



Production cost of composting horse waste at a stud farm in Hokkaido, Japan

Custo de produção de compostagem de resíduos de equinos criados em um haras de Hokkaido, Japão

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ABSTRACT

A Japan's equine industry is mainly focused on horse racing, including breeding and sport. It generates about USD 21.3 billion annually, providing jobs and income, but also produces organic waste that requires proper management for environmental sustainability. This study aimed to analyze the operational cost of composting horse waste at a stud farm located in Hokkaido, Japan. The costs of a composting operation at a Thoroughbred horse breeding facility were assessed, considering waste generated by 152 horses over a period of 121 days. During this period, 54 tonnes of horse waste were processed, resulting in 43.5 tonnes of organic compost ready for use as a biofertilizer. The effective operational costs and total operational costs were allocated throughout the process, and the real cost of the waste was equivalent to the final disposal cost plus the cost of the raw materials that composed the waste, resulting in an estimated final cost of USD 820.70 per tonne of compost produced. The analysis showed that 68.6% of the total is linked to equine breeding, mainly due to labor, welfare, and hygiene costs. While the composting of horse waste offers significant environmental benefits, it requires high initial investment and elevated operational costs.

Keywords: Sustainability; Management; Economy; Organic Compost; Equine breeding.

RESUMO

A indústria equina japonesa é voltada principalmente para as corridas de cavalos, incluindo a criação e o esporte. Ela movimenta anualmente US\$ 21,3 bilhões, gerando empregos e renda, mas também produz resíduos orgânicos que exigem manejo adequado para garantir a sustentabilidade ambiental. O objetivo do trabalho foi analisar o custo operacional da produção de compostagem de resíduos equinos de um haras localizado em Hokkaido, Japão. Foram avaliados os custos operacionais da compostagem na criação de cavalos de corrida da raça 'Puro-Sangue Inglês', considerando os resíduos produzidos por 152 animais ao longo de 121 dias. Nesse período, foram processadas 54 toneladas de resíduos equinos, resultando em 43,5 toneladas de composto orgânico (biofertilizante). Os custos operacionais efetivos e totais foram distribuídos ao longo do processo, sendo que o custo real do resíduo correspondeu à soma do custo final de descarte e do custo das matérias-primas que compunham o resíduo, resultando em um custo final de US\$ 820,70 por tonelada de composto. A análise mostrou que 68,6% do valor está relacionado à criação de equinos, devido aos custos com mão de obra, bem-estar e higiene dos animais. Embora a compostagem de resíduos equinos ofereça benefícios ambientais significativos, exige alto investimento e custos operacionais elevados.

Palavras-chave: Sustentabilidade; Gestão; Economia; Composto orgânico; Equinocultura.

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1 INTRODUCTION

Throughout history, horses have played a crucial role in the cultural, economic, and social development of humanity, having been key figures in activities such as transportation, agriculture, trade, and warfare due to their strength, endurance, and versatility. This close relationship between humans and horses, and their use as a driving force, promoted connectivity between regions and cultures, while also fostering innovation and the growth of various societies (Prins; Gordon, 2023).

The equine industry moves approximately USD 300 billion globally. Although horses are now primarily used for sports and leisure, they still play a relevant role in rural labor (Lindner, 2024). According to the Food and Agriculture Organization of the United Nations there are 56.6 million horses worldwide, mainly distributed across the Americas (55.3%) and Asia (23.6%) (FAO, 2021). In Japan, equine husbandry—especially the horse racing industry—plays a significant role in the economy. The leading organization in this field is a government-affiliated subsidiary that generates approximately USD 21 billion annually in betting revenue, along with USD 340 million in Thoroughbred horse transactions, according to the Japan Racing Association (JRA, 2023).

However, the production of horse waste poses a significant environmental challenge. A stabled adult horse, with an average weight of 453.6 kilograms [kg], can generate 22.7 kg of raw waste daily - including manure and urine - plus an additional 4 to 7 kg from straw or sawdust bedding used in stalls. Thus, one million horses can produce up to 8 million tonnes of waste per year (Elghandour *et al.*, 2019). Improper management of this waste leads to environmental and economic impacts such as soil and water pollution, greenhouse gas emissions, and the proliferation of disease vectors. Moreover, the high costs of disposal and handling become even more critical in areas near urban centers.

