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Effect of carbon to nitrogen ratio and aeration rate on phosphorus and exchangeable cation contents and their leaching in the soil during olive pomace and turkey manure co-composting

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Abstract

The environmental issues related to olive oil by-products and turkey manure are continuously increasing. This ecological hazard could be mitigated by the composting process. This study aimed to investigate the effect of the initial carbon to nitrogen ratio (C/N) and aeration rate (turning frequency (TF)) on mineral contents (P, K, Ca, and Na) and their leaching in the soil surface. Olive pomace (OP) and turkey manure (TM) were co-composted to prepare six mixtures at three levels of initial C/N (20, 22, and 28) and two levels of TF (once and twice a week). The results revealed a substantial effect of TF, twice a week, resulting in a loss of 36.5%, 36%, and 27% for K, Ca, and Na contents, respectively, whereas TF, once a week, preserves the maximum of nutrients in heaps with good compost maturity.

The initial C/N of 28 had significantly reduced P and K by 14% and 13%, respectively, and had increased Ca and Na contents by 85% and 30 %, respectively. The leaching of almost all the studied minerals has been demonstrated after composting. Exchangeable cations have been leached more under heaps with higher C/N ratios with TF of once per week, whereas P leaching has been recorded at the maximum level under the heap with an initial C/N of 20 and turned twice weekly. The resulting composts have generally displayed good mineral quality.

Keywords: Compost, Manure, Olive pomace, Soil, Exchangeable cation, Leaching

Introduction

Soil organic matter (SOM) contents are generally low in semi-arid agroecosystems; in most cases, it does not exceed 1.5% (dry matter basis) which makes these soils rapidly depleted [1, 25, 27]. The intensification of agricultural activities through frequent tillage leads to the depletion of soil quality and disturbance of physicochemical properties [4], which implies periodic restitution of organic amendments to preserve soil fertility [2, 13, 39]. In Moroccan semi-arid regions, soil phosphorus and nitrogen contents are generally low and poorly available due to the calcareous nature of the soil; however, potassium and calcium contents are relatively higher [4, 46]. On the other hand, agricultural livestock and agri-food intensification produce large quantities of organic wastes which can lead to environmental pollution and compromise the sustainability of agricultural production [11, 22]. Furthermore, organic waste, whether animal or plant matter, is a potential source of organic matter and plant nutrients [3,6]. Moroccan biowaste has been estimated by El-mrini et al. [23] at 34.7 million tons a year, while Azim et al. [11] have concluded that there is a potential for organic waste estimated up to 1 million tons of dry matter a year, and 13 million euros worth of N, P, and K that can be recovered from the horticultural wastes, only in the Souss Massa region in the south of Morocco. The positive effect generated by organic materials utilization is mainly related to soil fertility enhancement and crop production improvement [5, 6, 42]. Carbon sequestration improves both physicochemical and biological soil properties which enhance nutrient bioavailability such as major nutrients (nitrogen, phosphorus, and potassium) [10]. This is particularly important for semi-arid soils generally characterized by a low organic matter content which is generally between 1 and 3% [4]. This biowaste contains a high level of major nutrients, namely nitrogen (N), phosphorous (P), and potassium (K), that improve its suitability as an organic amendment [37,53]. Turkey livestock activities had significantly increased in Morocco, which led to a rise in turkey manure generation. Turkey manure composting is a suitable technology able to recycle nutrients, prevent greenhouse gas emissions, and supply nutrients that can improve soil fertility and enhance crop yields [3,32, 55]. Another sector that constitutes a source of potential pollution is olive oil production, which has experienced an important development following the implementation of the Green Morocco Plan in 2008 [12]. This food processing activity leads to a serious environmental problem mainly due to the production of large quantities of different by-products of three-phase crushing systems, such as olive pomace (OP) and oil mill wastewater (OMW), in a short period of time that does not exceed 4 months per year on average [24,45].

