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Revision of the total nitrogen and phosphorus content in a cattle manure-based organic fertiliser in North-West Russia

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This study aimed to verify the applicability of a mass balance method for estimating nitrogen (N) and phosphorus (P) content in the solid organic fertiliser produced from cattle manure in North-West Russia. The study compared the relevant established norms in Russia, the data calculated by the mass balance method, and the average experimental data on N and P content in cattle manure (ex housing) and the organic fertilizer ready to use from the selected cattle-breeding complex with 1250 heads and a manure output of 70 t day^{-1}. Three animal categories were considered. The difference between the calculated and experimental data was 10% maximum but the experimental data and the established norms differed by above 15%. This proves the demand to revise the norms in the Russian regulatory documents to improve the accuracy of fertiliser application rates and the estimation of agricultural land required. Even an increase of 10% in the nutrient content of the organic fertiliser results in an increase in the required agricultural land from 451 to 526 ha for spreading the organic fertiliser from the 1250 heads of cattle at the selected farm.

Key words: excretion, animal manure, organic waste, ecology, treatment, nutrients

Introduction

Cattle manure is a mixture of animal manure, bedding material, and different waters from animal housing, such as washing of feed troughs and manure channels and cleaning of premises. It is a valuable raw material for producing organic fertilisers. However, if it is not properly utilised, it becomes a waste and increases the risk of environmental pollution. An accurate inventory of manure nutrients, total nitrogen (N) and phosphorus (P) in particular, can improve nutrient use efficiency.

Mass balance method is currently a common technique in European countries to estimate the quantity and quality of manure (Poulsen and Kristensen 1997, Gustafson et al. 2007, Keener & Zhao 2008, Walczak et al. 2013, Groenestein et al. 2014, Luostarinen et al. 2017). Other methods include sampling and chemical analysis of manure and various table values produced either from large datasets of analysed manure samples or calculated manure data or both (Luostarinen and Kaasinen 2016).

In the Russian Federation, the numerical values of nutrients (total N, P as P_2O_5, and potassium K) and the moisture content of the cattle manure are specified for all relevant animal categories in the regulatory documents, which describe recommended practices for engineering and designing of systems for manure removal and pre-application treatment (Management Directive 2017, 2020). These values were defined and approved in the 1970s and have not been revised in the reissued documents since. Consequently, they do not adequately reflect all currently applied diets, animal housing systems, and animal productivity (Klementyeva 2017) and their usability is limited to overall estimation of regional manure production at best.

The chemical composition of the bedding material is specified in the regulatory document for engineering and designing of cattle farms and complexes (Management Directive 2018). Bedding material can have a notable effect on manure quantity and quality. The current Russian bedding rates for cattle of 0.5 kg day^{-1} per animal in loose housing with bedding on fully solid floors and 1.5 kg day^{-1} per animal in tied housing with bedding on fully solid floors increase the amount of manure produced. Sawdust with a 22% moisture content is the most widely used bedding material. It features 0.25% N content and 0.13% P content in dry matter and improves the overall manure nutrient content.

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The current cattle manure processing technologies applied in the Russian Federation produce liquid and/or solid organic fertilisers. Passive composting of solid manure on an open watertight concrete pad (no set dimensions given) in piles is the most common practice to obtain a solid fertiliser in North-West Russia. During passive composting manure is mixed with a moisture absorbing material and composted into an organic fertiliser under specified conditions. The piles are structured in triangular heaps with a height of 2–3 meters and a width of 2.5–6 meters, while the length varies. The minimum mass of the composted mixture in one pile is set to be at least 100 tons. Technological passages of at least 2.5–3.0 m wide are provided between the rows of the compost piles. The period of maturing after the temperature has reached 60 °C in all parts of the pile is at least two months in the warm season (May-October) and at least three months in the cold season (November-April). Rainwater and leachate are collected to special facilities.

The resulting product is first verified for compliance with the relevant State Standard (2008) in terms of e.g. total N, P as P_2O_5, dry matter, organic matter, and pathogenic microflora content. The sampling is an obligatory procedure for each organic fertiliser batch on all livestock enterprises. If a farm makes several compost piles, the samples are collected from each pile and a composite sample is taken to the laboratory. In case of compliance, the organic fertiliser can be spread on agricultural land. The application rate is calculated by the total N content and the crop nutrient requirements for the target crop yield. In case of non-compliance, additional processing is required.

