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Agronomic Characteristics of the Compost-Bedded Pack Made with Forest Biomass or Sawdust

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Abstract: To ascertain the agronomic value of the material resulting from the compost-bedded pack (CBP) in dairy barns, a cross-over experiment was designed with eight dry non-pregnant Holstein cows. The study was performed in two 11-week periods. Bedding materials used were: (1) CBP with sawdust (S) and (2) CBP with forest biomass (FB). Samples were taken from the raw bedding materials and from the CBP across the experiment. We conducted an additional study preparing two piles, one of each CBP material, to accomplish a composting process of 3 months, where samples were also taken. Granulometry and some chemical composition characteristics of FB made it a suitable bedding material to be used as CBP, but its high moisture content limited the ability to absorb liquid manure. Both the degree of stability of the organic matter and the temperature evolution of CBP suggest that a real composting process did not occur. Finally, the composting process of the piles did not lead to any relevant change in CBP materials. From the agronomic point of view, S and FB present potentially valuable characteristics as regards organic amendment in the soil, thanks to their high organic matter content and low nutrient content.

Keywords: compost-bedded pack; dairy cows; forest biomass; organic amendment; sawdust

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1. Introduction

Fifty-five percent of the world's population lives in urban areas, a proportion that is expected to increase to 68% by 2050 [1]. In this process, the number of both farms and farmers has decreased, thus raising, at the same time, the urban population [2]. One of the main consequences of this rural flight is an increase in forestland. Human activities have directly caused approximately 60% of the new global tree growth [3]. Dry weather and damaged ecosystems with an accumulation of dead biomass due to rural abandonment increase the risk of forest fires. The accumulation of high fuel loads over large areas is the main reason behind the occurrence of large fires [4,5]. In this context, it is necessary to find new ways to reduce these high fuel loads to prevent large fires.

The compost-bedded pack (CBP) is a loose housing system that is becoming more and more established on dairy farms in which cows are maintained for a long time on the compost. Improvements in the health, welfare and performance of cows, ease of farm chores and reduced building costs have been described in comparison with other housing systems [6–8]. The composting process allows manure and urine to be stored, as long as the pack is managed adequately, involving twice-daily tilling and periodic bedding addition [7,9,10]. Tilling incorporates manure and air into the pack, thus promoting aerobic microbiological activity, heating the pack and drying the lying surface for cattle to lie on [11]. Bedding addition increases the water-holding capacity of the pack to control CBP moisture. Compost-bedded pack barns in dairy cow farming mainly use sawdust (S) as a bedding material, but forest biomass (FB) could be an alternative material. When both materials were tested as CBP, some important microbial species affecting cow health were better controlled using FB, although in terms of cow comfort, FB did not appear to work as well as S [12]. However, the welfare assessment conducted did not detect health problems in the cows [12].

Once the CBP material is moved away from the barn, it is used as organic fertilizer on the farm. The lack of information about the agronomic value of this fertilizer source led us to study (a) the agronomic characteristics of the CBP obtained either with FB or S, after maintaining cows for three months on the pack, and (b) the agronomic characteristics of both composted materials after conducting an additional composting process of three months once the cows were moved away.

2. Materials and Methods

Two different composting processes were established. The first involved maintaining cows on CBP, either FB or S, for 11 weeks. Once this one was completed, a second process began, based on composting piles from the two CBPs for 3 months.

2.1. Bedding and Compost Management

Eight dry non-pregnant Holstein cows were individually allocated in roofed concrete floor pens, 5 m long and 2.5 m wide. Each pen was divided in 2 areas: a feeding area equipped with a feed bunk and a water trough, and a resting area. Pens were separated by a metal fence that allowed contact between animals. Cows were randomly assigned to 1 of 2 treatments in a cross-over design with 4 cows per treatment. The study was performed in 2 11-week periods with a 4-week washout period between them. Bedding materials used were: (1) CBP with S (CBP-S) and (2) CBP with FB (CBP-FB). The bulk density for these bedding materials was 182 ± 6.3 g/L and 240 ± 16.2 g/L for S and FB, respectively. During the washout period, cows laid on traditional wood shaving bedding. At the beginning of each period, pens were filled with 30 cm of the new bedding material. All CBPs were tilled twice daily (10 a.m. and 5 p.m.) at 30 cm depth with a rototiller, and an average of 0.8 kg/m^2/d of new bedding material was added on each pen CBP surface before tilling, when pen CBP moisture was greater than 60%. Compost-bedded pack moisture was measured weekly in both areas (feeding and resting) of each pen. Averages of 7.8 kg/pen/d in CBP-S and 7.9 kg/pen/d in CBP-FB of new bedding materials were added. Both CBPs were removed at the end of week 11 of each period. Daily ambient temperature and environmental humidity were obtained from 2 data loggers (UX100-003, Hobo, Algete-Madrid, Spain) located in the barn. At the end of the second experimental period, the composted bedding material of each pen was composited and used to prepare 2 composting piles, one of each bedding material, to obtain a composted material after 3 months of the composting process. Each pile, in the shape of a truncated pyramid and located in a roofed barn, was 4.8 m long, 2.5 m wide and 1.15 m high, with an approximate volume of 7.5 m^3. The piles were turned and rebuilt weekly to facilitate the aerobic process. It was necessary to water the piles on five occasions to maintain pile moisture between 45 and 65%. Daily ambient temperature and environmental humidity were obtained as described before.