The composting process is considered an effective method for transforming biodegradable waste into a stabilized and safe compost used as an organic amendment to enhance soil quality and improve its fertility [14, 43,32, 36, 44, 48, 53]. It is important to mention that OP compost contains a high organic matter content suitable for use as an organic amendment to improve physicochemical soil properties [13]. Composting, qualified as eco-friendly, is widely used around the world and has drawn more attention during the last decades [18, 21,26, 57]. If well monitored, it generates mature end-products which could be very useful as a high-quality organic soil amendment, bringing stable and mature organic matter and improving the soil's nutrient contents such as nitrogen, phosphorus, and potassium, required for plant growth but are insufficiently available in semi-arid soils [2]. The nutrient-rich compost can be used as an organic amendment to avoid the use of synthetic fertilizers [34,35]. The mineral quality of co-composts made of olive pomace and turkey manure has not been explored enough in terms of mineral leaching. To the best of our knowledge, no prior research has specifically addressed either the evolution or the leaching of exchangeable cations and phosphorus from OP- and TM-based compost in the soil. In the same way, controlling the main important factors of composting to enhance the mineral content remains an important aspect to study in order to bring added value to sustainable agriculture through the production of high-quality compost, rich in organic matter and/or mineral content. This study intends to investigate the effect of the initial carbon/nitrogen ratio (C/N) and turning frequency (TF) on mineral content evolution during heap co-composting of OP and TM and to assess the mineral leaching of those minerals by the end of the process in the soil underneath the heaps.

Methods

Composting process

Six different heaps of OP and TM were prepared for composting. The OP was a by-product of the olive oil artisanal factory with a discontinuous process (three-phase system), while the TM was collected from poultry livestock near Settat province in North West of Morocco. The durum wheat straw (WS) was used as a bulking agent, and the heaps were moistened and composted aerobically at different manual turning frequencies (TF). All of the composting mixtures were monitored for 6 months. It is worth noting that this experiment has been carried out previously, and part of the results have been published in an earlier article (see Tables 1, 2, and 3 in the Supplementary Material).

Temperature control

The temperature was monitored with a compost thermometer at three depths in the heaps (top, medium, and bottom). The ambient temperature was provided by the INRA Settat microclimate station in Morocco (see Fig. S1 in the Supplementary Material).

Physicochemical analysis

Four mineral elements were monitored during the experimentation: available phosphorus (P) content was determined by colorimetry at 882 nm using a spectrophotometer (Shimadzu, China) according to the Olsen Method [41]. Flame photometry was used to perform exchangeable potassium (K^+), sodium (Na^+), and calcium ($Ca2^+$) analyses in compost samples. The solutions of soil extract prepared using ammonium acetate 1N solution were handled in a flame photometer apparatus (Elico, Italy) [33]. All analyses were performed in duplicate. In addition, the four studied minerals were analyzed in the soil in contact with the heaps. A composite sample of several points was generated and studied before composting, and the soil underlying each heap was analyzed after composting at a depth of 20 cm.

Statistical analysis

The effect of the initial C/N ratio and TF on the final mineral contents in heaps was carried out by a two-way ANOVA test at $p < 5\%$. The comparison of the average mineral content in the soil, under different heaps before and after composting, was performed by a one-way ANOVA test at $p < 5\%$. The effect of the initial C/N ratio and TF on the final mineral contents in the soil under the six heaps was carried out by a two-way ANOVA test at $p<5\%$. The statistical analysis was performed using Minitab software (version 19).

Results and discussion

Phosphorus content

Figure 1 shows the evolution of the available phosphorus as affected by the initial C/N ratio and TF. The amount of phosphorus in all of the mixtures went down at the end of the second month and during the third month of composting. It might be explained by its consumption by different microorganisms for microbial growth, as suggested by Nguyen et al. [40]. This decline is consistent with the findings of Saleem et al. [47], who reported a decline in available P and a change of labile P into recalcitrant forms during composting. Composting could be an effective method of managing manure for P stability and lowering its losses in runoff water following land application, according to the same authors. Wei et al. also established that the availability of P decreases in various composts [56]. In the latest 2 months of the composting period, P content recorded a slight increase in all experiments. According to Nguyen et al. [40], this change in P level could be due to dry matter depletion, as well as the mineralization of organic P into mineral form [2]. After 6 months of composting, the final available P values in the mixtures ranged from 1515.48±269.86 mg kg^{-1} to 1902.11±93.00 mg kg^{-1} in the final composts for the six studied heaps. When C/N was increased from 20 to 28, statistical analysis revealed a significant reduction effect of initial C/N on available phosphorus (P) levels, estimated at 14%. On the available P, no significant reduction effects of TF were observed.

