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NEEDS FOR INCREASING THE STORAGE INFRASTRUCTURE FOR MANURE IN POLAND IN THE LIGHT OF THE REQUIREMENTS OF THE NEW ACTION PROGRAMME TO IMPLEMENT THE NITRATES DIRECTIVE

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ABSTRACT: The aim of the research was to determine the need to increase the infrastructure for storing livestock manure in Poland in groups of farms divided on the basis of the number of animal herds. Using individual data from Statistics Poland and using the balance method, the maladjustment of the infrastructure to the new legal requirements regarding the storage of manure was estimated. It was determined that meeting the standards included in the new action program in force in the country under the Nitrates Directive will require the construction or expansion of manure plates with an area of 2,539.6 thousand m^2, new tanks with a capacity of 3,437.2 thousand m^3 and covering the existing ones with a capacity of 3,170.6 thousand m^3. Total investment costs were estimated at PLN 5,907,913.40 thousand, i.e. approximately EUR 1.4 billion. The requirements in force for most entities since January 1, 2025, will bring far-reaching changes, leading to the concentration of animals in very large herds and deepening the regionalisation of production. Both positive and negative effects of this process on the natural environment were indicated.

KEYWORDS: livestock farms, manure storage, slurry, environmental impact, legislation

Introduction

In the process of food production on farms, by-products are produced, among which animal excrements and their mixtures with bedding material and water may have a significant impact on the natural environment. On the one hand, they are a rich source of nutrients for plants and, therefore, a desirable fertiliser of natural origin, which is an important element of a closed-cycle economy in agriculture that influences the volume of crops (Cai et al., 2019; Cassman et al., 2003; Edmeades, 2003; Rutting et al., 2018; Soliwoda et al., 2020). At the same time, they are a significant source of water eutrophication in the country and the region (Batool et al., 2022; Eriksson et al., 2007; Baltic Marine Environment Protection Commission, 2023; Neverova-Dziopak, 2021; Pastuszak et al., 2018) and are responsible for the emission of ammonia (NH_3), nitrous oxides and nitrous oxide (N_2O), methane (CH_4) and other volatile compounds (Dourmad et al., 1999; Ijaz et al., 2023; Leip et al., 2015; Oenema et al., 2009; Velthof et al., 2014; Webb et al., 2012).

However, the use of by-products of animal breeding as a source of nutrients for plants in our country is only possible periodically, which, given the almost constant amount of their production (keeping animals in buildings all year round) or the increased amount of collection outside the grazing period, necessitates their long-term storage (Gaj, 2018; Pietrzak, 2013). However, the process involves losses of components, which, depending on the conditions of manure collection and storage, can be enormous and have a very negative impact on the quality of water, soil within and around the storage area, air, and the amount of gas emissions, including greenhouses.

An important factor influencing the formation and intensity of point pollution and the possibility of using the potential of livestock manure (hereinafter referred to as manure) is the method of their storage and processing in entities collecting and using them (Amon et al., 2001; Blanes-Vidal et al., 2008; Dennehy et al., 2017; Hartung & Phillips, 1994; Kierończyk, 2012; Kierończyk & Marcinkowski, 2015; Köninger et al., 2021, Owen & Silver, 2015; Petersen, 2018; Pietrzak & Nawalany, 2008; Pietrzak et al., 2018; Sapek & Sapek, 2006; Smurzyńska et al., 2016; Sørensen et al., 2019).

The problem of negative external effects related to the storage of manure was so important that it was noticed by the EU legislator (including the Nitrates Directive, 1991), as well as the national legislator (Act, 2007), and storage conditions have so far been the subject of changing legal regulations in force in Poland. At the same time, due to the significant shortcomings of farms in having and using appropriate infrastructure for storing natural fertilisers, significant public funds were involved to support investments in the area.

The aim of the research was to determine the structure and amount of natural fertilisers depending on how they are stored on farms. Based on data from Central Statistics Office (CSO) (SP), using the balance method, the main aim was to determine how many entities and to what extent the infrastructure for storing natural fertilisers is not adapted to the requirements of the action program introduced in the country under the Nitrates Directive. The research estimated the amount of manure stored in violation of applicable legal requirements or program regulations coming into force on January 1, 2025, at the latest. Simulations were also performed to determine what level of infrastructure for storing manure is necessary to meet all legal requirements, assuming no reduction in animal numbers. The costs that agricultural farms will have to bear as part of the adjustment in this respect were also estimated.

Studying the effect of implementing normative recommendations intended to reduce the pressure of farms on the natural environment positions them in the mainstream of normative ecological economics (Śleszyński, 2022). However, the main focus was on identifying the technical and economic consequences of legal regulations and the interactions that may arise as a result of them between the natural environment and the functioning and development of individual groups of farms and, more broadly, the agricultural sector in Poland. Due to the way the research is conducted, it should be placed in the field of environmental economics (Borys, 2013; Venkatachalam, 2007).

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An overview of the literature

The scope of equipping farms with infrastructure for storing manure in Poland has been the subject of numerous studies and research. However, they concerned only groups of farms located in specific regions of the country (Kopeć & Gambuś, 2008; Kowalewska et al., 2009; Kruszyński, 2012; Kupiec, 2023; Kupiec & Zbierska, 2007; Kuś & Kopiński, 2006; Wasilewski, 2005), with a specific production focus (Szymańska, 2012; Wierzbicki & Krajewski, 2004), or were based on the opinion of agricultural producers themselves (Wrzaszcz, 2012). Calculations for the entire population were made based on the authors' estimates resulting from their expert knowledge (Lipiński, 2012; Romaniuk & Wardal, 2006), had covered the period before significant changes in legal regulations were introduced in the country (Kagan, 2016) or did not take into account the changes taking place in recent years in agriculture itself and changes in investment costs (Kagan, 2017).

