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How can nutritional strategies and feed technologies in pig production affect the logistical costs of manure distribution?

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ABSTRACT - The objective with this study was to evaluate the impact of different swine nutritional strategies and technologies, as well as the land spread system, on logistical costs of pig manure distribution. For this, pigs were fed a conventional diet (C0) or a diet supplemented with 0.01% phytase (C1); organic minerals (40% substitution; C2); synthetic amino acids at reduced dietary crude protein levels (C3); or a combination of the three strategies (C4). All pig manure was weighed, then its chemical composition was determined. The mineral values and volume of manure produced were extrapolated to corresponding pig farm sizes in Sao Paulo state (300, 650, and 1000 sows) from real pig manure levels to produce simulations. To determine the logistical cost of manure distribution, two distribution systems were considered: vacuum tank tractor and vacuum tank truck (4.30 and 15 m^3, respectively). The land spread truck system had the highest cost/hour worked due to the higher fuel consumption. However, this cost might be different over greater distances. Manure production, as well as the nutrient levels of N, P, and K, were lower for swine fed diets supplemented with nutritional technologies. Therefore, the different nutritional technologies reduced the transportation and distribution cost of pig manure by reducing the area and, consequently, the distances that need to be traveled for distribution. However, from an agronomic point of view (i.e., to meet a crop fertilization demand per hectare), manure from pigs fed diets supplemented with nutritional technologies had a higher application rate on land.

Keywords: enzyme, organic mineral, swine, waste

Introduction

Nowadays, challenges such as production cost and environmental concerns affect the pig production system. However, the use of dietary techniques and technologies, and the adoption of nutritional strategies in pig nutrition (e.g., reductions in crude protein [CP] levels, enzymatic additives) have led to improvements in pig nutrient utilization, a reduction of nutrient excretion, mainly nitrogen (N) and phosphorus (P), and a reduction of the cost of diets (Boyd et al., 2018; Wang et al., 2018).

In addition, an appropriate manure destination is a concern for producers and a demand from society. When manure is disposed of in an erroneous way, it can be responsible for the eutrophication of water bodies and soil contamination, among other problems (Li and Chen, 2005; Xiong, 2017; Zhang and Chen, 2017). However, manure is a source of nutrients that can be used as organic fertilizer or treated for biogas production (Domingo-Olivé et al., 2016; Yuan et al., 2018).

Pig manure storage techniques before its use for crop fertilization are important to reduce the organic material and microbial charge (Girotto and Chiochetta, 2004). Among various pig manure storage systems, the most common are deep pit, decantation pound, and biodigester (Cardoso et al., 2015). Those systems are efficient in reducing organic material of pig manure and keeping its fertilizer power (Gosmann, 1997), without significant effects in P and K concentration (Vivan et al., 2010).

There are two main steps that impact the cost of manure used as fertilizer: the choice of the manure distribution method, in which a tractor coupled to a distribution tank is the most common (Diesel et al., 2002), and the chemical composition and concentration of manure, mainly in terms of N and P, which define the necessary area for distribution, as well as the distance for crop requirements (Dartora et al., 1998; Martin, 2007).

Thus, if in one hand, the use of nutritional techniques and technologies can bring a benefit in terms of reducing the costs of animal feed (Boyd et al., 2018; Sitanaka et al., 2018), on the other hand, they can interfere in the chemical composition of the manure (Caniatto, 2011; Cowieson et al., 2016), and consequently, in the manure logistical and distribution costs.

From the logistic point of view, although the use of tractors is the most common, due to the availability of this equipment in most farms, the use of trucks can represent an economic gain of scale due to the higher volume of manure that can be loaded (Nolan et al., 2012).

Studies aiming to evaluate manure distribution costs are available in the literature (Konzen, 2003; Pereira et al., 2009; Nolan et al., 2012). However, studies that correlate the impact of the use of nutritional technologies on pig diets with the cost of transport and disposal of manure as fertilizer were not found. It was also hypothesed that the land spread truck system would have a higher initial investment value, but it would be more cost-effective than the traditional vacuum tank tractor distribution system because of its greater transportation capacity.

The objective with this study was to evaluate the impact of different nutritional technologies in pig production on manure transportation and distribution costs to crops, by means of land spread tractor or truck systems, in three pig production scales (350, 600, and 1,000 housed sows).

