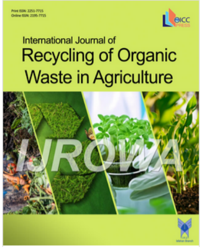

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Decomposition of composted barn bedding: comparison with cattle manure under variable conditions for biofertilizer potential

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Original Research

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Abstract:

Purpose: This research assesses the compost barn system's effectiveness in dairy cattle production, aiming to merge high productivity and quality with animal well-being and environmental sustainability. It examines the loss of mass and basal soil respiration rates in bedding materials like sawdust and wood shavings, focusing on the impacts of various storage heights, moisture levels, and temperatures.

Method: The study was conducted via two experiments. The first measured mass loss in standard bovine waste and compost barn materials across three storage heights (2 cm, 4 cm, 8 cm), two moisture conditions (wet and dry), and two temperatures (20 °C, 30 °C). The second experiment investigated mass loss rates and basal soil respiration in entisol and oxisol soils under different moisture and temperature conditions.

Results: Findings indicate the compost barn treatment reduces bovine manure decomposition rates compared to traditional methods, with taller stacks showing lesser decomposition. Dry conditions increased decomposition rates, contrary to microbial respiration trends. Temperature significantly affected decomposition, with varying effects between experiments. Higher temperatures boosted microbial respiration. Entisol treatments had lower decomposition but higher microbial respiration than oxisol treatments.

Conclusion: The compost barn system is a sustainable, viable option for dairy cattle producers, promoting animal well-being and environmental integrity. By effectively managing these factors, producers can enhance agricultural productivity and support eco-friendly practices.

Keywords: Compost barn; Decomposition; Microbial respiration; Soil; Bovine manure

1. Introduction

The dairy farming sector actively pursues cutting-edge technologies to achieve elevated productivity, premium quality, and, notably, prioritized animal welfare (Barberg et al., 2007). Amid the array of confinement systems, the compost barn stands as a prominent choice (Piovesan and Oliveira, 2019), recognized for its superior provision of animal comfort and ease of management (Schogor et al., 2018). This system affords increased freedom of movement, designated resting areas, and ample access to water and food, ensuring the overall well-being of the livestock (Mota et al., 2017). The compost barn's bedding, typically comprising sawdust, wood shavings, and other organic plant materials, plays a pivotal role in temperature regulation, thereby maintaining optimal comfort for the cattle (Liberalesso, 2017; Mota et al., 2017). However, it necessitates consistent upkeep (Liberalesso, 2017; Mota et al., 2017). Sustaining elevated temperatures in the inner layers of the bedding is crucial for fostering biological activity and eliminating pathogens, while the upper layers are designed to maintain lower humidity levels, creating a hygienic and snug environment for the animals (Liang et al., 2003; Barberg et al., 2007; Black et al., 2013).

In the management of bedding, a routine practice involves periodic turning to integrate waste, facilitate aeration, and stimulate aerobic microbial activity (Suler and Finstein, 1977). At a depth of 15 to 30 cm, temperatures can vary between 44 to 65 °C, with moisture content falling within the 40 to 60% range (Liang et al., 2003; Klein and Agne, 2013; Seganfredo, 2020). The carbon to nitrogen ratio assumes critical importance in compost microbial activity. Ratios surpassing 30/1 are recommended for effective composting, whereas ratios below 20/1 result in complete carbon consumption without nitrogen stabilization (Schogor et al., 2018). Hence, the exploration of environmentally sustainable disposal methods and the examination of how this bedding decomposes in the environment become imperative (Leso et al., 2013; Kim et al., 2015). Presently, a prevalent practice involves directly applying the bedding to the soil, a method recognized for supplying essential nutrients to plants and enhancing soil quality (Mota et al., 2020). However, this practice, when it involves untreated cattle manure, can negatively impact the physical and chemical properties of some soils, such as saline-sodic soils (Sharifi et al., 2021). Additionally, an assessment of the decomposition of these residues in agriculture remains a notable gap in research (Damasceno, 2012).

The intricate decomposition process of residues in dairy farming is subject to the influence of the decomposer community, soil characteristics (including nutrients, texture, moisture, and temperature), and the specific properties of sawdust and wood shavings bedding (Seganfredo, 2020). Furthermore, external environmental factors, such as aeration and ambient humidity, contribute to shaping this intricate process (Seganfredo, 2020). A profound understanding of the bedding decomposition process proves pivotal for optimizing the management of dairy farming residues and mitigating environmental impacts (Ryckeboer et al., 2003; Sun et al., 2023). Notably, the decomposition of sawdust and wood shavings bedding can wield a significant influence on soil quality (Kögel-Knabner, 2002; Liu et al., 2020). The organic matter derived from the bedding actively contributes to the formation of aggregates, fostering water retention, enhancing soil structure, and rendering nutrients more accessible to plants (Ryckeboer et al., 2003; Sun et al., 2023). However, a cautious approach is imperative, as excessive bedding application can result in adverse effects such as soil compaction, acidification, and loss of fertility (Kögel-Knabner, 2002; Liu et al., 2020).

In this context, a profound exploration into the intricacies of the decomposition process of sawdust and wood chip litter from the composting barn becomes imperative (Leso et al., 2020). The comprehension of microbial activity dynamics, nutrient release, and their potential repercussions on soil health stands as a fundamental pillar in the realm of effective waste management (Liang et al., 2003; Black et al., 2013; Leso et al., 2013). Equally crucial is the formulation of robust management strategies that optimize litter decomposition, ensuring the sustainable utilization of this compost waste (Damasceno, 2012; Leso et al., 2020). Therefore, the objective of this study is to analyze and quantify the rate of mass loss in compost barn manure under different environmental conditions, using conventional cattle manure as a control for comparison. This investigation will consider vital variables like humidity, temperature, and stacking conditions, acknowledged for their substantial influence on the decomposition process. Our hypothesis postulates that elevated (non-extreme) levels of humidity and temperature will nurture vigorous microbial activity, thereby expediting mass loss. Furthermore, we anticipate that reduced stacking will also bolster microbial activity, contributing to escalated mass loss. Through a comprehensive exploration of these factors, we aim to glean valuable insights that will significantly augment our understanding of bedding decomposition within the compost barn milieu. These findings, in turn, will play a pivotal role in shaping sustainable soil management practices, positively influencing agricultural systems and environmental stewardship.