2.2. Sampling

Samples were taken from the raw bedding materials, the CBP and the composted piles. Raw bedding material was sampled throughout the experiment. Thus, in total, 4 samples of each one were collected and then stored at 4 °C until analysis. Particle size of the raw bedding materials was measured using an electromagnetic sieve shaker (RP 200N, CISA Cedaceria Industrial S. L., Barcelona, Spain) to obtain their physical characterization. With regard to the CBP material, temperature was recorded daily and moisture weekly in the feeding and resting areas during each experimental period. Temperature was measured at 15 cm depth with a thermometer and a 15-cm sounding line (K/JR-200 + 800 °C, Ventix, Sant Adrià de Besós, Spain). Sampling for chemical analysis was performed at week 11. Samples were collected at 15 cm depth, from the middle of the feeding and resting area of each pen, and later composited by pen. The amount of sample collected by pen was 5 kg. Samples were stored at −18 °C until analysis. Thus, we collected 4 samples per each material and period. Finally, the sampling of the piles was carried out every 10 days, collecting in total 9 samples of 6 kg each, and then samples were stored at −18 °C until analysis. Temperature was measured at 40 cm and 1 m depths with a thermometer and a 1-m sounding line (K/JR-200 + 800 °C, Ventix, Sant Adrià de Besós, Spain). Three samples were taken from each pile in the middle of 3 of the 4 sides of the truncated pyramid, at different depths to obtain a representative sample from each side, and were then composited by pile. The fourth side was next to a wall to facilitate the containment and prevention of landslide, making it inaccessible. In addition, during the composting process, the evolution of wet bulk density was monitored by weighing material of a known volume, according to [13]. Wet bulk density values were transformed to dry bulk density values by multiplying them by the corresponding dry matter (DM) content of samples.

2.3. Chemical Analysis

At the moment of analysis, samples were defrosted at room temperature. A watery extract was obtained from each fresh sample using 40 g and 200 mL of distilled water. After 30 min of stirring, the extract was centrifuged at 3600 rpm for 15 min. In the supernatant, the following determinations were carried out: pH and electric conductivity (EC) using a pH meter (Crison GLP 21; Hach Lange Spain, S.L.U., L'Hospitalet de Llobregat, Spain) and a conductivity meter (Crison GLP 31; Hach Lange Spain, S.L.U., L'Hospitalet de Llobregat, Spain), and ammonia nitrogen by means of an ammonium selective electrode (Orion 9512, Termo Fisher Scientific, Barcelona, Spain). Moisture content was determined by drying samples for 24 h at 103 °C. Ash content was determined in the dry and ground (1-mm screen) sample by loss on ignition at 600 °C for 2 h based on the AOAC method 942.05 [14] to ascertain the organic matter (OM) content of samples. Chemical stability degree (SD), as a way to predict composting ability, was determined by Klason lignin determination in accordance with [15]. In dry and ground samples (1-mm), nitrogen content was determined by the Kjeldahl procedure based on the AOAC method 976.05 [14]. The C/N ratio was estimated from the OM and nitrogen content in accordance with [16]. Mineral nutrient content was determined by flame photometry in the case of K (Model 410, Corning, Halstead, UK) and by spectrophotometry in the case of P (Model Cary 60, Agilent Technologies, Singapore, Malaysia) after dissolution of ash obtained from the ignition of samples at 470 °C in 3 N HNO_3.

