Characterization of composting mixtures and compost of rabbit by-products to obtain a quality product and plant proposal for industrial production

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Keywords
Industrial scale composting plant,
Piles with several C/N,
Rabbit by-products.

Summary
In this study we have observed the effects of using rabbit manure and slaughtering by-products in a composting process. Three piles of this material, 4700 kg each, with different amount and C/N ratio, have been investigated and experimental tests were carried out in an industrial horizontal axe reactor using a prototype of turning machine. The composting time lasted 85 days; 2 experimental cycles were conducted: one in Winter and one in Summer. In the Winter test, mesophilic reaction started only in the control mixture (animal manure + slaughtering by-products without straw). It is noteworthy that, the 3 investigated mixtures produced soil amendment by compost with good agronomical potential but with parameters close to the extreme limits of the law. In the Summer test, there was thermophilic fermentation in all mixtures and a better quality compost was obtained, meeting all the agronomic and legislative constraints. For each pile, we examined the progression of fermentation process and thus the plant limitations that did not allow a correct composting process. The results obtained in this study are useful for the development of appropriate mixtures, machines, and plants assuring continuance and reliability in the composting of the biomass coming from rabbit industry.

Caratterizzazione delle matrici e del compost da deiezioni e sottoprodotti della macellazione cunicoli finalizzata ad una produzione industriale di qualità con soluzioni meccanico-impiantistiche specifiche

Parole chiave
Compostaggio scarti cunicoli,
Miscele a diverso rapporto C/N,
Prototipo in scala industriale.

Riassunto
In un impianto sperimentale realizzato, in scala industriale, per la stabilizzazione delle deiezioni e degli scarti di macellazione di un'azienda cunicola è stato predisposto un capitolato di prove di compostaggio che ha previsto la formazione di n. 3 cumuli, di massa pari a 4700 kg, ottenuti secondo diversi rapporti C/N. Il ciclo di processo è stato lo stesso per tutti i cumuli e cioè: preparazione miscela; avanzamento della biomassa pari a circa 1,0 m/giorno mediante prototipo di macchina rivoltatrice opportunamente progettato; rilievo di temperatura ambiente e in vari punti della biomassa ogni 2 giorni; periodico campionamento (ogni 20-30 giorni) della biomassa (miscela iniziale, prodotto intermedio, prodotto finale) per la valutazione dei parametri chimico-fisici che caratterizzano il processo biossidativo e le qualità del compost; ultimazione della prova dopo 85 giorni. Sono stati condotti 2 cicli sperimentali: una in inverno e una in estate. Nella prova invernale, la reazione mesofila si è verificata solo nella miscela di controllo (concime animale + macellazione sottoprodotti senza paglia). Dalle 3 matrici studiate sono stati ottenuti compost con buone potenzialità agronomiche, ma con parametri prossimi ai limiti di legge. Nel test estivo, vi è stata fermentazione termofila in tutte le miscele ed è stato ottenuto un compost di migliore di qualità, rispettando tutti i vincoli agronomici e legislativi. I risultati ottenuti in questo studio sono utili per la definizione di miscele appropriate, dei controlli analitici sulle stesse, di macchine e soluzioni impiantistiche per assicurare continuità ed affidabilità nella produzione industriale di compost da biomasse provenienti dall'allevamento e dalla macellazione del coniglio.

Introduction

The production cycle of rabbit should produce a commercial meat cut of approximately 2.5 kg in approximately 70 days. During this period, the animals have a diet based on the following: products and by-products of oil-rich seeds, dry forage, grains, by-products of the sugar processing, with the addition of dietary protein supplements, alpha-tocopherol, iron sulfate pentahydrate. In the first 25 days of the growing period, the diet is also supplemented with iron, zinc, organic selenium, vitamin A and D3. The average feed intake is approximately 120 g/day per head with a production of manure approximately 195 g/head per day (King 1984).

The scientific research carried out in the rabbit industry investigates primarily all the production aspects. However, many breeders point out the need to study the environmental aspects concerning the intensive production and processing of rabbit meat. This is due to the fact that on many industrial farms the costs of the waste management, have become very high in comparison to the company's turn-over, reaching even 3% of the total costs (Associazione Scientifica Italiana di Coniglicoltura 2008, not published data).

From a scientific and technical viewpoint, in the livestock sector, economic investment in primary production (milk or meat) can be supported (Amirante *et al.* 2005, Bellomo *et al.* 2005) if breeding cycles are closed with recovery of by-products and the disposal reduction costs of manure and waste.

Besides, the compost application can be considered as supply of nutrient and source of organic matter (humus content) for agricultural soil and, according to chemical and physical characteristics of soil and compost and to other agronomic practices, by contributing to maintain or improve the soil fertility. On the other words, the compost utilization, improving the sustainable use of the soil, allows for using the available and limited resources in a sustainable way.

Extensive data can be found concerning the research into composting process, but the available data refer to manure of fowls (Tiquia and Tam 2000), hogs (Larney *et al.* 2000, Larney *et al.* 2002, Larney *et al.* 2006), bovines (Saludes *et al.* 2007), and other domestic animal species. Similar studies have not been carried out until now on rabbit manure. However, laboratory tests have been conducted on the composting of organic mixtures, which also contain chicken and rabbit carcasses, in order to monitor the development of the process (Barrena *et al.* 2009).

