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Impact of olive mill wastewaters on soil fertility of an Algerian olive grove

M. Hamlat[1*], M. Ourari[1], L. Djafri-Bouallag[1], A. Derridj[2]

[1] Laboratory of Ecology and Environment. Department of Environment Biological Sciences. Faculty of Nature and Life Sciences, Université de Bejaia, Targa Ouzemmour, 06000 Bejaia, Algeria.
[2] Laboratory of Production, Improvement, Protection of Plants and Foodstuffs. Mouloud Mammeri University, 15000 Tizi Ouzou, Algeria

*Corresponding author: mouradhamlat@gmail.com; Tel: +213 07 78 77 79 32

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ABSTRACT/RESUME

Abstract: *Olive mill wastewaters (OMW) are a problem of environmental pollution that affects all countries of Mediterranean basin. In this study, OMW from a local variety (Chemlal) are used as fertilizer and are spread at different concentrations (5 l/m², 10 l/m² and 20 l/m²) in an olive orchard (ITAFV, Sidi-Aich, Algeria).*
Eight physicochemical parameters are analyzed, first on the OMW then on the soil in order to follow spreading impact and its evolution over time. The high acidity of OMW does not have a great influence on soil pH, because of its limestone nature. At low concentrations, these effluents improve soil fertility, by increasing rate of organic matter (0.74%) and fertilizing elements concentrations, especially phosphorus (29.1 mg/kg), nitrogen (286 mg/kg) and potassium (271.2 mg/kg). On the other hand, on high concentration, the high value of potassium that reaches a threshold of 581.8 mg/kg, can induce a risk of pollution and impair soil fertility. All parameters analyzed show a decrease in their rate over time, with a tendency to return to initial state of soil before spreading.

I.Introduction

Olive industry is an essential economic sector for many Mediterranean countries as it is an important source income for rural populations. Indeed, these countries alone hold about 94% of world production [1]. Area of Algerian olive orchard grew from 165 000 ha to 500 000 ha between 1999 and 2016; thus showing an increase of 200 %. The development of olive industry and importance of production have consequences for environment. Indeed, extraction of olive oil generates two residues: olive pomaces and Olive mill wastewaters (OMW). These latter residues, released without treatment into the environment, pollute surface and groundwater by their high concentrations of organic compounds, polyphenols and mineral elements. They can also induce soil clogging [2].

Many studies are carried out to look for best strategies or technologies of valorization or elimination of these residues based on biological, physicochemical or thermal treatments. Thus, some authors recommend use of OMW as a dietary supplement for livestock [3]. Other pathways are also proposed such as biotechnological valorization [4], biomethanation [5] or extraction of antioxidants [6].Work carried out in Tunisia recommends their valorization for agricultural purposes [7].
In the same context and in order to stop this pollution, the present work plans to valorize the residues of Algerian olive industry, as fertilizers by determining their impact on fertility and soil quality of an olive grove composed by a local variety, (Chemlal), in Soummam Valley (Bejaia) of Algeria.

II.Materials and methods of study

II.1. Characterization of study station

This study is carried out at the experimental station of Technical Institute for Fruit and Vine Growing (ITAFV), located in Takerietz town at 50 km south-west of Béjaïa in Algeria (Fig.1).

Station is located at an altitude of 134 m, latitude of 40° 64' 3" north and a longitude of 2° 57' 3" east. It is characterized by an average annual temperature of 18.3 °C, with a mild and wet winter and a very hot summer. Rainfall is irregular, ranging from 400 to 600 mm per year. Prevailing wind is that of north-east coming from Mediterranean. These meteorological data are provided by agro-meteorological station of ITAFV

Figure 1. Geographical location of experimental station of Technical Institute for Fruit and Vine Growing (ITAFV) of Takerietz-Béjaïa-Algeria (Google Earth, 2018)

II.2. Experimental protocol

Olive grove is divided into twelve elementary plots with an area of 288 m^2 (12 m x 24 m). The plots are separated by a row of olive trees to avoid any interaction between the different experimental conditions. Each plot has two trees.

The work consists in spreading olive mill wastewaters (OMW) at different concentrations on the twelve plots of the olive orchard. Concentrations used are C_1 (5 l/m^2), C_2 (10 l/m^2), C_3 (20 l/m^2) and C_0 as a control. Each condition is subject to three repetitions. Spreading of OMW was only once, during the period of vegetative rest between December and February. During this experiment, a total of 29400 l of OMW was used.

II.3. Sampling

Samples of OMW and of soil are taken.