With the advancement of environmental technologies and increasing demand for sustainable practices, the utilization of horse manure has gained attention, being used both in organic composting - for fertilization and carbon sequestration—and in bioenergy production through biogas and direct combustion (Yildirim; Açar, 2024). Countries such as the United States (National Institute of Food and Agriculture, 2024) and the United Kingdom (Department for Environment, Food and Rural Affairs, 2021) have implemented policies to encourage sustainable management of horse manure, offering financial support and technical assistance to horse owners and breeders.

In this context, organic composting emerges as a sustainable alternative for transforming horse waste into a nutrient-rich biofertilizer. The application of organic compost to soil provides essential nutrients and stable organic matter, promoting both plant nutrition and the improvement of the soil's physical and chemical properties. The process involves the controlled decomposition of organic matter through the activity of microorganisms, moisture, and oxygen, leading to enhanced soil structure, increased water and nutrient retention, and greater resistance to adverse conditions such as drought and salinity (Khan *et al.*, 2025). According to Zonta *et al.* (2021), horse manure compost has a carbon-to-nitrogen (C/N) ratio of approximately 30:1, as well as high levels of phosphorus, potassium, and essential

micronutrients. This makes it a potentially valuable alternative for improving soil fertility and organic matter content in agricultural systems (Shaji *et al.*, 2021). Despite its environmental and agronomic benefits, compost production involves significant costs related to raw material acquisition, labor, energy, equipment, and other operational expenses. Therefore, this study aimed to analyze the operational cost of composting horse waste at a stud farm located in Hokkaido, Japan.

2 MATERIAL AND METHODS

This study employed the case study method to analyze the production costs of organic compost derived from horse bedding waste at a stud farm located in the coastal municipality of Hidaka, in Hokkaido Prefecture, northern Japan. This methodology was adopted to enable the collection of detailed information and to better understand cost distribution across daily operations, providing support for future decision-making at the facility.

To calculate the operational production costs, the methodology proposed by the Institute of Agricultural Economics (IEA, 2023) was adopted. This approach classifies costs into two main categories using economic indicators: Effective Operational Cost (EOC): includes expenses related to inputs, labor, machinery and equipment operations, as well as administrative costs throughout the production cycle or analyzed period. Total Operational Cost (TOC): includes the EOC plus charges, contributions, taxes, and depreciation of machinery and improvements.

The effective waste management cost was estimated based on final disposal costs combined with the value of the raw materials incorporated into the waste stream. Costs were classified as variable and fixed. Variable costs included expenses related to labor - such as wages, taxes, mandatory insurance, housing, and fuel allowances - in compliance with Japanese labor laws, in addition to bedding inputs, energy/fuel, and administrative expenses. Fixed costs included depreciation of facilities and equipment, calculated using the straight-line method at a 10% annual rate for machinery and infrastructure, without accounting for repair expenses. Local taxes were also considered, applying the standard rate of 1.4% on the assessed value of machinery after statutory depreciation. The results were presented in a table detailing the costs of each operation and component, according to IEA (2023) criteria.

Data collection was carried out through interviews with stud farm operational staff, analysis of financial documents, and direct observation of activities. All values in Japanese yen (JPY) were converted into U.S. dollars (USD), using the 2024 average exchange rate (1 USD = 151.5 JPY, according to Macrotrends, 2024), ensuring comparability of composting and infrastructure operational costs. This research was conducted with voluntary participation and without identifying the respondents.

The study was conducted at a stud farm specialized in the breeding of Thoroughbred racehorses. The farm covers a total area of 360.1 hectares (ha) and includes 10 stable groups, each with 22 stalls measuring 3.5 meters (m) by 3.5 m, totaling 220 stalls that house approximately 180 animals. The study focused on 152 horses, including 50

broodmares, 13 foals at foot (under 6 months), 72 weanlings (6 to 12 months), and 17 yearlings (13 to 24 months), distributed among 139 stalls. Each animal consumed approximately 1.0% to 1.5% of its body weight in dry matter feed per day, along with unrestricted access to water. The farm's staff consisted of 76 employees divided among departments for mare breeding, foal rearing, maintenance, and office work.