Material and Methods

The quantity and chemical composition of the manure produced by pigs in each suggested nutritional strategy were obtained from an experiment previously developed by Palhares et al. (2009, 2010); manure production was evaluated for 17 weeks. For this purpose, 80 castrated male pigs (Landrace × Large White; ~ 30 kg initial body weight) were divided into five nutritional treatments based on different nutritional technologies, in an intensive breeding system and conventional sheds.

The five nutritional treatments were as follows: C0 - conventional diet based on corn and soybean co-products, meeting the nutritional requirements of castrated male pigs; C1 - diet C0 supplemented with 0.01% phytase; C2 - diet C0 with the substitution of 40% of the dietary minerals with organic minerals; C3 - diet C0 with reduced CP level, supplemented with essential amino acids; C4 - C3 diet with all previous strategies added (phytase supplementation of 0.01% + 40% substitution of minerals with organic minerals, CP reduction, and inclusion of essential amino acids).

Pig manure composition data were designed to closely simulate the possible real form of residues produced by Brazilian industrial pig farms; for this, the total residues (faeces, urine, wastewater, and possible feed waste) were collected from each pen. Pens were made up of an individual channel, covered by waterproof plastic canvas, coupled to a polyethylene bucket capable of storing all the effluent produced, which was weighed weekly. From 7 to 17 weeks, pig manure samples were analyzed to quantify N, P, K, and dry matter (DM) using chemical analysis; these results were extrapolated to weaned piglets, gestating and lactating sows, and boars.

The experimental data for manure production, as well as its chemical composition, were extrapolated to different scenarios representing three different commercial production scales: small-sized (300 animals), medium-sized (650 animals), and large-sized (1,000 animals) pig farm units. These categories were proposed by the Associação Brasileira dos Criadores de Suínos (ABCS), the institution that represents pig producers in Brazil. The values were considered rational, since 56% of the full-cycle production units in the state of São Paulo included farms of these sizes according to ABCS and Serviço Brasileiro de Apoio às Micro e Pequenas Empresas (SEBRAE) (ABCS and SEBRAE, 2016).

For the simulations of pig manure production, the volumes and calculations proposed by Kunz et al. (2005) were considered in each category, which were: production of 0.0162 m^3/animal/day for gestating females, 0.027 m^3/animal/day for females in maternity, 0.009 m^3/animal/day for males, and 0.0014 m^3/animal/day for weaned piglets. The following productive indices were respected: 2.4 births/sow/year, 11.22 terminated/female/year, and a male-female ratio of 1:20 (Martins et al., 2012).

For extrapolating the volume produced by the growth and finishing sectors, the pig manure volume produced through the previously conducted experiment was used. In addition, 20% pig manure production was added daily, simulating the addition of rainwater, water management practices, and sludge deposited at the bottom of the storage system (Seganfredo and Girotto, 2004; Palhares et al., 2009).

The storage system used in this study was a deep pit for 120 days for the stabilization of organic matter and destruction of pathogens contained in the residue (Gama, 2003; Kunz et al., 2005). In Brazil, among the other storage systems for allocating manure as fertilizer, this is the most accessible (Cardoso et al., 2015). The simulated volumes for manure production and those used for extrapolations are described in Table 1. Therefore, the use of pig manure as fertilizer was estimated to reduce N levels by 50% due to N volatilization (Vivan et al., 2010).

A circular space capable of absorbing the total pig manure was defined, according to the quantity and volume of N present in each proposed condition and scenario. Nitrogen was used as the basis, because it is the most prevalent nutrient in the manure.

For manure distribution, a corn cropland with a production target of 6 t/ha was suggested for use over two periods: at the time of sowing and at cover fertilization, according to the fertilization recommendations of the Instituto Agronômico de Campinas (Aguiar et al., 2014). Thus, the following distributions were suggested: 40 kg/ha of N for the fertilization of corn cropland at sowing and 80 kg/ha of N for the fertilization of corn cropland cover.

To define the pig manure distribution area, the following formula was used:

$$A_i = \frac{QD_i \times MP_{mi}}{\delta_{mt}} \quad (1)$$

Thus, the area A_i required for the distribution of pig manure produced from each condition *i* (C0-C4) was the product resulting from the multiplication between the amount of residue QD_i produced by each condition and the percentage of nutrients MP_{mi} (*m* representing N) present in the pig manure, divided by the nutrient requirement δ_{mt} per hectare of corn cropland. This dose represents the ideal agronomic concentration for crop application.

