three-phase continuous system and the third ensures a traditional crushing. The present olive pomace was used as fertilizer at different percentages (0%, 10%, 15%, 25%, 50%, 75%, 100%) in pots for *faba bean* cultivation, to see the influence of the use of this pomace on the physico-chemical fertility of the soil. The test began with drying the pomace, grinding and sieving it to 1 mm, then seeding the bean grains in pots with different percentages of soil and pomace from the three extraction systems, averaging 5 grains per pot. The test lasted four months from February 2017 to May 2017 at the civil engineering and environment laboratory of the high school of technology in Salé-Marocco, at a variable temperature and humidity depending on outdoor climatic conditions.

Each pot was regularly irrigated three times a week with an equal amount of well water. The test was repeated three times.

The physico–chemical characteristics of the pomace studied are presented in Table 1 (Ameziane et al., 2018).

The soil used in this study comes from 'Salé' (Salé, Morocco, latitude 34°03'11" North, longitude 6°47'54" West, altitude above sea level: 34 m). It was sampled from the topsoil (0–20 cm) of a callistemon. It is a sandy soil and its properties are presented in Table 1 (Ameziane et al., 2018).

At the end of the plant period, the soil contained in the pots is dried at 40°C and stored for physico–chemical analysis.

Table 1. Physico-chemical parameters of the pomace from the three extraction systems and the soil (Ameziane et al., 2018)

Physico-chemical parameters	Olive pomace			Soil
	Olive pomace from the traditional press system (GT)	Olive pomace from the two-phase system (G2Ph)	Olive pomace from the three-phase system (G3Ph)	
Clay in %	-	-	-	9 ± 0.044
Sand in %	-	-	-	68 ± 0.088
Silt in %	-	-	-	23 ± 0.044
pH	6.04 ± 0.02	5.90 ± 0.02	5.94 ± 0.03	7.61 ± 0.044
Electrical conductivity in mS cm^{-1}	2.62 ± 0.10	2,47 ± 0.09	3.21 ± 0.36	0.085 ± 0.149
Moisture in %	43.33 ± 1.87	52.81 ± 0.77	53.56 ±1.63	4.51 ± 0.044
Organic matter in %	77.02 ± 0.88	74.69 ± 13.36	92.03 ± 4.65	1.58 ± 0.158
Total organic carbon in %	49.72 ± 0.36	49.32 ± 0.36	50.79 ± 0.31	0.83 ± 0.597
Total nitrogen in %	0.00257	0.00175	0.00402	0.134
The available Phosphorus in %	0.00015	0.02	0.04	0.0103
Calcium in %	0.29	0.23	0.28	0.48
Exchangeable potassium in %	6.70	4.60	9.4	0.0445
Magnesium in %	0.04	0.03	0.03	0.0243
Sodium in %	0.9	1	1	0.0092

The values obtained represent the average of three repetitions.

The water used for faba bean irrigation comes from a well of the Higher School of Technology of Sale, whose physico–chemical characteristics (Table 2) are in compliance with the Moroccan standard for irrigation water (Secretariat of State at the Ministry of Energy, Mines, Water and Environment, in charge of Water and Environment, 2007):

Table 2. Physico-chemical parameters of irrigation water (Ameziane et al., 2018)

Physico–chemical parameters	Characteristics of irrigation water
pH	7.49 ± 0.047
Electrical conductivity in mS cm^{-1}	1.024 ± 0.016
Temperature in °C	18.13 ± 0.058
Suspended matter mg L^{-1}	0.232 ± 0.033
Salinity in ppb	655 ± 0.1
Nitrates in mg L^{-1}	7.04 ± 0.007
Chlorides in mg L^{-1}	192.5 ± 0.044
Boron in mg L^{-1}	0
Sulphates in mg L^{-1}	21.33 ± 0.005
Ortophosphates in mg L^{-1}	0.0134 ± 0.0001
The sodium absorption ratio (SAR) $meq^{1/2}$ $(l^{1/2})^{-1}$	0.53 0.5

The values obtained represent the average of three repetitions.

Methods

To carry out physico-chemical characterization, a representative soil sample is sieved to 2 mm and dried in an oven at 40 °C to determine the pH, electrical conductivity (EC), total organic carbon (TOC), exchangeable potassium (K_2O), available phosphorus

(P_2O_5), total Kjeldhal nitrogen (NTK), exchangeable sodium (Na^+), cation exchange capacity (CEC).

pH and EC are measured in the aqueous extract using the ratio 2:5 (w/v) for pH (Rodier et al., 2009), and the ratio 1:5 (w/v) for EC (ISO 11265, 1994).

Total nitrogen is measured by the Kjeldahl method (Bremner et al., 1982), total organic carbon by the Walkley and Black method (Walkley & Black, 1934) and organic matter was estimated by the following formula OM in % = %TOC×1.72 (Dabin, 1970).