A research study is in progress at an industrial farm breeding rabbits, with an annexed slaughterhouse processing the on-site-bred animals, located in Martina Franca area, province of Taranto (Southern Italy), in order to investigate the process of complete stabilization and humification of the waste and by-products of the farm breeding. In the present paper results will be shown about chemical-physical biomass characterization and designing for specialised composting plants.

Materials and methods

The experimental tests were carried out from February the 2nd 2009 to April the 19th 2009 (Winter test) and from July the 11th 2009 to September the 31st 2009 (Summer test). The breeding farm consisted of 20,000 heads and 2,000 breeding rabbits; the annexed slaughtering plant had the European Commission Licence and 1,500 heads/week were slaughtered. The average manure production was 3,000 kg/day, while the slaughtering by-products corresponded to 1,500 kg/week. Before mixing with the manure, slaughtering by-products underwent to a treatment in an autoclave at 133 °C and 3 bar per 20 minutes. The slaughtering waste-water was treated in an active sludge purifying plant, then it was distributed on the land. The sludge was almost completely re-used in the purifying process. An industrial scale plant with simplified design criteria was developed, based on a plant adapted for other mixtures, in a previous research study (Figure 1). Three piles with a width of 2.0 m were designed on the plant's assembly chain. The starting mixtures were each one with a mass of approximately 4.7 t, but with different compositions:

1. Mixture 1 (M1): manure (92.5%), purifying sludge (0.5%), and slaughtering by-products (7%), with C/N=15.90. In previous researches, this composition was the most suitable for composting the farm by-products and has been used as a control mixture (Bianchi *et al.*, 2009);
2. Mixture 2 (M2): manure (91.1%), purifying sludge (0.5%), and slaughtering by-products (6.8%) + straw (1.6%), with C/N = 16.20;
3. Mixture 3 (M3): manure (89.5%), purifying sludge (0.5%), and slaughtering by-products (7%) + straw (3%) with C/N = 18.15.

A common agronomic straw shredder was used to chop the straw, which had a width of 5 cm; while all components of each mixture were mixed together with a rototiller. This is the most realistic option to be adopted on farms that cannot have specific machines for shredding straw and mixing components, which is why it was not possible to obtain a higher percentage of straw in the mixture 3, and consequently, a higher C/N ratio. It is necessary

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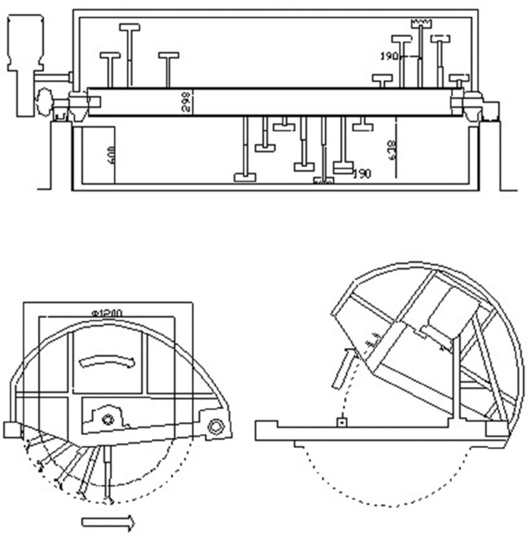
to take into account that in the case of an industrial plant, a final product characterised by high amounts of straw of considerable size was of little interest to buyers (Figure 2).

Using the turning-over and aerating machine, each of these piles was turned and aerobic conditions were maintained by way of advancement of the mass of approximately 1 m/day, for a period of 80 days. During this period the temperature of the environment, outside and inside the plant, was monitored as well as the temperature inside the mass, at a distance of 10 cm from the bottom of the pit and 10 cm at the top of the pile. At variable intervals, between 20 and 30 days, the following analytical determinations were carried out both during Winter and Summer composting heaps: total nitrogen, total organic carbon (TOC), humidity (%), pH in H_2O, electrical conductivity. On the final sample taken from each heap the following parameters were measured: iron, nickel, lead, zinc, and other components affecting soil fertility. The determinations were effected as the official protocols of fertilizers analysis listed by the Ministry of the Agricultural and Forest Politics. These assessments were executed as the official methods and according to the law[1], repeating each analytical measurement 3 times. In order to analyse organic and inorganic nitrogen, an automatic steam flowing distiller was used, the UDK 130 D-Velp scientific (Velp Scientifica s.r.l. Usmate, MI, Italy), integrated with a DK 6 Heating D digester. EC and pH were measured in 1:10 (w/v) water-soluble extraction at 24 ± 1 °C. The conductivimeter and the pH-meter were a CRISON 524 and a CRISON microTT2050 (Crison Instruments, S.A. Alella, Barcelona, Spain), respectively. The moisture content was determined by drying a sample at 105 °C. Total nitrogen (N) was determined by the Kjeldahl method; TOC, total extracted carbon (TEC) and humified organic carbon (HA+FA)-C were determined according to the Springer and Klee



Width of the turn-over machine	4,200 mm
Advancing passage	1,200 mm
Volume turned for each passage	2,880 mm^3
Advancing speed (go)	2,500 mm/h
Fit power	15.0 kW

Figure 1. *Diagram of the prototype turning-over and aerating machine.* Image is drawn approximately to scale and measurements are in millimeters.