OMW used are collected from decantation pond of oil mill located at the same experimental station (ITAFV). Samples are stored in smoked glass bottles (to avoid photooxidation) in the refrigerator at 4 ° C until analysis.

Twenty-four soil samples are taken from twelve elementary plots that make up orchard. In each plot, two samples are taken along a diagonal, spread over two different horizons: horizon A (0 to 30 cm deep) and horizon B (30 to 60 cm deep). The two samplings of same plot from the same depth are mixed together. Soil is cleared of all plant debris and is then spread on paper and left in the open to dry.

II.4. Study methods

II.4.1. Analysis of olive mill wastewaters (OMW)

In order to characterize spread OMW, eight physicochemical parameters are analyzed: pH, dry matter content (DM), mineral matter content (MM), and organic matter content (OM) [8]. Chemical oxygen demand (COD) was determined by the potassium dichromate method [9].

After mineralization of OMW in an acid medium, total phosphorus is determined by colorimetry, potassium is analyzed by flame spectrophotometry and total nitrogen content is determined by Kjeldahl method. [10]

II.4.2. Soil analysis

Eight physico-chemical parameters are analyzed in soil samples: hygroscopic humidity (H), pH, total limestone, total nitrogen (N), assimilable phosphorus (P: modified Olsen method, 1967) and exchangeable potassium (K) [11] as well as particle size analysis and organic matter (OM: Anne's method, 1945) [12].

These soil analyses are performed at two time intervals. First is carried two months after OMW spreading (time necessary for their infiltration and incorporation into soil). Second is carried 12 months after spreading in order to follow evolution of studied parameters.

II.4.3. Statistical analyzes

In this study, we used the multifactorial analysis of variance, in order to follow the action of three factors (the different concentrations of OMW, soil horizons, treatment time) on the variability of soil parameters, taken into consideration (pH, MO, N, P, K).

When ANOVA reveals significant differences, analysis continues with a multiple comparison of means (Tukey's test). This allows the different conditions to be classified in order of influence.

We also used the correlation coefficient (Pearson), in order to follow the variations of studied parameters in relation to the concentrations of OMW. The used software is XLSTAT (2014)

III.Results and discussion

Two physicochemical analyzes are carried out on soil samples and those of olive mill wastewater.

III.1. Olive mill wastewaters (OMW)

OMW are in form of a reddish brown liquid to black, cloudy in appearance. These are vegetation waters obtained from fruit and water used in the process of extracting olive oil. Values of nine parameters analyzed are given in Table 1.

Table 1. *Physico-chemical composition of spread olive mill wastewater.*

Parameters analyzed	Values
pH	4.7
Dry matter content (DM)	10.26 %
Mineral material content (MM)	8.9 g/l
Chemical oxygen demand (COD)	87.5 g/l
Organic matter content (OM)	93.7 g/l
Phosphorus content (P)	0.24 g/l
Potassium content (K)	4.59 g/l
Nitrogen content (N)	1.28 g/l

Acid pH of OMW analyzed (4.7) is consequence of organic acids presence such as phenolic acids and fatty acids [13]. This acidity has an environmental impact and is a limiting factor for purification process and causes the destruction of soil microflora. [14].

Dry matter content of effluent is 10.26 %. It corresponds to all organic matter and mineral matter.

The organic matter content of OMW is around 93.7 g/l. This fraction includes sugars, proteins, phenols and lipids. Several researchers working on Tunisian OMW find quantities of organic matter close to values presented in this work [7, 15]. These authors believe that these values are very high. These large amounts of organic matter require a relatively high chemical oxygen demand (COD) [16]. The COD represents oxygen consumption necessary for oxidation of all organic and mineral substances present in the effluent. It is an important indicator of water quality; it allows evaluating their polluting load [17].

The COD of olive mill wastewaters evaluated in the present study (87.5 g/l of O_2) greatly exceeds Algerian standard for effluent discharges from the agro-food industries, which is limited to 120 mg/l of O_2 [18]. This excessive chemical oxygen demand is a limiting factor for the survival of aerobic organisms.

Mineral matters content of the OMW analyzed is 8.9 g/l. They mainly consist of Potassium (4.59 g/l), Nitrogen (1.28 g/l) and Phosphorus (0.24 g/l). These values are close to those obtained by [19, 20] on samples of Maghrebian OMW. These elements are very important for the good development of plants. However, their excess causes environmental pollution, especially in aquatic environments by causing eutrophication. Indeed, the high availability of nutrients (P, N, K) causes the proliferation of biomass (algae), which leads to a depletion of the water in dissolved oxygen (O_2), essential for life of living organisms [21].