Research on the issue was also conducted in other EU countries. It concerned the diversification of equipping farms with buildings and structures for storing manure (Hennessy et al., 2011; Loyon, 2018; Eurostat, 2013), indicated the necessary adjustment expenditure on infrastructure and the scope of burdens on farms resulting from the costs of compliance with regulations regarding the storage of manure (EPA, 2016; Report, 2013; Menghi et al., 2015; Kuhn et al., 2019; Sommer & Knudsen, 2021; Sutton et al., 2015; Thorsøe et al., 2022; Wagner et al., 2017).

The presented research results for Polish farms are based on the most currently available data, organise the available information, and take into account current conditions. From a utilitarian perspective, they provide knowledge to all stakeholders (especially political decision-makers) not only about the deficiencies in the infrastructure for storing manure but also about the potential costs of adaptation investments and the expected effects on the processes taking place in agriculture.

Selected determinants of infrastructure for storing manure

Of significant importance for the legal provisions currently in force in Poland regarding the storage of manure and their territorial scope was the judgment of the Court of Justice of the European Union of November 20, 2014, in which it was found that Poland had insufficiently designated nitrate pollution hazard zones, which constituted a breach of the Nitrates Directive (Łacny, 2017). Poland's incorrect implementation of this directive resulted in the abolition of Particularly Vulnerable Areas, and since 2020, the entire country has been covered by an action program to reduce nitrate pollution (Kopczyńska, 2022; Szalińska et al., 2018).

According to the legal regulations currently in force in Poland, from 2020 onwards, farms breeding animals or importing manure from other entities should have slurry tanks with tight walls and bottoms, which should be covered with a flexible cover or a floating cover (Regulation, 2023). In entities breeding animals on a very large scale (with more than 210 livestock units – LU), the capacity of the tanks should enable the storage of produced liquid for a period of at least 6 months. However, in relation to solid manure in the group, the impermeable surface for their storage should enable the accumulation for a minimum period of 5 months. Other agricultural farms will be obliged to meet the same requirements from January 1, 2025, at the latest (Regulation, 2023).

The condition of the equipment of farms with infrastructure for storing manure was the result of many years of investments in agriculture. Some of them were created thanks to financing and co-financing from both national and EU budget funds. The process of subsidising the investment was spread over time and resulted in a significant increase in the area of manure plates in the entire population of farms, as well as the number and capacity of tanks for liquid natural fertilisers (Table 1).

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Table 1. Infrastructure for storing natural fertilisers was created as a result of financing or co-financing from structural funds

Program/measure/sub-measure/type of operation	Manure plates (surface)	slurry tanks (capacity)
"Investments in agricultural farms" SAPARD program	55 281 m^2	32 351 m^3
"Adjusting farms to European Union standards" Rural Development Program 2004-2006	3 712 951 m^2	3 124 142 m^3
"Investments in agricultural holdings" SOP "Agriculture" program 2004-2006	53 758 m^2	41 724 m^3
Rural Development Programme 2007-2013		
"Facilitating the start for young farmers"	10 642 m^2	205 073 m^3
„Modernization of farms"	90 372 m^2	112 146 m^3
"Restoring agricultural production potential destroyed as a result of natural disasters and introducing appropriate preventive measures"	33 m^2	218,5 m^3
Rural Development Programme 2014-2022		
Sub-measure M4.1 – Support for investments in agricultural farms. Type of operation – Modernization of agricultural farms	51500 m^2	175600 m^3
Sub-measure M4.1 – Support for investments in agricultural farms Type of operation – Investments in farms located in Natura 2000 areas	647,4 m^2	515,3 m^3
Sub-measure M4.1 – Support for investments in agricultural farms Type of operation – Investments aimed at protecting water against nitrate pollution from agricultural sources (Investments in farms located in Particularly Vulnerable Areas)	85200 m^2 and 29000 m^3	151000 m^3
Sub-measure M6.1 – Assistance in starting a business for young farmers. Type of operation – Premiums for young farmers	8300 m^2	6800 m^3
Sub-measure M6.3 – Start-up aid for the development of small farms. Type of operation – Restructuring of small farms	3700 m^2	1500 m^3
Total	**3 986 209 m^2**	**3 645 997 m^3**

Source: author's work based on Bułkowska et al. (2009), Bułkowska (2011), Czudec et al. (2017), Klepacka (2009), Ministerstwo Rolnictwa i Rozwoju Wsi (2014), ARiMR (2023).

Co-financing of investments in infrastructure for storing manure was accompanied by a change in the number of animals in the country. In the years 2018-2022, compared to 2012-2016, the population of the main farm animal species converted into livestock units (LU) increased significantly (Figure 1).

Based on the increase in the global animal population, it can be concluded that in recent years, the amount of natural fertilisers produced as a by-product of animal breeding has also increased. At the same time, due to the demand for animal products, there are no indications that the production of natural fertilisers will be limited in the near future (Kopiński & Witorożec-Piechnik, 2023; OECD/FAO, 2023; Stoś et al., 2022).

In the analysed period, however, there was a very significant reduction in the number of farms keeping livestock. The change concerned both farms conducting agricultural activity solely based on animal production or combining it with plant production. In 2020, there were 582,000 such entities, which means their number decreased by 340,000 compared to 2010. At the same time, the population of farms in Poland decreased by only 192,000 to 1,317 thousand in 2020 (GUS, 2021). Therefore, the process of concentration of the growing animal population in an increasingly smaller number of farms and its regionalisation in the country continued. It was accompanied by progressive specialisation of production, which was visible, especially at the level of final and commodity production.

Despite significant subsidies for investments in infrastructure for storing manure, the number of farms with devices for storing natural fertilisers decreased significantly over 2010-2020 (GUS, 2010; GUS, 2020).