[1] European Commission (EC) 2003. Regulation (EC) No 2003/2003 of the European Parliament and of the Council of 13 October 2003 relating to fertilisers (Text with EEA relevance). *Off J*, **L 304**, 21/11/2003.

Italian Legislation. 2006. Decreto Legislativo No 217 of 29 April 2006. Revisione della disciplina in materia di fertilizzanti. *Off J*, **141**, 20/06/2006 (*Suppl*, 152).

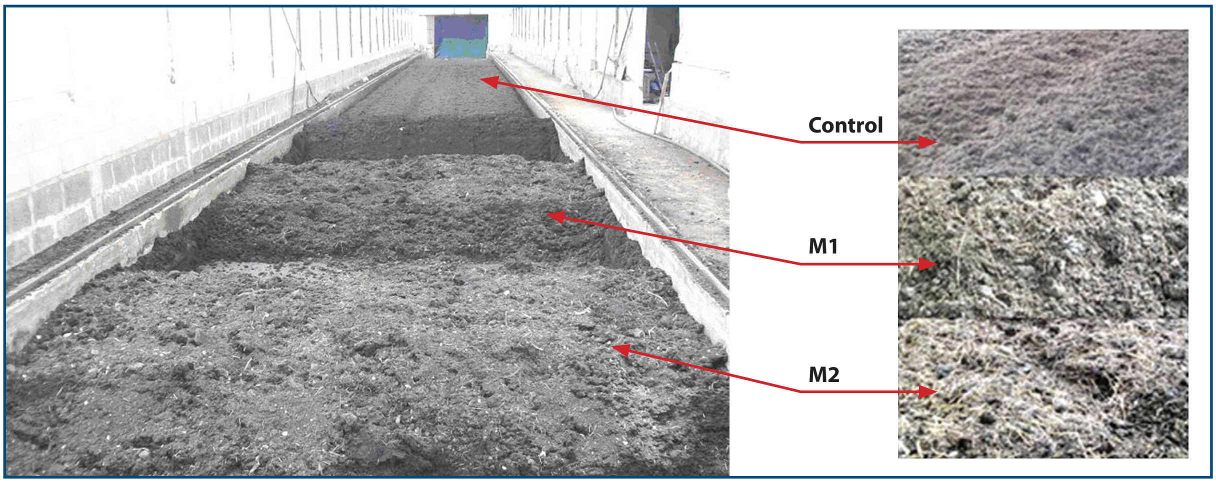


Figure 2. *Views of the advancing passage of the plant and details of the mixtures studied: it showed the high amount of straw and the considerable size of fragments in M3 mixture.*

method. Total Zn, Cu, Pb and Ni were determined by Inductively Coupled Plasma-Optical Emission spectrometry (ICP-OES) after digestion in HNO3 65% in a pressurized microwave.

According to Sequi and colleagues (Sequi *et al.* (1986), the humification rate (HR) was calculated as:

$$HR = 100 \times (HA+FA) - C/(TOC)$$

statistical analysis was carried out using GLM procedures[2]. The differences between average values were analysed with a probability level of $P \leq 0.05$, using the Tukey test.

Results and discussion

Control mixture (Figure 3 and Figure 4) has a very high level of nitrogen and a relatively low level of carbon; the humidity is slightly higher than the optimal limits reported by researchers in the range of 50-60% for different compost mixtures. In fact, humidity above 65% hinder the diffusion of oxygen in the biomass, in contrast to aerobic activity of microorganisms, and can facilitate the onset of anoxic conditions (EPA 1995, Kaneko and Fujita 1985, Suler and Finstein 1977). Therefore, these by-products may not be used in mixtures for the recovery of biomass with high humidity (e.g. sludge from other purifying processes or pomace too wet); on the contrary, these by-products provide quality mixtures with low humidity and high carbon content biomass, such as green and lignocellulosic waste.

Winter test

During the Winter test, an increase of the temperature profile along the cross-section, starting from the lowest layer of the pile, points out that the fermentation starts more rapidly in the upper layers and that inadequate mixing takes place as well. In the control mixture the difference in temperature between the upper and the lower layers reaches 7 °C, while in the other mixtures the difference does not exceed 3 °C (Figure 3).

During the Winter trials (Figure 3), the temperature remains for a long period of time rather low. Anyway, the building that shelters the pile from the outside environment does not offer adequate thermal insulation, considering that the temperature in the building is at the most 2 °C higher than the outside environmental temperature (Figure 3). On the contrary, in the specific case, the used perimetral and covering materials must be able to retain the heat produced by the biomass.

The Control mixture is the only heap where a bio-oxidation process takes place (Figure 3). In the first 30 days the temperature rised from 12 to 39 °C, then it did not vary appreciably for a week. In the following 10 days, the temperature decreased, while it increased again from 36 to 40 °C in the next 10 days (Figure 3). Finally, it decreased in the last 20 days of the trial (Figure 3). The final mixture temperature was the same as the environmental temperature, which, due to the fact that the seasons changed, resulted in being higher compared to the temperature at the beginning of the trial.