To define the total area for pig manure distribution, the distance (km) to be traveled for the distribution was determined. At first, it was based on the isolation of the radius (*r*) from the area (A) of a circle, considering each proposed condition and scenario:

$$r = \sqrt{\frac{A}{\pi}} \quad (2)$$

$$D_i = \frac{r_i}{2} \quad (3)$$

In summary, it was suggested that the distance D_i to be traveled by manure distribution vehicles should be considered as the mean radius r_i of the circumference of the defined area for pig manure distribution.

Table 1 - Volume of residues produced and stored in manure weights for different conditions and scenarios

		C0	C1	C2	C3	C4
300 sows	m^3/year	1551.31	1488.87	1487.97	1381.63	1346.74
650 sows	m^3/year	3361.18	3225.87	3223.93	2993.54	2917.94
1001 sows	m^3/year	5176.21	4967.85	4964.86	4610.05	4493.62

Two pig manure distribution systems were considered: a 75-hp tractor coupled to a vacuum tank with a capacity of 4.30 m^3, and a 238-hp truck coupled to a 15 m^3 vacuum tank. Systems were simulated to allow for both the free and open-source manure distribution.

The prices and technical coefficients were collected from the suppliers of the Mesoregion of Campinas, São Paulo, Brazil, following the methodology suggested by the Grupo de Pesquisa e Extensão em Logística Agroindustrial. Prices were converted into US dollars at an exchange rate of US$ 1.00: R$ 2.246.

The vehicle prices used in the simulation were collected from the suppliers of the equipment, as were the prices of the other items used in the cost simulation. In addition, the following conditions were used: price of diesel (US$/L): US$ 1.07, vehicle life of 12,000 h, residual value (US$) of 20%, and maintenance rate of 30% of the value of the useful life. The depreciation value (Dep_i) was estimated by the difference between the price of a new vehicle (Vn) and the residual value (VR_i), divided by the useful life (VU_i) of the vehicle.

$$VR_i = Vn \times 20\% \tag{4}$$

$$maintenance = \frac{(Vn \times 30\%)}{VU_i} \tag{5}$$

$$Dep_i = \frac{(Vn - VR_i)}{VU_i} \tag{6}$$

The conservation cost (CC_i) was defined by the sum of the depreciation and maintenance costs (US$/h):

$$CC_i = depreciation + maintenance \tag{7}$$

The cost of vehicle driver services was estimated to be US$ 346.39 per 160 h worked per month. The estimated labor taxes were 70% of the amount paid. Thus, the estimated value per hour worked was US$ 3.68. The consumption of diesel ($ConsD_i$; L/h) was estimated by multiplying the power of each vehicle (hp) by the constant 0.12:

$$ConsD_i = (hp \times 0.12) \tag{8}$$

Moreover, the cost of diesel (CD_i) was estimated by multiplying the diesel consumed by the price of diesel (PD):

$$CD_i = (hp \times 0.12) \times PD \tag{9}$$

The mechanization costs (CM_i; US$/h) resulted from the sum of the costs of the diesel consumed and the maintenance value for each condition and simulated scenario:

$$CM_i = maintenance + CD_i \tag{10}$$

Finally, the technical cost of transportation (CTT_i; US$/h) was estimated by the sum of labor costs (CMO_i) and mechanization costs (CM_i):

$$CMO_i = \frac{(salary + labour\ benefits + labour\ expenses)}{hours} \tag{11}$$

$$CTT_i = CMO_i + CM_i \tag{12}$$

The area, as well as the distances to be covered by the land spread systems, was determined from the percentage concentration of N in the pig manure samples obtained in the previous study and the extrapolation of the volumes of waste produced. Thus, the first step was to determine the area required for the total absorption of pig manure and, hence, the distance (km) to be traveled according to each condition.

To define the cost of transportation and total pig manure distribution over the estimated area, the first step was to calculate the time taken for all the activities (load, one-way trip, unload, return trip) in hours; later, the value in US$/hour worked for each land spread system was estimated. The second step was to define the average speed employed at each distribution point. At this point, the outward speed was considered to be 25 km/h for both land spread systems and the return speed was increased by 5 km/h, since the tank would be empty (Nolan et al., 2012). The loading and unloading times were also considered in the model, according to the manual operation of the equipment itself. For the land spread tractor system, loading times of 3:20 min were respected, while the unloading times were 4:30 min. For land spread truck systems, the loading and unloading times were considered to be 8:00 min.

