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RESEARCH

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Effect of initial C/N ratio and turning frequency on quality of final compost of turkey manure and olive pomace

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Abstract

In Morocco, the potential of agricultural waste is estimated at 34.7 MT/year. Composting is an effective way for waste management. If badly monitored, it can affect the environment. Initial C/N ratio (C/Ni) and aeration appear to be major factors impacting the composting process. This work studied the effect of C/Ni and turning frequency (TF) on the olive pomace and turkey manure co-composting process and on the final compost quality. The study concerned the Moroccan agricultural region Chaouia-Ouardigha where these two by-products are abundant and not valued. Six heaps (H1 to H6), at three levels of C/Ni (20, 22, 28) and two levels of TF (once and twice a week), were studied. Statistical tests showed that the studied factors had no significant effects on pH, total nitrogen, electrical conductivity, and cation exchange capacity (CEC). However, C/Ni had a significant increase of 60% in nitrates. Varying from 20 to 22 or from 22 to 28, C/Ni reversed its significant effect on final C/N and CEC/organic carbon. TF reduced significantly OM and final C/N by about 22% and 9% respectively. The dendrogram showed that the six heaps could form at the end two groups: group 1 (four heaps) and group 2 (two heaps) with a similarity of about 75 and 90 respectively. C/Ni of 22 and TF of twice a week seem to be an optimum to produce a final compost of better quality. This work shows that (1) C/Ni and TF significantly impact several final quality parameters of composts from olive pomace and turkey manure, and (2) composting has a strong effect of reducing the variability between heaps initially different to produce very similar final composts.

Keywords: Agriculture by-products, Initial C/N ratio, Turning, Morocco, Compost quality, Waste management

Introduction

Composting refers to the decomposition of moist organic material under aerobic conditions [11]. It is also described as the aerobic degradation of organic waste, where heat is released by microbial metabolism, leading to temperature increase [28] and transformation of organic matter into stable compost by exothermic oxidation and endothermic humification processes [32] to produce an organic fertiliser [33]. Composting is an effective and economical method for the treatment of animal manure prior to land application [24] and for recycling food wastes [6, 8]. Used as bio-fertilisers, composts can improve the physicochemical and biological properties of soils, increase plant growth and production yield, and improve carbon sequestration in the soil [52].

The duration of the composting process depends on the type of raw material and its efficiency, which is conditioned by several factors such as frequency of aeration, composting technology, and moisture [54].

Controlling is essential to optimize time and quality in composting process [4]. Factors affecting the composting process were widely studied. Some authors have also developed tools to technically and economically optimize composting according to the biomass/co-products available and the objectives pursued [12, 49]. The main factors affecting the composting process are oxygen, moisture, bulk density, nutrients (especially carbon and nitrogen), pH, inoculation, addition of enzymes, and temperature. Temperature can be regulated in certain ranges. It can be reduced or increased by turning or wetting. Nutrients and pH cannot be regulated during the process and can only be managed by a suitable starting mixture [38].

Also, the result and the speed of composting can be affected by the diversity of the raw materials to be composted such as carbon/nitrogen ratio, pH, and the distribution and abundance of microbes. So, the starting composition is a determining factor that affects the objectives of composting whether it is the stabilization of organic matter, pathogens destruction, or reducing cost of obtaining fertile soil [30].

However, the C/N ratio (carbon to nitrogen) and aeration appear to be the major indicators of aerobic composting, its efficiency, and the emission of several nitrogen compounds [16, 21, 43].

Aeration can be provided by ventilation or turning. A major advantage of the turning method is the homogenization of the heap [45]. The turning frequency is commonly considered to be a factor that affects composting kinetics as well as the quality of the compost [46]. Limited oxygen supply in composting materials led to lower temperatures, reduced microbial activities, non-uniform moisture and temperature, anaerobic conditions, limited decomposition [11], greenhouse gas emissions increase (such as nitrous oxide, N2O, and Methane, CH4), production of odours (Hydrogen sulphide, H2S), an extension of composting duration and a reduction in compost quality [28]. However, excess of aeration can lead to heat loss, reducing moisture thus increasing composting time [2, 11], increasing nutrient losses, and decreasing the composting process [48]. Active or passive, aeration remains an important element of composting with a higher performance of active aeration which reduces the maturation period by 37.30% compared to passive (natural) aeration [10]. Aeration must be controlled so as not to have an opposite effect during composting. A study of vegetable–fruit wastes composting with six aeration rates concluded that all of them removed coliforms, but the lowest faecal coliform content was associated with the lowest aeration rate [7].

The initial C/N ratio is one of the most important factors impacting compost quality [41]. An ideal range for composting of initial C/N ratios is 25 to 30 [34]. Other authors mention that international technical standards require a C/N range of 20 to 30 [59]. A high initial C/N ratio will lead to a slower start of the process and a longer composting time than usual, while a low initial C/N ratio will result in high ammonia (NH3) emission [48]. The C/Ni effect during composting was studied by several authors. Organic matter and Nitrogen losses are significantly affected by the C/Ni ratio, while this one had no effect on pH and temperature evolution [57]. The initial C/N ratio mainly influences the maturity of the composts, while aeration was the major factor influencing the stability of the compost [24]. A low initial C/N of 15 significantly affects several parameters during co-composting pig manure and sawdust [27]. An initial C/N ratio of 25 reduces Copper (Cu) and Zinc (Zn) mobility, while their total contents increase during pig manure composting. Moreover, the C/N ratio could affect the activity of the urease enzyme by influencing the content of metal ions [61]. Other studies have investigated the effect of C/Ni on pathogen reduction [37].

The Chaouia-Ouardigha region in Morocco is characterized by two expanding activities: the traditional extraction of olive oil and turkey breeding. In Morocco, the thousands of small artisanal oil mills called "maâsras", after extracting olive oil, sell the dried pomace to other industries either for the production of olive pomace oil, soap, or used directly as boiler fuel. As for turkey manure, it is used by direct spreading as a fertiliser. This causes environmental pollution on several levels [3]. Apart from our first two articles which studied the impact of the co-composting of three-phase olive pomace with turkey manure on the maturity, stability [18], and microbiological quality of the final composts [3], no research has studied, in that region, the effect of turning frequency and C/Ni ration on the performance of co-composting on heaps of these two by-products. This study will promote the circular economy in that region by proposing how to succeed simple composting with abundant agro-industrial by-products.

The objective of this work is to 1) study the effect of two factors, initial C/N (C/Ni) and Turning frequency (TF) on the process of co-composting on heaps of olive pomace and turkey manure as well as the quality of the final compost, and 2) study the variability of the composting process.