2.4. Statistical Analysis

Chemical composition of raw bedding materials was compared using the GLM procedure of SAS (v. 9.3; SAS Institute Inc., Cary, NC, USA, 2011). Data related to the CBP material were analyzed by using the MIXED procedure of SAS (v. 9.3; SAS Institute Inc., Cary, NC, USA, 2011). The model contained the fixed effects of treatment, period and treatment × period interaction, and the random effect of pen was nested within the sequence, where the sequence is the order in which treatment is applied to the experimental unit. The Tukey multiple comparison test was applied to conduct mean separation across treatments and periods when the treatment × period interaction was significant. Regression analyses were performed to obtain the equations and the coefficients of determination between variables studied in the composted piles and the sampling days using the REG procedure of SAS (v. 9.3; SAS Institute Inc., Cary, NC, USA, 2011). The scopes of linear regression, obtained for each composted pile, were compared by means of a *t*-test after checking the homogeneity of variances.

3. Results and Discussion

3.1. Comparison between Bedding Materials

Sawdust obtained from sawmills is a bedding material commonly used in CBP barns for dairy cows [17,18], while FB is an alternative material that, in the present study, was composed of tree bark and vegetal fibers from a Mediterranean forest. Both materials showed an acidic pH, a low EC value, high OM content and low nutrient content, resulting in a high C/N ratio (Table 1). These characteristics are common of bedding materials used in CBP, together with a low moisture to assure the absorption capacity of animal urine and a particle size < 25 mm to promote the microbial activity due to the increased growing surface [11,18]. However, certain differences between both materials can be highlighted regarding their physical and chemical properties. Sawdust was slightly acidic with a higher EC value and OM content and lower in moisture and nutrients, resulting in a higher C/N ratio in S than in FB (Table 1; $p < 0.001$). In addition, S showed a lower moisture than FB and a finer granulometry because the proportion of particles < 2 mm was 49.2% and 22.0% for S and FB, respectively.

Table 1. Chemical composition and granulometry of raw bedding materials.

Item	Material		SEM	*p*-Value
	S [1]	**FB** [2]		
pH	5.01	6.01	0.112	0.001
EC, mS/cm	0.43	0.23	0.011	0.001
Moisture, %	10.2	32.1	1.97	0.001
OM, % DM	99.1	88.6	0.43	0.001
Stability, %	28.6	52.2	0.22	0.001
Organic N, % DM	0.20	0.35	0.026	0.001
C/N ratio	286	131	20.0	0.001
P, % DM	0.006	0.024	0.0020	0.001
K, % DM	0.054	0.131	0.0088	0.001
Particle size, %				
>25 mm	0.0	0.0	0.02	0.434
25–12.5 mm	0.6	8.6	0.76	0.001
12.5–10 mm	0.7	6.2	0.50	0.001
10–6.3 mm	8.3	13.2	0.74	0.001
6.3–5 mm	6.8	10.3	1.26	0.077
5–2 mm	34.3	39.7	2.99	0.232
<2 mm	49.2	22.0	4.62	0.002

[1] S = sawdust. [2] FB = forest biomass.

Stability was greater in FB than in S (Table 1; $p < 0.001$). The authors of [19] pointed out that the lignin content of hardwoods (angiosperms) is usually in the range of 18–25%, whereas this content ranges between 25 and 35% in the case of softwoods (gymnosperms). These higher values can be attributed to the great lignin content of pine bark, between 38 and 58%, an ingredient visually present in FB.

The content of C and N and the C/N ratio of the sawdust used in the present experiment was similar to that reported by [11], but with a P and K content ten times lower. In the case of FB, there is a lack of information with regard to this material when used in CBP barns. A similar bedding material obtained from the forest (conifer forest litter) to be used in CBP was described by [17], with similar C and macronutrient contents, and with a C/N ratio more suitable than sawdust for a composting process and greater than 50 to minimize ammonia losses [20]. However, the material described by [17] and the FB used in the present experiment differ in their granulometry. In our case, 61.7% of the material was less than 5 mm, while this percentage was lower for the conifer forest litter. This, together with the remaining particle fractions, suggests that the forest material described by [17] was more heterogenous and coarse than FB, probably due to the grinding machinery used. Differences in granulometry explain the differences in bulk density, which were 123 and 240 kg/m^3 for conifer forest litter and FB, respectively.

3.2. Comparison between Compost-Bedded Pack (CBP)

3.2.1. Temperature and Moisture

Temperature and moisture affect the biological transformation of organic materials, particularly in aerobic conditions. Moisture and oxygen availability allow the microbial activity which leads to a temperature increase due to exogenous chemical reactions of molecule degradation. In a process such as composting, this temperature increase is observed as an indicator of an adequate evolution. However, in the case of CBP, the objective was not the biological transformation of the material as in the composting but the availability of safe housing for animal breeding. The presence of a C-rich material and the availability of a N source from feces and urine, moisture and oxygen provide the conditions for microbial growth and, consequently, a temperature increase.

