Olive Mill Wastewater for Degraded Soil Restoration

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Abstract—**In Southern Tunisian arid regions, the main issues of soil degradation on the surface by wind erosion (loss of nutrients and organic matter) and in depth by reduction of water reserves were diagnosed. In order to preserve these soils, improve biological activity and maintain their productivity, a restitution of organic amendments becomes necessary. Among the remedial solutions, the composting of olive tree by-products (Olive Mill Wastewater (OMW), Ramial Chipped Wood (RCW)) could be used for these soils. In this context, an experiment in pots was carried out on *Medicago sativa* L. in order to evaluate the effects of compost on ecosystem services of a sandy soil sampled from an experimental olive orchard in Chammakh. Two treatments (OMW with RCW and RCW) were applied and compared to a control soil having a sandy texture, with %sand being at least equal to 80%. The results showed that the highest nitrogen content is recorded with the composite compost (OMW with RCW) (0.26 g kg^{-1}). The Electric Conductivity of treated soil decreased by 60% over time. The RCW was the most effective treatment for improving soil phosphorus properties and above-ground biomass. The OMW combined with RCW compost allowed to keep almost the same soil moisture (147.23 g kg^{-1}) but almost 3 times more compared to a control soil (52.30 g kg^{-1}).**

Index Terms—**Compost, ecosystem services, olive mill wastewater, soil restoration.**

I. Introduction

Currently, concerns about land degradation are increasing. On marginal soils, the effects of this degradation are multiple and are mainly manifested by the decrease of organic matter (OM) in the surface horizons. Numerous remediation solutions have been implemented on the scale of experimental plots in order to evaluate, deepen and improve their effects on the physical, chemical and microbiological aspects of soils and then to disseminate them. Among the recommended techniques, regular amendment of OM in the form of compost or composted manure is considered as an effective solution to remedy the decline in fertility of sandy soils, for example, as well as the development of biological activity and plants [1], [2].

Composting is defined as a controlled process of degradation of organic constituents of plant and animal origin by a succession of microorganisms that evolve under aerobic conditions, thus leading to an increase in temperature and the elaboration of a humified and stabilized OM that constitutes the compost [3]. During the first days of composting, the presence of easily biodegradable organic matter leads to a high microbial activity generating a high heat production and a rapid rise in temperature in the composting windrow. The thermophilic phase is characterized by a sudden increase in temperature of 60-70 ℃. Only thermoresistant microorganisms (mainly bacteria) can survive these thermal conditions. Pathogens do not survive at these temperatures and their destruction as well as nematodes and weeds will take place [4], [5]. During this phase, a significant part of the OM is lost as CO_2 and a drying of the compost due to water evaporation is often observed. About 60 days later, the amount of easily degradable organic matter is reduced, causing a slowdown in microbial activity. The heat generated by the biological degradation is then lower than the losses due to surface exchanges and evaporation, leading to a cooling of the windrow. During this phase, which lasts almost 2 months, mesophilic microorganisms colonize the compost again. Finally, the maturation phase which results in a less sustained biodegradation of the incoming waste and in the biosynthesis of humic compounds from the residual OM of the first stage. During the composting process, the organic matter content will be reduced and the total nitrogen content will be increased, resulting in a lower C/N ratio [6].

In southern Tunisia, olive farming occupies more than 80% of the cultivable area in the broad coastal strip where it is the only alternative to land abandonment and desertification [7]. However, this cultivation of olive trees for more than 100 years without inputs with 4 and 8 annual cross plowing have eventually reduced the carbon content of these soils to levels below 10 g kg^{-1} [8]. The valorization of organic by-products of olive groves such as Olive Mill Wastewater (OMW) (aqueous residue of the olive press, rich in polyphenols) and Ramial Chipped Wood (RCW) could be an alternative transformation and valorization of these available materials by filling the deficit in organic inputs, ensuring a sustainable source available for organic agriculture and the restoration of soils very depleted in organic carbon. It is in this context that the present experiment (an experiment in pots) aims to study the short-term impact of different treatments composed of a compost based on organic olive tree by-products using a short-cycle test plant adapted to the region: a legume (Fabaceae), alfalfa (*Medicago sativa* L.).