Accurately determined quantitative and qualitative characteristics of ex animal manure (animal excrement), ex housing manure (the manure at the exit from the animal house) and ex storage (composted) manure will improve defining more exactly the area of agricultural land required for fertiliser application, optimising the crop rotation-based organic fertilisation and, in the long term, increasing the environmental sustainability of rural areas. On the other hand, knowing the exact amount of N and P supplied to the agricultural land with organic fertilisers will allow estimating the possible diffuse nutrient load on the nearby water bodies. This problem is especially urgent for the North-western Federal District of the Russian Federation since most of its territory is found within the Baltic Sea catchment area and falls under falls under the emission reduction targets of the Baltic Marine Environment Protection Commission (HELCOM 1993) with official targets for nutrient load reductions.

This study aimed to verify the applicability of a mass balance method for more exact estimation of N and P content in the solid organic fertiliser produced from cattle manure in the specialised large-scale livestock complexes in North-West Russia in comparison to other data collection methods, i.e. sampling and chemical analysis and using current established norms.

Materials and methods

The study compared three types of data on the total N and total P content in cattle manure using a pilot dairy farm as an example. The data was collected for cattle excrement (manure ex animal), ex housing cattle manure and an organic fertiliser produced by composting solid cattle manure. The data types were the following:

- Russian regulatory data – the numerical values from the current regulatory documents governing manure management,
- Calculated data – the numerical values obtained by a mass balance method,
- Experimental data – the numerical values obtained by statistical analysis of the sampled and chemically analysed data from a pilot farm.

The total amounts of manure and organic fertiliser were also accounted for using the mass balance method and by counting the trailers of known volume taking manure to the composting pad and the full organic fertiliser applicators spreading the composted organic fertiliser. Comparable values were also calculated with the mass balance method.

The regulatory data

There are two types of relevant regulatory documents in Russia – Management Directives and State Standards. A Management Directive is an advisory document, which regulates the manure quantity and the content of nutrients at ex animal level, but a failure to comply with it has no legal consequences. The Management Directive provides the initial data for calculating the quantitative and qualitative characteristics of the manure-based organic fertilisers ready for use. A State Standard is a mandatory document, which regulates the nutrient and pathogen content in organic fertilisers. This way the recommended data from Management Directives are the basis for calculating the mandatory indicators in State Standards. The discrepancy between the indicators of produced organic fertilisers and the indicators from the State Standards are strictly monitored by the Russian state.

The total N and P content in animal excrement (nutrients ex animal) is specified by the above mentioned Management Directives for dairy cows, heifer calves and heifers (Table 1, Management Directive 2017).

Table 1. Russian regulatory data on total nitrogen and phosphorus content in dairy cattle manure at ex animal level (faeces + urine)

Animal category	Average nutrient content at ex animal level, g animal^{-1} day^{-1}		Average manure quantity, kg animal^{-1} day^{-1}
	$N_{ex\ an}$	$P_{ex\ an}$	
Dairy cows*	205 (faeces 123, urine 82)	48 (faeces 47.1, urine 0.9)	55
Heifer calves	62.3 (faeces 37.3, urine 25)	18.4 (faeces 8.3, urine 0.1)	7.5
Heifers	108 (faeces 60, urine 48)	27.9 (faeces 27.6, urine 0.3)	35

*lactating cows and dry cows

In organic fertilisers ready for use and produced from solid cattle manure, the minimum total N content of 0.3% and P content of 0.09% are required (fresh manure) (State Standard 2008) .

Calculated data

To produce comparable data for an example of a dairy farm, a typical cattle complex located in the Leningrad Region was selected for manure mass balance calculation. The farm's main activities are milk production and cattle breeding (Table 2), it has 1250 heads and its manure output is 70 t day^{-1} (no grazing). The produced solid manure is processed into an organic fertiliser by passive composting on an open concrete pad with sawdust as a moisture-absorbing material to obtain a homogeneous mixture with a moisture content below 75%. The loss of the amount and nutrients (N and P) of ex housing manure and organic fertiliser was calculated with the coefficients resulting from the relevant long-term studies at IEEP. Total nitrogen loss during composting has been estimated at an average of 25% and the total phosphorus loss at 5% (Briukhanov et al. 2019, Uvarov et al. 2019). The data on N loss is supported by observations during many years of research and monitoring of such manure composting. The P was lost with the leachate collected and later used for irrigation of perennial grass.

In the mass balance calculation, the quantity of total nitrogen and phosphorus was calculated for all animal categories listed in Table 2. Then, the average value of total N and P for dairy cows under the three lactation phases was calculated with due account for the duration of lactation period.