Climatic conditions during the CBP process are shown in Table 2. The average ambient temperature was 14.7 ± 3.63 °C in Period 1 and decreased from 19.5 to 9.1 °C. In Period 2, the average ambient temperature was 11.2 ± 2.49 °C and increased from 5.9 to 14.1 °C Thus, Period 2 was colder than Period 1, as reflected in the lower temperatures recorded in CBP in Period 2. In Period 1, the mean CBP temperature was 34.7 ± 5.64 °C in CBP-S and 28.3 ± 6.87 °C in CBP-FB, and in Period 2, 31.2 ± 5.88 °C and 25.9 ± 3.08 °C in CBP-S and CBP-FB, respectively. The lower CBP temperatures recorded in CBP-FB would indicate a lower microbial activity due to the greater OM stability of this material and bigger particle size. However, in both cases, these temperatures were below the recommended range values for an effective composting [10,21,22], although this frequently occurs in the context of CBP management [7,11,23]. Average environmental humidity was 81.5 ± 4.21 in Period 1 and ranged between 74.1 and 90.4%. In Period 2, average environmental humidity was 74.5 ± 7.18% and ranged between 61.6 and 87.3%. In CBP-S, the initial moisture was 10% on average and the mean value was 54.1 ± 16.97% in Period 1, and 55.0 ± 16.43% in Period 2. In CBP-FB, the initial moisture was 32% on average and the mean moisture was 62.0 ± 14.00% in Period 1, and 59.4 ± 7.21% in Period 2. A similar moisture content was expected in both CBPs because we decided to add new bedding material when the moisture was greater than 60%, applying an average amount of 7.8 kg/d and 7.9 kg/d in CBP-S and CBP-FB, respectively. However, the moisture was slightly higher in CBP-FB than in CBP-S. The moisture and granulometry of FB could also have contributed to this final result.

Table 2. Climatic conditions, temperature and moisture content of compost-bedded pack (CBP) made with sawdust (CBP-S) and forest biomass (CBP-FB) during the time periods studied.

	Period 1	**Period 2**
Climatic conditions		
Temperature, °C	14.7 ± 3.63	11.2 ± 2.49
Humidity, %	81.5 ± 4.21	74.5 ± 7.18
CBP temperature, °C		
CBP-S	34.7 ± 5.64	31.2 ± 5.88
CBP-FB	28.3 ± 6.87	25.9 ± 3.08
CBP moisture, %		
CBP-S	54.1 ± 16.97	55.0 ± 16.43
CBP-FB	62.0 ± 14.00	59.4 ± 7.21

3.2.2. Chemical Characteristics

The chemical composition of CBP samples at week 11 is shown in Table 3. The pH values recorded were basic and there were increases in the pH and EC values from the raw bedding materials to CBP samples. This increase can be attributed to feces and urine provided by the cows. The pH and EC values were affected by the treatment × period interaction (p = 0.001 and p = 0.003, respectively). In Period 1, CBP-FB pH was higher than CBP-S pH, whereas CBP-FB EC was lower than CBP-S EC. In contrast, CBP-FB pH was lower than CBP-S pH in Period 2, whereas CBP-FB EC was not different from CBP-S

EC. The low EC value recorded in CBP-FB in Period 1 could be due to its higher moisture resulting in a higher dilution rate because this determination was made with a wet sample.

Table 3. Chemical composition of compost-bedded packs (CBP) after 11 weeks of use.