In addition, similar studies, carried out on OMW in Mediterranean countries [5, 20, 22] shows more or less variable values for the different parameters analyzed. This variability can be explained by the growing conditions, the used variety, the degree of maturity of olives, the extraction system and the quality of added water during the oil extraction phase [2, 23, 24].

Despite their polluting profile, OMW are considered to be a rich source of organic compounds and mineral elements which can meet the nutritional needs of plants. Indeed, many authors attribute to them a fertilizing action due to their high potassium concentration and to a lesser degree in nitrogen, phosphorus [7, 25], and organic matter [15, 16, 19]. These authors consider that they can be used as a natural soil amendment.

Estimation of fertilizing elements input per hectare, after spreading olive mill wastewaters, is recorded in Table 2. These data shows that the three doses of OMW provide to soil appreciable fertilizing elements amounts (reported to kg/ha). Indeed, fertilization on olive grove with intermediate dose of OMW (10 l/m^2) corresponds to a conventional fertilization high in phosphorus and very high in potash and nitrogen [7].

This wealth justified the rational and controlled use of olive mill wastewaters as a fertilizer, and constitutes a possible solution for pollution control and valorization [19].

Table 2. *Nutrients provided to the soil, by olive mill wastewaters depending to spread dose (kg/hectare).*
Abbreviations: OMW-olive mill wastewater, OM-organic matter, N-nitrogen, P-phosphorus, K-potassium.

OMW (l/m^2)	OM (kg/ha)	P (kg/ha)	K (kg/ha)	N (kg/ha)
5	4685	12	229.5	64
10	9370	24	959	128
20	18740	48	918	256

III.2. The soil

III.2.1. Edaphic characteristics of study station

Three soil-specific physicochemical parameters (moisture, particle size analysis and total limestone content) and five parameters that can evolve after spreading (pH, MO, K, N and P) are evaluated in the olive orchard. Values of first parameters are given in Table 3.

These values of different parameters reported on textural triangle [26] classify soil of the orchard studied in sandy-loam category. These soils are permeable to water and air because of their porosity, resulting to good aeration, good soil drainage and good root development. Leaching of higher horizons is favored. Content of total limestone seems relatively high compared to international standard [27]. These high concentrations are probably due to calcareous nature of source rock [28].

Table 3. *Evaluation of the analyzed specific soil characteristics*

Parameters (%)	Horizon A (0-30 cm)	Horizon B (30-60 cm)
Moisture	1.39	1.16
Sand	70.40	75.90
Silt	13.70	12.10
Clay	13.80	11.93
Total limestone	25.40	27.60

III.2.2. Effect of spreading olive mill wastewater on soil fertility

Analysis of variance (table 4) shows that the three considered factors (concentrations of OMW, soil horizons, treatment time) is significant ($p < 0.001$) for all traits studied (pH, OM, N, P and K). OMW * horizon, OMW * time, horizon * time and OMW * horizon * time interaction are significant (p 0.001) in the P and K traits. Horizon * time is significant ($p < 0.01$) for OM and OMW*horizon * time is significant ($p < 0.05$) for N. No significant pH interaction was observed.

Table 4.*Mean square and significance of all studied traits*
, **, * = Significant at $p<0.05$, $p<0.01$ and $p<0.001$ respectively, ns = not significant.*

Source	df	pH	OM	N	P	K
OMW	3	0.158***	7.980***	79721.276***	1273.077***	196817.150***
Horizon	1	0.145***	3.270***	252139.076***	2572.248***	131021.056***
Times	1	0.295***	2.016***	46552.432***	1592.525***	157356.207***
OMW * Horizon	3	0.004ns	0.503***	18486.343***	283.015***	18236.228***
OMW * Time	3	0.019ns	0.379***	7574.58***	174.944***	20315.086***
Horizon * time	1	0.013ns	0.144**	4.496ns	549.995***	18643.689***
OMW * Horizon * time	3	0.004ns	0.027ns	741.120*	133.740***	2574.217***
Error	32	0.007	0.017	233.758	18.444	292.086

The estimated means for the soil characteristics (pH, OM, N, P, K) according to the various interactions of the studied factors (OMW, Horizon, time) are recorded in table 5 and the average values of the soil characteristics for each factor in table 6.