2. Materials and methods

Soils and manure analyzed

In this study, two natural soils classified by the Brazilian Soil Classification System (Santos et al., 2018) were used: one with a clayey texture, classified as Dystrophic Red Oxisol, and another with a sandy texture, classified as Quartzarenic Entisol (Santos et al., 2018). According to the Soil Taxonomy (Soil Survey Staff, 2022), these classifications correspond to Rhodic Haplustox for the Dystrophic Red Oxisol and Quartzipsamments for the Quartzarenic Entisol, which are equivalent and internationally recognized soil orders. The oxisol sample was collected from the experimental area of the Santa Catarina Agricultural Research and Rural Extension Company (EPAGRI/CEPAF) located in Chapecó, SC, Brazil (27°07′39″ S, 57°37′39″ W, at an altitude of 679 m). Similarly, the entisol sample was obtained from Araranguá, SC, Brazil (29°00′19.98″ S, 49°31′03.84″ W). The use of different soils aimed to test their various granulometric and physicochemical characteristics, which may influence soil aeration and other properties, and consequently, the cattle manure decomposition process. Both soil samples were taken from native forest areas, free from pesticide application or agricultural activity, at a depth of 0 – 0.20 m. Regarding the livestock waste, we collected it from a conventional dairy cattle farm in Chapecó (latitude and longitude: 27°00′36.4″ S 52°40′53.8″ W). Additionally, the compost barn bedding was also gathered in Chapecó, SC, Brazil (27°05′39.8″ S 52°34′11.8″ W, at an altitude of 700 m).

In the laboratory, the cattle manure collected were fractionated, and subsamples were taken for assessing chemical attributes. These subsamples were air-dried, sieved through a 2-mm mesh sieve, and subsequently sent to the laboratory. The measured attributes include pH by potentiometric method, indicating the acidity or alkalinity of the samples; humidity by gravimetric method, representing the moisture content; percentages of P_2O_5, K_2O, N, Cu, Zn, Fe, and Mn by Optical Emission Spectrometry, providing insights into nutrient concentrations; carbon (C%) and nitrogen (N%) percentages by elemental analyzer, essential components for organic matter characterization; and the carbon-to-nitrogen (C/N) ratio, offering information on the relative abundance of these two elements.

The soil's chemical characteristics were assessed at the Soil

Analysis Laboratory of the Agricultural Research and Rural Extension Company of Santa Catarina - EPAGRI in Chapecó/SC. Soil samples were dried naturally and then subjected to various analyses, including clay content determined through densitometry, pH measured potentiometrically, phosphorus assessed using the mehlich-1/colorimetry method, potassium analyzed through the mehlich-1/flame photometer method, organic matter quantified via spectroscopy, and aluminum, calcium, and magnesium concentrations determined by KCl/atomic absorption spectrophotometry. These analyses followed the methodology described by (Tedesco et al., 1995).

Experiment one

For this study, we used 500 mL cups as our sample units. These cups were marked at three different heights: 2 cm, 4 cm, and 8 cm. Then, we filled them with either compost barn or conventional livestock waste until reaching the respective marked height. Our experiment comprised two treatments: i) compost barn and ii) conventional, and for each waste height (2 cm, 4 cm, and 8 cm), we had 20 replicates. Out of these replicates, 10 were kept moist, while the other 10 were kept dry, resulting in a total of 120 cups. Half of the cups (60) were maintained at a temperature of 20 °C, and the remaining 60 were placed in a temperature-controlled environment at 30 °C (Fig. 1).

Experiment two

Each sample unit comprised a 500 mL cup containing a mixture of 10 g of soil (either oxisol or entisol) and 10 g of livestock waste (compost barn, conventional waste, or a blend of conventional waste with sawdust). For the basal respiration measurements (microbial activity), the treatments remained the same, but the samples were stored in glass jars. The treatments included i) compost barn, ii) conventional waste, and iii) conventional waste + sawdust. We had 8 replicates for each treatment, with 4 of them kept moist (with the addition of water every 7 days) and the other 4 kept dry, making a total of 32 replicates. These treatments were repeated for each type of soil and under each temperature condition, resulting in 96 replicates in total: 32 for Oxisol at 20 °C, 32 for Oxisol at 30 °C, 32 for Entisol at 20 °C, and 32 for Entisol at 30 °C.

The decomposition experiment took place in temperature-controlled rooms at 20 °C and 30 °C. Regular maintenance was carried out every 7 days, involving precise weighing of the samples using an analytical balance, followed by the addition of 2 mL of water with a pipette to the designated moistening units. The entire experiment spanned a duration of 91 days.

To gauge microbial activity, we employed the basal respiration method for soil (RBS) as described by Alef (1995). The samples were carefully placed in glass jars and stored inside BODs (Biological Oxygen Demand incubators) set at 20 °C and 30 °C, matching the decomposition temperatures,