To define the cost of pig manure transportation and distribution, the store and corn cropland were both considered in the same area. We followed the methodology of Kunz et al. (2005), without adding the slope of the 35% area. For pig manure distribution by the land spread system, the cost/hour worked for the truck and tractor was US$ 46.44 and 17.17, respectively. The pig manure application rate was 27.3, 29.6, 30.2, 31.4, and 30.3 m^3/ha in the C0-C4 conditions, respectively, considering that these values would meet maize N requirements.

To obtain the land spread system cover area (4.3 or 15 m^3) from the application volume, the method proposed by Zamparetti and Gaya (2004) produced the following values: 1577.6, 1454.75, 1425.61, 1370.51, and 1419.94 m^2 for the land spread tractor system in C0-C4, respectively, and 5502.95, 5070.71, 4973.05, 4780.83, and 4953.27 m^2 for the land spread truck system in C0-C4, respectively.

With the values for the land spread systems and the distance (km) to be covered in each scenario and condition, a one-way trip was considered to be 50% of the total calculated distance, and a return trip was the distance (%) served by one unload subtracted from the space corresponding to the return trip. Thus, the total time spent in each scenario and condition was estimated and multiplied by the cost/hour worked.

It is important to remember that the costs involved in the production and use of manure as fertilizers include the costs of production factors (e.g., diet, water, energy); counterpart of the manure fertilizing power; costs of manure distribution; costs of spreading manure; and costs associated with storage and treatment. However, for the present study, only the logistic cost of waste disposal was assumed.

To determine any possible significant effects from the use of nutritional technologies on pig manure production, pig manure production data were analyzed using the general linear model procedure of SAS (Statistical Analysis System, version 9.2). The data were analyzed for the normality of residues by the Shapiro-Wilk test and the homogeneity of the variances by an ANOVA; when they differed from each other, the data were subjected to a Tukey test at the 5% significance level.

The model was as follows:

$$Y_{ij} = \mu + t_i + e_{ij}, \qquad (13)$$

in which μ is the overall average, Y_{ij} is the dependent variable (pig manure production), t_i is the effect of nutritional treatments (i = C0, C1, C2, C3, C4), and e_{ij} is the random residual.

Results

The animals fed diets supplemented with different nutritional technologies presented lower manure volumes (Table 2), smaller amounts of N, P, and K in the manure (Table 3) and had a lower total area (ha) for manure distribution, compared with animals fed conventional diets (Table 4).

The land spread truck system presented the highest total cost per hour worked in terms of waste distribution, compared with the land spread tractor system (Table 5).

The time for manure distribution was lower for manure from pigs fed diets containing nutritional technologies (Table 6). In addition, the land spread truck system required less time than the land spread tractor system.

Manure from pigs fed diets supplemented with different nutritional technologies had lower logistical and distribution costs (Table 7). In addition, the land spread tractor system had lower logistical and distribution costs than the land spread truck system.

Table 2 - Production of manure (L/animal/day) from growing and finishing pigs fed diets supplemented with different nutritional technologies[1]

	C0	C1	C2	C3	C4	SEM	P-value
Manure produced (L/animal/day)	2.5c	2.3bc	2.2bc	1.9ab	1.8a	0.0001	<0.0001

[1] C0 - conventional diet based on corn and soybean co-products, meeting the nutritional requirements of castrated male pigs; C1 - diet C0 supplemented with 0.01% phytase; C2 - diet C0 with the substitution of 40% of the dietary minerals with organic minerals; C3 - diet C0 with reduced level of crude protein, supplemented with essential amino acids; C4 - diet C3 with all previous strategies added (supplemented with 0.01% of phytase + replacement of 40% of the minerals with organic minerals).