Table 5. *Interaction means of all traits studied and all combinations. Abbreviations: OMW-olive mill wastewater, OM-organic matter, N-nitrogen, P-phosphorus, K-potassium. For each column separately, values with different letters are significantly different as revealed by Tukey test at P = 0.05*

OMW (l/m^2)	Horizon	Time (month)	pH	OM (%)	N (mg/kg)	P (mg/kg)	K (mg/kg)
C_0	1	2	7.98 abc	0.17 f	108.63 ef	14.94 def	69.83 jk
C_1	1	2	7.82 bcd	0.74 de	268.52 c	29.13 c	271.29 de
C_2	1	2	7.63 de	1.9 b	328.04 b	47.87 b	439.45 b
C_3	1	2	7.56 e	2.96 a	464.77 a	66.05 a	581.82 a
C_0	1	12	8.03 abc	0.17 f	110 ef	15.27 def	71.25 jk
C_1	1	12	7.96 abc	0.41 ef	208 d	18.18 cdef	120.03 hij
C_2	1	12	7.89 abc	1.18 c	272.2 c	22.25 cde	225.57 ef
C_3	1	12	7.86 abcd	1.93 b	328.17 b	29.13 c	329.83 c
C_0	2	2	8.05 ab	0.08 f	67.73 f	9.30 ef	51.23 k
C_1	2	2	7.91 abc	0.37 ef	116.01 e	14.53 ef	168.12 gh
C_2	2	2	7.82 bcd	1.06 cd	188.02 d	20.82 cdef	247.43 ef
C_3	2	2	7.78 cde	1.73 b	215.93 d	27.7 cd	319.98 cd
C_0	2	12	8.10 a	0.07 f	65.73 f	8.90 f	50.33 k
C_1	2	12	8.04 ab	0.2 f	73 ef	10.50 ef	93.08 ijk
C_2	2	12	7.98 abc	0.63 e	91.43 ef	13.27 ef	144.33 hi
C_3	2	12	7.94 abc	1.14 c	110.83 ef	20.67 cdef	198.63 fg

Table 6. *Means of all traits studied for OMW, Horizon and time.*
OMW-olive mill wastewater, OM-organic matter, N-nitrogen, P-phosphorus, K-potassium. For each column separately, values with different letters are significantly different as revealed by Tukey test at P = 0.05

	pH	OM (%)	N (mg/kg)	P (mg/kg)	K (mg/kg)
OMW					
C_0	8.042 a	0.123 d	88.025 d	12.103 d	60.663 d
C_1	7.933 b	0.429 c	166.381 c	18.087 c	163.131 c
C_2	7.830 c	1.190 b	219.922 b	26.051 b	264.196 b
C_3	7.784 c	1.943 a	279.925 a	35.888 a	357.568 a
Horizon					
A	7.842 b	1.182 a	261.040 a	30.353 a	263.635 a
B	7.952 a	0.660 b	116.086 b	15.712 b	159.144 b
Temps					
2	7.819 b	1.126 a	219.705 a	28.792 a	268.645 a
12	7.975 a	0.716 b	157.421 b	17.272 b	154.133 b

The soil of olive grove had an alkaline pH of 7.98 ± 0.05 for horizon A and of 8.05 ± 0.085 for horizon B. The spreading of OMW causes a lowering of soil pH (Fig.2).

This lowering of pH value of the soil is inversely proportional to spread concentration of OMW; the correlation coefficient being -0.90 for horizon A and -0.91 for horizon B.

The Tukey test shows a significant lowering of pH for the conditions C_2 and C_3 of surface horizon. On the other hand, condition C_1 does not present any difference with C_0 witness. For horizon B, only the C_3 condition shows a significant action, while C_1 and C_2 conditions belong to same class as witness C_0 (Tab.5).

Lowering of pH can be explained by richness of these effluents in organic acids and polyphenols [25].

The soil pH value of horizon A is lower and significantly different from that of horizon B (Fig. 2). This is confirmed by the Tukey test which shows that the two horizons belong to different classes (Tab. 6). This is due to the weak influence of OMW on the deep horizon.

One year after spreading the OMW, soil pH values, measured after 2 months, show a significant increase, compared to those measured after 12 months (Fig. 2). This indicates that the soil pH is evolving towards its initial level before spreading.

In summary, despite the acidity of OMW (pH = 4.7), their spreading does not cause any notable variation on the deep horizon and only slightly affects the pH of surface horizon. This can be explained by the richness of limestone of soil (25.4 to 27.6%), which gives it a buffering capacity and allows it to attenuate action of acidity of OMW [7, 15]. This result is in agreement with those of some authors, who conclude that the spreading of OMW on alkaline and calcareous soils, common in Mediterranean areas, does not affect soil pH [2].