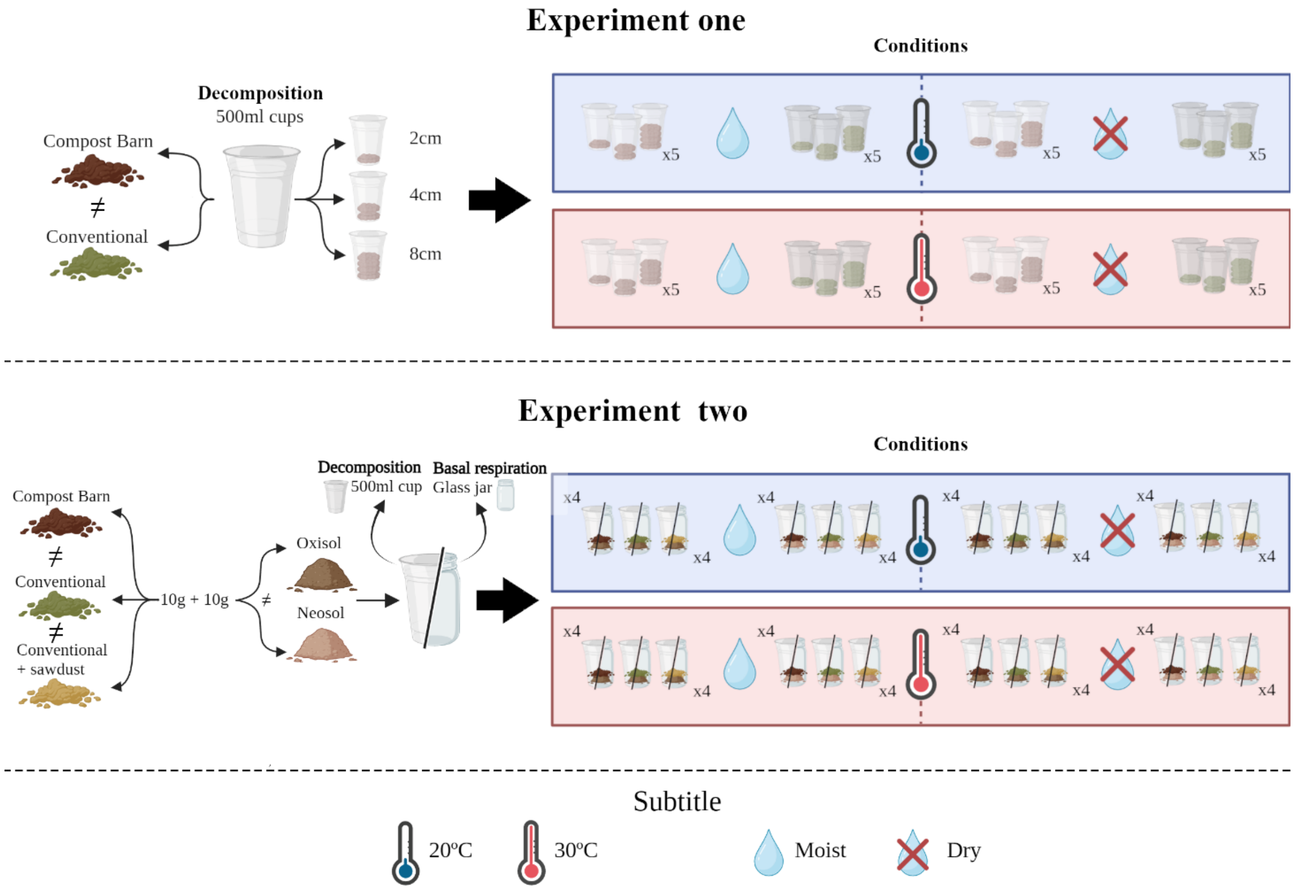

Figure 1. Schematic experimental design of experiment one (a) and two (b).

while ensuring no exposure to light. Daily assessments were conducted by exchanging NaOH containers inside the glass jars and subsequently titrating the samples. Moreover, every 7 days, the sample units that required moisture were provided with 2 mL of distilled water. This microbial activity evaluation phase extended over a period of 14 days, representing the stabilization period.

Statistical analysis

In the experiment 1 we examined differences in manure remaining mass (dependent variables) among temperature room (20 °C vs. 30 °C), water amount (4 mL vs. 0 mL) and depth size (2 cm vs. 4 cm vs. 8 cm) manure type (natural vs. compost barn) treatments and interaction of these factors using factorial Generalized Linear Models (GLM; Binomial distribution with link = logit and test = F in package "*vegan*" and function "*glm*") followed by orthogonal contrast analysis as post hoc tests. In the experiment 2 we examined differences in manure remaining mass (Binomial distribution) and soil respiration (Gaussian distribution with link = log and test = F; dependent variables) among temperature room (20 °C vs. 30 °C), water amount (4 mL vs. 0 mL) and soil type (Oxisol vs. Entisol) treatments and interaction of these factors using factorial GLM followed by orthogonal contrast analysis as post hoc tests.

Contrast analysis was used to assess differences among the categorical variables (Crawley, 2007). In this orthogonal contrast analysis (orthogonal), the remaining mass percentage and respiration of soil of different treatments were ordered increasingly and tested pairwise with the closest values, then sequentially added to the model values with no differences for testing in the next in a steps (i.e., model simplification, for more see chapter 9 of (Crawley, 2007).

Additionally, the manure remaining mass (Binomial distribution) and soil respiration (Gaussian distribution) in the experiment 2 (dependent variables) were tested individually by one-way GLMs among four (compost barn, natural manure, natural manure with razor and only soil) different treatments over every condition of temperature, water amount and soil type followed by Tukey post hoc tests (function "*lsmeans*"). All analyses were carried out in R (The R Core Team, version 4.1.3).

3. Results and discussion

Manure chemical characterization

The compost barn treatment demonstrated a higher pH of 8.3, whereas the conventional treatment had a lower pH of 6.6. In terms of humidity, the compost barn showed a lower percentage at 55.65, while the conventional treatment had a higher humidity level at 66.12 (Table 1). When examining nutrient content, the compost barn displayed higher percentages of P_2O_5 (1.64%), K_2O (1.91%), N (2.28%), Cu (0.0012%), Zn (0.029%), Fe (1.131%), and Mn (0.0121%) compared to the conventional treatment (Table 1).

Additionally, the compost barn exhibited a higher carbon content (46.36%) in contrast to the conventional treatment (33.46%; Table 1). Nitrogen content was also higher in the compost barn (1.4%) compared to the conventional treatment (1.1%; Table 1). The C/N ratio, reflecting the relationship between carbon and nitrogen, was 33/1 for the compost barn and 30/1 for the conventional treatment (Table 1).

Soil characteristics

Entisol exhibited a lower clay content (31%) compared to oxisol (38%). Both soils were slightly acidic, with pH levels of 5 for entisol and 5.1 for oxisol (Table SM1). The soil fertility index was higher in entisol (5.9) than in oxisol (5.5). Oxisol had higher phosphorus content (17.6), potassium levels (316), and organic matter (4.3%) compared to entisol (8.3; 32; 1.6%, respectively; Table SM1). On the other hand, entisol had higher aluminum content (1.2), magnesium content (3.2), sum of exchangeable hydrogen and aluminum ions (7.74), and cation exchange capacity at pH 7.0 (18.83) than oxisol (0.5; 0.3; 4.89; 5.84, respectively; Table SM1).

Table 1. Chemical characterization of the manure used in both experiments, Compost barn and Conventional.

Parameters	Compost barn	Conventional
pH	8.3	6.6
Humidity%	55.65	66.12
P_2O_5%	1.64	1.11
K_2O%	1.91	1.32
N%	2.28	1.64
Cu%	0.0012	0.013
Zn%	0.029	0.012
Fe%	1.131	0.976
Mn%	0.0121	0.0032
C(%)	46.36	33.46
N(%)	1.4	1.1
C/N Relation	33/1	30/1

Oxisol exhibited lower copper (0.4) and iron content (67) compared to entisol (7.9; 59, respectively; Table SM1). Entisol showed a higher zinc content (1.5) than oxisol (12.9). However, oxisol had a substantially higher manganese content (103) compared to entisol (15.6). Oxisol also exhibited a significantly higher sum of bases (58.87), calcium (37.71), and potassium (4.29) than entisol (16.31; 10.27; 1.4, respectively; Table SM1). Both soils showed similar Ca/Mg ratios, with entisol at 2.22 and oxisol at 2.23, influencing soil structure and nutrient interactions. Both soils also exhibited similar Mg/K ratios, with entisol at 3.3 and oxisol at 3.93. The Ca/K ratio was higher in oxisol (8.79) than in entisol (7.33; Table SM1).

Manure decomposition processes

In both experimental scenarios, the compost barn treatment consistently exhibited diminished rates of cattle manure decomposition in contrast to the conventional treatment. This observation implied a reduction in nutrient cycling within the confined environment, attributing the role of a carbon source to the bedding in the compost barn system during the decomposition process (Schogor et al., 2018). However, the heightened carbon source altered the C/N ratio, potentially diminishing microbial decomposition (Schogor et al., 2018). Notably, the compost barn displayed a higher percentage of carbon compared to conventional manure, although the C/N ratios of the analyzed manures were proximate (33/1 and 30/1, respectively).
An intriguing aspect was the compost barn system's integration of aerobic composting even within the barn, achieved through periodic turning of the mixture comprising feces, urine, and bedding material. This practice infused oxygen, fostering intense aerobic microorganism activity (Leso et al., 2020). Consequently, this could augment the cycling of carbon (C), nitrogen (N), phosphorus (P), and potassium (K) from the compost barn bedding during the manure's residence in the composting barn (Damasceno, 2012). Hence, this more advanced stage of decomposition in compost barn manure might elucidate the observed decrease in mass loss when juxtaposed with conventional manure.