The quantity of total nitrogen/phosphorus in excrement per animal was calculated with the mass balance method as follows. The retention of nutrients in animals was subtracted from the nutrients in the feed given to the cattle. The retention of nutrients in milk is for nitrogen N = Protein / 6.38, g kg^{-1} and for phosphorus 0.96 g kg^{-1}. The retention of nutrients in weight gain is for N 25.6 g kg^{-1} gain and for P 6.1 g kg^{-1} gain. The retention of nutrients in fetus is for N 9.6 g kg^{-1} and for P 10.2 g N kg^{-1} (Kaasik et al. 2019). N-losses (NH_3-N) from the animal house were not measured but set at the standard value 10% N in urine used by (Kaasik et al. 2019). The complex supplies 4.5 kg N year^{-1} cow^{-1} and 2.4 kg P year^{-1} cow^{-1} with 1.8 tons cow^{-1} of sawdust as a bedding material annually (Table 3).

Table 2. Initial data provided by the cattle complex selected for the study

Animal category	Number of animals	Housing system	Ration composition				
			Feed rate, kg animal day $^{-1}$	Dry matter digestibility %	Dry matter content, %	Protein, %, dry matter basis	Phosphorus, g kg $^{-1}$, dry matter basis
Lactating cows, lactation phase days 11–90, average milk yield – 34 kg animal day $^{-1}$	215	Tied housing with bedding	48.5	72	48.3	17	4.8
Lactating cows, lactation phase days 91–210, average milk yield – 25 kg animal day $^{-1}$	186		39.2	69	48.5	16	5.1
Lactating cows, lactation phase days 211–300, average milk yield – 18.5 kg animal day $^{-1}$	52		36.9	67	47.2	15	4.8
Dry cows (days 301–365)	359		37.2	68	32.2	17	4.6
Heifer calves (<6 months of age)	203	Loose housing with bedding	6.4	69	36.7	17	4
Heifers (>6 months of age)	235	Loose housing without bedding	23	65	36.7	17	3.6

Table 3. Moisture and nutrients content of applied bedding material

Bedding material	$W_{bedding}$, %	N content in oven-dry substance, %	P_2O_5 content in oven-dry substance, %
Peat	60	1.5–2.0	0.2–0.3
Grain crops straw (chopped)	14	0.5	0.3
Sawdust	22	0.25	0.3

Experimental data

For further comparison, the manure from the farm complex was also sampled for chemical analysis. Manure samples were collected from the housing unit and from the composting pile as shown in Figure 1.

Fig. 1. Sampling places (a = cattle excrement, ex-animal ; b = ex-housing manure, c = organic fertiliser ready for use, ex-storage)

The samples were analysed in the laboratory of analytical methods of environmental engineering of IEEP – branch of FSAC VIM in compliance with the relevant State Standards (State Standard 1985a, 1985b, 2011). These sampling and analysing methods associated with manure and organic fertilisers were consistent with generally accepted European guidelines (Myrbeck et al. 2019, Salo et al. 2020). Samples were collected in three replicants.

In four cattle houses with on average 80 animals each, eight subsamples of excrement were collected for each animal category considered (cows, heifer calves and heifers) and from at least five different places in each lot. The subsamples were then combined into a composite sample by piling on a 2×2 m tarpaulin and shovelling. The laboratory samples of 0.5 kg each were collected from the composite samples for analysis. As a result, 18 laboratory samples of manure were sent to the laboratory: six per each animal category.

The ex housing manure samples were taken from the manure pit of the conveyor or directly from the vehicle transporting manure from the animal houses to the manure storage. They were collected as composite samples similarly as described above and 18 laboratory samples were sent to the laboratory.

Several subsamples of the composted organic fertiliser were taken from the upper, middle and lower layers of the manure pile, with the sections for sampling being pre-selected along the pile length. A manure-sampler (a solid manure auger) gave subsamples of at least 100 g from five points in each layer to a minimum depth of 20 cm from the pile surface (Fig. 2).

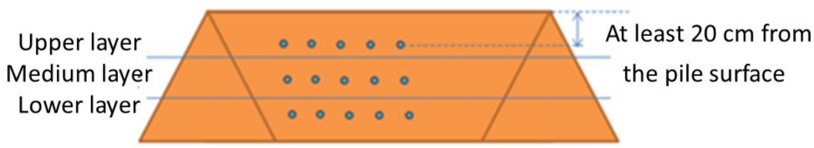

Fig. 2. Sampling points in the manure compost pile

The subsamples were combined into a composite sample by piling on a 2×2 m tarpaulin and shovelling. A laboratory sample of 2 kg was taken from the composite sample for analysis. As a result, three organic fertiliser samples were sent to the laboratory.