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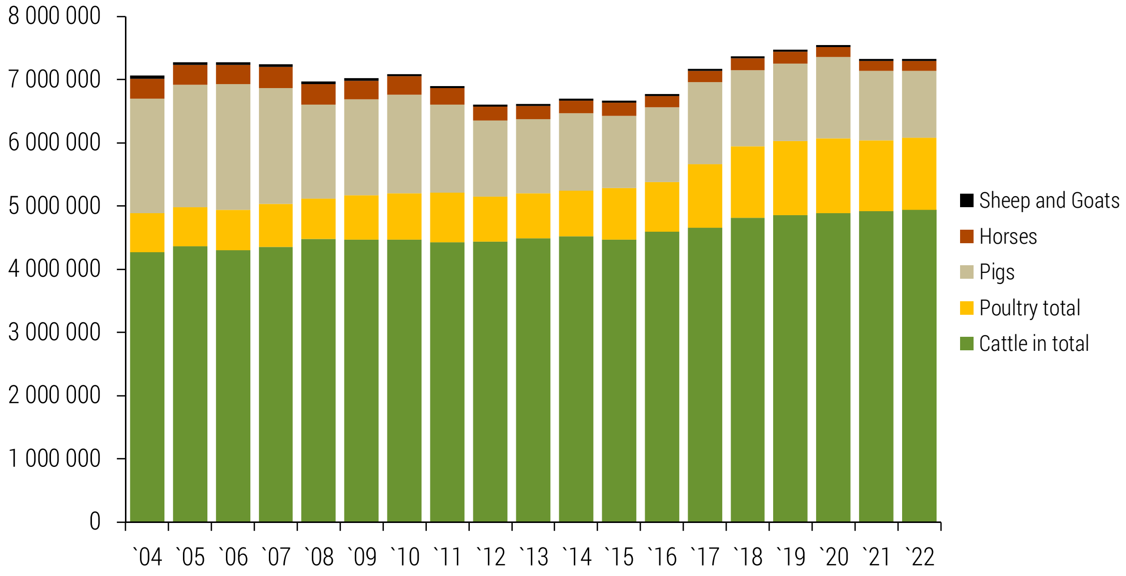

The main species of farm animals were taken into account, i.e. cattle, pigs, horses, sheep, goats and poultry, including the dominant poultry. The number of animals expressed in livestock units was determined using the conversion factors included in the nitrate program (Regulation, 2023).

Figure 1. Number of farm animals (Livestock Unit) in 2004-2022 in Poland

The main cause of the phenomenon was the mass abandonment of farms, especially those with very small, small and medium herd numbers, from keeping farm animals, and thus, their manure plates and tanks were excluded from production functions. At the same time, the infrastructure existing on these farms was sometimes co-financed with public funds, is inactive from the point of view of storing manure and is very unlikely to be used in the future.

Research methods

The total amount of natural fertilisers stored contrary to the requirements of the nitrate program was determined using the balance method using individual data from the 2020 General Agricultural Census. The study covered the entire population of farms in Poland, and the calculations were made on individual data.

The extent of the inadequacy of the infrastructure for manure storage was calculated individually on each farm based on the amount of fertilisers stored in piles without a manure plate and the amount and storage period in other devices. For modelling purposes, in both cases, it was assumed that the adaptation investments would consist of the construction of new manure plates and the cost of construction for storing 1 m^3 of manure was estimated on the basis of calculations made for a model example of a shallowly sunken manure plate.

Similarly to the case of manure, the capacity of tanks for liquid fertilisers with unadjusted capacity was estimated based on the storage period of slurry. Regardless of the type of manure, the same cost of building 1 m^3 of tanks was assumed. The investment costs were calculated based on commercial offers from construction companies specialising in the type of investments, and the offers were obtained in mid-2022.

It was also assumed that all slurry stored in open tanks was stored contrary to the assumptions of the nitrate program. Tanks of this type will require investment to cover them. The capacity, and therefore the potential level of investment expenditure, was determined based on the volume of manure stored in them in 2020. The study took into account various forms of potential covering of

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tanks, i.e. using expanded clay, floating foil – floating PVC tarpaulin, special cover made of floating elements made of plastic, and construction of a tent roof[1].

The research also included an analysis of the inadequacy of the infrastructure for storing manure on farms grouped depending on the size of the herd of farm animals.

Results of the research

Based on the results obtained, it was determined that a total of over 12 million tons of manure in Poland was stored in conditions of unsuitable infrastructure for its storage, which constituted over 27.7% of the total mass of stored solid fertilisers in 2020 (Table 2).

Table 2. Amount of manure stored in unadapted infrastructure in 2020, depending on the size of the animal herd

Animal herd size (livestock units LU)	Manure (thousand tons)			Slurry (thousand m³)		
	no devices	insufficient capacity	total	tank coverage	insufficient capacity	total
a	b	c	d=b+c	e	f	g=e+f
absence of animals	349,0	73,9	422,8	48,3	31,2	79,5
0,01 – 20,00	4 011,0	502,0	4 512,9	666,4	362,6	1 029,0
20,01 40,00	1 949,2	534,5	2 483,7	274,9	492,0	766,8
40,01 – 60,00	894,0	368,1	1 262,1	229,1	432,0	661,2
60,01 – 100,00	876,5	406,0	1 282,5	319,9	550,6	870,6
100,01 – 210,00	624,6	329,2	953,8	416,3	614,5	1 030,8
over 210	885,9	289,6	1 175,5	1 215,7	954,3	2 170,0
Total	**9 590,1**	**2 503,2**	**12 093,3**	**3 170,6**	**3 437,2**	**6 607,8**

Ultimately, by the end of 2024, as part of the adaptation activities, there was a need to change the storage of almost 9.6 million tons of manure stored in piles. The capacity of the existing infrastructure is too small, which indicates the need to expand it to accommodate the 2.5 million tons of manure stored in other facilities.