Methods

Experimental protocol

Turkey manure (TM) and olive pomace (OP) were obtained from livestock farming and an artisanal crushing unit in Settat province. The wheat straw (WS) comes from the Sidi Elaidi experimental station (altitude 230 m, 33.17° N, 7.40° W) in Morocco. The main physico-chemical characteristics of the three raw materials are given in Table 1. Six trapezoidal heaps (H1 to H6) of different compositions (Table 2) were installed and monitored for composting. H5 and H6 are identical to study the statistical variability of the

Table 1 Initial physicochemical characterization of turkey manure, olive pomace, and durum wheat straw

Chemical parameters	Turkey manure	Olive pomace	Wheat straw
OM (% w/w)	58.91	60.28	64.49
NTK (% w/w)	3.74	1.18	0.93
pH	6.27	5.03	nd
EC (ds m-1)	6.93	1.37	nd
$NO3^-$(mg kg-1)	1283.85	214.88	nd
C/N	9.21	29.85	41.16
%Humidity	29.44	16.57	35.00

nd not determined, *w/w* weight/weight

Table 2 Proportions de WS, TM and OP, C/Ni and TF of the six heaps

Heap	%WS	%TM	%OP	C/Ni	TF	Height (m)	Width (m)	Length (m)
H1	10	26.4	63.6	20	Twice a week	1.2	1.3	1.5
H2	10	26.4	63.6	20	Once a week	1.2	1.3	1.5
H3	60	10	30	28	Twice a week	1.5	1.4	1.8
H4	60	10	30	28	Once a week	1.5	1.4	1.8
H5	20	20	60	22	Once a week	1.6	1.4	1.8
H6	20	20	60	22	Once a week	1.6	1.4	1.8

H5 and H6 (identical): heap object of the present study; H1 to H4: subject of a previous study. Their results are used only for statistical interpretation

composting process and were installed about 20 days after other heaps, due to logistical difficulties. The studied factors levels are (20, 22, and 28) and (once, twice a week) for C/Ni and TF respectively. The "Climatic conditions" factor is not studied. The composting site was located in the previous experimental station. Heaps H1 to H4 have already been the subject of a recent publication [18] where the effect of the factors C/Ni and TF was not studied. In this article, we are going to use the results of heaps H1 to H4, together with those of H5 and H6, to analyse the studied factor effect. The results of heaps H5 and H6 (which are identical) will also be used here to analyse the evolution of their physicochemical parameters, as well as to study the variability of the composting process.

Temperature monitoring

Temperature was monitored with a compost thermometer (0–110 °C). The compost temperatures were measured at three zones for each heap (top, middle, and bottom). The ambient temperature was collected from the Sidi Aidi experimental station, Regional Center, Settat, Morocco.

Physicochemical analysis

Eight physicochemical parameters were analysed at the same time for H5 and H6 from the beginning to the end of composting 9 times: pH and electrical conductivity (EC) (1:10 w/v Sample-water extract, dS/m) were measured using a pH-meter electrode and a conductivimeter respectively [40]. Organic carbon OC (% w/w) was determined by titration using potassium dichromate [60]; then, organic matter (OM) content was calculated according to equation 1 (OM = 1724 OC). Total nitrogen TNK (% w/w) was determined by the Kjeldahl method (Buchi, Switzerland). Nitrates $NO3^-$ (ppm) were determined by complexation with chromotropic acid and measurement of absorbance in a spectrophotometer (Spectronic, USA) at 410 nm [26]. The C/N ratio was calculated. Cation exchange capacity CEC (meq/100 g) was determined by extraction with sodium and ammonium acetate and solutions were burned in a flame photometer (Elico, Italy) [53]. CEC/OC was also calculated: CEC/OC = CEC value (meq/100 g)/OC value (% w/w) (Table 3).

Statistical analysis

The effect of composting time on the analysed physicochemical parameters for H5 and H6 was analysed by one-way analysis of variance (ANOVA) with two replicates (P <

Table 3 Physicochemical properties of composts at initial and final time for H1 to H4

	H1		H2		H3		H4	
	Initial	**Final**	**Initial**	**Final**	**Initial**	**Final**	**Initial**	**Final**
pH	6.54	7.30	6.79	7.20	6.46	6.60	6.55	6.80
TNK(%)	1.82	2.26	1.84	2.77	1.36	2.58	1.21	2.81
$NO3^-$ (ppm)	704.00	780.96	847.00	1144.68	1042.00	2287.80	1601.00	2443.68
OM (%)	61.72	43.66	58.96	58.58	66.37	54.1	58.96	64.76
C/N	19.73	11.26	18.65	12.26	28.34	12.15	28.17	13.38
EC (dS/m)	5.03	3.62	6.78	5.49	5.97	6.19	6.05	7.58
CEC (meq/100 g)	15.98	90.76	14.67	103.80	10.87	108.15	29.57	125.00
CEC/OC	0.45	3.58	0.43	3/06	0.28	3.45	0.86	3.33

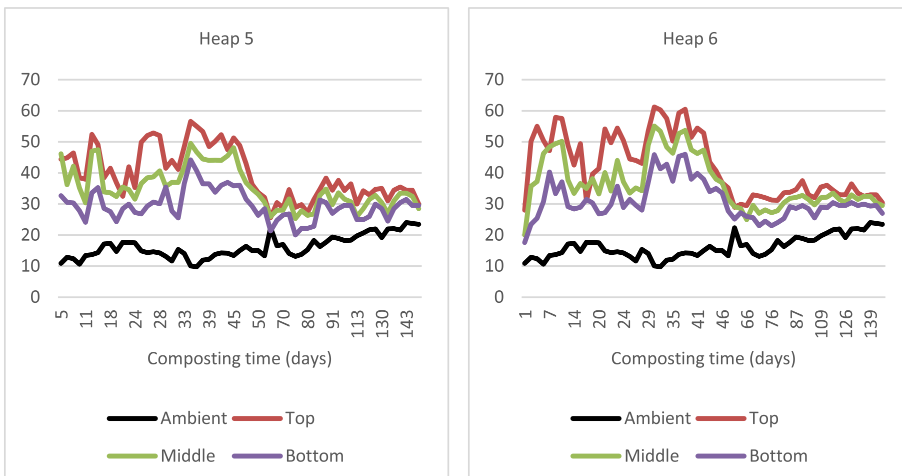


Fig. 1 Ambient and heap temperature evolution during co-composting of TM and OP for H5 and H6. Ambient (black); Top (brown); Middle (green); Bottom (violet)

0.05). The variability study of the composting process, between H5 and H6, is carried out by one-way ANOVA test (two replicates) for all the analysed parameters and for the nine analysis times. The effect of C/Ni and TF factors on the physicochemical parameters at the end of composting for H1 to H6 was studied by unbalanced two-way ANOVA (P < 0.05) without replicates. Tukey's test is calculated only for factor for which the effect is significant. The software used is the SPSS software (Version 20).

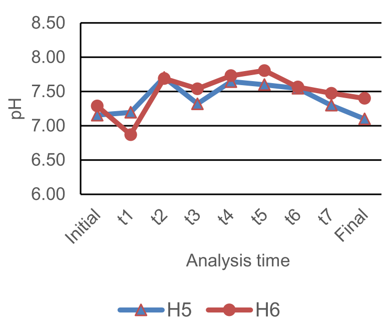
Results and discussion

Temperature evolution

Temperature is one of the major parameters to assess the progress of composting process as it indicates the rate of microbial activity [3, 39]. H5 and H6 show (Fig. 1) similar and typical appearance of composting phases with interference between the mesophilic and thermophilic phases. The mesophilic phase is below 45 °C [19, 50]. Then, the thermophilic phase where the temperature varies from 35 to 65 °C allows their hygienization [17]. Finally, the maturation phase where the temperature converges to an equilibrium

Table 4 Mesophilic and thermophilic durations, and maximum temperatures (T °C, max) in the heaps H1 to H6

	H1	H2	H3	H4	H5	H6
Mesophilic + thermophilic durations (days)	28	43	61	61	45	42
T °C, max	62	56	60.1	59.6	56.6	61.3
% WS	10	10	60	60	20	20
C/Ni	20	20	28	28	22	22



H5

Source	DF	sum of squares	Mean square	F	P
Composting time	1	0,0030	0,0030	4,84	0,159
Error	2	0,0013	0,0006		
Total	3	0,0043			

H6

Source	DF	sum of squares	Mean square	F	P
Composting time	1	0,011	0,011	441,00	0,002
Error	2	0,0001	0,00003		
Total	3	0,011			

DF : Degrees of freedom

Fig. 2 pH evolution during co-composting of TM and OP (left) and ANOVA test associated (right)

with the ambient temperature, and compounds that are not further degradable (lignin, humus complexes) are formed and become predominant [17].