Effect of moisture on decomposition

Taking all treatments into account, we observed that the moist treatments had a higher remaining mass compared to the dry treatments (Fig. 2 (a) and (b); Table 2). This pattern held true when analyzing the treatments individually (Table SM2). Specifically, both the compost barn and conventional treatments showed higher remaining mass (mean ± standard deviation) in the moist soil (70.31% ± 11.06 and 53.79% ± 22.77, respectively) compared to the dry soil (66.82% ± 10.59 and 14.18% ± 10.94, respectively).
A similar pattern was observed in experiment two, with higher remaining mass values found in the moist treatments (Fig. 3 and Table 3a). When specifically analyzing the compost barn treatment (Table SM3a), the remaining mass was slightly higher in the moist soil (84.40% ± 6.70) compared to the dry soil (81.90% ± 2.72), though not statistically significant. Both the conventional and conventional sawdust treatments also showed higher remaining mass in the moist soil (82.70% ± 7.87 and 80.26% ± 5.24, respectively) compared to the dry soil (78.82% ± 3.13 and 78.45% ± 2.43, respectively).

Impact of temperature on decomposition

When examining the remaining mass at different temperatures, we observed higher values at 20 °C than at 30 °C (Fig. 2 (b) and (d); Table 2). This trend was also evident in the individual treatments (SM2), with both the compost

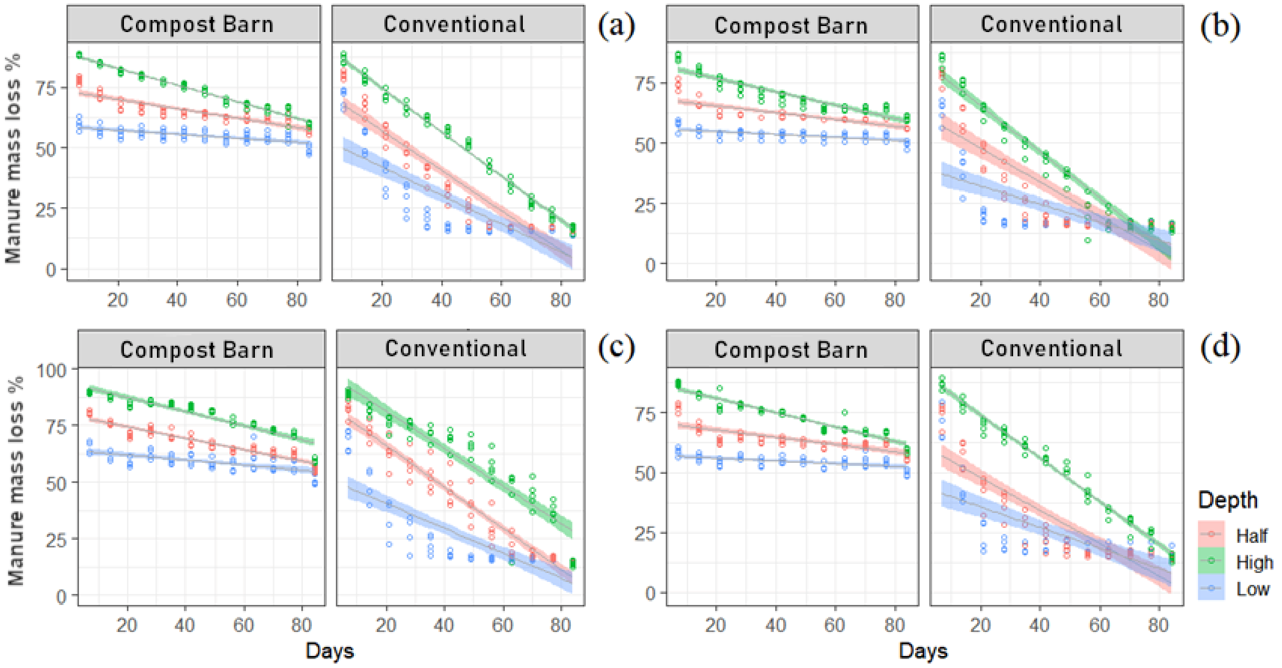

Figure 2. Litter remaining mass (%) of conventional and compost barn over time in days among depth size (2 cm vs. 4 cm vs. 8 cm), temperature (20 °C; a and c vs. 30 °C; b and d), and moisture systems (a and b) by water amount (c and d) treatments.

Table 2. Simplified factorial generalized linear mixed-effects analysis and contrast analyses performed for testing temperature (30 °C and 20 °C), moisture (4 mL and 0 mL of water), layer depth size (2, 4 and 8 cm) and livestock manure (Compost barn and Conventional) on livestock manure remaining mass in a microcosm experiment.

	Df	AIC	BIC	logLik	deviance	χ^2	Df	Pr(> χ^2)	Contrast
Null model	14	10651	10725	-5311.7	10623				
Moisture	26	10572	10709	-5259.8	10520	103.8	12	< 0.001	4 mL < 0 mL
Null model	14	10725	10799	-5348.6	10697				
Temperature	26	10572	10709	-5259.8	10520	177.7	12	< 0.001	30 °C < 20 °C
Null model	10	11580	11633	-5780.0	11560				
Amount	26	10572	10709	-5259.8	10520	1040.4	16	< 0.001	2 cm < 4 cm < 8 cm
Null model	14	12290	12364	-6131.0	12262				
Manure type	26	10572	10709	-5259.8	10520	1742.3	12	< 0.001	Conv < CB
Null model	3	12693	12709	-6343.5	12687				
Interaction	26	10572	10709	-5259.8	10520	2167.5	23	< 0.001	

barn and conventional treatments showing higher remaining mass at 20 °C (71.18% ± 10.96 and 56.49% ± 21.21, respectively) compared to 30 °C (65.96% ± 10.34 and 46.71% ± 22.81, respectively). Crucially, it should be noted that at a temperature of 20 °C, wet manure slowed down the decomposition process. Conversely, under higher-temperature conditions (30 °C), wet manure decomposition accelerated, indicating a context-dependent aspect (Cavallet et al., 2022; Rezende et al., 2023). These findings underscore the significant role of temperature, with lower values favoring dry decomposition and higher values favoring decomposition under moister conditions. Such characteristics advocate for the utilization of the compost barn in climates characterized by higher temperatures and substantial precipitation.