II. Material and Methods

A. Ramial Chipped Wood (RCW)

The term Ramial Chipped Wood (RCW), refers to the wood of twigs or branches of less than 7 cm in diameter crushed by a machine. This type of woody material is extremely rich in mineral nutrients, compared to e.g. wood or straw. The wood of the trunk contains less lignin and its valorization for traditional uses, lumber in particular, is otherwise more profitable [9].

RCW constitutes a unique substrate for decomposing microorganisms and soil fauna, which gives it interesting

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properties for improving all types of soils. In addition, several studies have deduced a bio-stimulation of soil fertility by using RCW in agriculture with the prospect of increased retention capacity and reduced inputs [10].

B. Physico-Chemical Properties of a Compost Based on RCW

Before the experiment was set up, a representative sample of RCW-based compost was taken and analyzed in the laboratory to study physico-chemical properties (Table I). In general, the optimal pH for the microorganisms activities during biological treatment is around 7. Therefore, monitoring this parameter during composting is essential because it allows to improvethe fermentative process during microbial metabolisms [11]. At the beginning of the cycle, there is a slight acidification (pH < 7) due to the production of organic acids from the degradation of biodegradable substances. Acidification of the heap may also result from the dissolution of carbon dioxide in water generating carbonic acid. The pH then registered an alkaline phase (pH > 7). This phase coincides with warm fermentation, after which the pH is getting closer to neutrality due to the presence of humic compounds.

TABLE I: PHYSICO-CHEMICAL PROPERTIES OF COMPOST BASED ON RCW

Parameters	Values
pH	6.2
Electrical Conductivity (EC) (mS cm^{-1})	1.7
Humidity (g kg^{-1})	100
Organic Matter (OM) (%)	95
Mineral matter (MM) (%)	5
Total Carbon **(TC)** (%)	55
N (g kg^{-1})	4.7
C/N	117
Potassium (K) (mg kg^{-1})	43
Phosphore (P) (mg kg^{-1}**)**	232.5
Sodium (Na) (mg kg^{-1})	70
Densit é Apparente (DA) (g cm^{-3})	0.19

During composting, the decomposition of OM is carried out according to natural transformation chains. The organic components of the available materials allow the deduction of total carbon and are integrated into biogeochemical cycles according to metabolic reactions to lead to mineral elements (K, P, Na) or to more complex molecules forming humus [6] (Table I). Moreover, carbon allows the development of microorganisms and nitrogen is often the limiting factor for the development of bacteria. The C/N ratio is a fundamental indicator of the dynamics and stability of OM. In a composting cycle, it is necessary to maintain an optimal C/N for the beginning of microbial activity. During their evolution, organic substrates lose carbon more rapidly, which will be metabolized and degraded as carbon dioxide, than nitrogen, which is metabolized and lost as volatile nitrogen compounds [11].

C. Olive Mill Wastewater

Olive Mill Wastewaters (OMW) are vegetation waters that are generated during olive oil extraction [12]. They represent the remaining biomass considered as aqueous residues of olive crushing. These effluents require an environmentally sound management for olive oil producing countries where large volumes are produced in very short time intervals [13]. OMW are rich in OM (phenolic compounds, lipids, sugars, proteins, etc.) and mineral salts (potassium, sodium, magnesium, etc.) (Table II). They can increase the biological activities of soils and consequently their fertility [12].

Previous studies have shown that spreading quantities of olive mill wastewaters ranging from 100 to 200 m^3 ha^{-1} for 6 successive years on a sandy soil planted with olive trees has improved the soil structure by aggregating the fine soil, improving the water retention capacity and creating a mulch to prevent water evaporation [14].