Table 3 - Nitrogen (kg/ton), phosphorus (kg/ton), potassium (kg/ton), and dry matter (%) levels presented in manure of growing and finishing pigs fed diets supplemented with different nutritional technologies[1]

	C0	C1	C2	C3	C4
N (kg/ton)	79.23	71.88	71.01	68.86	69.17
P (kg/ton)	1.01	0.98	0.79	0.97	0.78
K (kg/ton)	4.82	3.83	4.37	4.41	3.90
DM (%)	11.62	13.10	12.00	13.95	14.11

[1] C0 - conventional diet based on corn and soybean co-products, meeting the nutritional requirements of castrated male pigs; C1 - diet C0 supplemented with 0.01% phytase; C2 - diet C0 with the substitution of 40% of the dietary minerals with organic minerals; C3 - diet C0 with reduced level of crude protein, supplemented with essential amino acids; C4 - diet C3 with all previous strategies added (supplemented with 0.01% of phytase + replacement of 40% of the minerals with organic minerals).

Table 4 - Total area (ha) and distance traveled (km) for manure distribution, according to the volume and nitrogen level of the manure of growing and finishing pigs fed diets with different nutritional technologies[1]

	C0	C1	C2	C3	C4
300 sows					
Distance (km)	2.13	2.00	1.98	1.87	1.88
Total area (ha)	56.98	50.24	49.24	43.92	44.39
650 sows					
Distance (km)	3.13	2.95	2.92	2.76	2.77
Total area (ha)	123.05	109.30	107.09	95.68	96.37
1000 sows					
Distance (km)	3.89	3.66	3.62	3.42	3.44
Total area (ha)	190.06	168.25	164.59	146.91	148.63

[1] C0 - conventional diet based on corn and soybean co-products, meeting the nutritional requirements of castrated male pigs; C1 - diet C0 supplemented with 0.01% phytase; C2 - diet C0 with the substitution of 40% of the dietary minerals with organic minerals; C3 - diet C0 with reduced level of crude protein, supplemented with essential amino acids; C4 - diet C3 with all previous strategies added (supplemented with 0.01% of phytase + replacement of 40% of the minerals with organic minerals).

Table 5 - Total cost (per hour worked) between two suggested manure distribution systems

	Land spread tractor system	Land spread truck system
Maintenance (US$/h)	3.87	1.63
Diesel consumption (L/h)	4.01	12.72
Cost (US$/h)	9.66	30.52
Mechanization (US$/h)	13.49	42.76
Labor (US$/h)	3.68	3.68
Total (h)	17.17	46.44

Table 6 - Time (hours) required for pig manure distribution, considering the implemented nutritional technologies[1] and production scale

	C0	C1	C2	C3	C4
300 sows					
Tractor	72.44	67.57	67.33	61.06	59.59
Truck	35.55	33.67	33.60	30.58	29.93
650 sows					
Tractor	190.90	178.89	178.05	161.25	157.07
Truck	85.02	80.53	80.29	73.50	71.42
1000 sows					
Tractor	328.32	305.45	303.23	273.62	267.98
Truck	141.05	132.56	131.74	120.23	117.68

[1] C0 - conventional diet based on corn and soybean co-products, meeting the nutritional requirements of castrated male pigs; C1 - diet C0 supplemented with 0.01% phytase; C2 - diet C0 with the substitution of 40% of the dietary minerals with organic minerals; C3 - diet C0 with reduced level of crude protein, supplemented with essential amino acids; C4 - diet C3 with all previous strategies added (supplemented with 0.01% of phytase + replacement of 40% of the minerals with organic minerals).

Table 7 - Cost of the transportation and distribution of manure (US$/m^3) from pigs fed diets supplemented with different nutritional technologies[1]

	C0	C1	C2	C3	C4
300 sows					
Tractor	0.802	0.779	0.777	0.759	0.760
Truck	1.064	1.050	1.049	1.028	1.032
650 sows					
Tractor	0.975	0.952	0.948	0.925	0.924
Truck	1.175	1.159	1.157	1.140	1.137
1000 sows					
Tractor	1.089	1.056	1.049	1.019	1.024
Truck	1.265	1.239	1.232	1.211	1.216

[1] C0 - conventional diet based on corn and soybean co-products, meeting the nutritional requirements of castrated male pigs; C1 - diet C0 supplemented with 0.01% phytase; C2 - diet C0 with the substitution of 40% of the dietary minerals with organic minerals; C3 - diet C0 with reduced level of crude protein, supplemented with essential amino acids; C4 - diet C3 with all previous strategies added (supplemented with 0.01% of phytase + replacement of 40% of the minerals with organic minerals).