Exchangeable potassium content

Figure 2 depicts a significant lowering effect of the TF and initial C/N. The mean values (average on the three C/N levels) were 18,950 and 12,025 mg kg^{-1} for TF1 and TF2, respectively, which mean a decrease rate of about 36.5%. This finding implies that TF raises the risk of K leaching during composting. Between C/N 20 and C/N 28, initial C/N

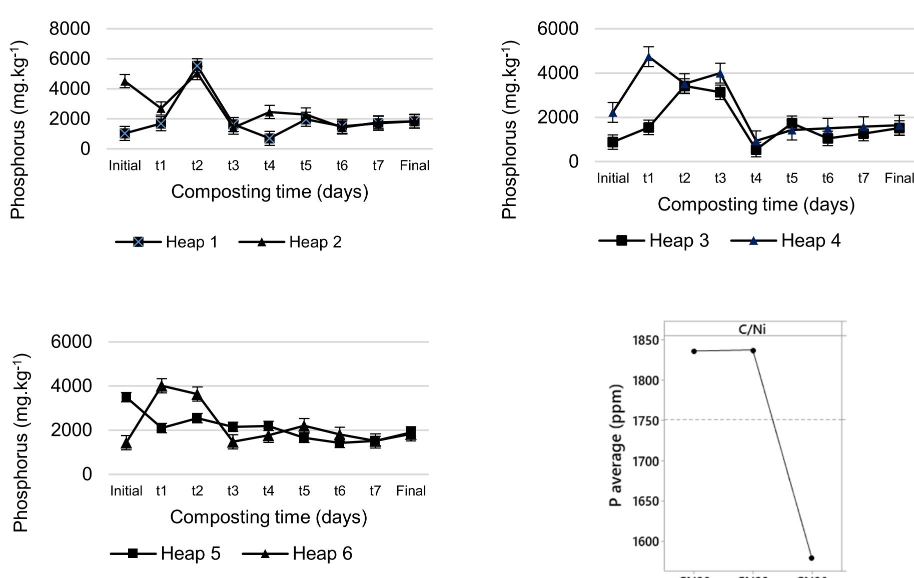


Fig. 1 Evolution of available phosphorus content during the composting period and factors' effect diagram associated

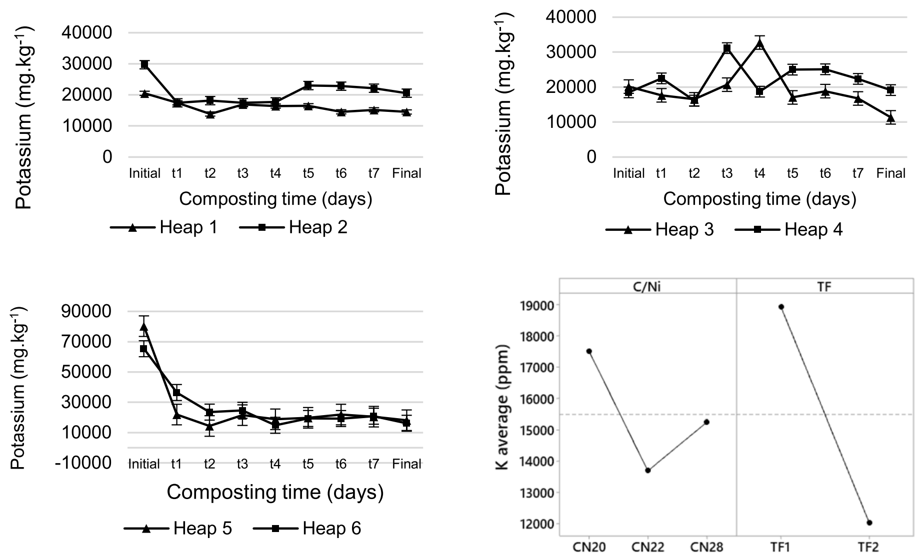


Fig. 2 Evolution of exchangeable potassium content during composting for the six heaps and factors' effect diagram