TABLE II: PHYSICO-CHEMICAL PROPERTIES OF THE OMW USED

Parameters	Values
Humidity (%)	87.9
pH water	5.5
Electrical Conductivity (EC) (mS cm^{-1})	18.6
Chemical Oxygen Demand (COD) (g L^{-1})	105
Biological Oxygen Demand (BOD5) (g L^{-1})	55
Organic matter (g L^{-1})	107
Reducing sugars (g L^{-1})	11.4
Glucose (g L^{-1})	3.9
Phenols (g L^{-1})	5.8
Fat (g L^{-1})	4.5
Mineral matter (g L^{-1})	13.7
Nitrogen (g L^{-1})	1.4
Phosphorus (g L^{-1})	0.32
Potassium (g L^{-1})	7.5
Magnesium (g L^{-1})	0.65
Sodium (g L^{-1})	1.31
Calcium (g L^{-1})	0.71

D. The Soil

The soil was collected from a plot where 116-year-old olive trees were grubbed before replanting, located within the Office des Terres Domaniales (OTD) of Chammakh-Zarzis (33°34'48.53 "N; 10°57'11.02 "E). The soil is a calcareous Arenosol type [15]. Prior to the installation of the experiment, a representative sample of the Chammakh soil was sampled, air-dried, crushed and sieved to study their physicochemical properties. The results of the analyses are reported in Table III. The soil contains at least 80% sand with a very dominant fraction of very fine sand (between 75 and 100 µm). After more than a century of cultivation and cross-plowing 4 times a year to eliminate weeds, the surface horizon is characterized by a very low OM content (<0.5 g kg^{-1}) (Table III).

TABLE III: PHYSICO-CHEMICAL PROPERTIES OF CHAMMAKH SOIL

Parameters	Values
pH	7.8
Electrical Conductivity (EC) (mS cm^{-1})	0.95
Humidity (g Kg^{-1})	40
Organic matter (OM) (g Kg^{-1})	0.11
Total Carbon (TC) (g Kg^{-1})	0.06
N (g Kg^{-1})	0.14
C/N	4.35
Potassium (K) (mg Kg^{-1})	95.4
Phosphorus (P) (mg Kg^{-1})	15.4
Apparent density (DA) (g cm^{-3})	1.27

Active limestone (%)		5.5
Total limestone (%)		15
Grain size (%)	Silt (L)	5
	Clay (A)	13
	Fine Sand (FS)	76.5
	Coarse Sand (CS)	3.46

E. Experimental Devise

The experiment was carried out in pots of volume of 7 liters. It was conducted with 3 different treatments composed mainly as follows: (a) a control (Chammakh soil), (b) a mixture composed of 85% sand and 15% RCW and (c) a mixed treatment (85% sand, 15% RCW and 1 liter of OMW) (Table IV). For each component, 3 replications were studied.

TABLE IV: DIFFERENT TREATMENTS OF THE EXPERIMENT AND THEIR RESPECTIVE COMPOSITIONS

Designation	Treatments	Composition
T1	Control	100% soil
T2	RCW	85% soil and 15% RCW
T3	RCW+ OMW	85% soil, 15% RCW and 1 liter of OMW

F. Plant Material

The pot experiment was conducted on a species, alfalfa (*Medicago sativa* L.) of the Fabaceae family (legumes) (Fig. 1). It is a local variety whose germination occurs if the optimum temperature is 25 ℃ (the minimum is 7 ℃ and the maximum allowing growth is around 37 ℃). Reference [16] showed that alfalfa is drought resistant and that significant quantities can be produced during the summer period. Sowing was conducted on May 05, 2017. Controlled irrigation with homogeneous doses every other day was performed with water with pH and EC of 7.5 and 3.27 mS cm^{-1}, respectively.

Fig. 1. Experiment in pots of Alfalfa (*Medicago sativa* L.).

III. RESULTS

A. pH

Monitoring the evolution of soil pH in the pot experiment shows that this parameter varies with time. The pH at the end (pH end) decreases over time for the T1 treatment, increases for T3 and remains constant between the middle and the end of the experiment for the soil treated with RCW only (T2) (Fig. 2). Although the Olive Mill Wastewaters had an acidic pH (5.5), their addition does not change the soil pH. On average, the pH did not vary significantly, it was around 7.3.