Discussion

The pig manure volumes found by Chávez-Fuentes et al. (2017) corroborate the conventional condition (C0) in this study, reinforcing the efficiency of using nutritional technologies to reduce pig manure volume. In addition, our results suggest that the waste collection method we applied was successful.

Oliveira (1993) determined pig manure production to be 7 L/animal/day with 2.3 L corresponding to feces and 4.9 L corresponding to feces plus urine. It is important to point out that, in this study, waste was considered the feces, urine, feed wastage, and wastewater from the animals' drinking water only; this did not include the water for room washing, as waste was removed mechanically by scraping the structure. Despite our definition of pig manure, a lower production of pig manure, regardless of the treatment, was observed, compared with Oliveira (1993). According to the data presented by Oliveira (1993), 30% of all swine waste corresponds to the unconsumed drinking water used during cleaning operations.

This leads to a discussion about the amount of water, often treated, that is destined to processes that include the cleaning of bays and gutters. Thus, policies that increase awareness about water use, as well as a discussion of strategies aimed at improving water use (i.e., rainwater capitation for less noble purposes) should be discussed with producers for the viability of implementation.

When comparing the nutrient composition of pig manure produced in the different treatments, the manure produced by pigs fed diets with different nutritional technologies presented smaller amounts of N, P, and K compared with pigs fed a conventional diet. The different nutritional technologies led to an average reduction of 0.39 percentage points (pp) for N (with a maximum reduction of 0.61 pp in C3 compared with C0), 0.13 kg/ton for P (maximum reduction of 0.23 kg/ton for C4), and 0.69 kg/ton for K (maximum reduction of 0.99 kg/ton for C2).

Baral et al. (2017) characterized the chemical composition of N, P, and K in the pig manure used in their study, which was 3.68% dry matter (DM) with 3.5, 0.7, and 2.2 g/kg of N, P, and K, respectively, with storage time of 304 days. Oliveira et al. (2001) characterized the chemical composition of pig manure, noting a DM content of 1.6% with N, P, and K at 2.2, 0.6, and 0.9 kg/ton, respectively. Therefore, according to Normative Instruction 11, the storage time of pig manure should be 120 days (FATMA, 2014). Both results present N and K values below the values found in this study. However, it is important to note the difference between the DM of the present study and that of the other works.

It is known that N loss would be expected in manure with higher organic matter due to intense heterotrophic microbial activity (Baral et al., 2017), and the storage time is important to organic matter stabilization (Girotto and Chiochetta, 2004). Thus, when compared with literature data, the higher N concentration in this study is justified for absence of storage time.

It is worth mentioning that from the DM levels presented in the cited references, it is probable that the substrates used by these other authors presented high dilution. This did not happen with the material used in this study, since the waste was removed via scraping, as mentioned before. Diesel et al. (2002) characterized the high degree of manure solubility as one of the main problems in pig manure management. Still, the authors affirmed that the reduction of the volume destined for agriculture makes the use of the manure as organic fertilizer possible, as this presents a greater concentration of nutrients.

According to Nicholson et al. (2015), the highest N concentration in pig manure occurs with higher DM levels; this would justify the higher levels found in this study due to the DM levels presented.

Diets are known to impact the production and composition of pig manure. Bad water management practices in pig production increase manure volume. On the other hand, feeding directly impacts the nutritional composition of manure. In general, both energy and CP unbalanced diets and the excessive use of protein ingredients promote an increase in nutrient excretion, mainly N. The use of nutritional technologies (i.e., feed additives, organic minerals, and synthetic amino acids) and their diet nutritional matrix contribution result in better retention and lower liberation of nutrients in manure.

In summary, nutritional technologies reduced N, P, and K levels of pig manure compared with the conventional diet, probably by improving nutrient retention. In addition, regardless of the condition, pig manure presented higher nutritional levels of N, P, and K compared with the literature, due to the methods used to clean the facilities (scraping) and collect manure. This method reduced the dilution of the material, justified by the high DM values compared with other works, which directly affected the amount of pig manure produced as well as the chemical composition.

It is worth noting that there was a volume 3.5 times greater of pig manure produced in this study than the values suggested for Brazilian pig production, considering that this difference is due to the water used to wash pens. Thus, there is a need for policies and practices aiming at raising awareness about water use.