Item	Period 1		Period 2		SEM	*p*-Value		
	CBP-S [1]	CBP-FB [2]	CBP-S	CBP-FB		T	P	T × P
pH	8.00 ^{c}	8.43 ^{b}	8.96 ^{a}	7.81 ^{c}	0.078	0.001	0.021	0.001
EC, mS/cm	3.78 ^{a}	2.39 ^{b}	3.84 ^{a}	3.79 ^{a}	0.163	0.001	0.001	0.003
Moisture, %	61.3 ^{b}	69.7 ^{a}	63.7 ^{b}	63.2 ^{b}	1.09	0.002	0.037	0.001
OM, % DM	91.1 ^{a}	83.4 ^{c}	89.9 ^{a}	85.7 ^{b}	0.54	0.001	0.115	0.008
Stability, %	ND	ND	31.7	49.2	1.25	0.001	ND	ND
N, % DM								
Organic	0.89	1.12	1.07	1.21	0.036	0.001	0.002	0.101
Ammonia	0.07	0.08	0.05	0.04	0.014	0.999	0.034	0.444
Total	0.96	1.19	1.12	1.24	0.039	0.001	0.005	0.109
C/N ratio	48:1 ^{a}	35:1 ^{c}	40:1 ^{b}	35:1 ^{c}	1.1	0.001	0.002	0.005
P, % DM	0.24 ^{b}	0.28 ^{a}	0.28 ^{a}	0.25 ^{a,b}	0.009	0.879	0.458	0.003
K, % DM	1.22 ^{b}	1.64 ^{a}	1.78 ^{a}	1.62 ^{a}	0.098	0.038	0.001	0.015

[1] CBP-S = compost-bedded pack made with sawdust. [2] CBP-FB = compost-bedded pack made with forest biomass. $^{a\text{–}c}$ Means within a row with different superscripts differ ($p < 0.05$).

The treatment × period interaction also affected the OM content ($p = 0.008$). The OM content was higher in CBP-S than in CBP-FB in both periods, but this difference was greater in Period 1 than in Period 2. The content of organic N was affected by treatment ($p = 0.001$), being higher in CBP-FB than in CBP-S. These results could be due to the differences detected in the raw bedding materials where OM was higher in S than in FB, and organic N was higher in FB than in S (Table 1). The period also affected organic N ($p = 0.002$), being higher in Period 2 than in Period 1. With regard to ammonia N, this content was affected by period ($p = 0.034$), being greater in Period 1 than in Period 2. However, these differences are not relevant from the agronomic point of view. In addition, there was a treatment × period interaction in the C/N ratio ($p = 0.005$). Although this ratio was greater in CBP-S than in CBP-FB in both periods ($p = 0.001$), in agreement with the differences detected in the raw bedding materials, and it was greater in Period 1 than in Period 2 ($p = 0.002$), the difference between treatments was greater in Period 1 than in Period 2.

The contents of the other macronutrients (P, K) were affected by the treatment × period interaction ($p = 0.003$ and $p = 0.015$, respectively). For P and K, the content of CBP-FB was greater than in CBP-S in Period 1, but the content between treatments was not different in Period 2. However, considering the higher differences found between raw bedding materials, where the P and K content was higher in FB than in S, the differences between CBPs were lower and in accordance with the raw materials in Period 1, or were not observed in Period 2. In any case, these differences are not relevant from the agronomic point of view.

The pH value, EC, moisture and the contents of N, P and K increased in CBP samples with regard to the raw bedding materials with high OM content, due to the high macronutrient content supplied by feces and urine. This would explain the C/N ratio decrease in CBP. Thus, the final characteristics of CBP will be linked with the bedding material added throughout the process. Taking into account the amount added (7.8 kg/d and 7.9 kg/d in CBP-S and CBP-FB, respectively) and the bulk density of the bedding material, the amounts added were 15.6 m^3/cow/year and 12.0 m^3/cow/year, for CBP-S and CBP-FB, respectively. These values are inside the range reviewed by [18]. In addition, the chemical characteristics found in the present experiment for CBP-S are in the range found by [11] and [24] for wood shavings and wood chips.

The SD of the OM in CBP, measured in Period 2, was greater in CBP-FB than in CBP-S, in agreement with the differences recorded in the raw bedding materials. The SD measured in CBP-S remained far away from 50, the threshold used to consider a compost mature. Taken together with the temperature evolution of CBP, this suggests that there was not a real composting process.

3.3. Comparison between the Composted Piles

3.3.1. Temperature, Moisture and Bulk Density

From the beginning to the end of the composting period, ambient temperature increased from 22 to 26 °C and environmental humidity from 47 to 72%. The initial temperatures of the composting piles were 35.0 °C and 30.4 °C for S and FB, respectively, the final temperatures being 46.0 °C and 44.5 °C (Figure 1a). These temperatures were obtained after averaging data recorded at depths of 40 cm and 1 m. In both piles, a temperature increase was observed during the composting process, achieving the thermophile phase (>40 °C), and reaching sanitation temperature for S (≥55 °C more than 14 d according to European Regulation 2019/1009), while FB remained below this limit. The temperature achieved at d 90 in both piles would indicate that the composting process had not ended, probably due to the low C/N ratio and the lignocellulosic content of both materials, particularly in FB. The initial moisture of the S pile and the FB pile was 61.5% and 62.2%, respectively, whereas the final moisture was 47.9% and 55.4% (Figure 1b). The values over the period were adequate for a composting process, being over 50% in order to maintain microbial activity [25]. The piles were watered periodically, which helped to conserve the moisture. The bulk density evolution is shown in Figure 2. Dry bulk density increased slightly, and changes were due to mineralization and particle size reduction. Bulk density was higher in the FB pile than in the S pile.