The composting area was uncovered and built on a concrete base of 1,500 square meters (m²), bordered by 0.60 m-high retaining walls on three sides. It also included an underground cistern with a capacity of 150,000 liters (L), used for collecting leachate and disposing of pre-treated liquid waste from the septic tanks of each stable. To minimize environmental and sanitary impacts, the composting site was strategically located away from other farm facilities, reducing odors and the presence of pests. Additionally, it was surrounded by an earth berm acting as a natural barrier to prevent soil contamination in adjacent areas.

The agricultural machinery used on the farm and considered in this analysis included a 284-horsepower (hp) front loader, a 125 hp tractor, K-trucks with a load capacity of up to 350 kg, a 1.5 t forklift, a 2 t truck, and a 5,000 L vacuum tanker truck, ensuring operational efficiency at every stage of the process. Bedding materials consisted of wheat straw, purchased in 240 kg rolls, and vacuum-packed wood sawdust pellets in 30 kg packages.

The amount of bedding needed to prepare the stalls before horse entry was determined based on group measurements, yielding average values of wheat straw and sawdust per stall (expressed in kg per stall). The replenishment of materials after stall cleaning was calculated on a global basis, considering total consumption over the study period, without individual tracking per animal or stall. This approach allowed for a practical and representative assessment of input usage, reflecting the farm's routine management practices.

Over the 121-day composting cycle, which began on September 29, 2024, detailed data on waste generation and handling were collected. During the first 61 days - required to fill the composting area with a single windrow - parameters directly related to horse operations were recorded, such as the number of stabled horses per category, stall occupancy duration, frequency and duration of stall cleaning, and daily weighing of removed waste. These data provided a solid foundation for estimating the total volume of material generated.

However, due to the impracticality of measuring individual waste and bedding use, the final waste quantity was estimated at the end of this initial period. This was done by subtracting the total volume of bedding used from the total accumulated waste volume, yielding an approximate amount of manure produced. Throughout the entire 121-day cycle, the waste pile was managed for maturation through moistening, turning, and aeration, ensuring uniform decomposition and the production of organic compost. During this process, the waste gradually lost volume and mass as a natural consequence of decomposition. This principle was used to estimate the final amount of compost produced, taking into account natural losses. Additionally, operation times, machinery use, and labor demands were monitored throughout the cycle, allowing for a detailed analysis of costs and operational efficiency.

2.1 OPERATIONAL PROCESS FOR COLLECTING HORSE WASTE (61-DAY CYCLE)

Stall management involved five main steps: (1) Acquisition and distribution of bedding – included wheat straw, which was stored and distributed weekly, and sawdust, which was delivered directly to the stalls. (2) Manual stall preparation – bedding was arranged according to the specific needs of each horse category. (3) Manual stall cleaning – performed after the horses left the stalls, with waste collected and transferred directly to a K-truck. (4) Waste transport – the waste was transported to the composting area. (5) Bedding replenishment – new materials were manually applied to ensure animal comfort and hygiene. All operations were carried out using standard tools and PPE, including pitchforks, brooms, gloves, and boots.

2.2 OPERATIONAL PROCESS FOR COMPOST PRODUCTION (121-DAY CYCLE)

During the composting process, the windrows were periodically monitored to assess microbial activity and compost stabilization. Under the climatic conditions of Hokkaido, especially during colder seasons, pile turning was generally performed every two weeks between October and May in order to preserve internal heat and avoid excessive temperature loss, which could reduce microbial degradation efficiency. During warmer months (June to September), turning frequency could increase to three or four times per month, particularly during the initial stages of composting, in order to avoid overheating and potential spontaneous combustion events previously observed on the farm.

Temperature monitoring was initiated when approximately 80–90% of the bedding materials, mainly straw and sawdust, showed visible degradation. Measurements were performed weekly using a long-stem thermometer at three different points of the pile (both extremities and the central region). Compost maturity was considered adequate when internal temperatures remained below 40 °C, indicating reduced microbial activity and stabilization of the organic material.

Moisture management occurred primarily through natural rainfall. During dry periods, leachate collected in the underground cistern and pre-treated effluent from stable septic tanks were applied using a vacuum tanker truck to maintain suitable moisture conditions for microbial activity. Due to the operational nature of the farm, analyses such as microbiological characterization and continuous solid reduction monitoring were not routinely performed during the study period. The chemical data of the organic compost derived from horses generated at the stud farm in Hokkaido, Japan, are detailed in the supplementary material S1.