Given the levels of N and P, the calculated values for the volume produced and accumulated for 120 days of pig manure and the agronomic needs of a corn cropland with an estimated yield of 6 to 8 t/ha, it was possible to estimate the area required for the total absorption of the waste produced and the distance to be covered in the three proposed scenarios, according to each situation.

Manure from pigs fed diets supplemented with different nutritional technologies required a lower total area (ha) for its distribution compared with C0. Therefore, the distance (km) to be traveled for distribution of manure from pigs fed conventional diets was higher compared with the other conditions

(C1-C4). Due to the increase in the amount of N in the pig slurry, as well as an increase in the volume produced, there was an increase in the area required for the absorption of pig manure; the larger the volume and N concentration, the larger the area required for absorption.

However, manure from pigs fed conventional diets required an application rate of 27.2 m^3/ha of pig manure, a lower value compared with the other conditions (C1-C4), which presented application rates of 29.5, 30.1, 31.3, and 30.2 m^3/ha, respectively. This was determined based on the smaller amount of N present in the pig manure from conditions C1-C4, which implied larger volumes of pig manure to meet the simulated agronomic requirement.

Kunz et al. (2009) considered an application of 36 m^3/ha of pig manure for a cropland with an estimated production of 9 t/ha. However, Zamparetti and Gaya (2004) considered a recommended dose of 44 m^3/ha for a corn cropland at an estimate of 100 bags/ha and suggested an adjustment of the application when the mineral doses found in the substrate were not enough to meet the requirements of the cropland. Among the adjustments, the authors recommended a reduction in vehicle speed or a second application to meet the agronomic requirements of corn cropland.

In summary, the use of nutritional technologies and a reduction of the distance traveled for pig manure distribution, due to volume and nutrient composition changes, were influenced by N levels. This implied in higher application rates for the conditions that presented nutritional technologies (C1-C4). On the one hand, simply considering waste as a fertilizer without needing to meet the agronomic requirements of the crops with pig manure alone, the use of nutritional technologies for reducing N levels and the pig manure volume produced would be beneficial, as it would imply less distance to be traveled. On the other hand, the situation changes when trying to meet agronomic requirements only with manure from pigs fed nutritional technologies; in this condition, a greater number of trips would be required because of the lower fertilizing potential of the pig manure.

To calculate the costs of pig manure distribution in corn cropland, two land spread systems were suggested: truck (235 hp) and tractor (75 hp) coupled to a vacuum tank of 15 and 4.30 m^3, respectively. According to the models developed in this study, the land spread truck system presented the highest total cost per hour worked for waste distribution. In general, this cost is proportional to the greater capacity of the simulated system to transport larger volumes, since greater transportation capacity and force result in a higher purchase price and maintenance costs (Table 8). Thus, the total operational cost of the land spread truck system was US$ 46.44/hour worked, which is higher than the US$ 17.17/hour worked of the vacuum tank tractor system.

These values are similar to those found by Sandi et al. (2012). In a cost survey on pig manure transportation and distribution in the upper Uruguayan region of Santa Catarina, the authors determined a value of US$ 53.43 for the truck-drawn system (250 hp), with an average value of US$ 24.71 for tractor-drawn systems (75 hp), differing by US$ 6.99 and US$ 7.54 per hour worked between the truck and tractor systems, respectively.

Two factors were responsible for leveraging the cost per hour worked in this study: fuel consumption and cost of mechanization. At this point, the high operating cost for the land spread truck system is due to the higher fuel consumption, because of the greater power of the truck. This also explains the higher cost of mechanization, since fuel cost is considered in these values. For this value, the land

Table 8 - Cost of agricultural implementation

	Tractor	Tank (4.3 m^3)	Truck	Tank (15 m^3)
New value (US$)	28940.34	8014.25	97951.91	17809.44
Residual value (US$)	5788.07	1602.85	19590.38	3561.89
Depreciation (US$/h)	1.93	0.53	6.53	1.19
Maintenance fee (%)	22.26	13.36	22.26	13.36
Maintenance (US$/h)	1.21	0.20	4.31	0.45
Upkeep/repair expense (US$/h)	3.13	0.73	10.61	1.63

spread truck system presented a value three times higher than the cost of mechanization of the land spread tractor system.