Available Phosphorus by the Olsen method (Olsen, 1954). Exchangeable potassium and sodium are extracted by CH_3COONH_4 at pH 7 (Bower et al., 1952) and measured by flame photometer. The cation exchange capacity (CEC) was obtained by the Mehlich method (1942). The physico-chemical analyses were carried out in the environment and natural resources conservation laboratory of the Agricultural Research National Institute in Rabat.

Statistical analyzes

The obtained results correspond to the average of 3 repetitions. The experimental data were subjected to unidirectional variance analysis (ANOVA) and mean separations were made by the smallest difference (LSD) at the significance level of $p < 0.05$, using the Statgraphics centurion XVI program for Windows.

RESULTS AND DISCUSSION

Chemical characteristics of the soil and olive pomace

In this study, the used soil is sandy (68%) with a neutral pH (7.61) and an average moisture of 4.51%. It has a low content of organic matter (1.58%) as well as organic carbon (0.83%), which is the case for most Mediterranean soils (Ganlanakis, 2017). Its content of total nitrogen and available phosphorus is high and is worth respectively (0.134%) (0.0103%) as well as potassium (0.0445%) (Table 1).

The pomace average humidity varies from 43.33% to 53.56% depending on the used extraction system. They have a slightly acidic pH (5.9 to 6.04) and a very high content of organic matter (74.69% to 92.03%) and organic carbon (49.32 to 50.79%). They are low in nitrogen (0.00175% to 0.00402%), phosphorus (0.00015% to 0.04%) and sodium (0.9% to 1%) but rich in potassium (4.6% to 9.4%) (Table 1).

Olive pomace effect on the physical characteristics of the soil (pH, EC, OM)

pH

The different soil types pH varied slightly from basicity to neutrality during the germination test. Indeed, more the concentration of pomace increases, more the pH turns towards neutrality (Fig. 2). On the other hand, this pH remains favourable for the assimilation of mineral salts and micro-nutrients essential for the growth and development of most plants (Nefzaoui, 1985). Despite the acidity of the pomace (Table 1), the germination of the faba bean increased the pH to neutral even for the pot containing 100% pomace. This can be attributed to the microbiological activity of the microorganisms. Actually, when the soil is enriched with easily decomposable organic compounds, the release of ammonia always leads to a more or less durable increase in pH, depending on the doses and the plants' use (Moureaux, 1973).

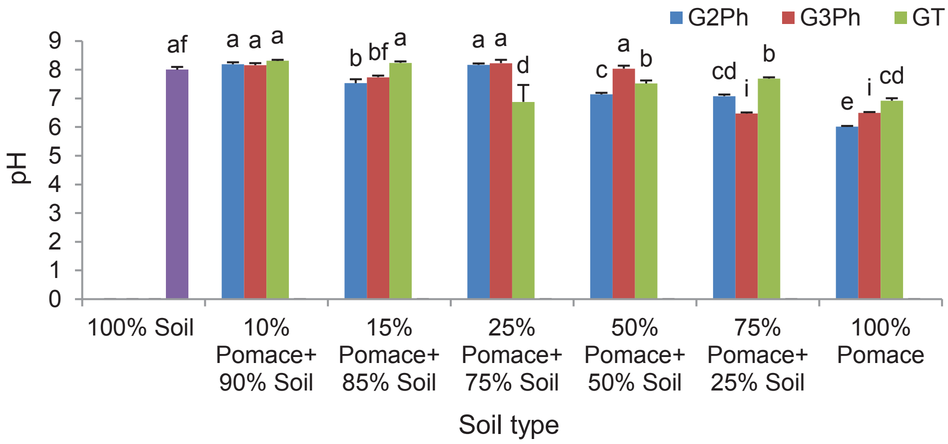

Figure 2. Effect of pomace addition on soil pH (Values with different letters are significantly different: $p < 0.05$).

Electrical conductivity

The electrical conductivity (EC) varies according to the added pomace quantity (Fig. 3), in fact the higher the pomace percentage is, the higher is the conductivity. This is normal given the richness of pomace in soluble salts, especially potassium salt (Table 1). However, the optimal tolerance range for the electrical conductivity of soils, which depends on the species and phase of cultivation, should not reach 2.5 mS cm^{-1} in order to avoid reverse osmosis and root drying (Montoroi, 1996). It can be said that the contribution of olive pomace to the soil studied did not significantly affect soil salinity, however there is a variation in soil salinity depending on the used type of pomace.

The pomace electrical conductivity variation is significantly different between the three extraction systems pomace. This can be attributed to the variation in the extraction process, the way olives are collected and preserved before extraction (Chimi, 2001).