The laboratory samples of excrement, ex housing manure and organic fertiliser ready for use were dried, ground and analysed for total N and total P content by the techniques specified in the State Standards (1985a, 1985b). All experimental data were presented as a percentage of fresh material. The experimental data were further analysed in Microsoft Excel and Statgraphics Centurion software packages for the mean values ($\bar{x}$) and SD (σ). The mean accuracy was determined by Student's t-test.

The total amounts of manure and organic fertiliser were also accounted for using the mass balance method and by counting the trailers of known volume taking manure to the composting pad and the full organic fertiliser applicators spreading the composted organic fertiliser. The manure mass was estimated using the average manure density of 0.85 kg m^{-3}. This value was taken from the regulatory manure management documents and supported by the long-term examining of cattle complexes with similar manure removal and processing practices. Comparable values were also calculated with the mass balance method.

Results

Animal excrement (ex animal manure)

The results of comparing the N and P content of cattle manure at ex animal level in the established Russian norms concerning all cattle farms and the calculated data (mass balance method) and average experimental values (analysed samples) for the pilot cattle complex are presented in Table 4. The lowest N and P content is given in the norms, while the experimental data measured on the pilot farm were between the norms and the calculated values for the same farm.

Table 4. Total nitrogen and phosphorus content in cattle manure at ex animal level (fresh manure)

	Dairy cows (DM=14.8%)	Heifer calves (DM=20%)	Heifers (DM=16.5%)
Established norms N, %	0.37	0.83	0.36
Calculated data N, %	0.55	0.98	0.74
Average experimental data N, % $\bar{x}$	0.49	0.88	0.61
$\bar{x} + \sigma$	0.54	0.95	0.66
$\bar{x} - \sigma$	0.44	0.81	0.56
Established norms P, %	0.09	0.14	0.1
Calculated data P, %	0.12	0.16	0.11
Average experimental data P, % $\bar{x}$	0.11	0.15	0.10
$\bar{x} + \sigma$	0.13	0.20	0.14
$\bar{x} - \sigma$	0.09	0.10	0.06

$\bar{x}$ = the mean value; σ = the square from variance, SD

Manure at ex housing level

The results of comparing the calculated data and average experimental values for total nitrogen and phosphorus content in the manure at ex housing level are presented in Table 5. The calculated data exceeded the experimental data by 10% maximum for total nitrogen and 5% maximum for total phosphorus in the dairy cattle complex. No data is available for this level in the norms.

Table 5. Total nitrogen and phosphorus content in cattle manure at ex housing level (fresh manure)

	Dairy cows (DM=19.1%)	Heifer calves (DM=23%)	Heifers (DM=21.5%)
Calculated data N, %	0.52	0.34	0.42
Average experimental data N, % c	0.46	0.27	0.33
$\bar{x} + \sigma$	0.50	0.30	0.38
$\bar{x} - \sigma$	0.42	0.24	0.28
Calculated data P, %	0.21	0.15	0.18
Average experimental data P, % $\bar{x}$	0.19	0.10	0.17
$\bar{x} + \sigma$	0.22	0.13	0.20
$\bar{x} - \sigma$	0.16	0.07	0.14

Organic fertiliser (manure at ex storage level)

The results of comparing the established norms, calculated data and the experimental values for the total nitrogen and phosphorus content in the cattle manure at ex storage level are presented in Table 6. Experimental values were analysed from an organic fertiliser from passively composted manure on the selected cattle complex. The difference between the calculated and the experimental data was below 10%. The discrepancy between the respective experimental data and State Standard norms reached 15%. The discrepancy between the calculated data and established norms was even higher, being 23%.

Table 6. Total nitrogen and phosphorus content in the organic fertiliser produced by composting solid cattle manure (manure at ex-storage level) (fresh manure)

	Organic fertiliser, N (DM=24.5%)	Organic fertiliser, P (DM=24.5%)
Established norms , %	0.3	0.09
Calculated data, %	0.4	0.18
Average experimental data, % $\bar{x}$	0.35	0.16
$\bar{x} + \sigma$	0.37	0.19
$\bar{x} - \sigma$	0.33	0.13

Discussion

Comparison of the calculated and experimental manure data from a dairy cattle farm with the established norms for average Russian dairy cattle manure showed that the established norms were too low to describe current dairy cattle production in Russia. The norms are from 1970s and the change in animal diets and the upgrade of the applied feeding, housing and manure processing technologies since then have resulted in an increase in the nutrient content in ex animal and ex housing level manure as well as in the organic fertiliser produced.