Table 1 Mineral content (mg kg^{-1}) of soil in contact with heaps

		P	K	Ca	Na
Heap 1	**SBC**	27.72 ± 1.86^a	277.50 ± 30.89^a	5375.00 ± 260.52^a	513.33 ± 49.67^a
	SAC	196.37 ± 3.80^b	4000.00 ± 141.42^b	7500.00 ± 141.42^b	600.00 ± 0.001^a
Heap 2	**SBC**	27.72 ± 1.86^a	277.50 ± 30.89^a	5375.00 ± 260.52^a	513.33 ± 49.67^a
	SAC	110.89 ± 5.67^b	5050.00 ± 212.13^b	7750.00 ± 212.13^b	650.00 ± 70.71^a
Heap 3	**SAC**	27.72 ± 1.86^a	277.50 ± 30.89^a	5375.00 ± 260.52^a	513.33 ± 49.67^a
	SBC	101.02 ± 2.74^b	4750.00 ± 70.71^b	7750.00 ± 70.71^b	1150.00 ± 70.71^b
	SAC				
Heap 4	**SBC**	27.72 ± 1.86^a	277.50 ± 30.89^a	5375.00 ± 260.52^a	513.33 ± 49.67^a
	SAC	75.12 ± 7.52^b	5800.00 ± 0.001^b	8000.00 ± 0.001^b	1400.00 ± 0.001^b
	SBC				
Heap 5	**SAC**	27.72 ± 1.86^a	277.50 ± 30.89^a	5375.00 ± 260.52^a	513.33 ± 49.67^a
	SBC	151.66 ± 3.26^b	5100.00 ± 0.001^b	7250.00 ± 70.71^b	700.00 ± 0.001^b
	SAC				
Heap 6	**SBC**	27.72 ± 1.86^a	277.50 ± 30.89^a	5375.00 ± 260.52^a	513.33 ± 49.67^a
	SAC	95.36 ± 10.75^b	6850.00 ± 70.71^b	7650.00 ± 70.71^b	750.00 ± 70.71^b

Legend: *SBC*, soil before composting [t_0]; *SAC*, soil after composting. Values followed by the same letter are not significantly different (p<0.05)

had a 13% reducing effect. In general, Fig. 2 shows that K levels tend to decrease over time for all heaps, which can be explained by the leaching of K cations after watering due to their high water solubility [2]. This finding is confirmed by the results shown in Table 1 where soil K content has significantly increased under the heaps after composting compared to the initial status. Irshad et al. also reported that there were decreases in the amount of water-soluble potassium present in the compost at successive phases of the composting process [31]. As a result, the final K values of all mixtures showed a decrease over the composting period in almost all the heaps. Consequently, the highest and lowest final K values were found to be 20,550.00±212.13 and 11,350.00±1343.50 mg kg^{-1} for heaps 2 and 3, respectively. This result could be explained by the initial physicochemical composition, which contributes considerably to the difference between different monitored mixtures, according to Cestonaro et al. [15]. Among the studied nutrients, K cation content has recorded the most significant variation for all the heaps. This finding complies with previous studies that concluded the loss of K content through composting process [2, 15].

Calcium content

As shown in Fig. 3, the TF had a significant decrease effect on calcium content, which was approximately 36% (average of the three C/N levels). However, the initial C/N had increased the Ca content by nearly 85% from 20 to 28. Calcium contents exhibited nearly identical evolution patterns for the various C/N ratios. Figure 3 shows that this evolution was characterized by a decrease in Ca content during the first 50 days of composting, owing primarily to mixture watering and Ca water solubility. The Ca content increased after day 50, which could be attributed to carbon loss as CO_2 as a result of organic matter biodegradation [28]. The Ca contents have increased after day 50 and might be due to carbon loss as CO_2 following organic matter biodegradation [28]. The decrease could also be explained by the organic matter stabilization which fixes the Ca ions in the compost matrix [49]. By the end of the composting process, stabilization of Ca contents is noted following compost maturation and biological activity stabilization. Overall, the Ca content declines over the composting period, which could be explained by its leaching. Table 1 illustrates that the Ca content of the soil under heaps after co-composting has increased significantly (≥ 7250.00 mg kg^{-1}) compared to the initial status of the experiment (5375.00 mg kg^{-1}). The final values in heaps ranged from 12,450.00±70.71 mg kg^{-1} to 22,000.00±282.84 mg kg^{-1} for heap 1 and heap 4, respectively. In contrast to the present results, Sellami et al. [52] concluded a significant increase in the Ca content was