The time spent for manure distribution was lower for pigs fed diets containing nutritional technologies. Moreover, this also led to less time spent by the land spread truck system for pig manure distribution in all proposed scenarios.

The size of the area directly impacted the travel time for pig manure distribution. As discussed earlier, the fact that nutritional technologies provide greater N retention leads to the need for smaller areas for pig manure distribution and, consequently, lower pig manure distribution costs.

The transportation and distribution costs of pig manure in this study were lower than the values observed in a technical report by Sandi et al. (2012). In this study, the costs were US\$ 1.80/m^3 and US\$ 3.34/m^3 for pig manure distribution in subsidized and non-subsidized government units, respectively.

It should be noted that, due to the collection method used in this study, the composition of the pig manure was more concentrated. This reduced the volume required to meet the simulated agronomic requirement, which directly affected the distribution costs. According to Martin (2007), a low dilution of pig manure leads to a lower cost of storage and transportation. In addition, pig manure distribution below 5 kg/m^3 of N becomes unfeasible, independent of the distance to be travelled, according to Seganfredo and Girotto (2004), who compared storage systems and pig manure distribution. The transportation costs in this study were lower due to the higher nutrient concentration/m^3 of pig manure compared with those found in the literature and in the field.

As expected, when comparing land spread systems, the land spread truck system required fewer trips to empty the storage system because of its greater transportation capacity. This directly affected the number of hours required to complete the total pig manure distribution. The greater power of the truck allows it to have a greater force to draw larger volumes of pig manure, reducing the number of trips required for pig manure distribution by 3.5 times. However, the land spread truck system had a higher transportation cost (US \$/m^3), which took twice as long compared with the land spread tractor system.

The large difference in terms of time required and number of trips performed for pig manure distribution according to the proposed method was not enough to alleviate the high cost per hour worked for the land spread truck system. It is possible that the cost reduction would be reversed with a higher travel speed for the land spread truck system. However, based on the scientific literature, there is little data for different speeds between the vehicles simulated in this study.

Carrying out an economic analysis on the means of transportation for manure distribution and treatment options for pig manure in Ireland, Nolan et al. (2012) observed that, at a distance of 14 km, the cost for waste distribution by means of tractor presented a smaller cost (€ 4.70) than that of the truck (€ 4.80). However, this relationship is reversed when comparing the same transportation systems over a 15 km distance, in which transportation by truck is more economically viable (€ 6.20) than the transportation by tractor (€ 7.80).

As expected, our results showed that an increase in the scale of pig production (from the simulations with 300, 650, and 1,000 animals) increased manure transportation and distribution costs exponentially due to the increase in the number of animals and manure production. However, there is a gain in scale for pig manure distribution, due to the greater dilution of fixed costs.

In summary, the different nutritional technologies had a direct impact on the time and cost of transportation and pig manure distribution, due to the higher N retention by the animals. This implies that smaller areas are necessary for the absorption of pig manure and, consequently, less labor is required for the land spread systems.

Moreover, even though the land spread tractor system required double the time for pig manure distribution compared with the land spread truck system, it presented a lower transportation and distribution cost. This is due to the higher hourly cost of the land spread truck system, which is driven by the cost of the fuel. However, in both scenarios, transportation and distribution costs had lower values compared with data from the literature. It is possible that this is a consequence of the lower application rate of simulated pig manure in this study, due to the higher nutrient concentration of pig manure in this study.

Conclusions

The inclusion of nutritional technologies into pig diets reduces pig manure production, as well as the nutrient levels of N, P, and K, compared with the control diet. However, the method used to collect and clean the pens leads to a discrepancy between pig manure production values found in this study and those suggested in the literature, indicating that environmental-educational measures and improvements in the management of water resources are required on pig farms.

The different nutritional technologies reduce transportation and distribution costs of pig manure by reducing the area and, consequently, the distances that need to be traveled for distribution. However, from an agronomic point of view – i.e., to meet a crop fertilization demand per hectare – manure from pigs fed diets supplemented with nutritional technologies has a higher volume of manure application on land.

The land spread truck system presents the highest cost/hour worked in relation to the land spread tractor system, which is driven by higher fuel consumption. Besides, the higher volume transported and, consequently, the less hours worked are not enough to make the land spread truck system more cost-efficient for pig manure distribution at the suggested distances compared with the land spread tractor system, which might be possible at greater distances.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

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