In comparison, M2 and M3 did not show a temperature increase in relation to the environmental temperature. The pile temperature profile followed that of the environmental temperature with deviations between 2 and 4 °C (Figure 3). It also does not show any significant microbial activity. Instead, in the control mixture the process reaches an incomplete fermentation, limited only to the mesophilic phase, with a maximum temperature much inferior to 60 °C. The process is influenced by the environment temperature and when the temperature remains under 15 °C it tends to stop the metabolism of the micro-organisms. However, when there is an increase from 13 to 22 °C, the increase leads to a re-activation of the bio-oxidation activity, despite the mass being in a phase of cooling-down. This also points out that on the 15th day of the trial there is a not completed stabilisation of the product, as showed also by undercomposed organic substances that are oxidized later.

During the whole process, including the phase of maturation, the humidity level of Control mixture remains higher than 55% (Figure 4); these values can be considered compatible with the evolution of biological reactions. Despite periodic irrigation, M2 and M3 dried out excessively after approximately 50 days of processing (Figure 4). At the moisture level of 30-35% (Figure 4), the microbial activity proceeded with difficulty or very slowly (EPA 1995, Kaneko and Fujita 1985, Suler and Finstein 1977). The differences among the final means of the 3 mixture proved to be statistically significant (Table I).

The C/N ratio of the studied biomasses (Figure 4) were not at all at such levels in order for the process of stabilisation to slow down; in fact, even though they were low at starting of composting process and the differences were not statistically significant (Table I), these values perfectly corresponded with the limits determined by Italian regulation[3] (*i.e.*: $C/N \leq 25$ for mixed compost amendment).

[2] SAS Institute Inc. 2010. SAS/STAT Software Release 9.2, Cary, NC, USA. Sustainable Compost Application in Agriculture, Completion April 2008. Landwirtschaftliches Technologie-Zentrum Augustenberg (LTZ), European Compost Network ECN e.V., p. 2.

[3] Italian Legislation. 2006. Decreto Legislativo No 217 of 29 April 2006. Revisione della disciplina in materia di fertilizzanti. *Off J*, **141**, 20/06/2006 (*Suppl*, 152).

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From the chemical point of view, the composts generally have pH ranging from neutral to sub-alkalinity with values higher than peats. However, this particular characteristic does not affect the use of compost in agriculture in open fields, for environmental restoration or for ornamental plant cultivations. In the nursery, an ideal growing media should provide pH values between 4.5 and 6. Since the compost pH were between 7.8 and 8.1, a small mixing with other materials proved to be enough to have materials with pH closer to the ideal values.

A pH between 5.5 and 8.5 is optimal for compost microorganisms. As bacteria and fungi digest organic matter, they release organic acids. In the early stages of composting, these acids often accumulate. The resulting drop in pH encourages the growth of fungi and the breakdown of lignin and cellulose. As composting proceeds, the organic acids become neutralized and mature compost generally has a pH between 6 and 8.

In this research, the pH stability in Control mixture did not only confirm that the complete thermophilic phase had not been reached, it also showed that during the maturation phase there had not been any significant activity of the nitrificant bacteria which transform the ammoniac subsequently into