The experimental data differed from the calculated data by 10% at maximum indicating the applicability of the mass balance calculation method in the North-West Russia. However, the difference between the established norms and the calculated data was above 25% for total N and above 18% for total P indicating the need to update the norms on the scientific basis, using modern calculation methods and experimental research.

Inaccurate sampling might also account for the some of the discrepancy between the experimental and calculated data. With nitrogen, the difference might come from N emission during sampling and analysis and also the estimation of N losses in the mass balance calculation (Luostarinen et al. 2018). For analysis, certain amount of nitrogen evaporates during drying of the samples. Evaporation also takes place at ex animal, ex housing and ex storage level. The losses during ex storage measures are considerably bigger than for the other steps in the manure management chain. These losses were included in the calculations according to EMEP/EEA emission principles (EMEP/EEA 2016).

The issues associated with manure nutrients have been the subject of much research in different countries with compatible results to the present study (Bewick 1980, Peters 2003, Poulsen et al. 2006, Hristov et al. 2009, Luostarinen et al. 2018, Kaasik et al. 2019). The accurate nutrient accounting in fresh manure and in manure-based organic fertilisers may contribute, e.g. to avoiding excess organic fertilisation of agricultural land, tracking the nutrient flow in functioning livestock complexes along the manure management chain, and ensuring the long-term sustainable functioning of livestock enterprises. Thus, the more precise and updated the data on the nutrient content in manure and manure-based organic fertilisers is, the better it supports accurate application rates and adjusts the need for the agricultural land correspondingly. This underlines the need to update the established Russian norms for manure nutrient content according to the current findings.

For example in this study, it was estimated that the pilot dairy cattle complex with the animal stock of 1250 heads would require the following agricultural land area to apply all the produced solid organic fertiliser (25550 t year $^{-1}$ under the nitrogen limitation of 170 kg ha $^{-1}$) depending on the data source: established norms: 451 ha; calculated nutrient content: 601 ha; and experimental nutrient content: 526 ha.

Thus, even a 10% difference in the value used for nutrient content in the organic fertiliser results in a significant increase in the required agricultural land from 451 to 526 ha. At the same time, the excessive organic fertilisation increases the risk of diffuse nutrient load to the nearby water bodies.

To improve the precision of manure use as a fertiliser and to reduce the loss of nutrients into waterways, additional studies with several other animal categories and more farms should further be conducted to reach sufficient data to update the Russian established norms.

An update of the Russian established norms could also assist in reaching the international targets set. According to the Country Allocated Reduction Targets of the HELCOM Baltic Sea Action Plan, Russia needs to reduce N input to the Baltic Sea by 10380 tons and P input by 3790 tons (HELCOM 2012, 2017). The progress should be measured by modern monitoring methods and enhanced calculation models that reliably reflect the impact of all pollution sources. The results of this study provide for a more accurate estimation of nutrients flow in farming and, consequently, for more efficient decision-making associated with the measures to reduce the nutrient load on the environment. This way it will contribute to achieving the HELCOM target indicators set for the Russian Federation.

Conclusions

The established Russian norms were the lowest in nutrient content for all cattle manure considered in this study and the difference to the experimental and calculated data was significant being the largest between the norms and the calculated data. This supports the conclusion of a need to update the Russian established norms to describe current animal production. When comparing the two methods of producing data on manure nutrient content, the calculated and the experimental data on N and P deviated only by below 10% in all cattle categories considered. Currently, the Russian large-scale farms must verify the compliance of fertiliser quality to the State Standards by certified chemical analyses including N, P and dry matter content. Comparing the present calculated data with the experimental ones showed that the calculation method could also be used for this verification and might improve the precision still. However, as the data presented here is only for one dairy cattle complex in only three animal categories, additional detailed studies are required also for other farm animal categories to prove the need to revise all the established norms from the regulatory documents. The issue is important as improved and updated knowledge on total N and P content in animal excrement and the resulting manure or manure-based fertiliser products will be beneficial to calculate the nutrient balances for the livestock complexes, to refine their manure management plans, and to keep a complete record of the farm nutrient flow.

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