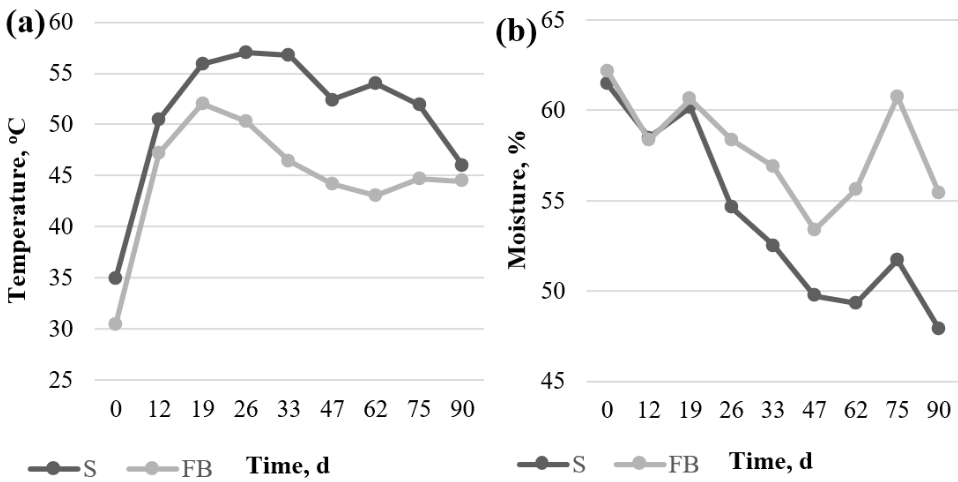

Figure 1. Effect of treatment (sawdust = S and, forest biomass = FB) on temperature (**a**) and moisture (**b**) of the composted piles.

3.3.2. Chemical Characteristics

Initial and final values of the variables measured in the piles are shown in Table 4. In a composting process, an initial acidification followed by a gradual alkalinization is a common evolution of the pH medium. However, in the present experiment, the changes in the pH values of the piles were small and did not respond to this pattern (Figure 3). The pH values were more basic in S than in FB, which implies greater risk of N losses in S. With regard to EC, an increase in its value was expected during the composting process due to OM mineralization. This happened in S but not in FB, proving that composting was less strong in the FB pile.

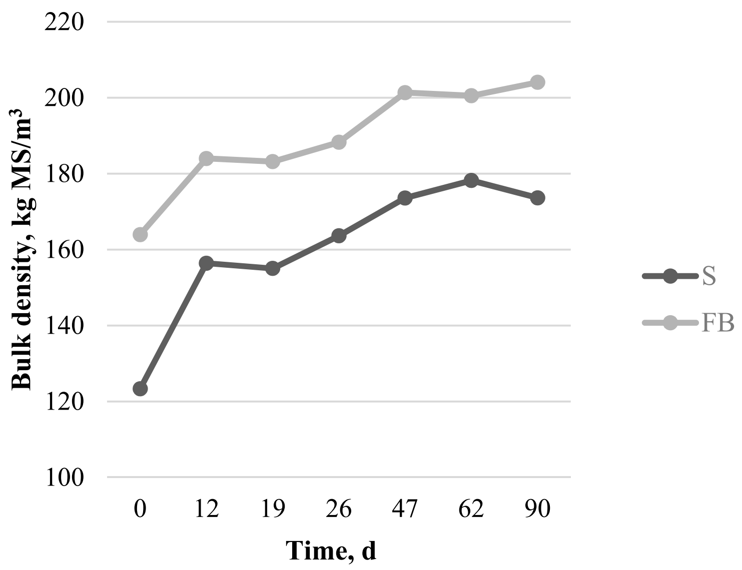

Figure 2. Bulk density evolution of samples taken from the composted piles (sawdust = S and forest biomass = FB).

Table 4. Initial and final values (mean ± SD) of the variables measured in the composted piles made with sawdust (S) and forest biomass (FB).