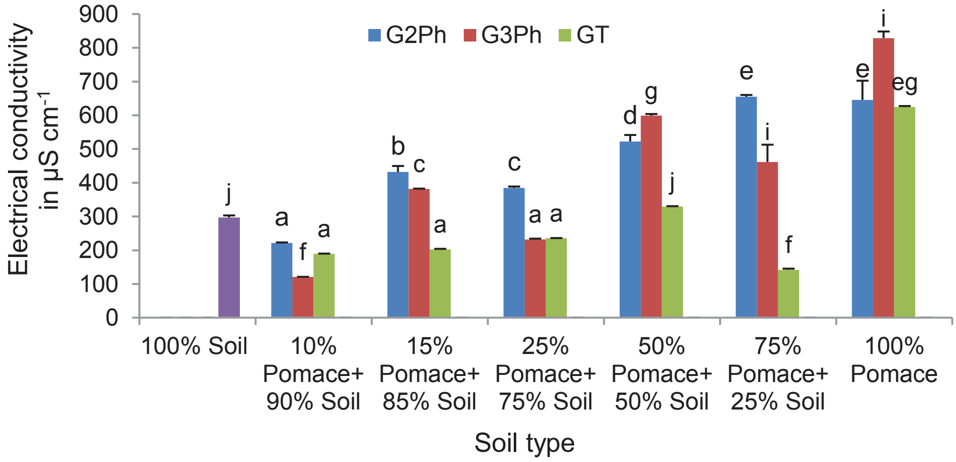

Figure 3. Effect of pomace addition on soil EC (Values with different letters are significantly different: $p < 0.05$).

Organic matter

Given the high organic matter of olive pomace, its addition to the soil has increased the concentration of the latter. This increase is significantly different between the different percentages of pomace for the three extraction systems (Fig. 4). The high content of organic matter in the soil promotes water retention and increases the overall stability of the soil (Lopez-Pineiro et al., 2007), which makes soils less susceptible to erosion. A similar study conducted in Turkey by Kavdir & Kili (2007) showed that the distribution of pomace on the soil improves its structure, stability and increases water retention capacity.

According to Fig. 4, the results obtained are similar for the pomace from the thre extraction systems.

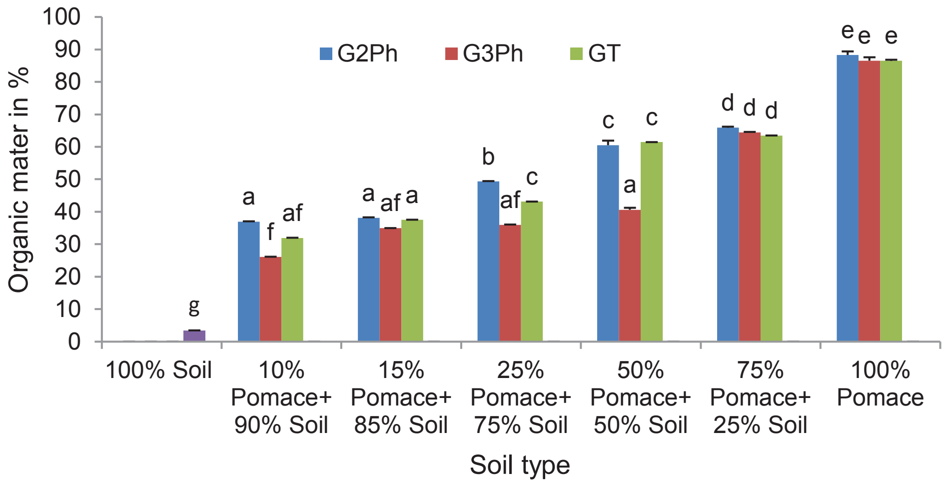

Figure 4. Effect of pomace addition on organic matter content (Values with different letters are significantly different: $p < 0.05$).

Effect on soil chemical parameters

Total organic carbon

Following the contribution of pomace to the soil in terms of organic matter, the organic carbon concentration will also be high. Indeed, there is a significantly different increase in the organic carbon concentration depending on the added pomace concentration (Fig. 5). In addition, the experiment conducted in the short and medium term by López-Piñeiro et al. (2008) in Spain showed a significant increase in the amount of organic carbon in soil treated for three years with a pomace from the two-phase system. This result is consistent with those obtained by other authors (Madejon et al., 2003; Montemurro et al., 2004), but it is necessary to determine the quantity and quality of the added pomace, as well as their application techniques. In fact, organic matter mineralization is enhanced when the pomace is distributed on the soil surface without incorporation (Proietti et al., 2015).

In terms of comparison between the pomace from the three extraction systems, it is clear that the pomace from the two-phase system provides a significant amount of TOC to the soil. Indeed, the TOC content for all percentages for this pomace type is significantly different from the control.