Elevated temperatures assumed a pivotal role in expediting manure decomposition, a phenomenon prominently evident in experiment 2. Temperature stood as a crucial determinant regulating the metabolism of organisms engaged in the decomposition process (Cavallet et al., 2022). Decreased temperatures corresponded to diminished metabolic activity and, consequently, lower rates of decomposition (Imbeah, 1998; Damasceno, 2012). Among the organisms involved in decomposition, thermophilic microorganisms exhibited heightened activity at elevated temperatures (Luísa and Nunes, 2003). A parallel trend, albeit on a smaller scale, was observed for mesophilic microorganisms, which became active at temperatures surpassing 20 °C and displayed optimal activity around 30 °C, fostering swifter and more efficient decomposition (Luísa and Nunes, 2003; Liberalesso, 2017). Hence, a reduction in ambient temperature translated to diminished organism activity (Luísa and Nunes, 2003; Liberalesso, 2017). Lower temperatures can also impede the evaporation of moisture from the manure (Kiehl, 1998), thereby influencing the overall mass loss dynamics.

Stacking height and its influence on decomposition

Regarding the stacking height, we observed that the treatment with the highest stacking (8 cm) resulted in the greatest remaining mass, followed by the intermediate stacking treatment (4 cm), and finally, the treatment with the lowest stacking (2 cm) (Fig. 2 and Table 2). This pattern was consistent across individual treatments (Table SM2), with both the compost barn and conventional treatments showing higher remaining mass at 8 cm (80.56% ± 5.84 and 69.75% ± 12.38, respectively), followed by 4 cm (68.23% ± 5.85 and 51.07% ± 19.20, respectively), and 2 cm (56.94% ± 3.53 and 33.96% ± 19.08, respectively). Finally, the remaining mass (Fig. 2; Table 2 and Table SM2) in the compost barn treatment (68.57% ± 10.95) was higher than in the conventional treatment (51.60% ± 22.53).

Increased stacking height correlated with reduced decomposition of cattle manure. Whether originating from compost barn or conventional systems, cattle manure decomposition was predominantly steered by anaerobic organisms (Damasceno, 2012; Leso et al., 2020). Optimal decomposition was achieved in smaller stacking layers, fostering improved aeration of the manure and promoting microbial activity (Black et al., 2013; Eckelkamp et al., 2016). Conversely, heightened stacking levels may induce moisture accumulation and impede temperature uniformity within the manure. This disparity led to insufficient temperature elevation across all layers, subsequently resulting in a deceleration of the decomposition process (Kiehl, 1998). Hence, the efficiency of compost barn manure decomposition hinged on achieving a delicate balance among multiple influencing factors, including moisture, temperature, and oxygen, in a context-dependent manner. Consequently, alterations in the environment can significantly mold microbial activity and, in turn, influence the cycling of manure (Kiehl, 1998).

Differences in decomposition between entisol and oxisol soils

Finally, the treatments with entisol had higher remaining mass than those with oxisol (Fig. 3 and Table 3a). Specifically (Table SM3a), in the compost barn and conventional treatments, the remaining mass was higher in entisol (83.81% ± 4.40 and 81.67% ± 4.19, respectively) compared

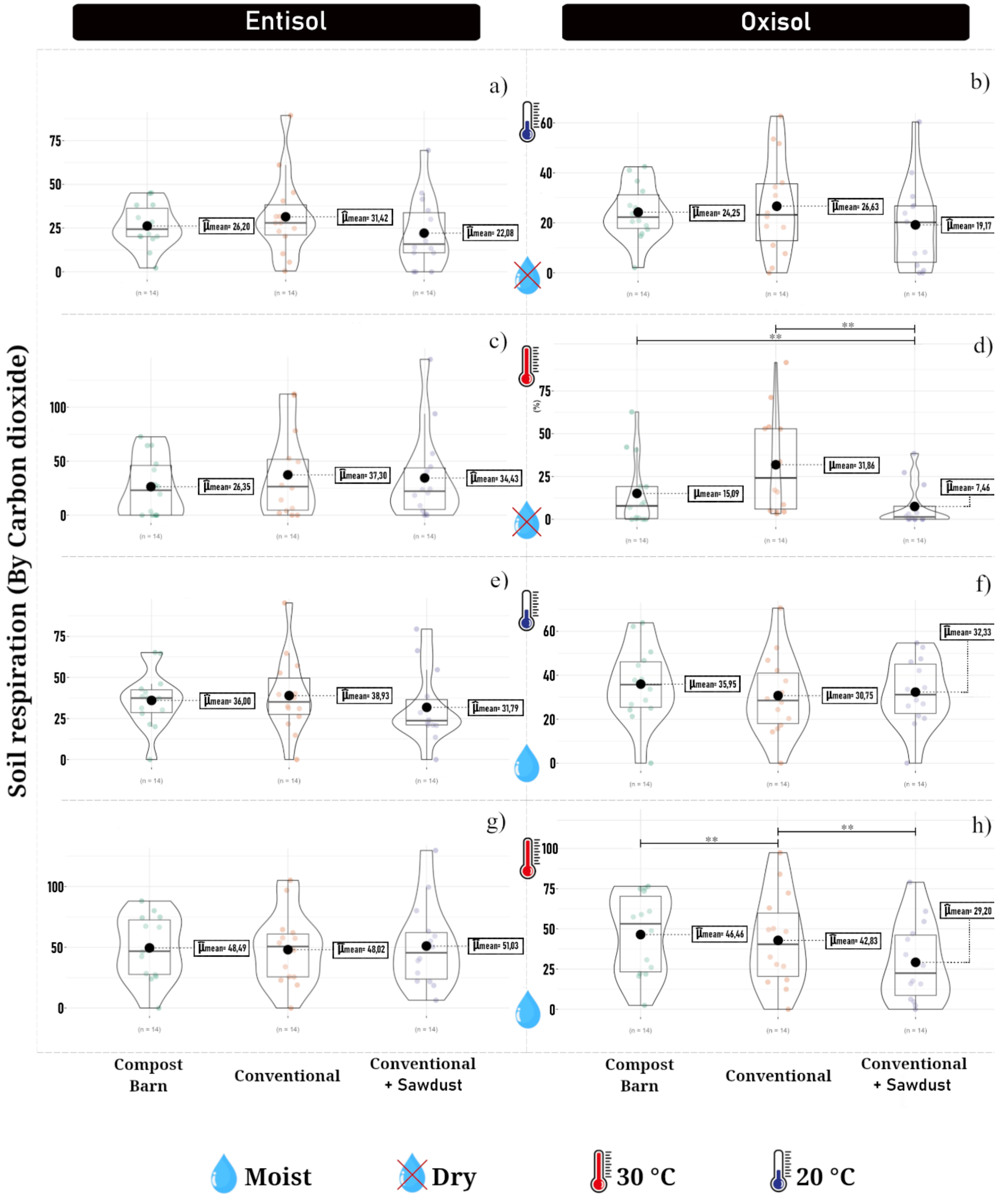

Figure 3. Decomposition by remaining mass (%) of livestock manure from compost barn, conventional, conventional with Sawdust and only soil between temperature (20 °C and 30 °C) and moisture conditions.

to oxisol (82.49% ± 5.94 and 79.85% ± 7.35, respectively). In the conventional sawdust treatment, the remaining mass was similar between oxisol (79.49% ± 4.57) and Entisol (79.21% ± 3.74).