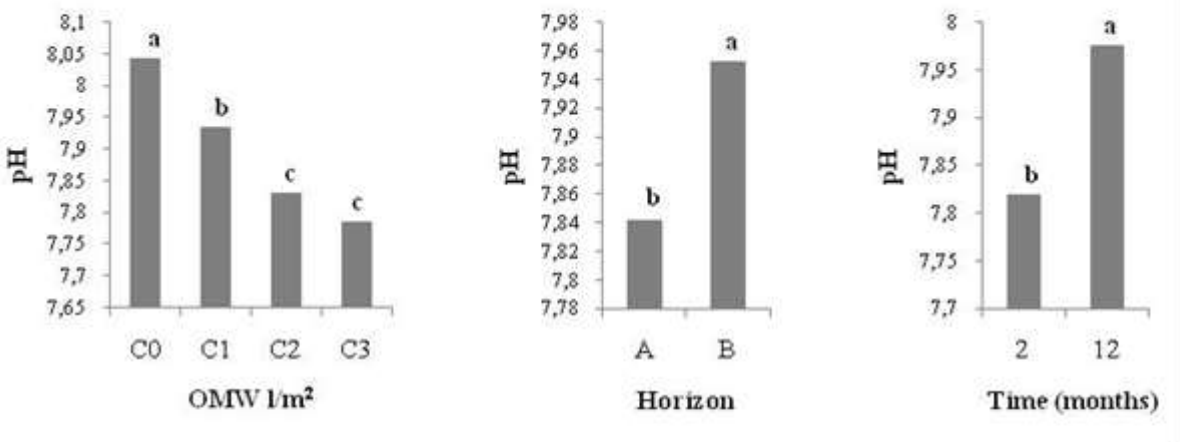

Figure 2. *Soil pH evolution, depending on the concentration of olive mill wastewater, in soil horizons and time.*
C_0*: witness,* ***C_1****: 5 l/m²,* ***C_2****: 10 l/m²,* ***C_3****: 20 l/m².*
Different letters above bars denote significantly different results as revealed by Tukey test at P = 0.05

Studied soil has an organic matter content of 0.169 ± 0.028 % for horizon A and 0.08 ± 0.02 % for horizon B. These levels are very low compared to French standards for interpretation of organic matter content of an agricultural soil [29], which sets the lower limit at 1.4%. Moreover, to develop, olive tree requires soils with organic matter content higher than 1% [30].

Two months after spreading, we notice at level of the two horizons, that organic matter content shows an increase proportional to concentration of OMW (Fig.3), the correlation coefficient being 0.97 for horizon A, and 0.98 for horizon B.

Tukey's complementary test shows for both horizons, that condition C_3 has the greatest action on soil enrichment in organic matter, followed by condition C_2. The action of condition C_1 seems weakest at horizon A and shows no action at horizon B, since it shares a common letter with witness C_0 (Tab.5).

The soil organic matter content of horizon A is greater and significantly different from that of horizon B (Fig. 3). This is confirmed by Tukey test, which shows that the experimental conditions studied belong to different classes, for the two horizons (Tab. 6). Similar observations on Tunisian soils show an increase in the organic matter content of the layers upper soil, with slight migration to the underlying horizons [15].

One year after spreading, organic matter content decreases under most conditions, at both horizons. Soil OM contents, measured between the 2nd and 12th month, show significant differences, since they belong to different Tukey groups (Fig. 3). This means that organic matter rate tends to return to the initial state before spreading.

This decrease in OM content is probably due to the mineralization of organic matter, the leaching action and absorption of the plant. The significant enrichment of soil in organic compounds induces the improvement of the water retention capacity of soil and the activity of microorganisms and consequently that of growth, fruiting and fertility of cultures [7].