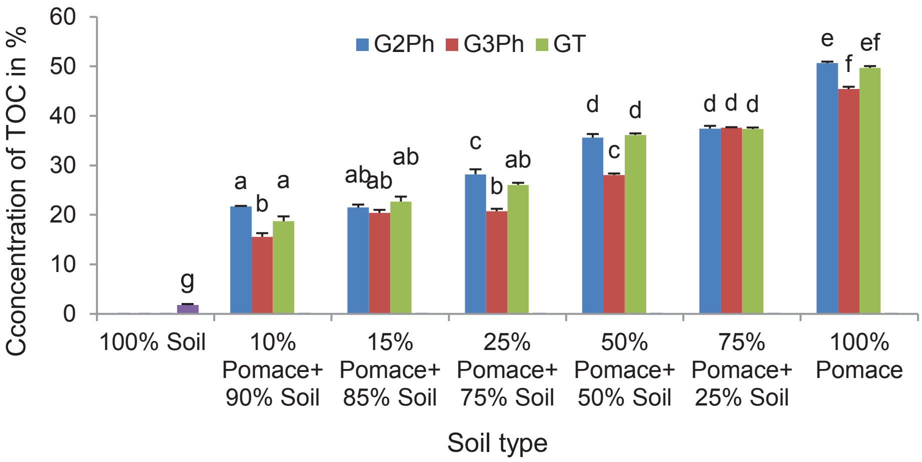

Figure 5. Effect of pomace addition on TOC content in soil (Values with different letters are significantly different: $p < 0.05$).

Total nitrogen

The initial soil (control) nitrogen concentration is 0.134% (Table 1), but following the faba bean germination test the plant assimilates its nitrogen needs and consequently the nitrogen concentration has decreased to 0.04% (Fig. 6). However, due to the addition of olive pomace, the concentration has increased, especially in pots containing 25%, 50%, 75% and 100% pomace mainly for those coming from the continuous system.

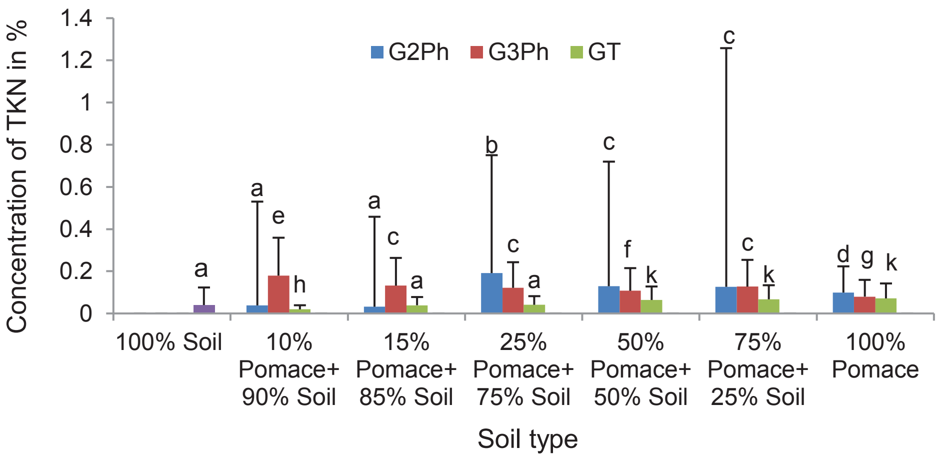

Figure 6. Effect of pomace addition on NTK content in soil (Values with different letters are significantly different: $p < 0.05$).

The same results were observed in an Italian study. Brunetti et al. (2005) showed that the application of olive pomace for two years, allowed a linear increase in total soil nitrogen in the first year, attributed to the increase in organic nitrogen content, but in the second year it is due to the increase in inorganic nitrogen. Despite the increase in nitrogen obtained by comparison with the control, olive pomace does not really have a sufficient nitrogen supply in comparison with the plants' needs. Indeed, when the nitrogen concentration is less than 1.5%, the soil immobilizes the nitrogen, while at a concentration higher than 2% the mineral nitrogen is unconfined (MacNaeidhe & Courtney, 1983).

Available phosphorus

When an amendment is applied to the soil, an increase in the available phosphorus is expected, as the main result of improved chemical fertility.

Given the low phosphorus concentration in the studied pomace (Table 1), the addition of the latter did not significantly increase the phosphorus concentration in the majority of percentages (Fig. 7). The same result has been obtained by other authors, indeed Nasini et al. (2013) and Brunetti et al (2005) have shown that the application of different types of olive pomace does not affect the available phosphorus of the soil.

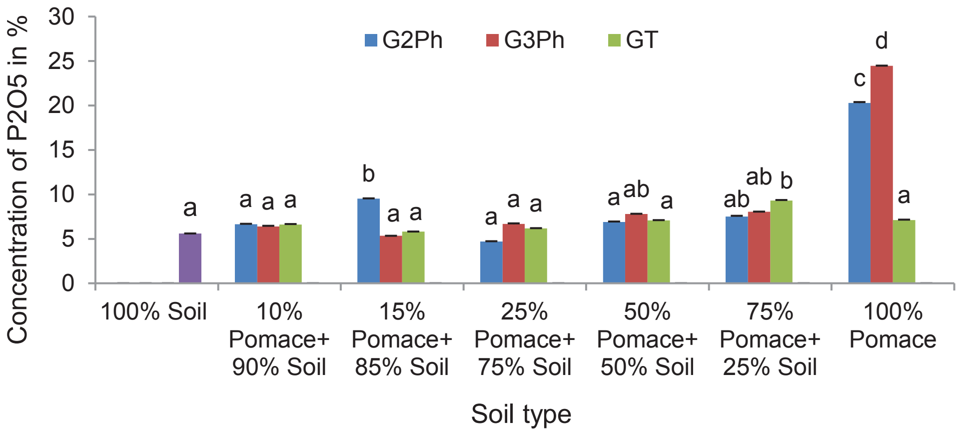

Figure 7. Effect of pomace addition on P_2O_5 content in soil (Values with different letters are significantly different: $p < 0.05$).