H5 and H6 experienced similar thermophilic phases during the same period (between the 30th and 45th day of composting). The highest heap maximum temperatures recorded were 56.6 °C on the 35th day and 61.3 °C on the 31st day for H5 and H6 respectively. During maturation, the temperature converges to an equilibrium with the ambient temperature whether it is for the top, the middle, or the bottom of the pile, thus indicating the stability of the compost.

H5 and H6 have kept mesophilic and thermophilic temperatures for similar lengths (45 days and 42 days respectively) since they are identical. Table 4 summarizes data on mesophilic and thermophilic durations and the maximum temperatures (T °C, max) of the six heaps.

As H1 and H2, H5 and H6 kept the temperature less than H3 and H4 because they have less straw and therefore less porous. Generally, the heaps in which C/Ni is high (H3, H4) recorded a delay in reaching the thermophilic phase given the low nitrogen content compared to carbon which delayed microbial proliferation.

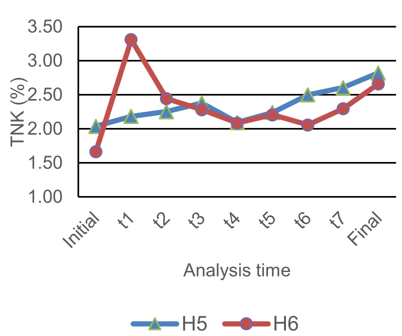
Evolution of pH

The curves show (Fig. 2) similar patterns for H5 and H6 with fluctuations before the pH stabilization phase. These fluctuations can be explained by the competition between mesophilic acidification microbes which produce organic acids, and alkalinization ones which lead to mineralizing organic carbon (production of carbon dioxide CO_2),

Table 5 ANOVA test associated with C/Ni and TF effects on pH

Source	DF	SS	SSS	*F*-value	*p*-value
C/Ni	2	0.365000	0.182500	5.41	0.156
TF	1	0.002500	0.002500	0.07	0.811
Error	2	0.067500	0.033750		
Lack-of-fit	1	0.022500	0.022500	0.50	0.608
Pure error	1	0.045000	0.045000		
Total	5	0.473333			

DF degrees of freedom, *SS* sum of squares, *SSS* sequential sums of squares



H5

Source	DF	sum of squares	Mean square	F	P
Composting time	1	0,615	0,615	85,92	0,011
Error	2	0,014	0,007		
Total	3	0,629			

H6

Source	DF	sum of squares	Mean square	F	P
Composting time	1	0,988	0,988	35,01	0,027
Error	2	0,056	0,028		
Total	3	1,044			

DF : Degrees of freedom

Fig. 3 TNK evolution during co-composting of TM and OP (left) and ANOVA test associated (right)

producing ammonia, and degrading fatty acids remaining in residual olive oil from pomace. Thereafter, pH gradually decreases towards stability, where the reactions are slower because C/N is reduced (which is confirmed in Fig. 7) and the nitrogen is used by the microorganisms for humification [58].

Unlike H5, the difference in pH between the start and the end of composting is significant for H6. But pH reduction is highly significant between the start of stabilization and the end of composting for the two heaps ending with a pH around neutrality proving the stability of the compost [1]. The high final pH values are associated with low C/Ni heaps (H1, H2, H5, and H6), which is also noted by [27]. The high total carbon content (high C/Ni) releasing more CO_2 from decomposing organic matter may explain the high final pH values [23]. However, the statistical test (Table 5) concludes that neither of the two studied factors has a significant effect on the pH of the composts.

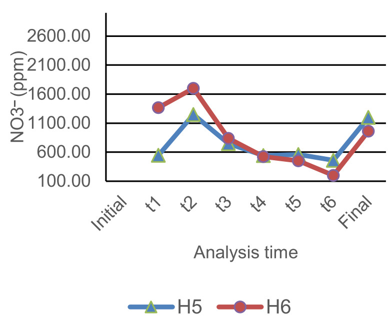
Evolution of TNK

H5 and H6 experienced a significant increase in the TNK concentration to arrive at the end of composting at 2.82% and 2.66% respectively (Fig. 3). This can be explained by the losses of dry matter as evaporated water and gas (CO_2, CH_4, and carbon monoxide CO) [25], or by the fixation of air nitrogen by nitrogen-fixing bacteria in the final phase of composting [42]. The decreases in TNK content observed in certain periods can be explained by the losses of nitrogen during composting as NH_3, N_2O, NOx [22]. The final values obtained agree with the results of [24] who found values of 2.60% for a C/Ni of

Table 6 ANOVA test associated with C/Ni and TF effects on TNK

Source	DF	ASS	SSS	*F*-value	*p*-value
C/Ni	2	0.03426	0.01713	1.02	0.495
TF	1	0.13506	0.13506	8.05	0.105
Error	2	0.03355	0.01678		
Lack-of-fit	1	0.02059	0.02059	1.59	0.427
Pure error	1	0.01296	0.01296		
Total	5	0.22468			

DF degrees of freedom, *ASS* adjusted sum of squares, *SSS* sequential sums of squares



H5

Source	DF	sum of squares	Mean square	F	P
Composting time	1	424713,00	424713,00	145,27	0,007
Error	2	5847,00	2924,00		
Total	3	430560,00			

H6

Source	DF	sum of squares	Mean square	F	P
Composting time	1	166742,00	166742,00	94,76	0,010
Error	2	3519,00	1760,00		
Total	3	170261,00			

DF : Degrees of freedom

Fig. 4 $NO3^-$ evolution during co-composting of TM and OP (left) and ANOVA test associated (right). Initial values not determined

21 when composting pig faeces with corn stalks. Neither studied factor has a significant effect on the final TNK of composts (Table 6).

Evolution de $NO3^-$

H5 and H6 recorded a significant increase and significant reduction in nitrate levels with final values of 1196.64ppm and 959.40 ppm respectively (Fig. 4). The increase is due to nitrifying bacteria [29]. The reduction is probably due to the inhibition of nitrifying bacteria by various composting products, competition with heterotrophic bacteria, the rise in temperature above 42 °C [46], or the transformation of nitrate in other forms of nitrogen (N_2O, NO_2^- (nitrite), N_2 (nitrogen), NH_4^+ (ammonium)) [48]. At the end of composting, there was a strong nitrification of H5 and H6, similar to that of the heaps H1 to H4.

Tables 7 and 8 show that the C/Ni factor has a significant increasing effect on the final $NO3^-$ between levels 22 and 28 (Fig. 5). When the C/Ni goes from 22 to 28, the $NO3^-$ content increases (average over the two TF levels) by 60%. Furthermore, the TF factor has an insignificant reducing effect.

Evolution of OM

During composting, aerobic microbes consumed oxygen to degrade organic matter [35]. At the start (Fig. 6), OM content is around 59% for H5 and H6. Then there are fluctuations. The decrease is explained by the continued mineralization of organic

Table 7 ANOVA test associated with C/Ni and TF effects on $NO3^-$

Source	DF	ASS	SSS	*F*-value	*p*-value
C/Ni	2	2.481070	1240535	63.71	0.015
TF	1	6.7496	67496	3.47	0.204
Error	2	3.8941	19470		
Lack-of-fit	1	1.0799	10799	0.38	0.647
Pure error	1	2.8141	28141		
Total	5	2.532889			

DF degrees of freedom, *ASS* adjusted sum of squares, *SSS* sequential sums of squares