Oxisol exhibited elevated cattle manure decomposition in comparison to entisol. various soil properties, including texture, pH, nutrient availability, and microbial communities, wielded a substantial influence on the decomposition process (Delgado-Baquerizo et al., 2015; Krishna and Mohan, 2017).

The scrutinized soils manifested distinct characteristics, with oxisol constituting a highly weathered soil featuring a

Table 3. Simplified two-way factorial generalized linear mixed-effects analysis and contrast analyses performed for testing moisture (by water amount = 4 mL vs. 0 mL), soil type (Oxisol vs. Entisol), temperature room (30 °C vs. 20 °C) treatments and interaction among these factors on compost barn manure remaining mass (a) and soil respiration (b) in a microcosm experiment. The difference in treatments for each condition is described in the Table SM1 and SM2.

	npar	AIC	BIC	logLik	deviance	Chisq	Df	χ^2	Contrast
a. Remaining mass									
null model	14	7442.5	7473.3	-3715.3	7430.5				
Moisture	26	7251.1	7302.4	-3615.6	7231.1	199.4	12	< 0.001	Moist < Dry
null model	14	7328.5	7359.3	-3658.3	7316.5				
Soil type	26	7251.1	73.02.4	-3615.6	7231.1	85.4	12	< 0.001	Oxisol < Entisol
null model	14	7597.3	7628.1	-3792.7	7585.3				
Temperature	26	7251.1	7302.4	-3615.6	7231.1	354.2	12	< 0.001	30 °C < 20 °C
null model	10	7251.1	7302.4	-3615.6	7231.1				
Manure	26	6936.7	7070.0	-3442.3	6884.7	346.4	16	< 0.001	CL < Conv < CB
null model	3	7696.4	7711.8	-3845.2	7690.4				
Interaction	26	7251.1	7302.4	-3615.6	7231.1	459.2	23	< 0.001	
b. Respiration									
null model	14	2971.2	2994.1	-1479.6	2959.2				
Moisture	26	2918.0	2956.2	-1449.0	2898.0	61.1	12	< 0.001	Dry < Moist
null model	14	2933.4	2956.3	-6087.6	2921.4				
Soil type	26	2918.0	2956.2	-1460.7	2898.0	23.3	12	< 0.001	Oxisol < Entisol
null model	14	2931.5	2954.4	-1459.8	2919.5				
Temperature	26	2918.0	2956.2	-1449.0	2898.0	21.4	12	< 0.001	20 °C < 30 °C
null model	10	2918.0	2956.2	-1449.0	2898.0				
Manure	26	2915.9	3015.2	-1432.0	2863.9	34.1	16	0.005	CL < CB < Conv
null model	3	2990.5	3002.0	-1492.3	2984.5				
Interaction	26	2918.0	2956.2	-1449.0	2898.0	86.4	23	< 0.001	

higher clay content and a porous texture (Santos et al., 2018). In contrast, entisol represented a less developed sandy soil with lower organic matter content (Santos et al., 2018). The heightened clay content in oxisol imparted it with a superior water retention capacity (Santos et al., 2018). This augmented water retention capability likely contributed to the observed higher mass loss values, attributable to increased microbial activity facilitated by heightened moisture levels (Guangming et al., 2017).

Microbial respiration

Microbial respiration showed higher values in the moist treatments compared to the dry ones (Fig. 4 and Table 2b). Specifically (Table SM3b), in the compost barn, conventional, and conventional sawdust treatments, the microbial respiration was higher in the moist soil (41.97 mg CO_2 g^{-1} ± 22.06, 40.13 mg CO_2 g^{-1} ± 25.44 and 36.08 mg CO_2 g^{-1} ± 25.64, respectively) compared to the dry soil (22.97 mg CO_2 g^{-1} ± 18.93, 31.80 mg CO_2 g^{-1} ± 27.97 and 20.78 mg CO_2 g^{-1} ± 26.38, respectively).
Moreover, higher microbial respiration was observed in the treatments with a temperature of 30 °C than in those at 20 °C (Fig. 4 and Table 3b). Specifically (Table SM3b), in the compost barn, conventional, and conventional sawdust treatments, the microbial respiration was higher at 30 °C (34.34 mg CO_2 g^{-1} ± 28.09, 40.00 mg CO_2 g^{-1} ± 31.48 and 30.52 mg CO_2 g^{-1} ± 33.16, respectively) compared to 20 °C (30.59 mg CO_2 g^{-1} ± 15.25, 31.96 mg CO_2 g^{-1} ± 20.98 and 26.24 mg CO_2 g^{-1} ± 19.11, respectively).
Finally, the treatments with entisol exhibited higher microbial respiration compared to those with oxisol (Fig. 4 and Table 3b). Specifically (Table SM3b), in the compost barn and conventional treatments, the microbial respiration was higher in entisol (38.91 mg CO_2 g^{-1} ± 29.28 and 40.00 mg CO_2 g^{-1} ± 31.48, respectively) compared to oxisol (33.01 mg CO_2 g^{-1} ± 24.28 and 31.96 mg CO_2 g^{-1} ± 20.98, respectively).

4. Conclusion

The compost barn treatment consistently showed lower cattle manure decomposition rates compared to the conventional treatment in both experiments. Interestingly,