In terms of storing slurry, it was established that there was a need to cover (cover) tanks with a capacity of over 3.2 million m^3 in the country, which accounted for almost 13% of the total volume of stored slurry in 2020. It was also estimated that in order to balance the production of slurry with the infrastructure for their storage, there is a need to increase the capacity of tanks by over 3.4 million m^3. The total volume of unadopted infrastructure for storing slurry amounted to over 6.6 million m^3, which, in relation to the total amount of liquid fertilisers stored in the country, accounted for 27% of their volume.

The largest mass of manure requiring new or expansion of the existing infrastructure for its storage was located on farms with the smallest herds of animals, i.e. 20 LU and less. This group of farms accounted for over one-third of the total amount of manure stored without appropriate infrastructure. The next group with over 20% share were owners of herds ranging from 20.01 to 40 LU (medium-small herds). The concentration of investment needs in the groups was simultaneously dispersed among the largest number of agricultural entities. In the first group, i.e., in farms with the smallest herds, almost 136.6 thousand entities did not have the infrastructure for storing manure, and it was insufficient. It constituted three-quarters of the total number of entities with insufficient capacity of

[1] The cost estimation did not include the use of chaff and natural coating as a floating cover, i.e. two techniques that are included in the set of actions to reduce ammonia emissions from slurry tanks as part of BAT (Commission, 2017).

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manure plates in the country. There were almost 20.5 thousand farms with medium-small animal herds.

The greatest deficiencies in the infrastructure for storing slurry in terms of volume were found in the group of entities with the largest herds of animals in the country (over 210 LU). In total, maladjustment in this respect was found in a group of only 538 farms, which lacked coverage of 1.2 million m^3 of outdoor reservoirs and additionally new reservoirs with a capacity of over 950,000 m^3. In total, the group accounted for one-third of the volume of slurry stored in infrastructure that was not adapted to the requirements of the program.

Taking into account the amounts of fertilisers and the method of their storage, the need for the capacity of manure plates and the capacity of tanks for liquid fertilisers were estimated. Based on the calculations, it was determined that in order to meet the needs for proper storage of manure, manure plates with an area of over 2.5 million m^2 should be created (Table 3). The value of investment outlays on new boards was estimated at almost PLN 2 billion in total. However, the total value of investment outlays, and adaptation costs for all types of infrastructure amounted to over PLN 5.9 billion. The largest share in this pool was allocated to the construction of new tanks for storing manure and slurry, or manure water as leachate from manure plates. Investment outlays for the construction of new tanks with a capacity of 3,437.2 thousand m3 in the population of agricultural farms were estimated at almost PLN 3.4 billion. Coverage of open reservoirs nationwide with a capacity of 3,170.6 thousand m^3, according to the calculations, required investment outlays exceeding PLN 0.5 billion.

Table 3. Estimated value of investment outlays for new infrastructure for storing natural fertilisers

Animal herd size (livestock units LU)	Manure plates		Tanks investment cost (PLN thousand)			Total investments in new infrastructure (PLN thousand)
	additional area (thousand m^2)	investment costa[1]	tank coverage[2]	new tanks[3]	total	
a	b	c	d	e	f=d+e	g=c+f
absence of animals	88,8	69 700,3	8 218,1	30 604,8	38 822,8	108 523,10
0,01 – 20,00	947,7	743 958,3	113 282,6	356 068,0	469 350,6	1 213 308,90
20,01 40,00	521,6	409 438,9	46 725,0	483 119,3	529 844,3	939 283,20
40,01 – 60,00	265,0	208 051,4	38 949,5	424 261,5	463 211,0	671 262,40
60,01 – 100,00	269,4	211 420,9	54 388,6	540 737,5	595 126,2	806 547,10
100,01 – 210,00	200,3	157 240,2	70 772,7	603 456,1	674 228,8	831 469,00
over 210	246,8	193 775,6	206 668,9	937 075,3	1 143 744,2	1 337 519,80
Total	**2 539,6**	**1 993 585,5**	**539 005,4**	**3 375 322,5**	**3 914 327,9**	**5 907 913,40**

[1] Calculated cost of building 1 m^2 of manure plate allowing for the storage of 4.7618 tons of manure was set at PLN 785 gross;
[2] average cost of covering 1 m^3 of slurry assuming an average height of the open tank of 3 m estimated at PLN 170 gross;
[3] cost of building the tank per 1 m^3 of capacity was calculated at PLN 982 gross.

The necessary investment outlays had to be borne mainly by agricultural farms, which only from 2025 will be obliged to have the necessary infrastructure for manure. Entities with herds of no more than 210 LU accounted for almost PLN 4.6 billion, i.e. 77% of the expected adjustment costs. In this group, the highest investment outlays will be required in the group of owners of the smallest herds. Agricultural farms keeping 20 LU or fewer animals, in accordance with the requirements of the program, had to invest in infrastructure for storing fertilisers in the amount of over PLN 1.2 billion. Less than a quarter of the total value of estimated expenditures (over PLN 1.3 billion) will have to be spent on farms with herds of more than 210 LU. Most of the farms with inadequate infrastructure, and thus projected investment expenditure for this purpose, were concentrated in Wielkopolskie and Mazowieckie voivodships (Table 4).

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Table 4. Estimated value of investment outlays for new infrastructure for storage of natural fertilisers in voivodeship

Voivodships	Manure plates		Slurry tanks	Total new infrastructure
	number of farms	investment cost (PLN thousand)		
a	b	c	d	e=c+d
dolnośląskie	3 567	36 934,5	101 279,4	138 213,9
kujawsko-pomorskie	11 498	185 743,4	262 686,3	448 429,7
lubelskie	17 772	134 338,5	151 279,5	285 618,0
lubuskie	2 068	46 249,9	46 153,8	92 403,7
łódzkie	18 683	189 855,9	365 149,2	555 005,0
małopolskie	12 688	29 632,7	129 638,5	159 271,1
mazowieckie	28 892	302 495,4	664 603,5	967 098,9
opolskie	2 718	46 620,7	176 922,1	223 542,7
podkarpackie	12 534	23 568,4	58 770,8	82 339,3
podlaskie	11 485	167 479,6	633 204,6	800 684,2
pomorskie	5 667	62 812,7	121 081,2	183 893,9
śląskie	5 378	44 430,8	122 775,2	167 206,0
świętokrzyskie	12 354	66 805,6	82 443,5	149 249,1
warmińsko-mazurskie	7 514	127 587,6	225 155,5	352 743,1
wielkopolskie	24 835	497 256,7	714 438,8	1 211 695,5
zachodniopomorskie	2 420	31 773,1	58 746,2	90 519,3
Total Poland	**180 073**	**1 993 585,5**	**3 914 327,9**	**5 907 913,4**