Table 8 Tukey's test associated with C/Ni and TF effects on $NO3^-$

C/Ni	*N*	Mean	Grouping	
28	2	2365.74	A	
20	2	962.82		B
22	2	948.12		B

N sample size. Means that do not share a letter are significantly different

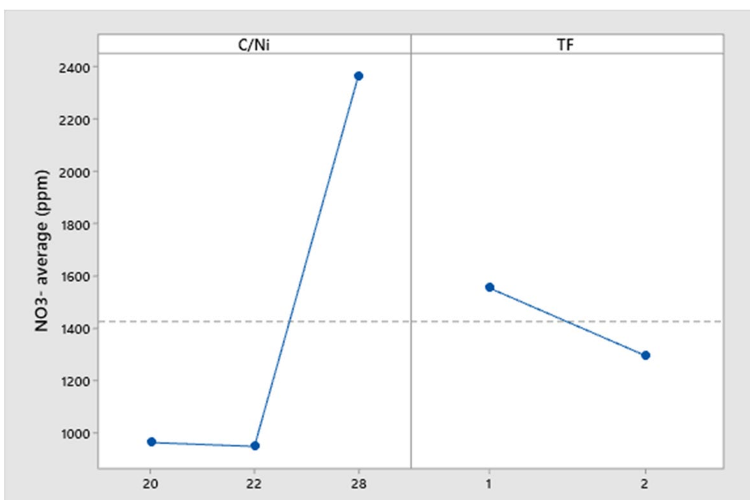
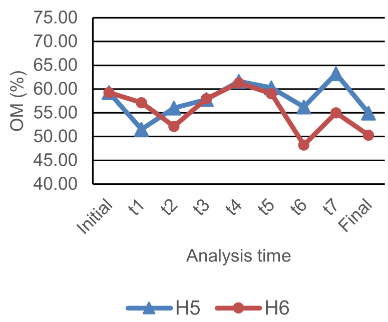


Fig. 5 Effect diagram of C/Ni and TF on $NO3^-$

compounds [45]. The increase can be explained by the concentration of OM as a result of the different forms of loss: dry matter loss [62] and water loss [47].

For both heaps, the reduction in OM between the start and the end of composting is significant. It was 7.30% and 15.12% to arrive at final values of 54.95% and 50.31% for H5 and H6 respectively. The statistical test (Tables 9 and 10) shows that only the TF factor has a significant reducing effect on OM. When TF increases, final OM decreases by an average of 21.8% (Fig. 7). This result is according to other studies [55, 56] where the author has shown that there is a decrease in carbon content with increasing TF. The C/Ni factor has no effect on OM.



H5

Source	DF	sum of squares	Mean square	F	P
Composting time	1	18,729	18,729	62,72	0,016
Error	2	0,597	0,299		
Total	3	19,326			

H6

Source	DF	sum of squares	Mean square	F	P
Composting time	1	80,362	80,362	18,43	0,05
Error	2	8,719	4,36		
Total	3	89,081			

DF : Degrees of freedom

Fig. 6 OM evolution during co-composting of TM and OP (left) and ANOVA test associated (right)

Table 9 ANOVA test associated with C/Ni and TF effects on OM

Source	DF	ASS	SSS	*F*-value	*p*-value
C/Ni	2	150.770	75.385	9.88	0.092
TF	1	163.580	163.580	21.43	0.044
Error	2	15.266	7.633		
Lack-of-fit	1	4.516	4.516	0.42	0.634
Pure error	1	10.750	10.750		
Total	5	257.204			

DF degrees of freedom, *ASS* adjusted sum of squares, *SSS* sequential sums of squares

Table 10 Tukey's test associated with C/Ni and TF effects on OM

TF	*N*	Mean	Grouping	
1	4	58.6555	A	
2	2	45.8657		B

N sample size. Means that do not share a letter are significantly different

Evolution of C/N

The C/N factor affects both the process and the quality of the compost [15]. It changes depending on the degradation degree of organic matter and nitrogen evolution. It gradually stabilizes during the maturation phase characterized by humification and formation of large molecular weight substances [48].

H5 and H6 show similar evolutions (Fig. 8). The reduction in C/N between the start and the end of composting is significant for both. It was 49% and 50% respectively. The C/N decreased to arrive at the end of composting for H5 and H6 at 11.30 and 10.97 respectively. Values below 12 prove the stability of composts [9]. The obtained result is in agreement with the statement of [13] who concluded that the C/N ratio decreases during composting to arrive at a final value below 20.

C/Ni and TF have a significant effect on the final C/N (Tables 11 and 12, Fig. 9). C/Ni effect changes depending on his level. Between 20 and 22, C/Ni reduced the final C/N (average over the two TF levels) by almost 10%. Between 22 and 28, C/Ni reverses the

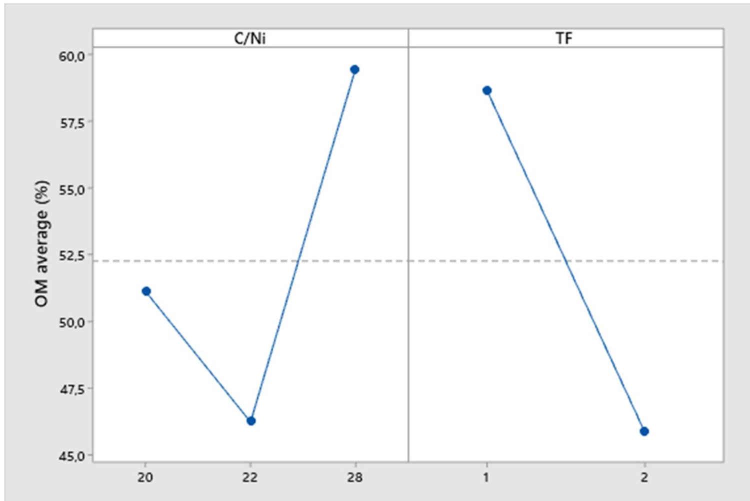
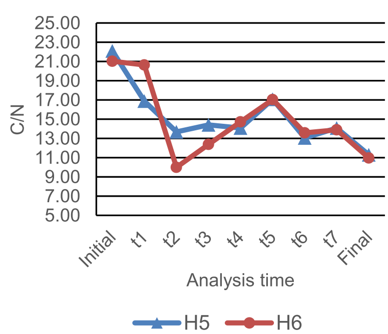


Fig. 7 Effect diagram of C/Ni and TF on OM



H5

Source	DF	sum of squares	Mean square	F	P
Composting time	1	114,494	114,494	4699,54	0,000
Error	2	0,049	0,024		
Total	3	114,543			

H6

Source	DF	sum of squares	Mean square	F	P
Composting time	1	121,648	121,648	971,34	0,001
Error	2	0,25	0,125		
Total	3	121,899			

DF : Degrees of freedom

Fig. 8 C/N evolution during co-composting of TM and OP (left) and ANOVA test associated (right)

Table 11 ANOVA test associated with C/Ni and TF effects on C/N

Source	DF	ASS	SSS	*F*-value	*p*-value
C/Ni	2	3.91415	1.95707	63.64	0.015
TF	1	1.31152	1.31152	42.65	0.023
Error	2	0.06151	0.03075		
Lack-of-fit	1	0.00795	0.00795	0.15	0.766
Pure error	1	0.05356	0.05356		
Total	5	4.09753			

DF degrees of freedom, *ASS* adjusted sum of squares, *SSS* sequential sums of squares

effect by increasing the final C/N average by almost 21%. This reversed effect of C/Ni can be explained by the competition between the chemical equilibriums according to the nitrogen availability, carbon biodegradability, pH, and temperature. Nitrifying bacteria

Table 12 Tukey's test associated with C/Ni and TF effects on C/N

	N	Mean	Grouping		
C/Ni					
28	2	12.7651	A		
20	2	11.7296		B	
22	2	10.5616			C
TF					
1	4	12.2580	A		
2	2	11.1128		B	