In addition, significant increases in soil available phosphorus have been found when pomace (rich in phosphorus) are used as soil amendment (Madejon et al., 2003; Paredes et al., 2005; López-Piñeiro et al., 2008). Indeed, the increase in available phosphorus is the consequence of the phospho-humic complex formation, which prevents the phosphorus insolubilisation in acid and calcareous environments (Giusquiani et al., 1995). Also a study conducted in Italy by Proietti et al (2015) showed that phosphorus increase occurs only in the first 15 cm of treated soil, while no difference was observed in the 15–30 cm layer between the control soil and the treated soil.

The pomace phosphorus addition to the soil is identical for the pomace from the three extraction systems.

Exchangeable potassium

The studied pomace have significant levels of exchangeable potassium in comparison to soil (Table 1). As a result, the higher is the percentage of pomace, the higher is the potassium concentration in the soil. However, this increase remains significant for pomace from the continuous system (Fig. 8). Our results are similar to those of other authors. Indeed, an increase of 4.9 times in exchangeable potassium compared to the control is obtained after 3 years of treatment in an Italian study, when olive pomace is used as an amendment (Proietti et al., 2015). In addition, adequate potassium fertilization allows better tolerance to drought, which is very frequent under Mediterranean conditions (Ganlanakis, 2017).

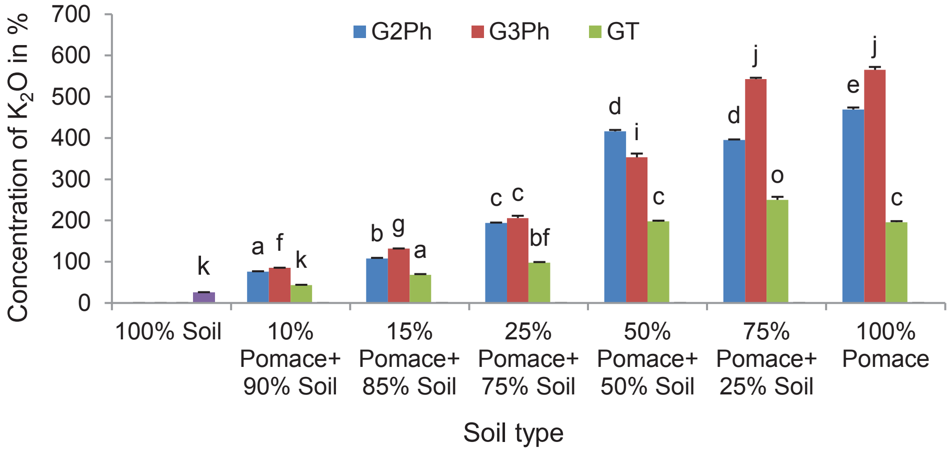

Figure 8. Effect of olive pomace addition on soil K_2O content (Values with different letters are significantly different: $p < 0.05$).

Sodium

The germination of the faba bean allowed an increase in the sodium concntration (Fig. 9) in the different percentages including the control compared to their initial concentration (Table 1).

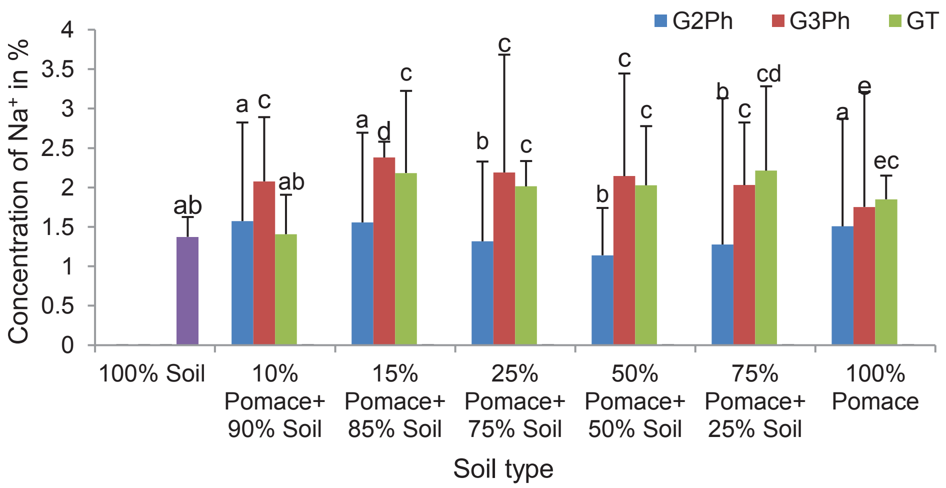

Figure 9. Effect of olive olive pomace addition on Na^+ content in soil (Values with different letters are significantly different: $p < 0.05$).