Item	S		FB	
	Day 0	**Day 90**	**Day 0**	**Day 90**
pH	8.72 ± 0.017	8.39 ± 0.035	7.45 ± 0.015	7.72 ± 0.100
EC, mS/cm	3.59 ± 0.145	5.58 ± 0.106	3.39 ± 0.025	3.10 ± 0.061
Moisture, %	61.5 ± 0.24	47.9 ± 0.15	62.2 ± 0.29	55.4 ± 0.18
OM, % DM	91.7 ± 0.18	87.4 ± 0.13	86.3 ± 0.30	82.9 ± 0.03
Stability, %	31.7	34.9	49.2	53.9
N, % DM				
Organic	0.88 ± 0.039	1.05 ± 0.058	1.16 ± 0.013	1.27 ± 0.054
Ammonia	0.049 ± 0.0004	0.004 ± 0.0002	0.013 ± 0.0006	0.001 ± 0.0005
C/N ratio	52.0	41.8	37.2	32.6
P, % DM	0.24 ± 0.017	0.31 ± 0.040	0.27 ± 0.021	0.24 ± 0.011
K, % DM	1.74 ± 0.071	2.02 ± 0.134	1.94 ± 0.269	1.87 ± 0.066

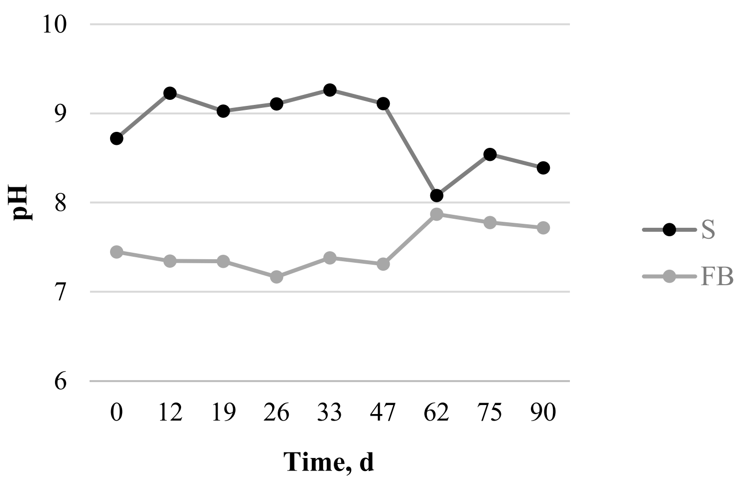

Figure 3. Evolution of pH of samples taken from the composted piles (sawdust = S and forest biomass = FB).

Although a small decrease in the OM in both piles was observed, the content was high in both cases at d 90, which would indicate only a partial transformation of this OM during composting. This could be explained by the high C/N ratio recorded at d 0, which reflected a N lack, and by the high presence of lignin in wood waste, which would explain the difficulty in the OM degradation. Thus, at the end of the process, a large quantity of OM remained non-degraded. Nevertheless, a slight increase in stability was observed, from 31.7 to 34.9% and 49.2 to 53.9%, respectively, for S and FB. According to [15], the value over 50% recorded in the FB pile at d 90 would indicate that the material was chemically stable and would produce a progressive degradation of OM in an eventual soil application and a consequent gradual release of nutrients. There was a slight increase in the content of N, P and K from d 0 to d 90 in the S pile, which can be explained by a concentration process due to the OM decrease. In the FB pile, this slight increase was only observed in the N content. The initial ammonia N content was low in both piles, in agreement with their low total N content. Although it was lower in FB than in S, its evolution over time was similar to that normally observed in a composting process because after a slight increase during the first days, it then decreased till d 90 (Figure 4). This decrease could be explained by utilization by microorganisms, the nitrification process or the loss caused by turning [26]. All these values were close to or below the upper limit proposed by [16] to consider a compost being mature.

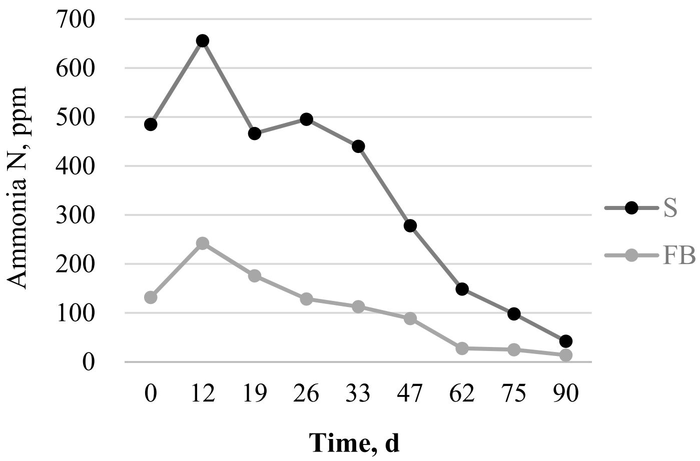

Figure 4. Evolution of ammonia N content of samples taken from the composted piles (sawdust = S and forest biomass = FB).