Conclusions

Both in agriculture itself and in its environment, significant changes take place over time, the pace and scope of which are sometimes underestimated and which have a significant impact on the scope and type of use of infrastructure for storing manure, the requirements imposed and the degree of maladjustment of farms to the program, nitrate, unit costs of building or purchasing manure tanks and plates, and finally, the needs and estimated value of investment outlays for adapting the infrastructure that farms in Poland will have to implement.

The loss of PLN 340,000 farms with animal production in recent years has not contributed to improving the infrastructure for storing livestock manure in Poland but has only deepened the problem. The existing manure plates and tanks for liquid fertilisers on the farms, often constructed with budgetary funds, will be used to a small extent in accordance with their original purpose.

In order to meet the conditions of the new nitrate program, manure plates with a capacity of 2,539.6 thousand m^3 should be built in the country, and taking into account data from 2020, new investments should be made by 180,037 farms storing manure. In terms of infrastructure for storing slurry, it is expected that there will be a need to cover tanks with a capacity of over 3.2 million m^3 and to increase the capacity of tanks by 3.4 million m^3.

Based on the parameters from 2020 and the investment costs from 2022, the value of investment outlays for adapting the infrastructure for storing manure and slurry in the entire population was set at PLN 5,907,913.4 thousand. According to the requirements of the program, the highest investment value (mainly in tanks) will be obliged to be made by a small group of farms keeping larger 210 LU and more animals (estimated amount PLN 1,337,519.80 thousand) and farms keeping 20 LU and fewer animals (investment needed for the amount of PLN 1,213,308.90 thousand).

An important factor influencing decisions regarding investments in fixed assets on farms, especially those related to environmental protection (non-productive), is the cost burden of production and the availability of financial capital. They largely depend on the scale of production (Konrad et al., 2019), which in the case of owners of small and medium-sized herds of animals and high uncertainty as to the future profitability of production may be a serious obstacle to the implementation of the directive's requirements (Petersen et al., 2021; Kulawik & Kagan, 2021). In conditions of strict enforcement of the infrastructure for storing manure, the most likely scenario will be a mass abandonment of animal production by unadapted farms. This will mainly affect small and medium-sized herds of animals, especially herds (below 40 LU). At the same time, the population growth process accelerated in very large herds with intensive production systems and the spatial concentration of animals in relatively small regions of the country. Due to the much higher potential of very large-intensive farms to reduce greenhouse gas emissions at the storage and fertilisation stage, this will be a beneficial aspect for nature conservation (Peterson et al., 2013). As a consequence, spatially dispersed small sources of nitrate emissions from places where manures are stored on farms, giving up animal production will also be eliminated. Taking into account rising transport costs, however, this will contribute to an increase in the concentration of fertilisation and nitrate emissions from agricultural fields in regions where large and very large herds of animals are located and will result in a potential increase in nitrate leaching and nitrous oxide emissions from agricultural fields (Basso & Ritchie, 2005; Beaudoin et al., 2005). It will also deepen the shortage of organic matter in remote soils from such production centres, limiting the possibilities of producing agricultural production by small and medium-sized farms in a closed cycle of matter circulation.

There are a number of proven (Palese et al., 2020) and modern technologies, including innovative ones, for the storage and processing of manure that constitute a substitute or significantly reduce the need to invest in manure plates and tanks for liquid fertilisers (Dróżdż et al., 2020; Huygens et al., 2020; Makara & Kowalski, 2018; Kupiec et al., 2019; Pietrzak et al., 2018; Sørensen et al., 2019; Sun et al., 2022). Such forms should not only be developed but also popularised as an alternative to costly traditional investments. Public aid directed to small and medium-sized farms may play an important role in reducing the costs of this type of investment.

References

Act from 10 July 2007. Act about fertilizers and fertilization. Journal of Laws No. 147, item 1033. https://isap.sejm.gov.pl/isap.Nsf/DocDetails.xsp?id=WDU20071471033 (in Polish).

Amon, B., Amon, T., Boxberger, J., & Alt, C. (2001). Emissions of NH_3, N_2O and CH_4 from dairy cows housed in a farmyard manure tying stall (housing, manure storage, manure spreading). Nutrient cycling in Agroecosystems, 60(1), 103-113. http://dx.doi.org/10.1023/A:1012649028772

ARiMR. (2023). *Sprawozdania z działalności Agencji Restrukturyzacji i Modernizacji Rolnictwa.* https://www.gov.pl/web/arimr/sprawozdania-z-dzialalnosci-agencji-restrukturyzacji-i-modernizacji-rolnictwa (in Polish).