N sample size. Means that do not share a letter are significantly different

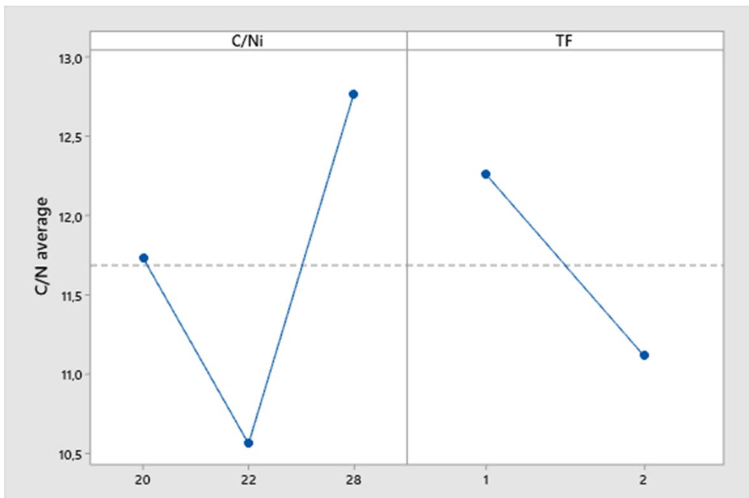


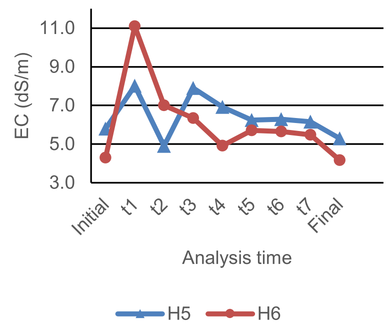
Fig. 9 Effect diagram of C/Ni and TF on C/N

activity is slowed down at high temperatures increasing the volatilization of ammonia thus increasing final C/N [48]. It also happens with the addition of straw when it results in a temperature rise and natural convection [31]. These findings do not agree with our results because TNK is not affected by any factor (Table 6). However, H3 and H4 had the highest initial OM (average of 62.67%, compared to 60.34% for H1 and H2, and 59.27% for H5 and H6) and kept it (low OM losses) at the end of composting: average reduction of only 4%, against 15% for H1 and H2 and 11% for H5 and H6. This explains a high final C/N of H3 and H4.

When TF increases, it reduces the final C/N average by almost 9%. This is because TF has a significant reducing effect on OM (Tables 9 and 10) which decomposes in the presence of oxygen [44].

Evolution of EC

EC indicates the salinity of a solid sample and influences the use of end-product as fertiliser [39]. H5 and H6 show (Fig. 10) fluctuations but stabilization during maturation phase. Fluctuations in pH during composting can be due to several causes: mineralization, water loss [47], dry matter loss, and precipitation of mineral salts [62] which increase EC. However, leaching (rain and watering) and low extractability of



H5

Source	DF	sum of squares	Mean square	F	P
Composting time	1	0,2601	0,2601	63,44	0,015
Error	2	0,0082	0,0041		
Total	3	0,2683			

H6

Source	DF	sum of squares	Mean square	F	P
Composting time	1	0,0169	0,0169	3,19	0,216
Error	2	0,0106	0,0053		
Total	3	0,0275			

DF : Degrees of freedom

Fig. 10 EC evolution during co-composting of TM and OP (left) and ANOVA test associated (right)

Table 13 ANOVA test associated with C/Ni and TF effects on EC

Source	DF	ASS	SSS	*F*-value	*p*-value
C/Ni	2	8.65463	4.32732	12.64	0.073
TF	1	2.65690	2.65690	7.76	0.108
Error	2	0.68480	0.34240		
Lack-of-fit	1	0.05760	0.05760	0.09	0.813
Pure error	1	0.62720	0.62720		
Total	5				

DF degrees of freedom, *ASS* adjusted sum of squares, *SSS* sequential sums of squares

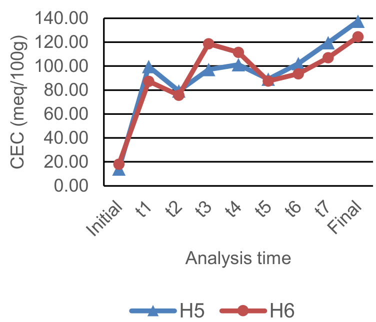
salts reduce it. Composting significantly reduced EC in H5. No significant change for H6, probably due to the equilibrium between ion concentration (mineralization and weight losses) and their dilution by leaching and consumption by microbial flora [2]. At the end of composting, EC is 5.29 ds/m and 4.17ds/m for H5 and H6 respectively. An EC value > 4 dS/m is considered a potential inhibitor [36] and the contribution of compost to the soil should be limited for species sensitive to salts when its EC value > 5 ds/m [5].

Statistically, neither the C/Ni factor nor the TF one has a significant effect on the final EC of the composts (Table 13).

Evolution of CEC

CEC allows the assessment of compost maturity [20, 45]. It increased especially during the maturation phase for H5 and H6. This increase is significant in H6. This is in accordance with Maheshwari [38] who explained that during the maturation phase, the humification process produces functional groups following the oxidation of organic matter thus increasing CEC.

The final values are 137.50 meq/100 g and 124.46 meq/100 g for H5 and H6 respectively (Fig. 11). Our result is consistent with [21] who stated that CEC increases during composting and reaches values greater than 60 meq/100 g, the criteria of compost maturity evaluation. None of the studied factors had a significant effect on CEC (Table 14).



H5

Source	DF	sum of squares	Mean square	F	P
Composting time	1	959,37	959,37	33,14	0,109
Error	2	28,95	28,95		
Total	3	988,31			

H6

Source	DF	sum of squares	Mean square	F	P
Composting time	1	915,887	915,887	172,27	0,048
Error	2	5,317	5,317		
Total	3	921,204			

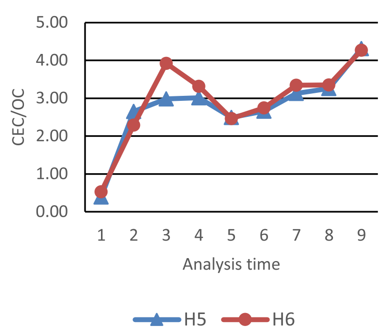
DF : Degrees of freedom

Fig. 11 CEC evolution during co-composting of TM and OP (left) and ANOVA test associated (right)

Table 14 ANOVA test associated with C/Ni and TF effects on CEC

Source	DF	ASS	SSS	*F*-value	*p*-value
C/Ni	2	647.005	323.502	7.30	0.121
TF	1	223.373	223.373	5.04	0.154
Error	2	88.684	44.342		
Lack-of-fit	1	3.618	3.618	0.04	0.871
Pure error	1	85.066	85.066		
Total	5				

DF degrees of freedom, *ASS* adjusted sum of squares, *SSS* sequential sums of squares



H5

Source	DF	sum of squares	Mean square	F	P
Composting time	1	15,4355	15,4355	1201,87	0,001
Error	2	0,0257	0,0128		
Total	3	15,4612			

H6

Source	DF	sum of squares	Mean square	F	P
Composting time	1	14,0019	14,002	2091,17	0,000
Error	2	0,0134	0,0067		
Total	3	14,0153			

DF : Degrees of freedom

Fig. 12 CEC/OC evolution during co-composting of TM and OP (left) and ANOVA test associated (right)

Evolution of CEC/OC

During the first half of composting, the CEC/OC of H5 and H6 has had its ups and downs (Fig. 12) because of OM fluctuations (Fig. 7). Then, it increased significantly to reach final values of 4.31 and 4.26 for H5 and H6 respectively [51]. proposed a ratio greater than 1.7 as a maturity index for composts based on agro-industrial waste.