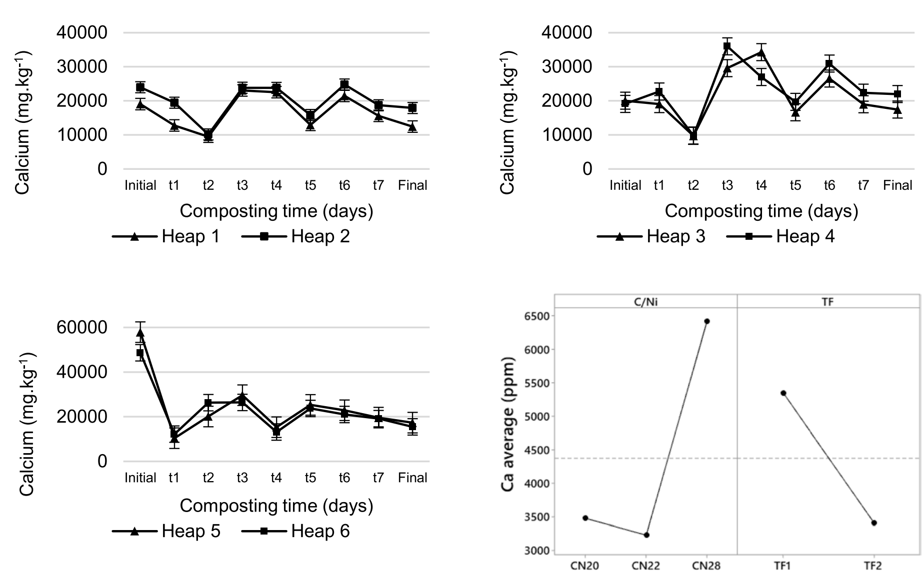


Fig. 3 Evolution of calcium content during composting for the six heaps and factors' effect diagram

probably due to wastewater utilization for moistening, which brought a higher amount of different minerals (P, K, and Ca).

Sodium content

The change in sodium content that occurred throughout the composting process is depicted in Fig. 4. The statistical analysis revealed a significant difference between treatments. Initial C/N had increased Na content by almost 30% between 20 and 28, while TF had reduced it by almost 27% from TF1 to TF2. During the period of time between the 52nd and 68th day of the composting process, the evolution of this mineral recorded the highest levels. The biodegradation of the organic matter and, as a result, the accumulation of sodium ions might provide an explanation for this phenomenon. Then, a decline was observed, possibly as a result of sodium leaching due to its high water solubility after wetting the heaps. The final Na values showed an increase, compared to the initial contents, at the end of the composting process for all the heaps. Saleem et al. [47] reported that total Na increased with composting time under either aerobic or anaerobic conditions and that mineral content tends to increase with composting time due to higher carbon losses. The final values ranged from 3200±0 to 8100±141.42 mg kg^{-1} for heaps 1 and 4, respectively. This fact of sodium accumulation on agricultural lands should be considered so that crop establishment and growth are not compromised and arable soils are not polluted [17]. In fact, an appropriate C/N ratio (28) leads to an increase in Na concentration due mostly to OM biodegradation, whereas TF causes a decrease in Na concentration due to its water solubility, which results in its leaching after watering.

Leaching analysis

At composting facilities, one of the most significant concerns is the leaching of soluble nutrients [30]. Table 1 shows that, for all studied minerals, their values have increased, over the composting period, in the soil in contact with the heaps. This increasing trend

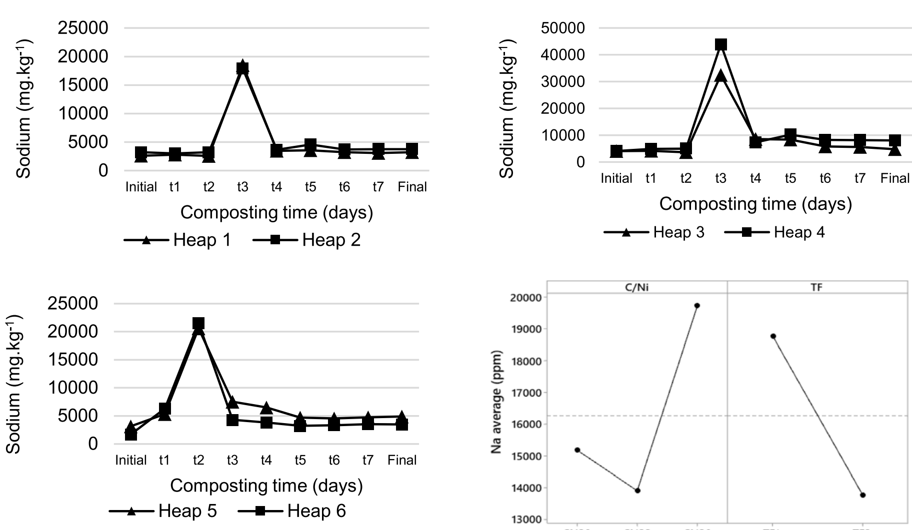


Fig. 4 Evolution of sodium content during composting for the six heaps and factors' effect diagram

has been recorded for all the mixtures for the four minerals (P, K, Ca, and Na). This may explain the reduction of heap mineral contents throughout the composting process.