Baltic Marine Environment Protection Commission. (2023). *State of the Baltic Sea 2023.* https://helcom.fi/baltic-sea-trends/holistic-assessments/state-of-the-baltic-sea-2023/

Basso, B., & Ritchie, J. T. (2005). Impact of compost, manure and inorganic fertilizer on nitrate leaching and yield for a 6-year maize–alfalfa rotation in Michigan. Agriculture, Ecosystems & Environment, 108(4), 329-341. https://doi.org/10.1016/j.agee.2005.01.011

Batool, M., Sarrazin, F. J., Attinger, S., Basu, N. B., Van Meter, K., & Kumar, R. (2022). Long-term annual soil nitrogen surplus across Europe (1850–2019). Scientific Data, 9, 1-22. https://doi.org/10.1038/s41597-022-01693-9

Beaudoin, N., Saad, J. K., Van Laethem, C., Machet, J. M., Maucorps, J., & Mary, B. (2005). Nitrate leaching in intensive agriculture in Northern France: Effect of farming practices, soils and crop rotations. Agriculture, Ecosystems & Environment, 111(1-4), 292-310. https://doi.org/10.1016/j.agee.2005.06.006

Blanes-Vidal, V., Hansen, M. N., Pedersen, S., & Rom, H. B. (2008). Emissions of ammonia, methane and nitrous oaide from pig houses and slurry: Effects of rooting material, animal activity and ventilation flow. Agriculture, Ecosystems & Environment, 124(3-4), 237-244. https://doi.org/10.1016/j.agee.2007.10.002

Borys, T. (2013). Nowe kierunki ekonomii środowiska i zasobów naturalnych w aspekcie nowej perspektywy finansowej Unii Europejskiej. Ekonomia i Środowisko, 44(1), 8-28. https://www.wir.ue.wroc.pl/docstore/download/UEWR5b867a79eb6549d993b70e22d36862c4/Borys_Nowe_kierunki_ekonomii_srodowiska.pdf?entityType=article (in Polish).

Bułkowska, M. (2011). Efekty WPR w odniesieniu do rolnictwa. In M. Wigier (Ed.), *Analiza efektów realizacji polityki rolnej wobec rolnictwa i obszarów wiejskich* (pp. 56-80). Warszawa: IERiGŻ-PIB. (in Polish).

Bułkowska, M., Hamulczuk, M., Kowalski, A., Rowiński, J., Wieliczko, B., Marek, W., Zawalińska, K., Drygas, M., Wilkin, J., Fałkowski, J., Frenkel, I., Rosner, A., Binienda, J., Stuczyński, T., Duer, I., Głowacki, M., & Habrzyk, A. (2009). *Ewaluacja ex-post Planu Rozwoju Obszarów Wiejskich 2004–2006.* https://www.irwirpan.waw.pl/dir_upload/site/files/KasiaZ/Ex-postRDP.pdf (in Polish).

Cai, A., Xu, M., Wang, B., Zhang, W., Liang, G., Hou, E., & Luo, Y. (2019). Manure acts as a better fertilizer for increasing crop yields than synthetic fertilizer does by improving soil fertility. Soil and Tillage Research, 189, 168-175. https://doi.org/10.1016/j.still.2018.12.022

Cassman, K. G., Dobermann, A. M., Walters, D. T., & Yang, H. (2003). Meeting the cereal demand while protecting natural resources and improving environmental quality. Annual Reviews of Environment and Resources, 28(1), 315-358. https://doi.org/10.1146/annurev.energy.28.040202.122858

Commission Implementing Decision (EU) 2017/302 of 15 February 2017 establishing best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council, for the intensive rearing of poultry or pigs, Pub. L. No. 32017D0302, 43 OJ L (2017). https://eur-lex.europa.eu/legal-content/EN/TXT/?toc=OJ%3AL%3A2017%3A043%3AFULL&uri=uriserv%3AOJ.L_.2017.043.01.0231.01.ENG

Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources, Pub. L. No. 31991L0676, 375 OJ L (1991). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31991L0676

Czudec, A., Kata, R., & Miś, T. (2017). *Efekty polityki rolnej Unii Europejskiej na poziomie regionalnym.* Poznań: Bogucki Wydawnictwo Naukowe. (in Polish).

Dennehy, C., Lawlor, P. G., Jiang, Y., Gardiner, G. E., Xie, S., Nghiem, L. D., & Zhan, X. (2017). Greenhouse gas emissions from different pig manure management techniques: a critical analysis. Frontiers of Environmental Science & Engineering, 11. http://dx.doi.org/10.1007/s11783-017-0942-6

Dourmad, J. Y., Sève, B., Latimier, P., Boisen, S., Fernandez, J., Van der Peet-Schwering, C., & Jongbloed, A. W. (1999). Nitrogen consumption, utilisation and losses in pig production in France. The Netherlands and Denmark. Livestock Production Science, 58(3), 261-264. https://doi.org/10.1016/S0301-6226(99)00015-9

Dróżdż, D., Wystalska, K., Malińska, K., Grosser, A., Grobelak, A., & Kacprzak, M. (2020). Management of poultry manure in Poland–Current state and future perspectives. Journal of Environmental Management, 264, 1-16. https://doi.org/10.1016/j.jenvman.2020.110327

Edmeades, D. C. (2003). The long-term effects of manures and fertilisers on soil productivity and quality: a review. Nutrient cycling in Agroecosystems, 66(2), 165-180. https://doi.org/10.1023/A:1023999816690

EPA. (2016). *Council Directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC). Article 10 Report for Ireland for the Period 2012-2015.* https://www.epa.ie/publications/monitoring--assessment/freshwater--marine/Nitrates_Dir_Art_10_Report_2012-2015_Final_070716.pdf

Eriksson, H., Pastuszak, M., Löfgren, S., Mörth, C. M., & Humborg, C. (2007). Nitrogen budgets of the Polish agriculture 1960–2000: implications for riverine nitrogen loads to the Baltic Sea from transitional countries. Biogeochemistry, 85, 153-168. https://doi.org/10.1007/s10533-007-9126-y

Eurostat. (2013). *Manure Storage Statistics.* https://ec.europa.eu/eurostat

Eurostat. (2024). *Manure storage facilities by NUTS 3 regions.* https://ec.europa.eu/eurostat/databrowser/view/aei_fm_ms__custom_11406817/default/table?lang=en

Gaj, R. (2018). Gospodarowanie obornikiem gnojówką i gnojowicą, jej przechowywanie i stosowanie, BAT. In J. Walczak (Ed.), *Ograniczenie zanieczyszczenia azotem pochodzenia rolniczego metodą poprawy jakości wód* (pp. 109-115). Warszawa: FAPA S-PRINT. (in Polish).