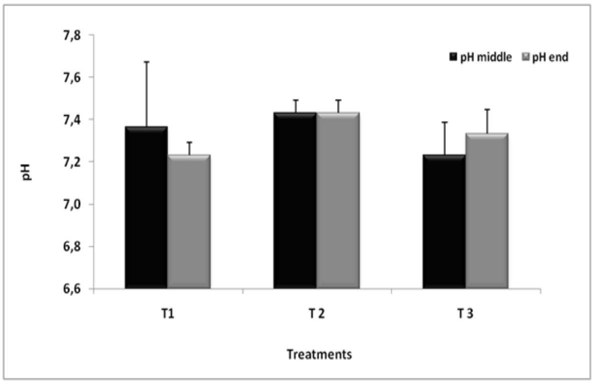

Fig. 2. Evolution of soil pH (pH middle and pH end) for the different treatments.

B. Electrical Conductivity (EC)

Fig. 3 showed that in the middle of the experiment, treatments T1 and T3 present the highest values of electrical conductivity (EC medium) in the soil of the experiment conducted in pots (10.32 and 15.18 mS cm^{-1}, respectively) while the application of RCW only (T2) gives an intermediate value (8.69 mS cm^{-1}). Also, final EC (EC end) decreases for all treatments. This decrease over time could be explained by the removal of salts by leaching of ions (mainly Na^+ and Cl^-) especially since drainage is rapid with RCW [17].

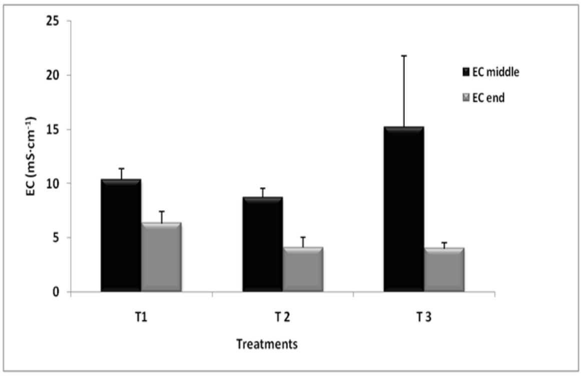

Fig. 3. Evolution of soil electrical conductivity (EC middle and EC end) for the different treatments.

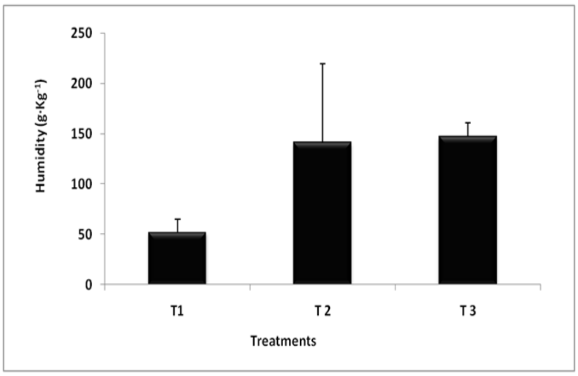

Fig. 4. Evolution of soil moisture for the different treatments.

C. Mass Humidity

Compost improves mass moisture very significantly compared to the control. The mass moisture varies between

52.30 g kg^{-1} (T1) and 147.23 g kg^{-1} (T3) (Fig. 4). The average value of moisture is equal to 113.5 g kg^{-1}.

D. Total Nitrogen (N)

Fig. 5 showed that treatment T3 has the highest nitrogen content (0.26 g kg^{-1}). The RCW compost treatment (T2) gives the lowest nitrogen content (0.21 g kg^{-1}) in the same range as the average (0.21 g kg^{-1}).

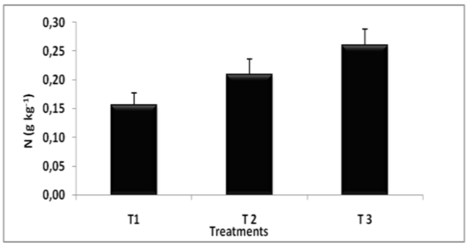

Fig. 5. Evolution of soil nitrogen content for the different treatments.