3 RESULTS AND DISCUSSION

3.1 EFFECTIVE OPERATIONAL COSTS (EOC) OF THE COMPOSTING PROCESS

The study examined and evaluated the costs of inputs used for bedding, electricity, labor, and expenses related to transport and fuel. The effective waste management cost included both the expenses associated with final disposal and the value of the raw materials consumed in its formation (Schützenhofer *et al.*, 2022). Initially, the amount of waste produced by the horses was analyzed, considering factors such as age class, number of animals, stall occupancy duration, and bedding type. It was found that waste production is directly influenced by these factors.

The results indicated that mares weighing over 450 kg produced less waste when housed on sawdust compared to wheat straw, especially when the stabling period was shorter. For example, three mares stabled for 12 days on sawdust generated 75.6 kg of waste, whereas six mares stabled for 61 days on wheat straw produced 951.6 kg (Table 1). For mares with foals, wheat straw was used in two scenarios: eight mares with foals produced 302.4 kg of waste in 14 days, while five mares with foals generated 4,672.5 kg in 21 days. These data show that both longer stabling periods and increased daily stall occupancy significantly affected the volume of waste produced.

For weanlings and yearlings, results also varied depending on bedding type and stall conditions. Weanlings housed on sawdust produced 1,573.2 kg of waste over 46 days, while 51 weanlings in wheat straw bedding produced 5,910.9 kg over 61 days. In the case of yearlings, stabling time and daily stall occupancy were decisive: twelve yearlings stabled for 53 days, 18 hours/day, produced 16,281.6 kg of waste, whereas five yearlings stabled for 12 days, only 3 hours/day, produced just 150 kg (Table 1). These data clearly demonstrate that bedding type, number of animals, stall time, and body weight all directly influence the amount of waste generated. Table 1 details the inputs used for stall bedding, which primarily serve to ensure the horses' welfare and facilitate cleaning, always aiming for a balance between efficiency and cost-effectiveness.

Table 1. Classification of equines and waste production data by bedding type in animal stalls, in Hokkaido, Japan

Classification of waste-producing equines	Type of bedding	Number of horses	Days	Stalling time (h)	Initial total amount of bedding (kg)	Total waste generated during the period (kg)
Mares (450 kg+)	Sawdust	3	12	3	360	57.6
Mares (450 kg+)	Sawdust	3	3	3	360	48.6
Weanling (230 kg+)	Sawdust	19	46	3	2,280	1,573.2
Mares with foals (450 kg+ e 100 kg+)	Wheat straw	8	14	3	480	302.4
Mares with foals (450 kg+ e 100 kg+)	Wheat straw	5	21	16	350	4,672.5
Weanlings (230 kg+)	Wheat straw	51	61	3	3,570	5,910.9
Weanlings (230 kg+)	Wheat straw	2	23	16	140	427.8

Classification of waste-producing equines	Type of bedding	Number of horses	Days	Stalling time (h)	Initial total amount of bedding (kg)	Total waste generated during the period (kg)
Yearlings (350 kg+)	Wheat straw	12	53	18	840	16,281.6
Yearlings (350 kg+)	Wheat straw	5	12	3	600	150
Mares (450 kg+)	Wheat straw	6	61	3	420	951.6
Mares (450 kg+)	Wheat straw	25	26	16	1,750	12,480

Source: Original research results

The quantities of bedding inputs used and their contribution to composting were recorded. Over the 61-day period, 41,091.4 kg of wheat straw were used for 127 horses, housed in 114 stalls, at a cost of USD 10,171.12. Sawdust was used on a smaller scale, totaling 4,015.3 kg for 25 horses, accommodated in 25 stalls, at a cost of USD 2,295.21 (Table 2). The direct weighing of both the bedding material used, and the waste removed allowed the determination of the initial quantity needed to line the stalls, as well as the replenishment required after cleaning. Based on these data, the volume of manure was calculated by subtracting the total amount of bedding inputs from the total quantity of waste collected at the end of the stabling period. As a result, it was estimated that the 152 horses directly produced 8,917.5 kg of manure over the 61 days (Table 2). Based on William *et al.* (2020), the direct measurement of bedding inputs and total waste output provides a precise and practical approach to quantifying manure production. This method accounts for both the initial stall lining and the ongoing replenishment required after cleaning. By subtracting the total bedding mass from the collected waste weight, it is possible to isolate the actual manure volume, providing reliable data for waste management planning, nutrient budgeting, and evaluating the efficiency of stall management efficiency.