GUS. (2010). *Powszechny Spis Rolny 2010. Przechowywania nawozów naturalnych.* https://bdl.stat.gov.pl/bdl/metadane/ (in Polish).

GUS. (2020). *Powszechny Spis Rolny 2020. Metody przechowywania nawozów naturalnych.* https://bdl.stat.gov.pl/bdl/metadane/ (in Polish).

GUS. (2021). *Powszechny Spis Rolny 2020. Raport z wyników.* https://stat.gov.pl/obszary-tematyczne/rolnictwo-lesnictwo/psr-2020/powszechny-spis-rolny-2020-raport-z-wynikow,4,1.html (in Polish).

Hartung, J., & Phillips, V. R. (1994). Control of gaseous emissions from livestock buildings and manure stores. Journal of Agricultural Engineering Research, 57(3), 173-189. https://doi.org/10.1006/jaer.1994.1017

Hennessy, T., Buckley, C., Cushion, M., Kinsella, A., & Moran, B. (2011). *National farm survey of manure application and storage practices on Irish farms.* https://www.teagasc.ie/media/website/publications/2011/TeagascNationalFarmSurveyOfManureApplication.pdf

Huygens, D., Orveillon, G., Lugato, E., Tavazzi, S., Comero, S., Jones, A., Gawlik, B., & Saveyn, H. (2020). *Technical proposals for the safe use of processed manure above the threshold established for Nitrate Vulnerable Zones by the Nitrates Directive (91/676/EEC).* https://doi.org/10.2760/373351

Ijaz, M. U., Hayat, M. F., Safi, S. Z., Hamza, A., Ashraf, A., & Arshad, M. (2023). Greenhouse Gases Emissions Assessments and Mitigation Opportunities from Animal Manure Processing. In M. Arshad (Ed.), *Climate Changes Mitigation and Sustainable Bioenergy Harvest Through Animal Waste: Sustainable Environmental Implications of Animal Waste* (pp. 215-239). Cham: Springer. https://doi.org/10.1007/978-3-031-26224-1

Józwiak, W., Kagan, A., Niewęgłowska, G., Skarżyńska, A., Sobierajewska, J., Zieliński, M., & Ziętara, W. (2014). *Efektywność, koszty produkcji i konkurencyjność polskich gospodarstw rolnych obecnie i w perspektywie średnio- oraz długoterminowej.* Warszawa: IERiGŻ PIB. (in Polish).

Kagan, A. (2016). *Wybrane prawne determinanty konkurencyjności wielkotowarowych przedsiębiorstw rolnych.* Warszawa: IERiGŻ PIB. (in Polish).

Kagan, A. (2017). *Ocena skutków ustanowienia programu azotanowego z punktu widzenia zmian w infrastrukturze do przechowywania nawozów naturalnych pochodzenia zwierzęcego oraz do składowania i przechowywania kiszonek.* Warszawa: IERiGŻ PIB. https://legislacja.rcl.gov.pl/docs//3/12305809/12475354/12475355/dokument335228.pdf (in Polish).

Kierończyk, M. (2012). Analiza wybranych czynników kształtujących emisję amoniaku podczas przechowywania obornika w warunkach eksploatacyjnych. Woda-Środowisko-Obszary Wiejskie, 12(3(39)), 93-102. https://www.itp.edu.pl/old/wydawnictwo/woda/zeszyt_39_2012/artykuly/Kieronczyk.pdf (in Polish).

Kierończyk, M., & Marcinkowski, T. (2015). Gospodarstwo rolne jako źródło emisj i amoniaku. Czasopismo Inżynierii Lądowej, Środowiska i Architektury, 62(3/I/15), 233-241. http://dx.doi.org/10.7862/rb.2015.108 (in Polish).

Klepacka, W. (2009). *Wyniki wdrażania Planu Rozwoju Obszarów wiejskich na lata 2004-2006.* https://ksow.pl/files/Bazy/Biblioteka/files/Wyniki_wdrazania_PROW_2004-2006.pdf (in Polish).

Köninger, J., Lugato, E., Panagos, P., Kochupillai, M., Orgiazzi, A., & Briones, M. J. (2021). Manure management and soil biodiversity: Towards more sustainable food systems in the EU. Agricultural Systems, 194, 103251. https://doi.org/10.1016/j.agsy.2021.103251

Konrad, M. T., Nielsen, H. Ø., Pedersen, A. B., & Elofsson, K. (2019). Drivers of farmers' investments in nutrient abatement technologies in five Baltic Sea countries. Ecological Economics, 159, 91-100. https://doi.org/10.1016/j.ecolecon.2018.12.022

Kopczyńska, J. (2022). Wdrażanie Ramowej Dyrektywy Wodnej w Polsce. Uwarunkowania prawne Gospodarka Wodna, 12, 17-22. https://doi.org/10.15199/22.2022.12.3 (in Polish).

Kopeć, M., & Gambuś, F. (2008). Zagrożenia zasobów wodnych na obszarach wiejskich województwa świętokrzyskiego w świetle wdrażania dyrektywy azotanowej. Elementy infrastruktury. Woda-Środowisko-Obszary Wiejskie, 8(24), 71-79. https://www.itp.edu.pl/old/wydawnictwo/woda/zeszyt_24_2008/artykuly/kopec.pdf (in Polish).

Kopiński, J., & Witorożec-Piechnik, A. (2023). Dependence of the Volume of Natural Fertilizer Consumption in Relation to the Level of Livestock Density in Poland. Annals of The Polish Association of Agricultural and Agribusiness Economists, 25(3), 149-160. https://doi.org/10.22004/ag.econ.340030

Kowalewska, A., Pręgowska, E., & Rzepiński, W. (2009). Analiza funkcjonowania gospodarstw rolnych na obszarach szczególnie narażonych w zlewni Sony w aspekcie ich wpływu na jakość wód. Woda-Środowisko-Obszary Wiejskie, 9(1), 5-19. http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-BATC-0002-0001 (in Polish).