A one-way ANOVA test was carried out to thoroughly examine the impact of various mixtures on the mineral content of the soil.

Available phosphorus content (P)

Figure 5 depicts a considerable difference in P content between soils under heaps. H1 compost recorded the highest level (196.38±3.8 mg kg^{-1}). Overall, P content has increased in the soil under all the heaps, ranging from 75.12±7.52 to 196±3.8 mg kg^{-1} for H4 and H1, respectively. This fact could be explained by the leaching of water-soluble P forms after multiple heap moistening and turning operations during the composting process. Initial C/N has significantly reduced the leaching of P under heaps by almost 43% when it is at its maximum level, while frequent turning has increased the leaching of P by almost 54%.

Exchangeable potassium content (K)

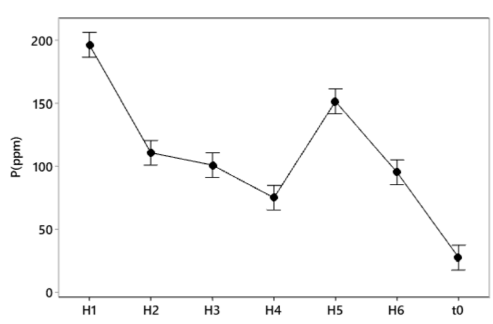
The same conclusion was reached for potassium content, where soils were significantly enriched in potassium by the end of the process. The final values have increased from 277±9.66 to 6890±70.7 mg kg^{-1} as a maximum for H6. As depicted in Fig. 6, the Tukey test has highlighted distinct groups of potassium content. Frequent aeration has significantly reduced the leaching of K under heaps by almost 19%, while initial C/N has no effect on K content under heaps.

Calcium content

For calcium cation, all soils exceeded 7250 mg kg^{-1}, while the initial value was beneath 5400 mg kg^{-1} (Fig. 7).

This significant difference is due to calcium cation's water solubility and watering operations during the composting process period. Initial C/N has significantly increased the leaching of Ca in the soil, with a content of 7325 and 7875 mg kg^{-1} for C/N 22 and 28, respectively, on the one hand, while there was no significant effect of TF on the other hand.

(a)

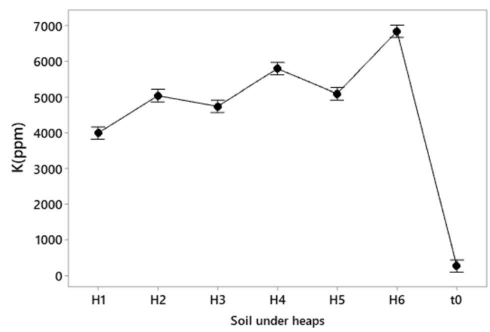


(b)

Soil under heaps	N	Mean	Grouping
H1	2	196.38	A
H5	2	151.66	B
H2	2	110.89	C
H3	2	101.02	C
H6	2	95.36	C D
H4	2	75.12	D
t0	2	27.723	E

Means with a different letter are differents significantly

Fig. 5 Statistical tests related to P content under the soil *($p<0.05$)*: **a** confidence intervals related to P means under the soil before (t_0) and after composting (under H1 to H6) (*one-way ANOVA test*); **b** Tukey test associated a



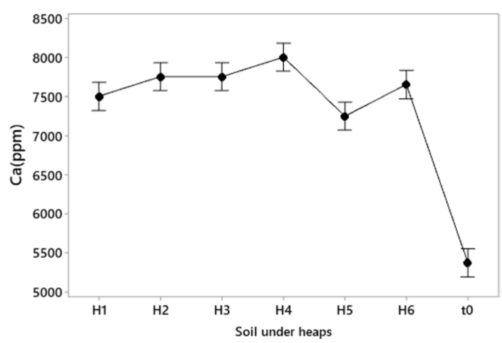
b

Soil under heaps	N	Mean	Grouping
H6	2	6850	A
H4	2	5800	B
H5	2	5100	C
H2	2	5050	C
H3	2	4750	C
H1	2	4000	D
t_0	2	277.5	E