E. Assimilable Phosphorus (P)

Fig. 6 showed the phosphorus content for the different treatments. The RCW compost appears to have the highest phosphorus content (45.39 mg kg^{-1}). On the other hand, treatment T3 records the lowest value (11.6 mg kg^{-1}) compared to the average (24.37 mg kg^{-1}).

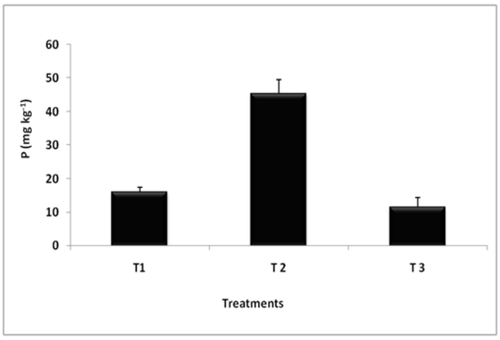

Fig. 6. Evolution of soil phosphorus content for the different treatments.

F. Total Potassium (K)

The results of the follow-up analyses of the evolution of total potassium in the soil suggest that, with the addition of a dose of Olive Mill Wastewater to the compost, the total potassium level increased by 60% compared to the treatment without OMW. It is also important to note that the application of compost appears to improve potassium content compared to the raw soil (584.37 and 115.38 mg kg^{-1}, respectively) (Fig. 7).

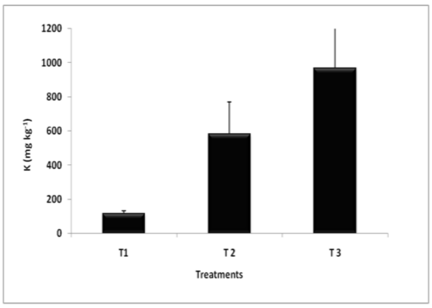

Fig. 7. Evolution of soil total potassium content for the different treatments.

G. Total Carbon (C)

In soils with low mineralogical reserves, organic matter is a major source of nutrients. It is relatively related to total carbon content. Fig. 8 showed that, compared to the control, the T3 treatment has the highest carbon value and is 10 times higher (6.61 g kg^{-1}) while RCW (T2) has the lowest value (1.71 g kg^{-1}). Also, the carbon content is higher in soils amended with OMW than in soils with compost based on RCW only.

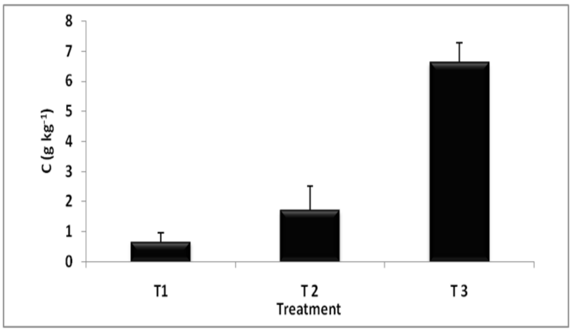

Fig. 8. Evolution of soil carbon content for the different treatments.

H. Carbon to Nitrogen (C/N) Ratio

Fig. 9 showed that RCW-only compost increases the C/N ratio by about 2 times compared to the control (4.15 and 7.91, respectively). The results also show that this ratio is greater than 25 for the T3 treatment, suggesting an excess of carbon over nitrogen. Therefore, the microorganisms will draw from the soil reserves instead of releasing them. This is the phenomenon of nitrogen starvation.

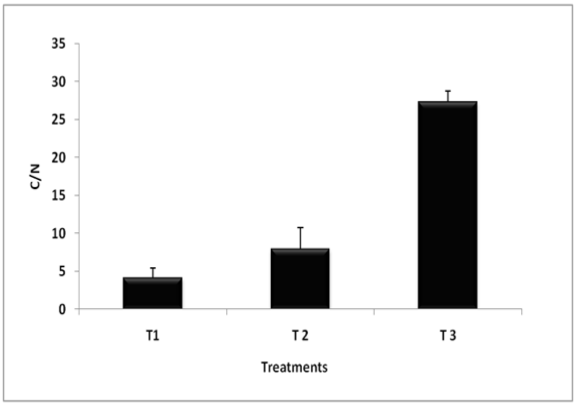

Fig. 9. Evolution of soil C/N ratio for the different treatments.