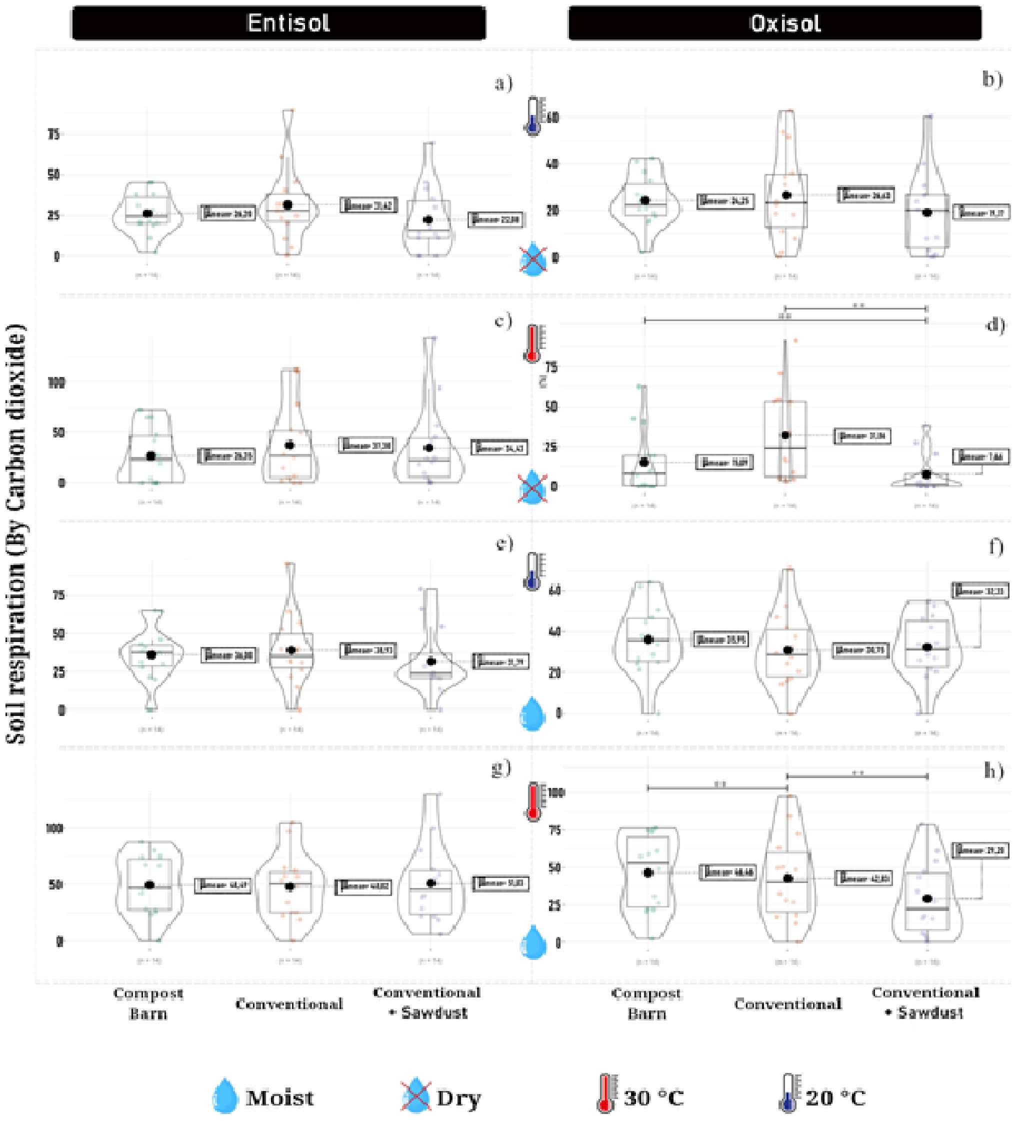

Figure 4. Soil respiration (by carbon dioxide) of livestock manure from compost barn, conventional, conventional with sawdust and only soil between temperature (20 °C and 30 °C) and moisture conditions.

dry manure exhibited higher overall decomposition rates than wet manure, although microbial respiration followed a different pattern. Despite the slightly lower mass loss in the compost barn, our findings indicated a comparable decomposition rate between the compost barn and conventional systems, suggesting the potential viability of compost barn material as a fertilizer. It is crucial to highlight that environmental factors, particularly temperature and moisture, play a significant role in manure decomposition. Therefore, effective management and sustainable practices are essential to optimize the decomposition process and ensure the efficient use of compost barn material in agricultural production, while fostering environmentally conscious practices.

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Authors contributions
CRDMB and RSR conceived the study. WGB, ERS, VFMS, BS and GRD collected field data. RSR managed and analyzed the data. WGB wrote the manuscript with feedback from RSR, CRDMB, ERS, GRD, VFMS and BS.

Availability of data and materials
The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Conflict of interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary material

Table SM1. Physico-chemical parameters of Dystrophic Red Oxisol (Oxisol) and Quartzarenic Entisol (Entisol).

Parameter	Entisol	Oxisol
Clay (%)	31	38
pH (H_2O)	5	5,1
Index SMP[1]	5.9	5.5
P (mg/dm^3)	8.3	17.6
K (mg/dm^3)	32	316
OM[2] **(%)**	1.6	1.2
Al ($cmol_c/dm^3$)	1.2	0.5
Ca ($cmol_c/dm^3$)	0.6	0.3
Mg ($cmol_c/dm^3$)	0.3	3.2
H + Al ($cmol_c/dm^3$)	4.89	7,74
CTC pH7.0	5.84	18.83
Bases (%)	16.31	58.87
Ca/Mg	2.22	2.23
Ca/K	7.33	8.79
Mg/K	3.3	3.93
Cu (mg/dm^3)	0.4	7.9
Zn (mg/dm^3)	1.5	12.9
Mn (mg/dm^3)	15.6	103
Fe (mg/dm^3)	67	59

[1] Index SMP: Buffer Saturation Method (estimates lime needed for acidity correction); [1] OM: organic matter; pH: hydrogen potential; P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium; H+Al: active acidity; Cu: copper; Zn: zinc; Fe: iron; Al: Aluminum; Mn: Manganese.

Table SM2. Simplified one-way generalized linear mixed-effects analysis performed for testing moisture (by water amount = 4 mL vs. 0 mL), soil type (Oxisol vs. Entisol) and temperature room (30 °C vs. 20 °C) among the moisture (by water amount = 4 ml vs. 0 ml) and temperature room (30 °C vs. 20 °C) on manure remaining mass (decomposition; a) and soil respiration (b) among compost barn, natural manure and natural manure with razor.

Condition	npar	AIC	BIC	logLik	deviance	Chisq	Df	Pr(> Chisq)
A. Decomposition								
Dry								
a. 20 °C in Entisol								
null model	3	793.2	802.3	-393.6	787.2			
Treatment	5	659.5	674.7	-324.7	649.5	137.7	2	< 0.001
b. 20 °C in Oxisol								
null model	3	683.7	692.9	-338.8	677.7			
Treatment	5	626.9	642.2	-308.4	616.9	60.8	2	< 0.001
c. 30 °C in Entisol								
null model	3	815.6	824.7	-404.8	809.6			
Treatment	5	730.8	746.1	-360.4	720.8	88.7	2	< 0.001
d. 30 °C in Oxisol								
null model	3	765.7	774.9	-379.8	759.7			
Treatment	5	726.1	741.3	-358.0	716.1	43.6	2	< 0.001
Moist								
e. 20 °C in Entisol								
null model	3	904.5	913.7	-449.2	898.5			
Treatment	5	796.4	811.6	-393.2	786.4	112.1	2	< 0.001
f. 20 °C in Oxisol								
null model	3	953.7	962.8	-473.8	947.7			
Treatment	5	872.6	887.8	-431.3	862.6	85.1	2	< 0.001
g. 30 °C in Entisol								
null model	3	685.9	695.1	-339.9	679.9			
Treatment	5	643.5	658.7	-316.7	633.5	46.4	2	< 0.001
h. 30 °C in Oxisol								
null model	3	967.7	976.8	-480.8	961.7			
Treatment	5	922.2	937.5	-456.1	912.2	49.4	2	< 0.001
B. Respiration								
Dry								
a. 20 °C in Entisol								
null model	3	356.1	361.3	-175.1	350.1			
Treatment	5	355.2	363.9	-172.6	345.2	4.8	2	0.087
b. 20 °C in Oxisol								
null model	3	347.8	353.1	-170.9	341.8			
Treatment	5	348.3	356.9	-169.1	338.3	3.5	2	0.172
c. 30 °C in Entisol								
null model	3	386.4	391.6	-190.2	380.4			
Treatment	5	385.3	394.1	-187.6	375.3	5.1	2	0.079
d. 30 °C in Oxisol								
null model	3	379.6	384.8	-186.8	373.6			
Treatment	5	360.5	369.2	-175.2	350.5	23.1	2	< 0.001
Moist								
e. 20 °C in Entisol								
null model	3	344.8	350.1	-169.4	338.8			
Treatment	5	343.8	352.5	-166.9	333.8	5.1	2	0.080
f. 20 °C in Oxisol								
null model	3	343.1	348.3	-168.5	337.1			
Treatment	5	345.1	353.7	-167.5	335.1	2.1	2	0.344
g. 30 °C in Entisol								
null model	3	365.1	370.3	-179.5	359.1			
Treatment	6	368.5	377.2	-179.2	358.5	0.5	2	0.747
h. 30 °C in Oxisol								
null model	3	370.4	375.6	-182.2	364.4			
Treatment	5	342.1	360.7	-171.1	342.1	2.0	2	< 0.001