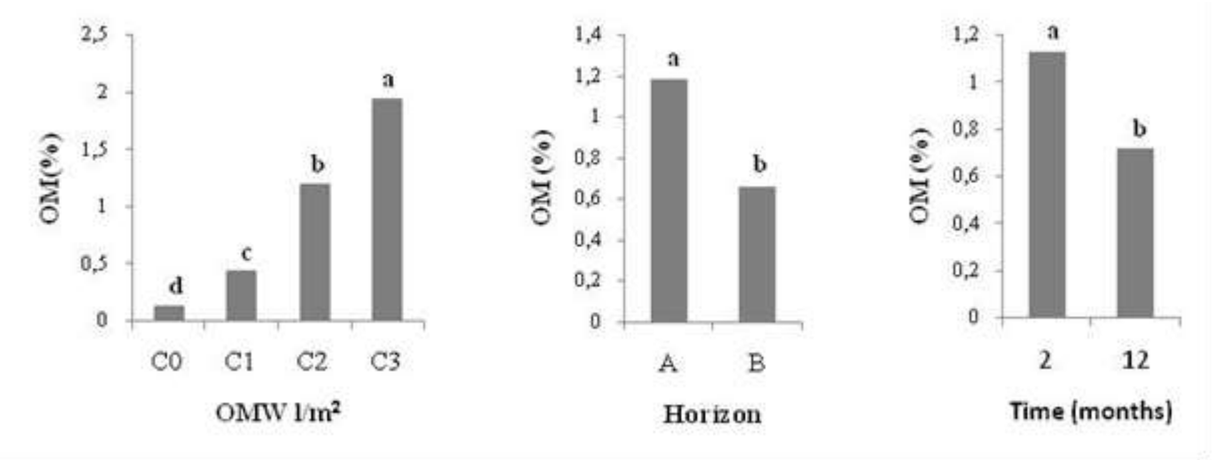

Figure 3. *Organic matter (OM) content evolution of soil, depending on the concentration of olive mill wastewater, in soil horizons and time.*
$\boldsymbol{C_0}$*: witness,* $\boldsymbol{C_1}$*: 5 l/m*^{2}*,* $\boldsymbol{C_2}$*: 10 l/m*^{2}*,* $\boldsymbol{C_3}$*: 20 l/m*^{2}*.*
Different letters above bars denote significantly different results as revealed by Tukey test at P = 0.05

Soil has a nitrogen content of 108.6 ± 18.19 mg/kg at surface and 67.73 ± 14.46 mg/kg at depth. These values classify the studied soil in the category of soil low in nitrogen. Indeed, this category is characterized by a nitrogen content of less than 200 mg/kg, according to soils fertility classification of Dabin (1970) [31].

After spreading the OMW, nitrogen rate increases in the different conditions of horizons A and B (Fig. 4). This increase is proportional to the concentrations of OMW (correlation coefficient being 0.99 for horizon A, and 0.91 for horizon B).

Tukey's complementary test shows that action of OMW depends on their concentration and the horizon considered. Indeed, for horizon A, the nitrogen content of soil is greater under condition C_3 followed by condition C_2 and finally by condition C_1. In contrast, at horizon B, the greatest action is observed under conditions C_3 and C_2. The nitrogen content under condition C_1 was found to be lowest (Tab. 5).

The nitrogen enrichment of soil is due to the richness of OMW in this element [19].

The surface layers of soil have significantly higher nitrogen contents than the deep layers (Tab. 6). This is confirmed by Tukey test which classifies the two horizons into different groups (Fig. 4). The work on OMW in Morocco attests that the high nitrogen contents are localized in upper layers [25]

Twelve months after spreading, the nitrogen content of soil shows a decrease in most of experimental conditions. All the nitrogen contents of soil, measured between the 2nd month and 12th month, show significant differences. Indeed, Tukey test classifies them in different groups (Fig. 4). This means that the nitrogen level shows a tendency to return to the initial state before spreading.

This reduction in nitrogen content could be attributed to leaching of soil, which is characterized by a silty-sandy texture and the olive tree's high requirement for this element [7].

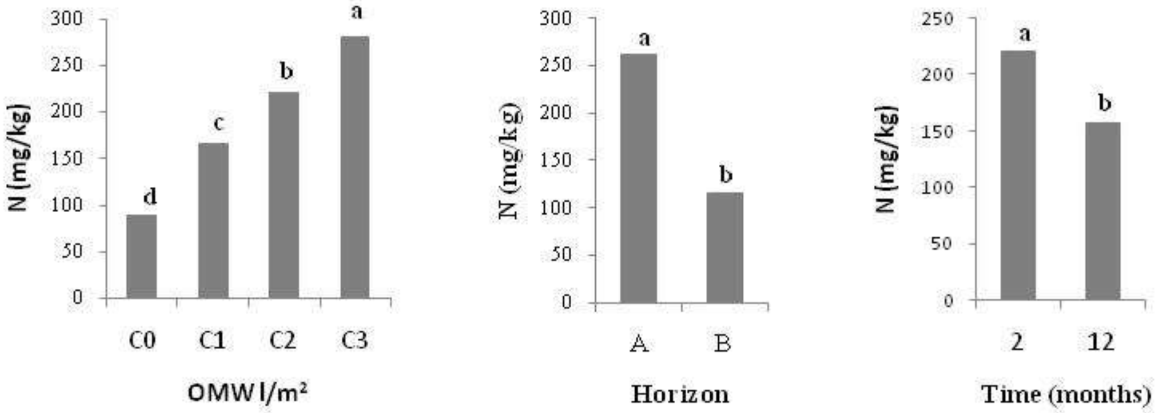

Figure 4. *Total nitrogen (N) content evolution of soil, depending on the concentration of olive mill wastewater, in soil horizons and time.*
C_0: *witness,* ***C_1:*** *5 l/m^2,* ***C_2:*** *10 l/m^2,* ***C_3:*** *20 l/m^2.*
Different letters above bars denote significantly different results as revealed by Tukey test at P = 0.05