Table 2. Waste production and associated costs (in USD), according to the type of bedding used in horse stalls over a 61-day period, in Hokkaido, Japan

Type of bedding	Price per kg (USD)	Initial total amount of bedding (kg)	Amount of bedding replenishment (kg)	Total bedding used (kg)	Total waste produced (kg)	Total cost (USD)
Wheat straw	0.25	8,150.0	32,941.4	41,091.4	49,326.8	10,171.13
Sawdust	0.57	3,000.0	1,015.3	4,015.3	4,697.4	2,295.21
Total	–	11,150.0	33,956.7	45,106.7	54,024.2	12,466.34

Source: Original research results

During the 61-day cycle, it was observed that the compost produced on the farm consisted of 76% wheat straw, 7.4% sawdust, and 16.6% manure. The contribution of bedding materials to the compost composition followed the trend reported in most

studies, which indicate that these materials can account for up to approximately 80% of the total collected waste. However, their presence can directly influence the chemical composition of the resulting organic compost (Keskinen *et al.*, 2017). Both the volume and mass of the waste varied throughout the composting process. According to Altieri *et al.* (2004), although the average volume loss during composting is about 40.7%, the average mass loss is 19.4% compared to the initial amount, with compost density varying depending on the inputs used. Based on this principle and considering the total amount of waste obtained (54,024.2 kg), the final organic compost production after 121 days was estimated at 43,543.5 kg.

Labor involved in compost production was divided into two teams. The first team, composed of stable hands (grooms), was responsible for horse care, stall cleaning, and waste transport to the composting area. The labor cost for this team totaled USD 11,926.44, representing 85.3% of total labor expenses. The second team, called the maintenance team, handled machinery operation and composting activities, with a cost of USD 2,045.70 (Table 3). Personal protective equipment (PPE) and tools used varied according to the duties performed. For the stable hands, the PPE kit included a full uniform, straw fork, broom, shovel, protective boots, gloves, and a dust mask, with a total cost of USD 112.00. In the maintenance sector, items included a full uniform, protective boots, gloves, safety goggles, and ear protection, with a total cost of USD 86.00 (Table 3).

Table 3. Labor costs (in USD) during the 121-day horse waste composting process in Hokkaido, Japan

Items	PPEs (USD)	Monthly workload (h)	Hourly cost ⁻¹ (USD)	Total of hours	Total cost (USD)
Groom	112.00	176	14.58	818.00	12,038.44
Maintenance staff	86.00	160	15.22	134.40	2,131.70
Total	198.00	–	–	952.40	14,170.14

Source: Original research results

The cost analysis of machinery use revealed that operations directly related to composting were the main contributors to fuel consumption. The wheel loader represented the highest individual cost, totaling USD 1,139.00, followed by the tractor. Together, these two machines accounted for 87.9% of total fuel consumption. Other equipment, such as the forklift and the K-Truck, used for transporting inputs and waste, incurred significantly lower costs (Table 4). According to Brown *et al.* (2025), intensive turning and material handling operations are among the main contributors to fuel consumption and environmental impacts in composting systems.

Table 4. Fuel costs (in USD) during machinery operation in the horse waste composting process in Hokkaido, Japan

Items	Total use (hours)	Cycle (days)	Total consumption (L)	Total fuel expenditure (USD)
Wheel loader (284 hp)	144	121	1,152	1,139.00
Fork-lift (1.5 t)	17	61	85	84.00
Truck (2 t)	168 km	61	24	23.70
Tractor (JD6125)	11.7	121	117	115.70
Vacuum tank (5,000 L)	11.7	121	–	–
K-Truck (350 kg)	690.7	61	57.6	65.00
Total	–	–	–	1,427.40

Source: Original research results

Finally, electricity costs were associated with the time the horses remained in the stalls and the cleaning time after their departure, over the 61-day cycle. The total electricity cost for the period was USD 2,802.22, resulting from 1,315.6 hours of consumption at a rate of USD 2.13 per hour.

3.2 TOTAL OPERATIONAL COSTS (TOC) OF THE HORSE WASTE COMPOSTING PROCESS

The only facility specifically designed for waste management and organic compost production was the composting area, which met the requirements established by Augustin and Rahman (2022). In the present study, the total construction cost of this 1,500-square-meter facility, built in 2012, was USD 245,544.00, with depreciation of USD 2,312.00 during the study period - an amount higher than some operational components such as fuel or maintenance staff costs (Table 5). The current estimated value of this facility is USD 69,349.00.