Table SM3. Contrast analysis performed for testing moisture (by water amount = 4 mL vs. 0 mL), soil type (Oxisol vs. Entisol) and temperature room (30 °C vs. 20 °C) among the moisture (by water amount = 4 mL vs. 0 mL) and temperature room (30 °C vs. 20 °C) on manure remaining mass (decomposition; a) and soil respiration (b) among Compost barn, natural manure and natural manure with razor.

Condition	Contrast	estimate	SE	Df	t.ratio	p.value
A. Decomposition						
Dry						
a. 20 °C in Entisol						
Compost barn	- Conventional	4.3	0.4	141	11.3	< 0.001
Compost barn	- Conventional + Sawdust	5.3	0.4	141	13.8	< 0.001
Conventional	- Conventional + Sawdust	1.0	0.4	141	2.6	0.029
b. 20 °C in Oxisol						
Compost barn	- Conventional	2.9	0.3	141	8.5	< 0.001
Compost barn	- Conventional + Sawdust	1.8	0.3	141	5.1	< 0.001
Conventional	- Conventional + Sawdust	-1.2	0.3	141	-3.4	0.002
c. 30 °C in Entisol						
Compost barn	- Conventional	1.7	0.5	141	3.5	< 0.002
Compost barn	- Conventional + Sawdust	5.1	0.5	141	10.6	< 0.001
Conventional	- Conventional + Sawdust	3.5	0.5	141	7.1	< 0.001
d. 30 °C in Oxisol						
Compost barn	- Conventional	3.3	0.5	141	7.0	< 0.001
Compost barn	- Conventional + Sawdust	1.6	0.5	141	3.3	0.003
Conventional	- Conventional + Sawdust	-1.8	0.5	141	-3.7	< 0.001
Moist						
e. 20 °C in Entisol						
Compost barn	- Conventional	3.7	0.5	141	7.4	< 0.001
Compost barn	- Conventional + Sawdust	6.5	0.5	141	12.9	< 0.001
Conventional	- Conventional + Sawdust	2.8	0.5	141	5.5	< 0.001
f. 20 °C in Oxisol						
Compost barn	- Conventional	-2.0	0.6	141	-3.2	< 0.005
Compost barn	- Conventional + Sawdust	4.7	0.6	141	7.3	< 0.001
Conventional	- Conventional + Sawdust	6.7	0.6	141	10.4	< 0.001
g. 30 °C in Entisol						
Compost barn	- Conventional	-1.2	0.4	141	-3.2	0.004
Compost barn	- Conventional + Sawdust	1.5	0.4	141	4.0	< 0.001
Conventional	- Conventional + Sawdust	2.7	0.4	141	7.3	< 0.001
h. 30 °C in Oxisol						
Compost barn	- Conventional	6.3	0.8	141	7.5	< 0.001
Compost barn	- Conventional + Sawdust	4.0	0.8	141	4.8	< 0.001
Conventional	- Conventional + Sawdust	-2.3	0.8	141	-2.8	0.016
B. Respiration						
Dry						
a. 20 °C in Entisol						
Compost barn	- Conventional	4.12	4.2	26	0.979	0.597
Compost barn	- Conventional + Sawdust	-5.22	4.2	26	-1.24	0.441
Conventional	- Conventional + Sawdust	-9.34	4.2	26	-2.219	0.087
b. 20 °C in Oxisol						
Compost barn	- Conventional	5.08	4.1	26	1.242	0.440
Compost barn	- Conventional + Sawdust	-2.39	4.1	26	-0.584	0.830
Conventional	- Conventional + Sawdust	-7.46	4.1	26	-1.826	0.181
c. 30 °C in Entisol						
Compost barn	- Conventional	-8.08	5	26	-1.617	0.257
Compost barn	- Conventional + Sawdust	-10.95	5	26	-2.192	0.091
Conventional	- Conventional + Sawdust	-2.87	5	26	-0.575	0.834
d. 30 °C in Oxisol						
Compost barn	- Conventional	7.63	4.3	26	1.765	0.201
Compost barn	- Conventional + Sawdust	-16.77	4.3	26	-3.878	0.002
Conventional	- Conventional + Sawdust	-24.4	4.3	26	-5.643	< 0.001

Continue of Table SM3.

Condition	Contrast	estimate	SE	Df	t.ratio	p.value
Moist						
e. 20 °C in Entisol						
Compost barn	- Conventional	4.21	3.2	26	1.328	0.393
Compost barn	- Conventional + Sawdust	-2.93	3.2	26	-0.925	0.629
Conventional	- Conventional + Sawdust	-7.14	3.2	26	-2.253	0.081
f. 20 °C in Oxisol						
Compost barn	- Conventional	3.62	3.7	26	0.974	0.600
Compost barn	- Conventional + Sawdust	5.2	3.7	26	1.398	0.356
Conventional	- Conventional + Sawdust	1.58	3.7	26	0.425	0.906
g. 30 °C in Entisol						
Compost barn	- Conventional	-1.54	4.1	26	-0.378	0.924
Compost barn	- Conventional + Sawdust	1.47	4.1	26	0.362	0.931
Conventional	- Conventional + Sawdust	3.01	4.1	26	0.74	0.742
h. 30 °C in Oxisol						
Compost barn	- Conventional	17.26	3.2	26	5.338	< 0.001
Compost barn	- Conventional + Sawdust	3.62	3.2	26	1.121	0.510
Conventional	- Conventional + Sawdust	-13.63	3.2	26	-4.218	0.001