Level of assimilable phosphorus (P) from the soil, before spreading, is 14.9 ± 2.87 mg/kg at surface and 9.3 ± 2.98 mg/kg at depth. These values classify studied soil among soils poor in P. Indeed, standards of interpretation of phosphorus contents, according to COMIFER grid (1993), set the lower limit at 35 mg/kg [32]. The level of phosphorus shows an increase proportional to the concentration of the spreading OMW (Fig. 5), correlation coefficient being 0.98 for the A horizon, and 0.99 for the B horizon.

The multiple comparison of means shows that the OMW have a significant action on phosphorus content in horizon A. This action is greater first in condition C_3, then in condition C_2 and finally in condition C_1. On the other hand, in horizon B, the action of OMW is limited to condition C_3, which presents a significant difference. The other conditions (C_2 and C_1) do not show any change, since they belong to same class as witness C_0 (Tab. 5).

The surface layers of soil show significantly higher phosphorus contents compared to the deep layers (Fig. 5). This is confirmed by Tukey test which classifies each condition of both horizons in different groups (Tab. 6). The OMW induce the enrichment of the upper layers of soil in phosphorus with a modest migration towards the underlying horizons [25].

The phosphorus contents of soil, measured after one year of treatment, show a significant decrease compared to those measured after 2 months of treatment, since Tukey test classifies them in two different groups (Fig. 5).

The reduction in phosphorus content of soil in the superficial horizon tells us about its evolution towards a return to initial state before spreading. This finding can be explained first by initial phosphorus intake, which is modest. Then by the lack of P in soil, absorption by plants and leaching which is favored by the texture of soil.

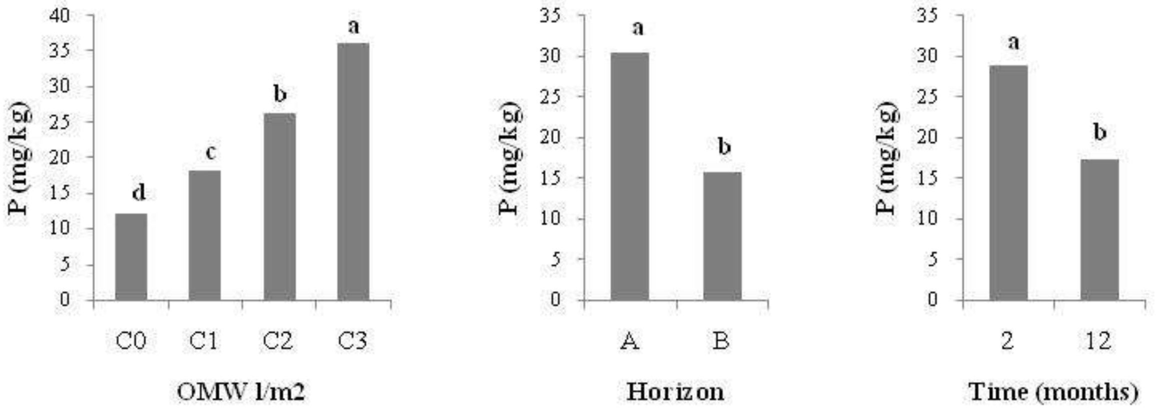

***Figure 5.** Assimilable phosphorus (P) content evolution of soil, depending on the concentration of olive mill wastewater, in soil horizons and time.*
***C_0**: witness, **C_1**: 5 l/m^2, **C_2**: 10 l/m^2, **C_3**: 20 l/m^2.*
Different letters above bars denote significantly different results as revealed by Tukey test at P = 0.05

The analyzed soil has a potassium level of 51 ± 7.72 mg/kg at depth and 69.8 ± 17.33 mg/kg at the surface. According to interpretation standards for exchangeable potassium from COMIFER grid, the studied soil is in the category of poor soils, since it does not exceed the critical threshold of 125 mg/kg [32].

Spreading of OMW resulted in an increase in potassium content under all experimental conditions, for both horizons (Fig. 6). This increase is proportional to the concentration of OMW (the correlation coefficient being 0.97 for horizon A, and 0.98 for horizon B).