The machinery used in the composting operation was part of the existing fleet on the property and was properly cataloged according to its role in composting activities. The acquisition and depreciation costs of the equipment are detailed in Table 6. The initial investment in machinery for composting operations totaled USD 152,980.00, with the current value reduced to USD 47,433.00, reflecting significant accumulated depreciation. Over 121 days of use, total depreciation amounted to USD 1,431.00, and annual taxes were USD 665.60. The most frequently used equipment in composting operations showed the greatest value loss. The wheel loader, purchased in 2008 for USD 44,554.00, underwent heavy wear, with a current value of only USD 8,255.00. In contrast, the K-Truck, acquired in 2019 for USD 4,620.00, maintained a proportionally higher residual value, at USD 2,728.00, due to its shorter usage time. The age and year of acquisition distinctly influence the residual value of each piece of equipment (Table 5).

Table 5. Cost and depreciation (in USD) of machinery used in composting operation in Hokkaido, Japan

Items	Acquisition price	Acquisition year	Current price (USD)	Depreciation (USD)	Annual tax (USD)
Wheel loader	44,554.00	2008	8,255.00	275.20	115.60
Fork-lift (1.5 t)	6,072.00	2007	1,012.00	16.70	18.60
Truck (2 t)	9,900.00	2018	5,261.00	87.70	73.70
Tractor (106 hp)	71,947.00	2013	22,578.00	752.60	316.10
Vacuum tank (5,000 L)	15,887.00	2017	7,599.00	253.30	106.40
K-Truck (350 kg)	4,620.00	2019	2,728.00	45.50	35.20
Total	152,980.00	–	47,433.00	1,431.00	665.60

Source: Original research results

All operational information was compiled into a cost spreadsheet, enabling a detailed analysis of expenditures. Over the 121-day study period, a total of 43,543.5 kg of organic compost was produced from equine waste in Hokkaido. The Effective Operating Cost (EOC) amounted to USD 31,330.10, with labor being the largest component (38.07%), followed by inputs — particularly wheat straw — which accounted for 32.46%. Electricity expenses also had a significant impact (8.94%), highlighting the process's dependence on electric power. Administrative costs, fuel, and personal protective equipment (PPE) contributed a smaller but still relevant share to the overall cost structure (Table 6).

The Total Operating Cost (TOC) was USD 35,738.70, including depreciation of machinery, facilities, and applicable taxes. The depreciation of facilities (USD 2,312.00) and machinery (USD 1,431.00) represented fixed components that reflect the loss in value of initial investments. These values are directly related to the acquisition and installation costs of equipment and infrastructure, underscoring the impact of these investments on the overall cost of operations over time. The ratio between TOC and EOC indicated that most of the composting production costs in Hokkaido are concentrated in daily operations (87.66%), with a smaller share attributed to fixed costs (12.34%). This suggests an operational structure heavily dependent on labor, inputs, and energy. Although fixed costs are relatively low, fluctuations in variable costs can significantly affect the total cost of the activity.

Table 6. Total operating costs (in USD) involved in the horse waste composting process in Hokkaido, Japan

Items	Unit	Cycle (days)	Unit price (USD)	Total (USD)	%
1. Fuel					
Diesel	L	121	0.98	1,362.40	4.35
Gasoline	L	61	1.12	65.00	0.21
2. Office costs (accounting and fees)	–	121	–	464.00	1.48
3. Electrical energy	h	61	2.13	2,802.22	8.94

Items	Unit	Cycle (days)	Unit price (USD)	Total (USD)	%
4. Inputs					
Wheat straw	kg	61	0.25	10,171.13	32.46
Sawdust	kg	61	0.57	2,295.21	7.33
5. Labor					
Groom	h	61	14.58	11,926.44	38.07
Maintenance staff	h	121	15.22	2,045.70	6.53
6. PPEs					
Groom	-	61	-	112.00	0.36
Maintenance staff	-	121	-	86.00	0.27
Effective Operating Cost (EOC)	-	-	-	31,330.10	100.00
Machinery depreciation	-	121	-	1,431.00	-
Facilities depreciation	-	121	-	2,312.00	-
Machinery tax	-	121	-	665.60	-
Total Operating Costs (TOC)	-	121	-	35,738.70	-