Means with a different letter are differents significantly

Fig. 6 Statistical tests related to K content under the soil *(p<0.05)*: **a** confidence intervals related to K means under the soil before (t_0) and after composting (under H1 to H6) (*one-way ANOVA test*); **b** Tukey test associated

a



b

Soil under heaps	N	Moyenne	Groupement
H4	2	8000	A
H3	2	7750.0	A B
H2	2	7750	A B
H6	2	7650.0	A B C
H1	2	7500	B C
H5	2	7250.0	C
t_0	2	5375.0	D

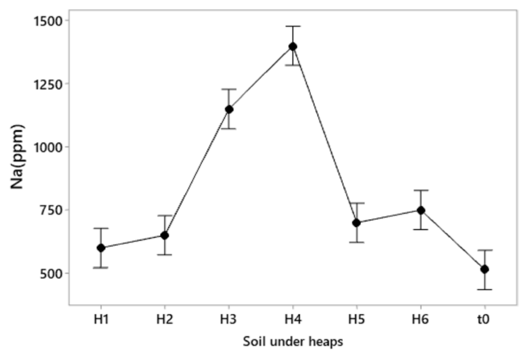
Means with a different letter are differents significantly

Fig. 7 Statistical tests related to Ca content under the soil *(p<0.05)*: **a** confidence intervals related to Ca means under the soil before (t_0) and after composting (under H1 to H6) (*one-way ANOVA test*); **b** Tukey test associated

Sodium content

A significant increase was recorded as well in sodium content from 513±9.43 to 1400±0.01 mg kg^{-1} for t_0 and H4, respectively (Fig. 8). After composting, the Na content in soil under heaps 4, 3, 6, and 5 increased significantly (over 700.00 mg kg^{-1}) compared to the initial status (513.33 mg kg^{-1}). However, the sodium content assessment in soils has revealed a non-significant difference between t_0, H1, and H2, as highlighted by the Tukey test.

Overall, among the six heaps, H1 demonstrated the least cation leaching level, specifically K, Ca, and Na, while recording the greatest phosphorus content loss. This finding is in agreement with those of Amlinger et al. [9] and Siedt et al. [51] who concluded that composts with a high C/N over 20 lead to immobilizing some nutrients. H1 compost has the lowest initial C/N ratio, resulting in greater water solubility that is exacerbated by a higher TF (twice a week). Consequently, soil analysis could play a key role in determining which C/N ratio and TF to adopt in order to mitigate mineral leaching, on the one hand, and prevent soil pollution, on the other hand. According to Hurley et al. [30], nutrient leaching potential varies depending on either the used feedstocks or the composting process itself. The result of this study is tightly associated with the feedstocks of a



b

Soil under heaps	N	Moyenne	Groupement
H4	2	1400	A
H3	2	1150.0	B
H6	2	750.0	C
H5	2	700.0	C
H2	2	650.0	C D
H1	2	600.0	C D
t_0	2	513.33	D

Means with a different letter are differents significantly

Fig. 8 Statistical tests related to Na content under the soil *($p<0.05$)*: **a** confidence intervals related to Na means under the soil before (t_0) and after composting (under H1 to H6) (*one-way ANOVA test*); **b** Tukey test associated

the mixtures, with different C/N ratios, and depends on the Turning frequency providing oxygen to the heap.

In the Chaouia region, P is not a pollutant of concern, which makes this leaching beneficial in terms of soil fertility enhancement. Compost application does not worsen P leaching [51, 54] and P could react with calcium and then be retained by adsorption to the soil matrix [16]. Soil organic matter plays a key role as a sink of nutrients [16] which mitigates the nutrient leaching in groundwater.

Mineral quality of the obtained composts

Composts, which are often referred to as “complete fertilizers,” can increase the fertility of the soil by delivering stable organic matter as well as macro- and micronutrients [51]. Furthermore, composts could be used as organic amendments and partially replace mineral fertilizers as a consequence [51]. This leads to improving the physicochemical characteristics of the soil, improving biological activity, and significantly promoting plant growth [2, 20]. The enrichment of the soil in mineral elements, by spreading compost, also makes it possible to minimize the effect of pollutants (metals, antibiotics, PAHs, etc.) [38].