In order to accelerate the composting process, it would be necessary to increase the N content in the original material by adding a N source to reduce its initial C/N ratio. In this sense, the practice used by some farmers of drying the material resulting in the CBP and reusing it in the barn could help achieve this objective. However, effort should be made to achieve the appropriate conditions to ensure the sanitation of material and avoid animal health problems. Another alternative to achieve this sanitation, when lignocellulosic materials are used, could be to lengthen the process (>6 months).

The progression of each chemical compound of these piles over time, expressed with the corresponding regression equation, is shown in Table 5. The relationship was statistically significant in both piles for OM, organic N, ammonia N and the C/N ratio, the slope being negative for OM, ammonia N and the C/N ratio, and positive for organic N. In those variables, the slope comparison showed that there were no statistical differences between treatments (data not shown). Moreover, in the sawdust pile, the relationship exists also for EC, moisture and total N, and in the forest biomass pile, for pH.

Table 5. Regression equations in each composting pile (sawdust = S; forest biomass = FB) between chemical variables and time (d) of composting period.

Item	S				FB			
	Equation	R^2	*p*-Value	RMSE	Equation	R^2	*p*-Value	RMSE
pH	9.19 − 0.009d	0.41	0.064	0.343	7.25 + 0.006d	0.53	0.026	0.178
EC, mS/cm	3.66 + 0.023d	0.95	0.001	0.176	2.03 + 0.001d	0.02	0.745	0.252
Moisture,%	59.9 − 0.146d	0.79	0.002	2.468	59.9 − 0.047d	0.25	0.174	2.681
OM, % DM	91.0 − 0.041d	0.90	0.001	0.499	85.3 − 0.027d	0.65	0.028	0.688
N, % DM								
Organic	0.88 + 0.003d	0.68	0.006	0.061	1.14 + 0.001d	0.48	0.039	0.037
Ammonia	0.06 − 0.001d	0.89	0.001	0.008	0.02 − 0.001d	0.75	0.002	0.004
C/N	52.0 − 0.145d	0.84	0.004	2.286	37.5 − 0.050d	0.73	0.015	1.073
P, % DM	0.26 + 0.001d	0.63	0.107	0.019	0.28 − 0.001d	0.27	0.292	0.028
K, % DM	1.83 + 0.004d	0.71	0.073	0.107	1.76 + 0.002d	0.29	0.270	0.127

3.4. Agronomic Suitability of the Materials

Both CBP materials contain high amounts of OM and a low nutrient content in comparison with cattle manure. Thus, they must be considered organic fertilizers to provide OM to the soil. The CBP review by [18] regards this material as a green waste compost, and stated that in the long term, the use of CBP as manure can result in considerably higher amounts of OM and a larger accumulation of N than cattle manure. The C/N ratio of both CBPs was high but within the wide range, from 10.5 to 49.3, reviewed by [18]. In addition, high ratios are expected when wood-derived materials are considered [11]. The incorporation in the soil of materials with a high C/N ratio can initially lead to a N inorganic immobilization because it is used by microbes, making it temporarily inaccessible to crops. This negative effect could happen if the material of the S pile was used due to its less stable OM, but not in the case of the FB pile material with a more stable OM. However, in accordance with the Spanish regulation RD506/2013 on fertilizing, both materials would be unmarketable because of a C/N ratio greater than 20. Thus, this final composting process did not bring about any meaningful change to CBP materials. Only if sanitation was achieved could this additional work be justified to add safety in cattle farms.

4. Conclusions

From the agronomic point of view, although both materials had a high C/N ratio to be registered as soil fertilizers, they present potentially valuable characteristics when it comes to organically amending the soil, as they are high in organic matter content and low in nutrients. Further, the organic matter of the forest biomass pile was well stabilized (more than 50%). Therefore, as sawdust and forest biomass are very likely to improve soil properties when added to the land, further studies focusing on improving the composting management should be made to achieve effective composting, assuring an adequate C/N ratio and the sanitation of this material in the case of its reutilization as a compost-bedded pack.

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