Source: Original research results

The organic compost production cost recorded in the present study was USD 820.70 per tonne, a considerably higher value compared to other studies that used wood shavings as bedding material - a lower-cost alternative to wheat straw and sawdust. The study conducted by Fabian *et al.* (1993), with financial values adjusted to current conditions, reported average costs per tonne of USD 126.30 for small-scale operations with up to five horses, USD 62.20 for medium-scale operations with 20 to 25 horses, and USD 19.90 for large-scale operations with 75 horses. In the business plan proposed by Bogardus (2019) for large-scale commercial compost production, the estimated cost per tonne was as low as USD 6.39, using waste from 4,000 horses.

The differences between these values and those observed in the present study can be primarily attributed to the higher cost of bedding materials and the cost of labor in Japan, which accounted for 34.9% and 33.7% of the total composting costs, respectively. In Fabian *et al.* (1993), the bedding material used was wood shavings, currently priced at approximately USD 90.00 per tonne, which significantly reduced production costs. In contrast, Bogardus (2019) sourced waste externally and did not include expenses related to input materials or labor. Additionally, in Japan, there is a need for dedicated composting infrastructure, which may vary depending on production scale (and can sometimes be subsidized by the government), whereas U.S. operations often utilize existing open areas, minimizing facility-related expenses.

Machinery costs for composting also varied significantly depending on the operation scale and technology used. In Bogardus (2019), the total investment in machinery exceeded USD 1,100,000.00, while in the present study, this value was significantly lower, at USD 153,000.00. On the other hand, Fabian *et al.* (1993) reported high variability in equipment costs, depending on the composting method selected. Small-scale systems used conventional agricultural equipment, such as tractors and loaders, with investments below USD 50,000.00, while larger operations required

specialized equipment, such as windrow turners and aerated systems, pushing costs beyond USD 200,000.00.

These cost differences highlight the importance of considering both scale and technology when evaluating composting systems. Regardless of the approach, composting demands significant investment, and structural and operational factors directly affect the final production cost, making it essential to compare systems to understand the specific contributions of machinery, inputs, and labor to the cost per tonne of compost produced (RCDSCC, 2003).

Despite the elevated production cost observed in the present study, the economic evaluation of equine waste composting systems should not be restricted solely to the final market value of the compost produced. In intensive equine production systems, particularly under Japanese conditions, composting also functions as an environmental management strategy capable of reducing liabilities associated with waste accumulation, odor generation, nutrient leaching, and sanitary risks. Therefore, part of the operational cost reflects not only fertilizer production, but also compliance with environmental management requirements and animal welfare standards.

In addition, the high participation of bedding materials and labor costs demonstrates the strong influence of regional production conditions on the economic performance of composting systems. Similar observations were reported by Keskinen *et al.* (2017), who highlighted that bedding type directly affects both operational expenditures and the physical characteristics of the final compost. Studies evaluating livestock waste management systems have also demonstrated that larger-scale composting operations generally present greater economic efficiency due to dilution of infrastructure and operational costs (Pergola *et al.*, 2018).

From a sustainability perspective, composting provides indirect agronomic and environmental benefits that are often not incorporated into conventional economic analyses, including nutrient recycling, organic matter recovery, reduction of environmental contamination risks, and improvement of soil quality. Consequently, the long-term feasibility of these systems may depend not only on direct compost commercialization, but also on avoided disposal costs, environmental compliance, and public incentive policies aimed at sustainable waste management.

From a qualitative perspective, the 121-day period was sufficient to ensure the complete degradation of the waste, transforming it into organic compost. This was made possible through continuous management of temperature, aeration, and moisture during the first six weeks of the process. Proper control conditions promoted the elimination of parasite eggs, insects, and weed seeds (Keena *et al.*, 2022; Ayilara *et al.*, 2020).

The adopted composting management system proved operationally efficient under the climatic conditions of Hokkaido, especially considering the challenges associated with low temperatures during autumn and winter. Reduced turning frequency during colder months likely contributed to the preservation of internal pile temperature and maintenance of microbial activity. Furthermore, the gradual reduction in waste volume and the stabilization of the final compost, evidenced by the

C:N ratio and nutrient composition, demonstrated that the process was technically effective despite the absence of intensive technological monitoring systems.