The sodium concentration for pots containing different percentages of pomace from the three-phase system and the traditional system is significantly high ($p < 0.05$) compared to the control. As a result, the pomace from these two extraction systems has increased the sodium concentration in the soil, and this is due to the high organic matter content and the soil ability to retain cations. Indeed, even if the sodium is the most abundant of all alkaline metals, by a representation of 2.6% of the earth's crust (Weast, 1972), it is retained with a low energy on the CEC, so it is easily washable and quickly replaceable by bivalent cations (Mg^{2+}, Ca^{2+}...) (Dabin, 1970). But with a high organic matter content, the storage reservoir for cationic nutrients increases (Duchaufour, 1954), thus increasing the concentration of these elements in the soil, of which sodium is a part.

Cation exchange capacity (CEC)

The cation exchange capacity of the soil containing different percentages of olive pomace is significantly different compared to the control ($p < 0.05$) (Fig. 10).

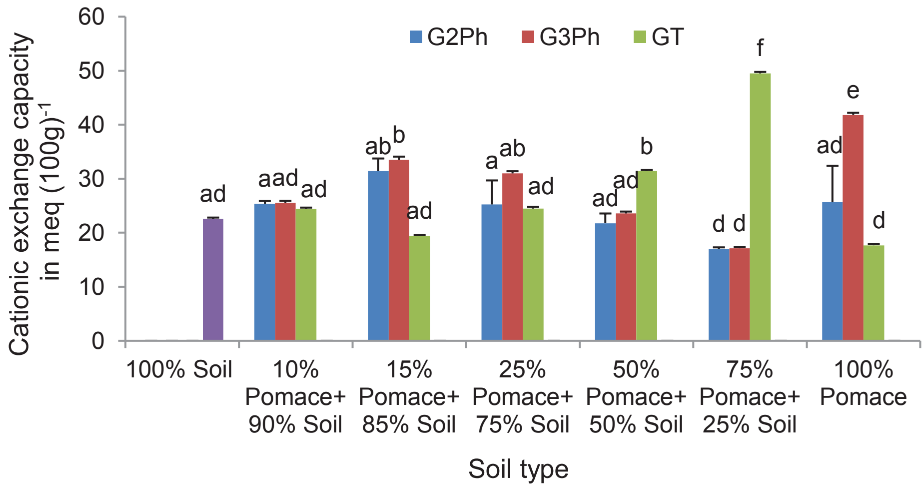

Figure 10. Effect of olive pomace addition on cation exchange capacity of the soil (Values with different letters are significantly different: $p < 0.05$).

It is accepted that the higher the soil CEC, the more it can retain cations, which improves its structure. The soil cation exchange capacity has significantly increased for the different percentages of pomace compared to control. This increase can be attributed to the high concentration of organic matter in pomace. Indeed, CEC is linked to the clay-humic complex, and is therefore dependent on the quantities of clay and OM it contains (Duchaufour, 1954). And given the pomace high organic matter, an increase in cation exchange capacity is expected as the main result of soil amendment by these pomace. As a result, olive pomace has certainly increased the soil reservoir of cations (K^+, Mg^{2+},Ca^{2+},Na^+), and thus fertilization interventions will be less and the plant will always have enough food.

The results are consistent with other studies using olive pomace as a fertilizer (Paredes et al., 2005; Lopez-Pineiro et al., 2006).

The pomace addition to the sandy soil of the High School of Technology of Sale has improved the soil chemical fertility, whatever the extraction system used is. Indeed, the objective was to see which type of olive pomace would provide an optimal contribution to the soil in terms of fertilizing element. While the results obtained were identical for the pomace from the three extraction systems.

All the results obtained during this experiment approve that the use of olive pomace as an amendment has positive effects on the physical and chemical characteristics of the soil. These results are consistent with other conducted studies, in terms of physical characteristics, the diffusion of pomace in the soil increases its porosity, water retention capacity and overall stability (Giusquiani et al., 1995; Kavdir & Killi, 2007). The increase in overall stability is attributed to an increase in organic matter (Lopez-Pineiro et al., 2007), which makes soils less susceptible to erosion.

In terms of chemical characteristics, the pomace addition over time improves the chemical fertility of the soil by increasing organic matter and nutrient content (total nitrogen, phosphorus and exchangeable potassium) without changing the pH value and soil salinity (Montemurro et al., 2004; Cucci et al., 2008; Chartzoulakis et al., 2010). In an experiment conducted in central Italy, the application of large quantities of pomace (50 t ha^{-1}) in an olive grove for 4 consecutive years caused a slight decrease in pH, an increase in organic matter, total nitrogen, exchangeable potassium, magnesium and phosphorus content (Nasini et al., 2013). Generally olive pomace contains a large amount of potassium salts, therefore, an increase in the exchangeable potassium content is expected in pomace-enriched soils (Proietti et al., 2015). On the other hand, adequate potassium fertilization allows a better tolerance to drought, which is very frequent under Mediterranean, conditions (Ganlanakis, 2017).