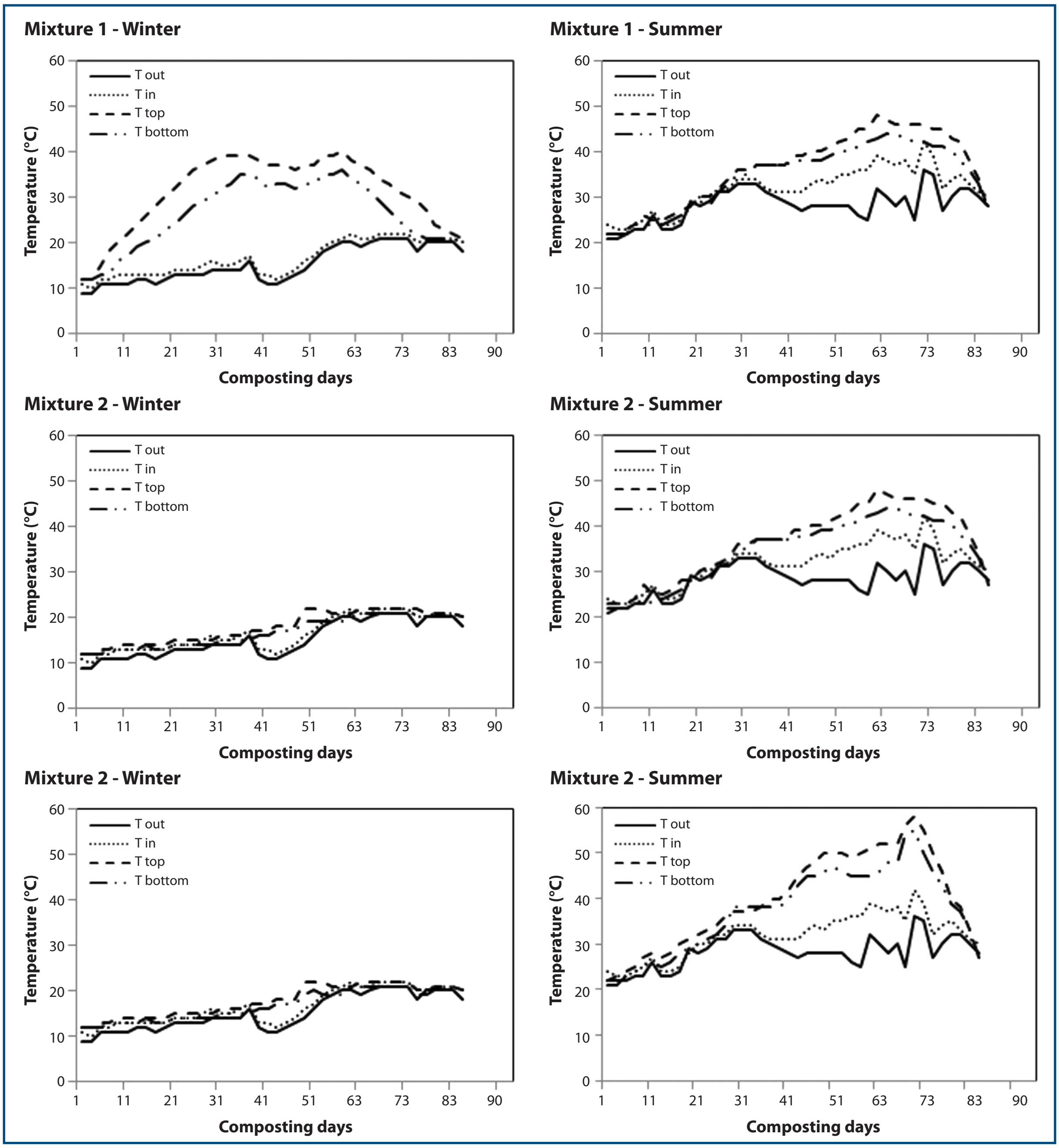

Figure 3. *Winter and summer test: temperature profiles registered during composting test.* Mixture 1 (C/N = 15.90), Mixture 2 (C/N = 16.2), Mixture 3 (C/N = 18.15). The Control mixture is referred to as Mixture 1.

nitrous and nitric acid (Saludes *et al.* 2007), with a decrease of pH level. In any case, the pH values can be considered optimal, for M1 and M2, as it was consistent with the national regulation which puts the limits between 6 and 8.5 (Table I).

The investigated mixtures presented average values of electrical conductivity from 3.56 to 4.06 dS/m with a tendency to assume maximum values towards the end of the process when the moisture level diminishes, although the differences were not statistically

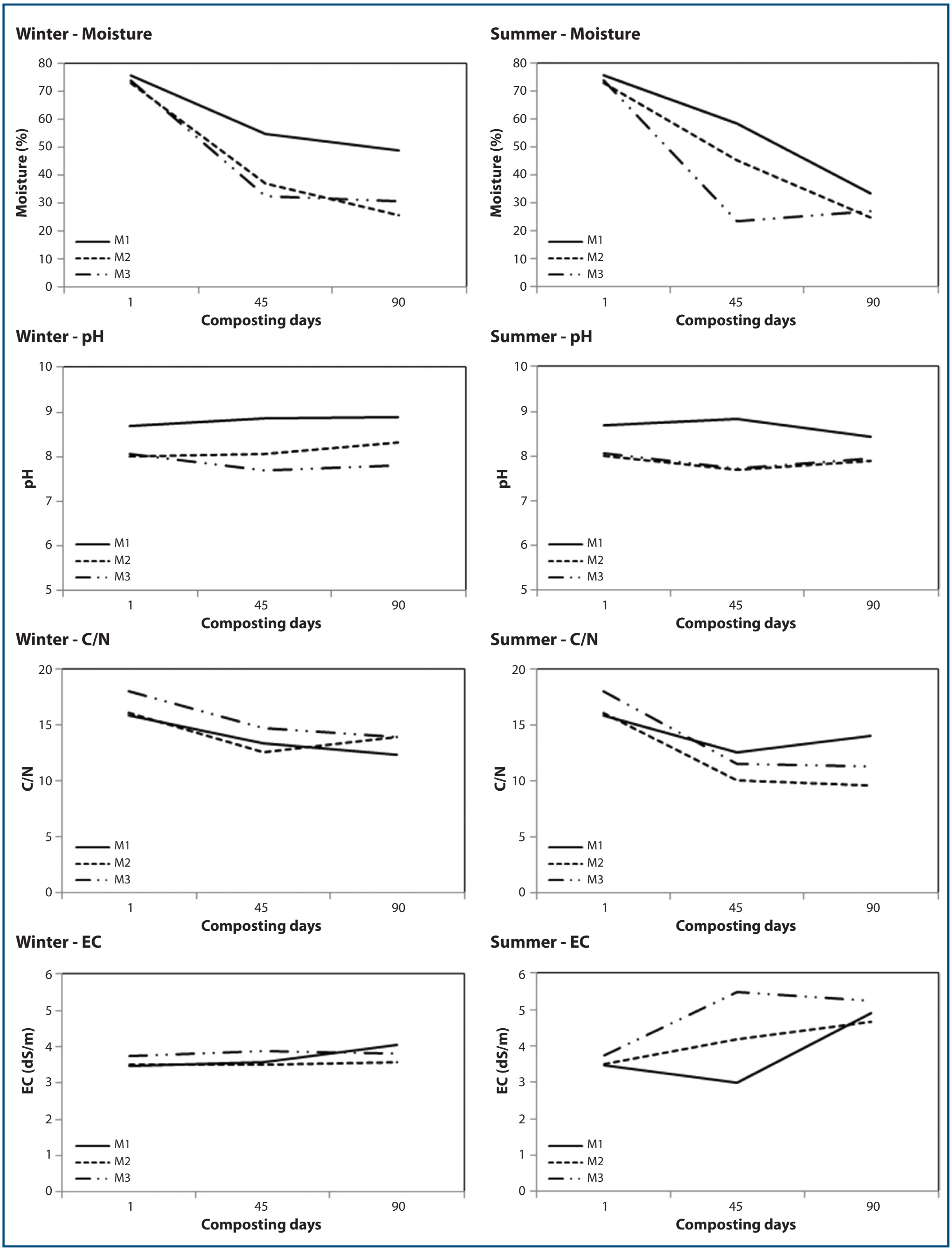

Figure 4. *Mixture PH, EC, C/N performance during winter and summer tests.* The Control mixture is referred to as Mixture 1.