The multiple comparison of the means shows in the two horizons that the most important action of OMW on the enrichment of soil in potassium is attributed to condition C_3. On the other hand, the weakest action is attributed to condition C_1 (Tab. 5)

The surface layers of soil show significantly higher potassium contents compared to the deep layers (Tab. 6). This is confirmed by Tukey test which classifies the two horizons in different groups (Fig.6).

We note at level of superficial horizon, that the C_1 dose has a potassium content of 271.29 mg/kg. This is in accordance with COMIFER fertilization standards (125 mg/kg $<C_1<$ 332 mg/kg) [32]. On the other hand, doses C_2 and C_3 present excessive potassium inputs to soil (> 332 mg/kg). These intakes reach the value of 581.8 mg/kg for highest dose (C_3).

Over-fertilization can lead to imbalances in soil and become harmful to crop. Indeed, excess of potassium inhibits assimilation of magnesium and calcium as well as that of trace elements, such as iron and zinc [33].

For the deep horizon, potassium content of soil has values compatible with fertilization standards and does not affect agronomic qualities of soil.

Twelve months after treatment, a decrease in the exchangeable potassium content was observed under all conditions and for both horizons analyzed. The soil potassium contents measured between the 2nd and the 12th month, show significant differences, since they belong to different Tukey groups (Fig. 6). This indicates the tendency of potassium content to return to its pre-application state. The reduction in potassium content can be explained by the runoff and leaching of mineral elements in a loamy-sandy soil [27] and by the importance of assimilation of K by olive tree [34].

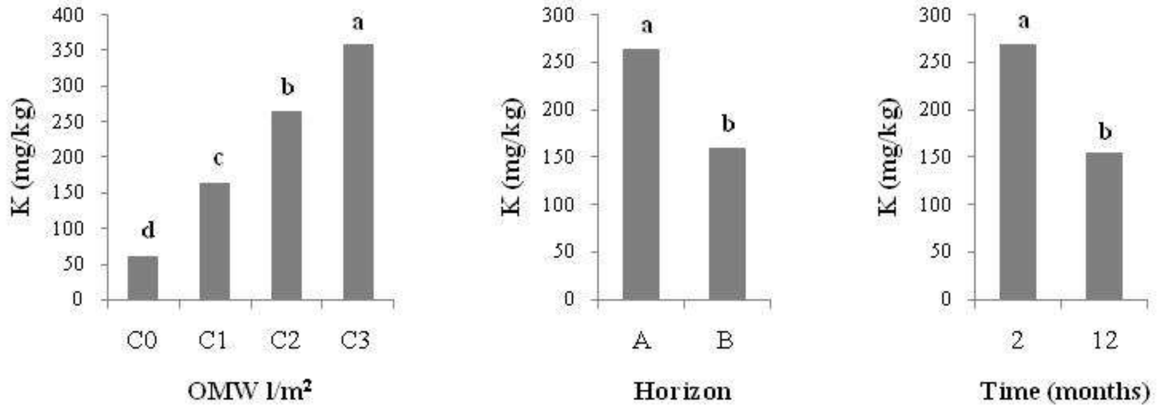

Figure 6. *Exchangeable potassium (K) content evolution of soil, depending on the concentration of olive mill wastewater, in soil horizons and time.*
C_0: *witness,* ***C_1:*** *5 l/m^2,* ***C_2:*** *10 l/m^2,* ***C_3:*** *20 l/m^2.*
Different letters above bars denote significantly different results as revealed by Tukey test at P = 0.05

IV. Conclusion

This study, which concerned valorization of olive mill wastewaters by spreading on a silty-sandy soil of an olive grove, shows evolution over time, for the analyzed parameters.

Acidity of OMW does not have a great influence on pH of soil, because of its limestone richness, which gives it a buffering capacity. The significant enrichment of soil with organic compounds improves its fertility and water retention capacity, as well as its biological activity. The OMW greatly enrich soil with total nitrogen and phosphorus, but these increases do not exceed tolerable limits. For potassium, OMW causes increases in its content in the soil but remains, however, in standards required for low doses. At high and medium doses, they can cause imbalances in soil and become harmful to crop.

Over time, the values of the fertilizing elements of the soil tend to return to their previous values before spreading of OMW.

Among three concentrations of OMW used, doses C_2 (10 l/m^2) and C_3 (20 l/m^2) were unfavorable to agronomic qualities of soil. On the other hand, the dose C_1 (5 l/m^2) has favorable provisions to fertility and does not present any risk of environmental pollution

The controlled spreading of OMW on agricultural soil could be considered as an ecological alternative to the use of chemical fertilizers

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