Laboratory analysis of the compost samples was performed by a certified Japanese laboratory, with results presented in Supplementary material (S1). The compost exhibited high moisture content (74.86%), exceeding the ideal range of 40–60%. The sample showed elevated levels of calcium (2.19%), nitrogen (1.94%), phosphorus (1.54%), potassium (1.25%), and magnesium (0.76%). The recorded pH was 7.48, and the C:N ratio of the moist compost was 21.31, falling within the recommended range for fertilizer use, confirming the efficiency of the decomposition process (Lakhtar *et al.*, 2023; Chen *et al.*, 2023). Furthermore, the presence of micronutrients such as iron, manganese, zinc, and copper was confirmed, with results similar to those found by Zonta *et al.* (2021).

This study has some limitations that should be considered. The analysis was conducted as a single case study under specific climatic and operational conditions in Hokkaido, Japan, which may limit direct extrapolation to other equine production systems. In addition, some operational parameters, such as continuous microbiological monitoring, oxygen concentration, and detailed solid mass reduction throughout the process, were not measured due to the commercial routine of the farm. Nevertheless, the study provides important practical and economic data from a real large-scale equine operation, contributing to the advancement of sustainable waste management strategies in the equine industry. Although the production cost was high under Japanese conditions, the system demonstrated technical feasibility and environmental relevance for sustainable management of equine waste.

4 FINAL CONSIDERATIONS

The operational costs of the equine waste composting process resulted in the production of 43.5 tonnes of organic compost over a period of 121 days, with a total cost of USD 35,738.70, equivalent to USD 820.70 per tonne. The infrastructure investment, which included machinery and the area allocated for composting, totaled USD 398,524.00, with accumulated depreciation of USD 3,743.00 during the study period. It was observed that 68.6% of the total costs were directly related to horse husbandry, mainly comprising bedding material and specialized labor, while the composting process itself accounted for 31.4% of the total costs. Thus, organic compost derived from equine waste proved to be a viable and sustainable alternative, due to both the environmental benefits it can provide and its contribution to improved waste management in equine production systems.

Although the final production cost of USD 820.70 per tonne was substantially higher than values reported in other international studies, the present analysis included costs commonly excluded in previous reports, particularly those associated with animal welfare, labor, bedding materials, environmental management, and infrastructure depreciation. In Japan, especially in Hokkaido, labor costs and bedding

inputs are considerably higher than in many livestock-producing regions worldwide, directly affecting the final operational cost of composting systems.

Furthermore, composting should not be evaluated exclusively from the perspective of direct fertilizer market competitiveness. The system also generates indirect economic and environmental benefits, including reduced costs with waste disposal, mitigation of environmental contamination risks, reduction of greenhouse gas emissions associated with inadequate waste management, and production of an organic soil amendment with agronomic value.

In regions with strict environmental regulations, composting may also represent a strategic environmental compliance measure for equine farms. In some countries, public subsidies and incentive programs partially offset infrastructure and operational costs related to manure management systems, improving the long-term economic feasibility of composting operations.

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SUPPLEMENTARY MATERIAL

S1. Chemical analysis of a sample of organic compost from horses generated at the stud farm in Hokkaido, Japan

Analysis items	Unit	Wet compost	Dry compost
Moisture	%	74.79	-
Total Nitrogen	%	0.49	1.94
Phosphorus (P ₂ O ₅)	%	0.38	1.54
Calcium (CaO)	%	0.55	2.19
Magnesium (MgO)	%	0.19	0.76
Potassium (K ₂ O)	%	0.31	1.25
Ash	%	5.87	23.27
Total Carbon	%	10.46	41.48
C/N ratio	-	21.31	-
pH	-	7.75	-
E.C.	ms cm ⁻¹	1.10	-
Manganese (Mn)	ppm	73.595	291.971
Zinc (Zn)	ppm	41.956	166.449
Copper (Cu)	ppm	6.451	25.593
Iron (Fe)	%	0.11	0.47
Nickel (Ni)	ppm	2.604	10.333
Cobalt (Co)	ppm	0.934	3.705
Nitrate nitrogen	ppm	104.350	413.985
Ammoniacal nitrogen	ppm	500.850	1,987.009
Inorganic nitrogen	ppm	605.290	2,400.990

Source: Hokkaido Prefectural Central Agricultural Station, Japan