The proper use of pomace can be considered a valuable method to increase the soil chemical and physical fertility while saving the high costs of chemical fertilizers.

CONCLUSION

The olive pomace application at doses of 10, 15, 25, 50, 75, and 100% modified the soil pH from basicity to neutrality, it increased the electrical conductivity of the soil, as well as the organic matter and organic carbon content compared to the control. The total nitrogen content has increased slightly, but remains insufficient in terms of fertility. For available phosphorus, the concentration is not significantly different for the majority of percentages. The exchangeable potassium is proportional to the percentages of the added pomace. Given the pomace richness in organic matter, the cation exchange capacity has increased for the different percentages, increasing with it the soil reserves in exchangeable bases. As a result, olive pomace has great potential to improve the structure of coarse-textured soils in the short term, in most Moroccan soils.

REFERENCES

Ameziane, H., Nounah, A., Khamar, M., Cherkaoui, E. & Kabbour, MR. 2018. Agrochemical Characterization of Olive Pomace Obtained by Different Systems of Extraction. *Der Pharma Chemica* **10**(12), 33–40.

Bower, C.A., Reitemeier, R.F. & Fireman, M. 1952. Exchangeable cation analysis of saline and alkali soils. *Soil Sci*. **73**, 251–261.

Bremner, J.M. & Mulvaney, C. S. 1982. Nitrogen-Total. In: Methods of soil analysis, part 2. A.L. Page, et al. (eds.). Agronomy Monog. 9 ASA and SSSA, Madison, WI, pp. 595–624.

Brunetti, G., Plaza, C. & Senesi, N. 2005. Olive pomace amendment in Mediterranean conditions: effect on soil and humic acid properties and wheat (Triticum turgidum L.). *J. Agric. Food Chem*. **53**, 6730–6737.

Chartzoulakis, K., Psarras, G., Moutsopoulou, M. & Stefanoudaki, E. 2010. Application of olive mill wastewater to a Cretan olive orchard: effects on soil properties, plant performance and the environment. *Agric. Ecosyst. Environ*. **138**(3–4), 293–298.

Chimi, H., Quality of olive oils in Morocco, 2001. *PNTTA Monthly Bulletin and Liaison*, **79**, pp. 1–4 (in French).

Cucci, G., Lacolla, G. & Caranfa, L. 2008. Improvement of soil properties by application of olive oil waste. *Agron. Sustain. Dev*. **28**, 521–526.

Dabin, B. 1970. *Chemical factors of soil fertility (exchangeable bases; salts; use of fertility scales)* – chapitre XI, pp. 221–237 (in French).

David, R. Lide, ed., CRC. 2005. Handbook of Chemistry and Physics, Internet Version, < http://www.hbcpnetbase.com>,CRC Press, BocaRaton, FL, 2661 pp.

Di Serio, M.G., Lanza, B., Mucciarella, M.R., Russi, F., Iannucci, E., Marfisi, P. & Madeo, A. 2008. Effects of olive mill wastewater spreading on the physico-chemical and microbiological characteristics of soil. *Int. Biodeterior. Biodegradation* **62**(4), 403–407.

Duchaufour Ph. 1954. *Properties of humic complexes in different soil types*. Ecole Nationale eaux et forêts, Nancy, 29 pp. (in French).

Federici, F, Fava, F, Kalogerakis, N & Mantzavinos, D. 2009. Valorisation of agro-industrial by products, effluents and waste: concept, opportunities and the case of olive mill wastewaters. *Chem Technol Biotechnol* **84**, 895–900.

Fendorf, S.E. 1995. Surface reactions of chromium in soils and waters. *Geoderma* **67**, 55–71.

Ganlanakis Charis, M. 2017. *Olive Mill Waste. Recent Advances for Sustainable Management. Galanakis* Laboratories, Chania, Greece : Academic press, 300 pp.

Giusquiani, P.L., Pagliai, M., Gigliotti, G., Businelli, D. & Benetti, A. 1995. Urban waste compost: effects on physical, chemical and biochemical soil properties. *J. Environ. Qual*. **24**, 175–182.

ISO 11265. Soil quality - Determination of the specific electrical conductivity. October 1994 (in French).

Kavdir, Y. & Killi, D., 2007. Influence of olive oil solid waste applications on soil pH, electrical conductivity, soil nitrogen transformations, carbon content and aggregate stability. *Bioresour. Technol*. **99**, 2326–2332.

Law n. 574. 11th November 1996. New standards for the agronomic use of vegetation water and oil mill discharges. Published in the Official Gazette n. 265 del 12 novembre 1996 (in Italian).

Lopez-Pineiro, A., Fernandez, J., Nunes, R., Manuel, J. & Garcia Navarro, A. 2006. Response of soil and wheat crop to the application of two-phase olive mill waste to Mediterranean agricultural soils. *Soil Sci*. **171**, 728–736.