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Table I. *Winter test: final characteristics of mixtures.* The Control mixture is referred to as Mixture 1.

Parameters	Limit (D.L. 217/06)	Mixture 1 C/N = 15.90	Mixture 2 C/N = 16.20	Mixture 3 C/N = 18.15
Moisture %		48.89 a	25.93 c	31.00 b
pH	6-8.5	8.90 a	8.31 b	7.80 c
Total Organic Carbon (%)	> 25	33.40 a	20.90 c	23.80 b
Ntot (%)		2.70 a	1.50 b	1.70 b
C/N	< 25	12.37 a	13.90 a	14.00 a
Electrical conductivity (dS/m)	4.06 a	4.06 a	3.56 a	3.81 a
(HA +FA)-C (%)	> 7	6.64 b	6.23 c	7.17 a
HR (%)		16	21	22
Cu (mg/kg)	150.0	82.20 a	55.59 b	55.90 b
Ni (mg/kg)	100.0	3.21 a	2.33 b	2.21 b
Pb (mg/kg)	140.0	< 0.1 a	< 0.1 a	< 0.1 a
Zn (mg/kg)	500.0	459.30 a	290.5 b	291.10 b

Means with the same letter are not significantly different for P≤0.05

Table II. *Summer test: final characteristics of mixtures.* The Control mixture is referred to as Mixture 1.

Parameters	Limit (D.L. 217/06)	Mixture 1 C/N = 15.90	Mixture 2 C/N = 16.20	Mixture 3 C/N = 18.15
Moisture %		33.56 a	24.75 c	27.18 b
pH	6-8.5	8.43 a	7.68 b	7.73 b
Total Organic Carbon (%)	> 25	34.70 a	27.79 c	29.72 b
Ntot (%)	/	2.47 b	2.90 ab	2.63 a
C/N	< 25	14.04 a	9.58 c	11.30 b
Electrical conductivity (dS/m)		4.9 a	4.68 a	5.25 a
(HA +FA)-C (%)	> 7	13.34 a	13 a	12.3 b
HR (%)		38	46.8	41.4
Cu (mg/kg)	150.0	93.21 a	101.55 a	91.74 a
Ni (mg/kg)	100.0	6.68a	6.90 a	7.17 a
Pb (mg/kg)	140.0	< 0.1 a	< 0.1 a	< 0.1 a
Zn (mg/kg)	500.0	403.72 b	553.45 a	514.68 a

Means with the same letter are not significantly different for P≤0.05

significant (Table II). The Italian D.L. 217/06 does not set limits for this parameter that, in the compost, can vary considerably, depending of feed-stock and processing. Compost may therefore contribute to or dilute the accumulative soluble salt content in the amended soil. Knowledge of soil salinity, compost salinity, and plant tolerance to salinity is necessary for a sustainable use of compost for agricultural purposes. For most turf and landscape plantings the final salinity (EC) of the amended soil should be less than 4.0 dS/m (Darlington 2010). Higher soluble salt levels would likely require leaching irrigations or other agronomical practices to reduce the negative effects of soil salinity.

The research carried out on the other chemical parameters present in the composted material shows that, even if in the starting mixtures there was a considerable quantity of organic substances which has the potential of being composted, eventually the compost processes did not proceed as expected (Table I). Moreover humified fractions of the 3 mixtures were very proximal to limit value.

As for the evolution of composting process, in Control mixture the temperature did not exceed 40 °C, due to excessive compressing of the biomass and therefore insufficient aeration. Also in the M2 and M3 poor microbiological activity occured inhibiting the active phase of the process. Nevertheless, the chemical parameters showed levels of TOC only slightly inferior to the minimum values allowed by D.L. 217/06. Also the C/N ratios were inferior to the allowed maximum values (Table I). The percentage of humic and fulvic acids is just below 7% for the Control and M2 mixtures and more than 7% for the M3; therefore the results for winter test can be considered not negative.

For the above reasons the humification rate (HR) showed to be very low (Table I) with values ranging from 6.2 to 7.2%. It can be hypothesized that by modifying the process parameters and the operative conditions, this index could increase; in fact, the corresponding values of humic and fulvic acids were approaching the allowed limits defined by law, exceeding the limit in the heap with the added straw (Table I).

No excessive values of heavy metals were registered, for they were within the limits fixed by Italian low (D.L. 217/06). However, the amount of zinc should be monitored, given that the during the tests, only for the control mixture, the level of zinc approached the maximum threshold values (Table I).