The nutrient content of composts is not widely regulated on a global scale. The French standard NF U44-051 stipulates that total P_2O5 and K_2O levels below 3% must be disclosed on product labels. It is also necessary that the sum of TNK, P_2O_5, and K_2O should not exceed 7% of raw material [7]. The European Quality Assurance Scheme for Compost and Digestate requires only that the amount of nitrogen (N), potassium (P), and magnesium (Mg) be mentioned. This regulation applies to the European Union [50]. In Germany, total nutrients (N, P_2O_5, K_2O, MgO, CaO) and soluble nutrients (N, P_2O_5, K_2O) must be reported on the label [19].

Table 2 shows that the obtained composts in this study comply with French standard NF U44-051 regarding the total (TNK+P+K) which is less than 7%. The K values of our composts are more or less close to those of Hachicha et al. [29]. They contain less P and Ca than the author in question. As stated by Ameziane et al. [8], the micronutrient

Table 2 Mineral content (%) of the six final composts

	H1	H2	H3	H4	H5	H6
P (%)	0.18±0.00	0.18±0.00	0.15±0.03	0.16±0.01	0.19±0.01	0.18±0.00
K (%)	1.45±0.01	2.06±0.02	1.14±0.13	1.92±0.01	1.82±0.02	1.62±0.06
Ca (%)	1.25±0.01	1.79±0.08	1.75±0.06	2.20±0.03	1.74±0.01	1.55±0.04
Na (%)	0.32±0.00	0.38±0.01	0.48±0.05	0.81±0.01	0.49±0.00	0.35±0.00
TNK (%)	2.26±0.03	2.77±0.06	2.58±0.03	2.81±0.01	2.82±0.05	2.66±0.00
TNK+P+K (%)	3.89	5.01	3.87	4.89	4.83	4.46

levels of the obtained composts fall within the ranges of olive-pomace-based composts (sodium: 0.05–4.1%; phosphorus: 0.1–3%; potassium: 0.12–4.4%).

Conclusions

Considering the vast volume of biowaste generated by olive oil industries and poultry farms, as well as the requirement for their valorization in order to restore soil fertility, the composting process appears to be an appropriate method for achieving this goal. In this investigation, the aerobic co-composting of OP and TM was accompanied with a drop in three of the four mineral contents that were the focus of this study over time. Six months of composting have been required to convert raw material into mature compost. A significant decreasing effect of TF on K, Ca, and Na contents has been recorded, while initial C/N had significantly reduced P and K contents but increased Ca and Na. Overall, TF preserves the largest amount of all examined nutrients in final composts when applied once a week. While an initial C/N of 28 will retain the most Ca and Na, a C/N of 20 will keep more P and K in the composts. However, it has been revealed that nutrients were leached over composting time. So, depending on which minerals we are interested in, this study suggests what values of starting C/N and TF to use to optimize the mineral content of composts. It also highlights the fact that composting process could be considered an accessible technology for recycling organic waste into organic amendments rich in minerals and thus capable to enhance soil fertility, preventing soil deterioration and contributing therefore to sustainable agriculture. Further research should be conducted to better understand the effect of other factors on the leaching of various minerals in the soil.

Abbreviations

ANOVA	Analysis of variance
C/N	Carbon to nitrogen ratio
EC	Electrical conductivity
H1	Heap 1
H2	Heap 2
H3	Heap 3
H4	Heap 4
H5	Heap 5
H6	Heap 6
P	Phosphorus
K	Potassium
Na	Sodium
Ca	Calcium
N_2	Nitrogen
N_2O	Nitrous oxide
NH_3	Ammonia

NH_4^+	Ammonium
NO_2^-	Nitrite
$NO3^-$	Nitrates
OC	Organic carbon
OM	Organic matter
CEC	Cation exchange capacity
OP	Olive pomace
pH	Potential of hydrogen
T °C	Temperature in Celsius
TF	Turning frequency
TM	Turkey manure
TNK	Total nitrogen Kjeldahl
WS	Wheat straw ppm (mg)

Supplementary Information

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Additional file 1. Supplementary tables and figure.

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Authors' contributions

RA and SE implemented the experimentation. RA conceptualized the study, wrote the original draft, analyzed the data, and reviewed the article. SE contributed to implementing the experiment, performing the statistical analysis, and writing the article. AZ contributed to implementing experimentation and providing resources. KA has contributed to developing the methodology, writing, and reviewing the article. The authors read and approved the final manuscript.

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Availability of data and materials

The data generated during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests

The authors declare that they have no competing interests.

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