Lopez-Pineiro, A., Murillo, S., Barreto, C., Munoz, A., Rato, J.M., Albarran, A. & Garcia, A. 2007. Changes inorganic matter and residual effect of amendment with two-phase olive-mill waste on degraded agricultural soils. *Sci. Total Environ*. **378**(1–2), 84–89.

Lopez-Pineiro, A., Albarran, A., Rato Nunes, J.M. & Barreto, C. 2008. Short and medium term effects of twophase olive mill waste application on olive grove production and soil properties under semiarid Mediterranean conditions. *Bioresour. Technol*. **99**, 7982–7987.

Lozano-García, B., Parras-Alcántara, L. & del Toro Carrillo de Albornoz, M. 2011. Effects of oil mill wastes on surface soil properties, runoff and soil losses in traditional olive groves in southern Spain. *Catena* **85**, 187–193.

MacNaeidhe, F.S. & Courtney, J. 1983. Vegetable crop production on peat soil. Proceedings *International Symposium on Peat Utilization*, Bemidji State University, Minnesota, U.S.A., pp. 229–238.

Madejon, E., Burgos, P., Lopez, R. & Cabrera, F. 2003. Agricultural use of three organic residues: effect on orange production on properties of a soil of the Comarca Costa de Huelva (SW Spain). *Nutr. Cycl. Agroecosyst*. **65**, 281–288.

Mechri, B., Issaoui, M., Echbili, A., Chehab, H., Mariem, F.B., Braham, M. & Hammami, M. 2009. Olive orchard amended with olive mill wastewater: effects on olive fruit and olive oil quality. *J. Hazard. Mater*. **172**, 1544–1550.

Mehlich, A. 1942. Rapid estimation of base-exchange properties of soils. *Soil Sci.* **53**, 1–14.

Mondini, C. & Sequi, P. 2008. Implication of soil C sequestration on sus-tainable agriculture and environment, *Waste Manage*. **28**, 678–684.

Montemurro, F., Convertini, G. & Ferri, D. 2004. Mill wastewater and olive pomace compost as amendments for rye-grass. *Agronomie* **24**, 481–486.

Montoroi, Jean-Pierre. 1996. *Sustainable mangrove soil management in Senegal during drought periods: water dynamics and salt geochemistry of a developed catchment area*. Paris : ORSTOM, 263 pp. (in French).

Morillo, J.A., Antizar-Ladislao, B., Monteoliva-Sánchez, M., Ramos Cormenzana, A. & Russel, N. J. 2009. Bioremediation and biovalorisation of olive-mill wastes. *Applied Microbiology and Biotechnology* **82**, 25–39.

Moureaux Claude. 1973. *Soil microbiology course.* Bondy : ORSTOM, 163 pp. (in French).

Nasini, L., Gigliotti, G., Balduccini, M.A., Federici, E., Cenci, G. & Proietti, P. 2013. Effect of solid olive-mill waste amendment on soil fertility and olive (Olea europaea L.) tree activity. *Agric. Ecosyst. Environ*. **164**, 292–297.

Nefzaoui, A. 1985. Valuation of lignocellulosic residues in the diet of ruminants by treatment with alkali, Application to pomace oil, Catholic University of Leuven, 345 pp.

Niaounakis, M. & Halvadakis, C.P. 2006. *Olive processing waste Management: Literature Review and Patent Survey*, second edition. Elsevier Ltd., Kidlington, Oxford, UK. 514 pp.

Olsen, S.R., Cole, C.V., Watanabe, F.S. & Dean, L.A. 1954. *Estimation of available phosphorus in soils by extraction with sodium bicarbonate*. USDA Circular 939, U. S. Gov. Print, Office, Washington, DC. 19 pp.

Paredes, C, Cegarra, J, Bernal, MP & Roig, A. 2005. Influence of olive mill wastewater in composting and impact of the compost on a Swiss chard crop and soil properties. *Environ Int*. **31**, 305–12.

Proietti, P., Federici, E., Fidati, L., Scargetta, S., Massaccesi, L., Nasini, L., Regni, L., Ricci, A., Cenci, G. & Gigliotti, G. 2015. Effects of amendment with oil mill waste and its derived compost on soil chemical and microbiological characteristics and olive (Olea europaea L.) productivity. *Agric. Ecosyst. Environ*. **207**, 51–60.

Rodier Jean, Bernard Legube, Nicole Merlet. 2009. *Water Analysis*. 9th edition. Dunod, Paris. 1511 pp.

Roig, A., Cayuela, M.L. & Sánchez-Monedero, M.A. 2006. An overview on olive mill wastes and their valorisation methods. *Waste Manage* **26**, 960–969.

Secretariat of State at the Ministry of Energy, Mines, Water and Environment, in charge of Water and Environment. Quality Standards: Water for irrigation. 2007 (in French).

Walkley, A. & Black, C.A., 1934. An examination of the method for determining soil organic matter and a proposal modification of the chromic acid titration method. *Soil Science* **37**, 29–38.

Weast, R.C., Ed. 1972. *CRC Handbook of Chemistry and Physics*, 53rd Edition. Cleveland, OH:The Chemical Rubber Company Press. p. B-64.