Summer test

The results of the experimental test carried out in the Summer are reported in Figure 3 and Figure 4. The temperature profiles show a much better composting evolution when the environmental temperature is favourable. In fact, in control mixture the thermophilic phase was reached (Figure 3) while in M2 and M3 the mesophilic phase was in an advanced state (Figure3). Also in this experimental test, the temperatures in the top of the biomass were higher than the lower layers (Figure 3).

The moisture content of piles subjected to composting processes is essential for microbial growth. In fact, excess moisture can cause a total occlusion of biomass pores from the water and create anaerobic conditions of the system; at the same time, when recording a water deficit almost complete, an interruption of degradation processes could be generated.

The starting material should present relatively high humidity to enhance the thermoregulation functions related to water evaporation and temperature control while avoiding early desiccation. With the progress of the aerobic processes and consequently with the decreasing biological activity, the moisture optimal values tended to decrease.

The moisture variations recorded during the composting process carried out in the Summer, as reported in Figure 4, show a decreasing trend during the whole process and the statistical analysis on the final means led to a statistically significant differences (Table II).

The observed decrease, however, did not affect the evolution of biological activity. In fact moisture contents less than 35% were observed only at the end of the curing phase, when composted material should have been almost stable (Figure 4 and Table II).

The composts obtained at the end of the process have C/N values within limits determined by D.L. 217/06 (Table II). Although the differences were not statistically significant (Table II). In fact, C/N ratios of the composts obtained during the Summer test are quite similar to those obtained during the Winter test (Tables I and II). M2 and M3 reached ratios close to the same values into the soil at the end of the process (Table II). The values of the C/N ratios recorded during the Summer test both in M2 and in M3 were lower than the corresponding values recorded during the Winter test (Tables I and II).

The pH values (Table II) can be considered optimal with regards to the national regulations and the variation of pH recorded in mixtures confirmed an acceptable thermophilic phase.

The mixtures showed average values of electrical conductivity (from 2.98 to 5.48 dS/m): the minimum value is observed in control mixture after 60 days from the beginning of the process; while in the M2 and M3 EC maximum values were recorded during the last 20 days. However, also in this case, the differences were not statistically significant (Table II). Also these results show that mixed composted amendments experimentally obtained can be considered for agronomic utilization purposes. However, they cannot be suggested as substrate for horticultural purposes as indicated by Italian legislation that limits this use for material with EC lower than 1 dS/m.

According to Ko and colleagues, generally the EC of animal composts are higher than those that characterize the other organic waste composts (Ko *et al.* 2008). Such high values are often linked to high salt levels. Therefore, these results suggest that these composts have to be tested thoroughly in field researches before their use as soil amendment can be recommended. At the same time, appropriate agronomic measures should be identified so to limit potential negative effects on agronomic crops. Casado-Vela and colleagues monitored the effect of application of 3 increasing amounts of composted sewage sludge with EC > 5 dS/m on the soil subjected to cultivation of sweet pepper (Casado-Vela *et al.* 2007). Their results showed that the application of 9 kg/m^2 increased significantly the soil EC beyond the threshold value recommended for the cultivation of sweet pepper.

Montemurro *et al.* (2009) investigated the composting process of olive oil pomace with other organic wastes comparing four different types of composts. They concluded that the high EC (7 dS m^{-1}) of one of these led to excluding it for agronomical utilization, even if it had high N content. The organic and humification parameters of composted material are very similar both in Winter and in Summer product (Table II), and the straw adding in the M2 and

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M3 allows for improving the compost quality. The 3 TOC averages are higher than the minimum values allowed by law and the C/N ratios correspond to the legislative requirements; the values for samples with straw are much better, for they are quite close to the soil C/N ratio (Table II). The percentage of humic and fulvic acids are more than 7% for the 3 heaps, confirming high quality of the compost (Table II).

On the contrary, the amount of zinc in the carried out tests approached the maximum limits in the control mixture and exceeded this limit in M2 and M3, this happened mostly during the Summer test. Probably it is necessary a dietary check at farming scale during rabbit weaning (Tables I and II).

Technical modifications on the plant and prototype of turn-over/aerating machine

The monitoring of temperatures and chemical-physical parameters of the mixtures show limits in the composting process that can be corrected with appropriate mechanical - plant engineering solutions. In fact, with low outside temperatures (Winter test), the composting plant failed in ensuring microclimatic conditions suitable to promote bacterial growth. Besides, in the same test, the growth failure of pH and the production of compost not fully stabilized, show insufficient ventilation and homogenization of the mass during the whole process, confirmed by an insufficient increase in temperature. To this, it must be added that the C/N ratio of the control mixture has not been adequately corrected with the addition of straw in mixtures M2 and M3, and this further affected the development of the process and the chemical and physical properties of final products (Tables I and II).

Therefore, according to the results reported above, in the trials conducted during the Winter, the composting process could be improved considering the following technical/operative parameters:

1. temperature;
2. particles of organic matrix;
3. aeration.

On the contrary, when the process was carried out during the Summer, the size of organic material seems less important.

Regarding the temperature control, in the specific case, the used perimeter and covering materials must be able to retain the heat produced by the biomass, especially in Winter. Moreover when the ambient temperature is too low, the possibility to heat the entering mass by way of pipes with circulating warm water on the bottom of the trough, could be considered. The adaptation would be limited to only 1/3-1/4 of the total length.