I. Above-Ground Biomass

To estimate the dry matter yield of the alfalfa, the aboveground dry matter content was determined after oven drying at 60 ℃ to constant weight. The results show that compared to the control soil (T1), the RCW treatment alone (T2) increased the yield by 2 times, while the application of Olive Mill Wastewater in addition (T3) decreased it by 10 times (0.2, 0.4 and 0.04 g, respectively) (Fig. 10). Moreover, during the experiment, the alfalfa with RCW compost remained dwarfed and yellow due to lack of nitrogen.

J. Discussion

Throughout the observation period and for all treatments, the effect of applying compost as an organic soil amendment on pH and EC appeared to be random and without remarkable differences (especially for pH). The follow-up period was probably too short to detect differences in these parameters and the composting procedure. On the other hand, [18] observed an increase in water conductivity and a decrease in soil density following the use of compost for organic agriculture.

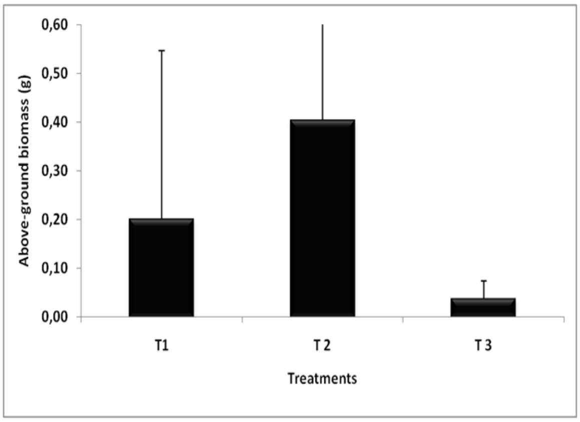

Fig. 10. Evolution of above-ground biomass for the different treatments.

The presence of water will bring mineral elements into solution, stimulate microbial life and contribute to good root development. By adding compost, it delivers more or less stabilized organic matter to the soil, which improves its pore structure and water status [1], [19]. These results suggest that compost helps to reserve moisture. In addition, the treatment containing extra Olive Mill Wastewater (OMW) slightly improves moisture than the RCW treatment.

Although the application of compost, whose effect varies according to the dose and type of compost, improves soil fertility by increasing the concentrations of assimilable phosphorus as in [20]-[24], The results obtained from the experiment conducted in pots for the monitoring of this parameter in the soil showed that these findings remain true (RCW treatment only) unless OMW is added in addition, which makes the rate decrease considerably but slightly below the values obtained for RCW and raw soil, respectively. Also, the results obtained are in perfect agreement with previous studies that have shown that compost increases potassium concentrations in soil [21], [23], [25]. In addition, although the short-term effect varied slightly, this experiment showed that compost improves soil nitrogen levels. In the long term, compost will be a significant source of nitrogen with a stronger residual and persistent effect, up to 5 years after application, on soil fertility than most chemical fertilizers [26], [27].

IV. Conclusions

The rehabilitation of degraded ecosystem services of olive soils aims to improve their organic status and biological activity to restore their physical and chemical properties in the long term. Composting of olive tree by-products could be considered as a remediation solution and would be an important way to valorize these available materials. The assessment of the effect of treatments based on organic olive tree by-products on the soil properties and biomass of alfalfa grown in pots was the subject of this work. The results of this study did not reveal significant effects on pH, EC, and mass moisture in the soil. On the other hand, a clear improvement was observed in the soils treated with Olive Mill Wastewater (T3) on the carbon content and thus on the soil organic matter and total potassium content. In the short term, a slight increase in nitrogen content was also observed for the T3 treatment. The RCW would seem to favour the content of assimilable phosphorus in the soil as well as the above ground biomass.

This study showed that compost improves physico-chemical properties of the soil. However, a specific agronomic evaluation in the field would be necessary to test each type of organic fertilizer. For the case of olive cultivation with a much slower response time, the initial dose of compost and its evolution in situ should be tested.

Conflict of Interest

The author declares no conflict of interest.

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