C/Ni factor has a significant effect on CEC/OC (Tables 15 and 16, Fig. 13). At low values of C/Ni (between 20 and 22), CEC/OC increases strongly. When C/Ni goes

Table 15 ANOVA test associated with C/Ni and TF effects on CEC/OC

Source	DF	ASS	SSS	*F*-value	*p*-value
C/Ni	2	1.21069	0.605343	28.07	0.034
TF	1	0.10487	0.104866	4.86	0.158
Error	2	0.04314	0.021568		
Lack-of-fit	1	0.04192	0.041918	34.42	0.107
Pure error	1	0.00122	0.001218		
Total	5				

DF degrees of freedom, *ASS* adjusted sum of squares, *SSS* sequential sums of squares

Table 16 Tukey's test associated with C/Ni and TF effects on CEC/OC

C/Ni	*N*	Mean	Grouping	
22	2	4.45147	A	
28	2	3.38718		B
20	2	3.31932		B

N sample size. Means that do not share a letter are significantly different

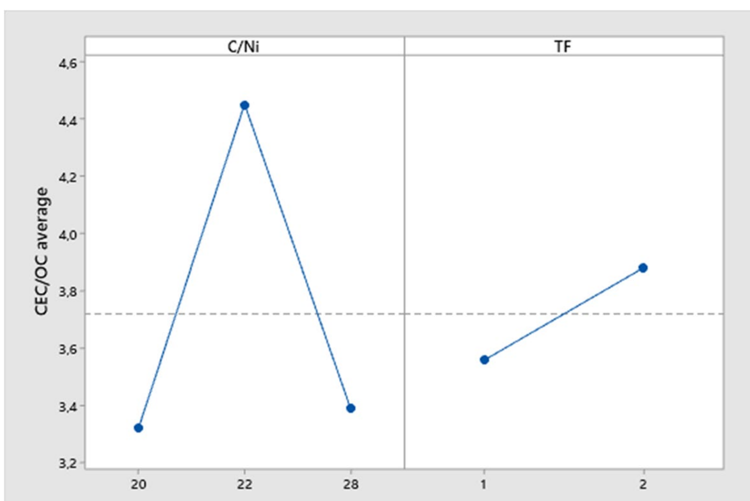


Fig. 13 Effect diagram of C/Ni and TF on CEC/OC

28, CEC/OC decreases sharply but remains widely above 1.7. TF does not have a significant effect on CEC/OC.

Comparison with other studies

Tables 17 and 18 show that our results converge with those of other studies for several analysed parameters, particularly relating to the effect of TF on OM and on the final C/N.

Table 17 Summary of C/Ni and TF effects on pH and TNK according to several authors

	pH				TNK			
	Our research	A1	A2	A3	Our research	A1	A2	A3
C/Ni	X	NS	NS	NS	X	E	NS	NS
TF	X	E	NS	NS	X	NS	E	E

Table 18 Summary of OM and final C/N according to several authors

	OM				Final C/N			
	Our research	A1	A2	A3	Our research	A1	A2	A3
C/Ni	X	E	NS	NS	E*	E*	NS	NS
TF	E*	E*	E*	E*	E*	E*	E*	E*

X no effect, *E* effect, *NS* not studied, *same results with other authors. A1 [46], A2 [45], A3 [28]

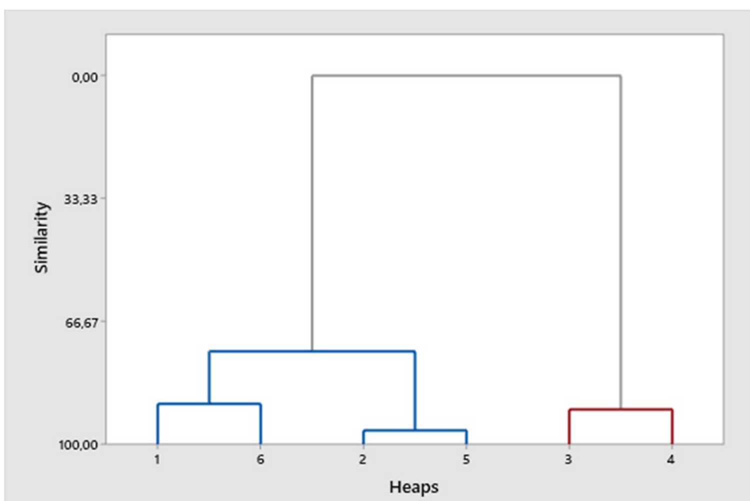


Fig. 14 Dendrogram of heaps 1 to 6

Similarity between the six heaps

By choosing a high degree of similarity, the dendrogram (Fig. 14) shows that the six heaps can form three distinct groups: the first one (H1, H6) with a similarity of 89.08; the second one (H2, H5) with a similarity of 96.28; the third one (H3, H4) with a similarity of 90.56. By accepting a lower degree of similarity, we can form only two groups: group 1 (H1, H6, H2, H5) with a similarity of about 74.84 and group 2 (H3, H4) with a similarity of 90.56. With initially different heaps in terms of C/Ni and TF, composting can have a significant variability reduction effect to give similar final composts to a minimum degree of about 75.

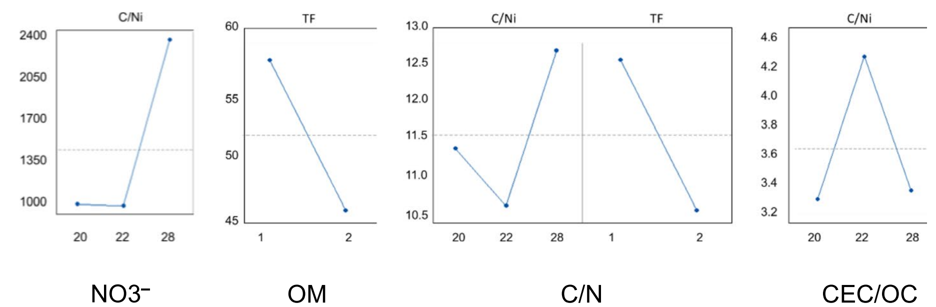


Fig. 15 Compilation of significative effects of C/Ni and TF factors on final compost parameters

Table 19 Results of the ANOVA test on the variability of the composting process (H5 and H6)

		Parameters							
		pH	**EC**	**OM**	**TNK**	**C/N**	**NO3⁻**	**CEC**	**CEC/OC**
Time analysis	**Initial**	NS	NS	**S**	**S**	**S**	**S**	NS	NS
	t1	NS	NS	**S**	NS	**S**	NS	NS	**S**
	t2	**S**	NS	NS	**S**	**S**	NS	**S**	**S**
	t3	NS	NS	**S**	**S**	**S**	**S**	**S**	**S**
	t4	NS	NS	**S**	**S**	**S**	**S**	**S**	**S**
	t5	NS	NS	**S**	**S**	**S**	S	**S**	**S**
	t6	**S**	NS	**S**	NS	**S**	NS	**S**	**S**
	t7	NS	NS	**S**	NS	**S**	NS	**S**	**S**
	Final	NS	NS	**S**	NS	**S**	**S**	**S**	**S**

NS non-significant variability, *S* significant variability

Optimization of final compost parameters

Figure 15 represents a compilation of the significant effects of studied factors on the analysed parameters. It appears that C/Ni of 22 combined with TF of twice a week can produce a final compost with an acceptable OM rate, a low final C/N, and a high CEC/OC ratio, with low but sufficient nitrification.

Variability of the composting process (H5 and H6)

Table 19 highlights the variability of the composting process. For pH and EC, H5 and H6 showed non-significant variability during almost the entire composting process. For TNK and NO3⁻, both heaps showed non-significant variability for half of the composting time. For the four other parameters, H5 and H6 showed significant variability almost throughout the composting process. The variability of these four parameters seems to be logical since they are interrelated: C/N is OM-based calculated, CEC depends essentially on OM and clay content [14], CEC/OC is a ratio of two parameters that has shown a significant variability between H5 and H6. Generally, the variability observed for certain parameters in certain composting periods can be explained by several factors: non-homogeneity of the composted raw materials, error on composting operation due to the manual method (homogenization of heaps, humidification), error on sampling and laboratory analysis. The error on the work-force is not an option since it was the same operator responsible for the composting operation.