Moreover, a specialized machine would be more suitable, in order to obtain straw residues with dimensions inferior to 50 mm, so higher C/N ratios in the starting mixtures.

The high temperature measured at the top of the mass, both during the Winter and Summer tests, is due to an increased bacterial activity in this more ventilated layer, so ΔT grows proportionally with the process approximation to complete fermentation. This is a limit of the turning machine that does not allow an adequate ventilation of the deepest layers. Therefore, it is clear that the turning elements do not adequately penetrate into the biomass and they are of an excessive length, as regards the product to be treated. In fact, the progress of the biomass of 1 m/day is achieved with only 1 daily passing of the machine while, on the studied biomass, the same progress should have been obtained with more daily passings, so to make more frequently the turning over and the mixing of the layers of biomass.

Therefore to improve aeration system and other performances, the following mechanical adjustments to the prototype of the turn-over/moving machine, have been programmed:

- reducing of the length of the turnover elements (Figures 1 and 5), which have been welded to the traversal reel and a lowering of the above relative to the ground in order to allow for a better penetration into the mass and to obtain a better turn-over over a shorter distance; in this way, besides a reduction in energy consumption, it is also possible to effect more trips compared to the covered distance, thereby mixing better the upper layers as well as the lower layers;
- modifying the shape and the profile of the turn-over elements (Figure 5) in order to improve the mixing and to aerate the mass still further when the machine is returning, therefore effecting a rotation in the opposite direction of the reel without moving back the material that has been pushed forward, therefore simply lifting it up.

Conclusions

Composting of by-products must be supported by a physical-chemical study of the starting raw materials and by the formulation of balanced mixtures, to activate the metabolism of thermophilic bacteria and to obtain soil composted amendment of high quality in terms of law.

The study of the chemical and physical evolution of mixtures and of obtained products is essential to assess the progress of the composting process, as well as to determine any mechanical and plant

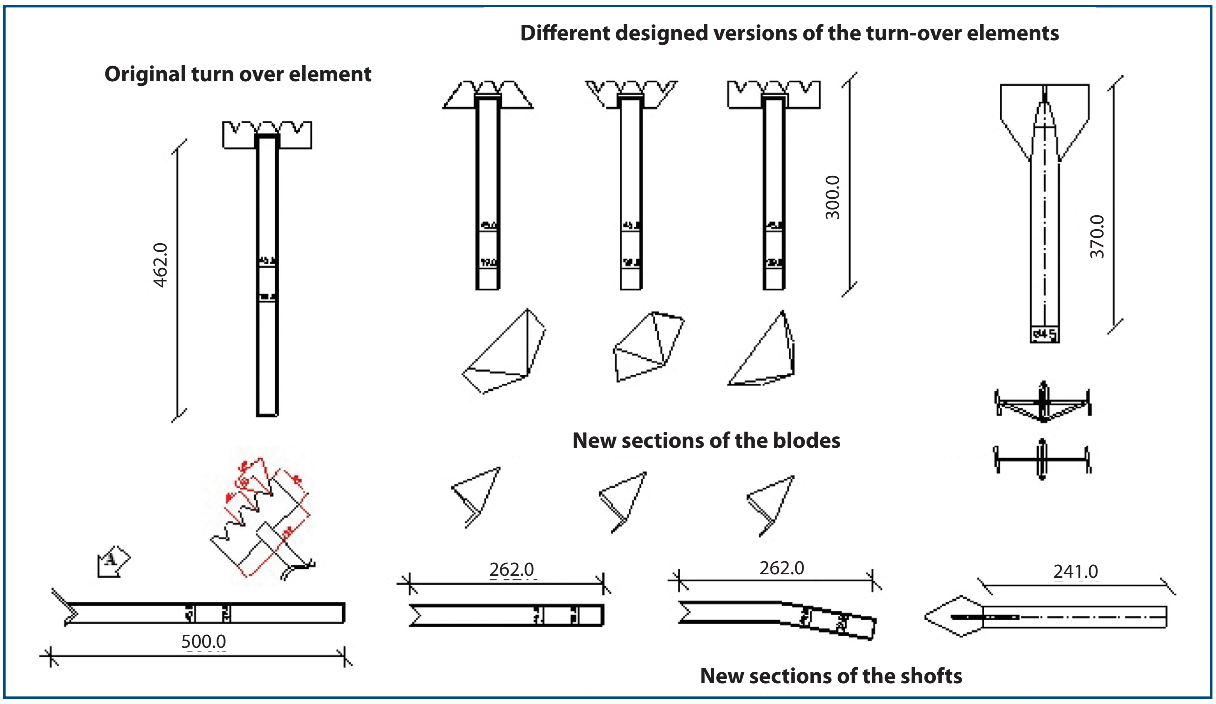

Figure 5. *Technical modifications on the prototype of turn-over/aerating machine.* Image is drawn approximately to scale and measurements are in millimeters.

engineering solutions that may improve it or allowed it to run optimally.

This study has identified the high potential to obtain high quality compost from manure and slaughterhouse waste rabbit. In addition, the results underlines that specific mechanical and plant solutions are necessary to allow for proper C/N ratio in the mixture and a proper homogenization - aeration of biomass. This experimental research defines plant solutions and modification of the turner machine, because of high humidity that characterizes the mixtures, and to ensure the realization of the complete process of aerobic stabilization that was only partially realized, especially at low outsider temperatures.

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