Conclusions

Under the exprimental protocol conditions described, this work confirms the effectiveness of composting as a way of recovering effluents from two major Moroccan sectors: olive growing and poultry farming. C/Ni has a significant effect on $NO3^-$, final C/N, and CEC/OC. TF significantly impacts OM and final C/N. Composting of these two wastes at an initial C/N ratio of 22 combined with turning frequency of twice a week can produce a final compost of better quality. From heaps of different initial compositions, composting has an important effect of reducing variability to give very similar final composts. Relating to the composting process, its variability can be reduced by grinding the composted raw materials, using a mechanical turner with control of the turning time, and using a calibrated humidifier. Carrying out composting under cover will neutralize the "climate conditions" factor as much as possible, thus increasing the performance of the process. Stable and mature compost can be applied to soil as an organic amendment to improve plant growth and soil fertility, as well as to enhance the function of soil for carbon sequestration. These results can easily be applied by turkey farming plants (TFP) and traditional olive oil mills (TOOM) to recycle their by-products by choosing the optimum parameters to produce better quality compost, while reducing environmental pollution.

To study more deeply this subject, we propose (1) to extend it to by-products from several TFP and several TOOM to analyse the variability of results in Chaouia-Ouerdigha region and (2) to study a wider scale of C/Ni and TF to offer TFP and TOOM an effective composting way but practical and without unnecessary technical constraints.

Abbreviations

ANOVA: Analysis of variance; C/N: Carbon to nitrogen; CEC: Cation exchange capacity; CH_4: Methane; CO: Carbon monoxide; CO_2: Carbon dioxide; EC: Electrical conductivity; H1: Heap 1; H2: Heap 2; H3: Heap 3; H4: Heap 4; H5: Heap 5; H6: Heap 6; H_2S: Hydrogen sulphide; N_2: Nitrogen; N_2O: Nitrous oxide; NH_3: Ammonia; NH_4^+: Ammonium; NO_2^-: Nitrite; NO_3^-: Nitrates; OC: Organic carbon; OM: Organic matter; 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.

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Authors' contributions

ES analysed and interpreted data. RA contributed to chemical analysis and revised the article. ZA was the supervisor. The author(s) read and approved the final manuscript.

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Declarations

Competing interests

The authors declare that they have no competing interests.

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References

1. Aboutayeb R, Elgharous M, Abail Z, Elhari M, Koulali Y (2013) Stabilization and sanitation of chicken litter by heap composting. Int J Eng Res Technol (IJERT) 2:529–534
2. Aboutayeb R (2015) Valorisation des fumiers de volailles de chair: compostage, épandage et étude des effets des fumiers de volailles et leurs composts sur les propriétés physicochimiques du sol sous cultures de maïs fourrager et de menthe verte
3. Aboutayeb R, EL-Mrini S, Zouhri A, Idrissi O, Khalid AZİM (2021) Hygienization assessment during heap co-composting of Turkey manure and olive mill pomace. Eur J Soil Sci 10:332–342
4. Ahmadi T, Casas CA, Escobar N, García YE (2020) Municipal organic solid waste composting: development of a telemonitoring and automation control system
5. Albrecht R (2007) Co-composting of sewage treatment plant sludge and green waste: new methodology for monitoring organic matter transformations (**PhD Thesis. University of Law, Economics and Sciences-Aix-Marseille III….**)
6. Ameziane H, Nounah A, Khamar M, Zouahri A (2020) Composting olive pomace: evolution of organic matter and compost quality
7. Arslan Topal E, Işıl AÜ, Topal M (2016) Effect of aeration rate on elimination of coliforms during composting of vegetable–fruit wastes. Int J Recycl Org Waste Agric 5:243–249. https://doi.org/10.1007/s40093-016-0134-6
8. Awasthi SK, Sarsaiya S, Awasthi MK, Liu T, Zhao J, Kumar S, Zhang Z (2020) Changes in global trends in food waste composting: research challenges and opportunities. Bioresour Technol 299:122555
9. Bernai MP, Paredes C, Sanchez-Monedero MA, Cegarra J (1998) Maturity and stability parameters of composts prepared with a wide range of organic wastes. Bioresour Technol 63:91–99
10. Bhave PP, Kulkarni BN (2019) Effect of active and passive aeration on composting of household biodegradable wastes: a decentralized approach. Int J Recycl Org Waste Agric 8:335–344. https://doi.org/10.1007/s40093-019-00306-7
11. Boyle PE, Savin MC, Wood LS (2015) The effect of turning frequency on in-vessel compost processing and quality. Discov Stud J Dale Bumpers Coll Agric Food Life Sci 16:14–23
12. Calisti R, Regni L, Proietti P (2020) Compost-recipe: a new calculation model and a novel software tool to make the composting mixture. J Clean Prod 270:122427
13. Chowdhury AK, Bari MM, Akratos CS, Vayenas DV, Pavlou S (2013) Olive mill waste composting: a review. Int Biodeter Biodegr 85:108–119
14. Curtin D, Rostad HPW (1997) Cation exchange and buffer potential of Saskatchewan soils estimated from texture, organic matter and pH. Can J Soil Sci 77:621–626
15. Zhu N (2007) Effect of low initial C/N ratio on aerobic composting of swine manure with rice straw. Bioresour Technol 98:9–13
16. Deportes I, Loyon, L, Mallard P, Guiziou F (2012) Programme de recherche de l'Ademe sur les emissions atmospheriques du compostage. Connaissances acquises et synthese bibliographique-rapport final (Doctoral dissertation, irstea)
17. Diaz LF, De Bertoldi M, Bidlingmaier W (2011) Compost science and technology. Elsevier
18. El-Mrini S, Aboutayeb R, Azim K, Zouhri A (2021) Co-composting process assessment of three-phase olive mill pomace and turkey manure in MOROCCO. J Southwest Jiaotong Univ 56(6):764–778
19. El Fels L (2014) Suivi physico-chimique, microbiologique et écotoxicologique du compostage de boues de STEP mélangées à des déchets de palmier: validation de nouveaux indices de maturité (Thèse de Doctorat, Université de Toulouse)
20. Fels E, Loubna MZ, El Asli A, Hafidi M (2014) Assessment of biotransformation of organic matter during co-composting of sewage sludge-lignocelullosic waste by chemical, FTIR analyses, and phytotoxicity tests. Int Biodeter Biodegr 87:128–137
21. Francou C (2003) Stabilisation de la matière organique au cours du compostage de déchets urbains: Influence de la nature des déchets et du procédé de compostage-Recherche d'indicateurs pertinents (Thèse de doctorat, INSTITUT NATIONAL AGRONOMIQUE PARIS-GRIGNON)
22. Gosse G, Mérillot JM (1996) Bilans environnementaux des cultures. In: Bilans environnementaux des cultures Colloque: INRA Editions
23. Guidoni LL, Castiglioni RV, Marques RB, Moncks FT, Botelho MF, da Paz L, Corrêa B, Corrêa ÉK (2018) Home composting using different ratios of bulking agent to food waste. J Environ Manage 207:141–150
24. Guo R, Li G, Jiang T, Schuchardt F, Chen T, Zhao Y, Shen Y (2012) Effect of aeration rate, C/N ratio and moisture content on the stability and maturity of compost. Bioresour Technol 112:171–178
25. Hachicha S, Chtourou M, Medhioub K, Ammar E (2006) Compost of poultry manure and olive mill wastes as an alternative fertilizer. Agron Sustain Dev 26. https://doi.org/10.1051/agro:2006005
26. Hadjidemetriou DG (1982) Comparative study of the determination of nitrates in calcareous soils by the ion-selective electrode, chromotropic acid and phenoldisulphonic acid methods. Analyst 107:25–29
27. Huang GF, Wong JWC, Wu QT, Nagar BB (2004) Effect of C/N on composting of pig manure with sawdust. Waste Manag 24:805–813
28. Jiang-ming Z (2017) Effect of turning frequency on co-composting pig manure and fungus residue. J Air Waste Manage Assoc 67:313–321
29. Kalemelawa F, Nishihara E, Endo T, Ahmad Z, Yeasmin R, Tenywa MM, Yamamoto S (2012) An evaluation of aerobic and anaerobic composting of banana peels treated with different inoculums for soil nutrient replenishment. Bioresour Technol 126:375–382

30. Karadag D, Özkaya B, Ölmez E, Nissilä ME, Çakmakçı M, Yıldız Ş, Puhakka JA (2013) Profiling of bacterial community in a full-scale aerobic composting plant. Int Biodeter Biodegr 77:85–90
31. Kirchmann H, Witter E (1989) Ammonia volatilization during aerobic and anaerobic manure decomposition. Plant and Soil 115:35–41. https://doi.org/10.1007/BF02220692
32. Kolář L, Kužel S, Peterka J, Borová-Batt J (2011) Utilisation of waste from digesters for biogas production. Biofuels engineering process technology. InTech, New York, pp 191–220
33. Kucbel M, Raclavská H, Růžičková J, Švédová B, Sassmanová V, Drozdová J, Raclavský K, Juchelková D (2019) Properties of composts from household food waste produced in automatic composters. J Environ Manage 236:657–666
34. Kumar M, Yan-Liang O, Lin J-G (2010) Co-composting of green waste and food waste at low C/N ratio. Waste Manag 30:602–609
35. Li Y, Luo W, Li G, Wang K, Gong X (2018) Performance of phosphogypsum and calcium magnesium phosphate fertilizer for nitrogen conservation in pig manure composting. Bioresour Technol 250:53–59
36. Luo Y, Liang J, Zeng G, Chen M, Mo D, Li G, Zhang D (2018) Seed germination test for toxicity evaluation of compost: its roles, problems and prospects. Waste Manag 71:109–114
37. Macias-Corral MA, Cueto-Wong JA, Morán-Martínez J, Reynoso-Cuevas L (2019) Effect of different initial C/N ratio of cow manure and straw on microbial quality of compost. Int J Recycl Org Waste Agric 8:357–365. https://doi.org/10.1007/s40093-019-00308-5
38. Maheshwari DK (2014) Composting for sustainable agriculture. Springer
39. Manu MK, Kumar R, Garg A (2019) Decentralized composting of household wet biodegradable waste in plastic drums: effect of waste turning, microbial inoculum and bulking agent on product quality. J Clean Prod 226:233–241
40. McLean EO (1983) Soil pH and lime requirement. Methods of soil analysis: Part 2 Chemical and microbiological properties, vol 9, pp 199–224
41. Michel Jr FC, Frederick C, Forney LJ, Huang AJ-F, Drew S, Czuprenski M, Lindeberg JD, Reddy CA (1996) Effects of turning frequency, leaves to grass mix ratio and windrow vs. pile configuration on the composting of yard trimmings. Compost Sci Util 4:26–43
42. Mustin M (1987) Le compost: gestion de la matière organique
43. Nasini L, de De Luca G, Anna Ricci F, Ortolani AC, Massaccesi L, Regni L, Gigliotti G, Proietti P (2016) Gas emissions during olive mill waste composting under static pile conditions. Int Biodeter Biodegr 107:70–76
44. Nemet F, Perić K, Lončarić Z (2021) Microbiological activities in the composting process: a review. Columella: J Agric Environ Sci 8:41–53
45. Ogunwande GA, Ogunjimi LAO, Fafiyebi JO (2008a) Effects of turning frequency on composting of chicken litter in turned windrow piles. Int Agrophys 22:159
46. Ogunwande GA, Osunade JA, Ogunjimi LAO (2008b) Effects of carbon to nitrogen ratio and turning frequency on composting of chicken litter in turned-windrow piles. Agric Eng Int: CIGR J 99(16):7495–7503
47. Onwosi CO, Igbokwe VC, Odimba JN, Eke IE, Nwankwoala MO, Iroh IN, Ezeogu LI (2017) Composting technology in waste stabilization: on the methods, challenges and future prospects. J Environ Manage 190:140–157
48. Oudart D (2013) Modélisation de la stabilisation de la matière organique et des émissions gazeuses au cours du compostage d'effluents d'élevage
49. Proietti P, Calisti R, Gigliotti G, Nasini L, Regni L, Marchini A (2016) Composting optimization: integrating cost analysis with the physical-chemical properties of materials to be composted. J Clean Prod 137:1086–1099
50. Pujol, Arnaud 2012. Modélisation du procédé de compostage-Impact du phénomène de séchage. Thèse de doctorat, Institut National Polytechnique de Toulouse.
51. Raj D, Antil RS (2011) Evaluation of maturity and stability parameters of composts prepared from agro-industrial wastes. Bioresour Technol 102:2868–2873
52. Regni L, Nasini L, Ilarioni L, Brunori A, Massaccesi L, Agnelli A, Proietti P (2017) Long term amendment with fresh and composted solid olive mill waste on olive grove affects carbon sequestration by prunings, fruits, and soil. Front Plant Sci 7:2042
53. Richards, LA 1954. Diagnosis and improvement of. saline and alkali soils. Handbook 60.
54. Ryckeboer J, Mergaert J, Vaes K, Klammer S, De Clercq D, Coosemans J, Insam H, Swings J (2003) A survey of bacteria and fungi occurring during composting and self-heating processes. Ann Microbiol 53:349–410
55. Soto-Paz J, Oviedo-Ocaña ER, Manyoma PC, Marmolejo-Rebellón LF, Torres-Lozada P, Barrena R, Sánchez A, Komilis D (2019) Influence of mixing ratio and turning frequency on the co-composting of biowaste with sugarcane filter cake: a mixture experimental design. Waste and Biomass Valorization 11(6):2475–2489.
56. Tiquia SM, Richard TL, Honeyman MS (2000) Effect of windrow turning and seasonal temperatures on composting of hog manure from hoop structures. Environ Technol 21:1037–1046
57. Tripetchkul S, Pundee K, Koonsrisuk S, Akeprathumchai S (2012) Co-composting of coir pith and cow manure: initial C/N ratio vs physico-chemical changes. Int J Recycl Org Waste Agric 1:15. https://doi.org/10.1186/2251-7715-1-15
58. Van Bochove, Eric 1993. L'étude du cycle de l'azote dans le processus de compostage: le cas du fumier de bovin. Thèse de doctorat, Université du Québec, Institut national de la recherche scientifique.
59. Vochozka M, Maroušková A, Šuléř P (2017) Obsolete laws: economic and moral aspects, case study—composting standards. Sci Eng Ethics 23(6):1667–1672
60. Walkley A, Armstrong Black I (1934) An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci 37:29–38
61. Wu S, Shen Z, Yang C, Zhou Y, Li X, Zeng G, Ai S, He H (2017) Effects of C/N ratio and bulking agent on speciation of Zn and Cu and enzymatic activity during pig manure composting. Int Biodeter Biodegr 119:429–436
62. Zhang D, Luo W, Li Y, Wang G, Li G (2018) Performance of co-composting sewage sludge and organic fraction of municipal solid waste at different proportions. Bioresour Technol 250:853–859