Kruszyński, M. (2012). Znajomość wymogów wzajemnej zgodności (cross-compliance) wśród rolników z województwa lubuskiego. Roczniki Naukowe Stowarzyszenia Ekonomistów Rolnictwa i Agrobiznesu, 14(2), 86-91. https://bibliotekanauki.pl/articles/863446.pdf (in Polish).

Kuhn, T., Schäfer, D., Holm-Müller, K., & Britz, W. (2019). On-farm compliance costs with the EU-Nitrates Directive: A modelling approach for specialized livestock production in northwest Germany. Agricultural Systems, 173, 233-243. https://doi.org/10.1016/j.agsy.2019.02.017

Kulawi, J., & Kagan, A. (2021). Potencjalna efektywność zastosowania kredytów oraz zdolność jego obsługi przez gospodarstwa rolne. In J. Kulawi (Ed.), *Luka Finansowa w rolnictwie a instrumenty finansowe. Studium przypadku na odstawie PROW 2023-2027* (pp. 94-122). Warszawa: IERiGŻ PIB. (in Polish).

Kupiec, J. M. (2023). *Wieloaspektowa ocean wywieranej presji gospodarstw rolnych na środowisko.* Poznań: Wydawnictwo Uniwersytetu Przyrodniczego w Poznaniu. https://doi.org/10.17306/m.978-83-67112-60-4 (in Polish).

Kupiec, J. M., & Zbierska, J. (2007). Gospodarowanie nawozami w wybranych gospodarstwach Wielkopolski w świetle wymogów dyrektywy azotanowej oraz dobrej praktyki rolniczej. Zeszyty Problemowe Postępów Nauk Rolniczych, 519, 153-165. (in Polish).

Kupiec, J. M., Bednarek, A., & Szklarek, S. (2019). Denitrification barriers as a tool for reducing nitrate emission from point sources pollution. In S. Abubaker (Ed.), *Proceedings of the 6th International Conference on Agriculture 2019 (AGRICO 2019),* Bangkok, Thailand, 38. https://www.researchgate.net/publication/336916862_Denitrification_Barriers_As_A_Tool_For_Reducing_Nitrate_Emission_From_Point_Sources_Pollution

Kuś, J., & Kopiński, J. (2006). Oddziaływanie dobrej praktyki rolniczej na gospodarstwo rolne. In J.S. Zegar (Ed.), *Z badań nad rolnictwem społecznie zrównoważonym* (pp. 23-40). Warszawa: IERiGŻ PIB. (in Polish).

Łacny, J. (2017). Opinia na temat wymogów wynikających z prawa Unii Europejskiej dotyczących terminu uchwalenia projektu ustawy – Prawo wodne, konsekwencji jego nieuchwalenia i związanych z tym kosztów, którymi może być obciążona Rzeczpospolita Polska. Zeszyty Prawnicze BAS, 3(55), 75-84. https://bibliotekanauki.pl/articles/2215727 (in Polish).

Leip, A., Billen, G., Garnier, J., Grizzetti, B., Lassaletta, L., Reis, S., Simpson, D., Sutton, M. A., de Vries, W., Weiss, F., & Westhoek, H. (2015). Impacts of European livestock production: nitrogen, sulphur, phosphorus and greenhouse gas emissions, land-use, water eutrophication and biodiversity. Environmental Research Letters, 10(11), 115004. https://doi.org/10.1088/1748-9326/10/11/115004

Lipiński, W. (2012). The present state and significance of technical water infrastructure in rural areas. In M. Pastuszak & J. Igras (Eds.), *Temporal and spatial differences in emission of nitrogen and phosphorus from Polish territory to the Baltic Sea* (pp. 227-241). Gdynia: National Marine Fisheries Research Institute.

Loyon, L. (2018). Overview of animal manure management for beef, pig, and poultry farms in France. Frontiers in Sustainable Food Systems, 2(36), 1-10. https://doi.org/10.3389/fsufs.2018.00036

Makara, A., & Kowalski, Z. (2018). Selection of pig manure management strategies: Case study of Polish farms. Journal of Cleaner Production, 172, 187-195. http://dx.doi.org/10.1016/j.jclepro.2017.10.095

Menghi, A., de Roest, K., Porcelluzzi, A., Deblitz, C., von Davier, Z., Wildegger, B., de Witte, T., Strohm, K., Garming, H., Dirksmeyer, W., Zimmer, Y., Bölling, D., van Huylenbroek, G., & Mettepenningen, E. (2015). *Assessing farmers' cost of compliance with EU legislation in the fields of environment, animal welfare and food safety.* http://www.crpa.it/media/documents/crpa_www/Pubblicazi/FarmersCost/fulltext_en.pdf

Ministerstwo Rolnictwa i Rozwoju Wsi. (2014). *Sprawozdanie z realizacji Programu Rozwoju Obszarów Wiejskich na lata 2007-2013.* Warszawa: Ministerstwo Rolnictwa i Rozwoju Wsi. (in Polish).

Neverova-Dziopak, E. (2021). Surface Water Eutrophication in Poland. In M. Zeleňáková, K. Kubiak-Wójcicka & A.M. Negm (Eds.), *Assessment and Prevention. Quality of Water Resources in Poland* (pp. 321-346). Cham: Springer.

OECD/FAO. (2023). *OECD-FAO Agricultural Outlook 2032-2032.* http://dx.doi.org/10.1787/agr-outl-data-en

Oenema, O., Witzke, H. P., Klimont, Z., Lesschen, J. P., & Velthof, G. L. (2009). Integrated assessment of promising measures to decrease nitrogen losses from agriculture in EU-27. Agriculture, Ecosystems & Environment, 133(3-4), 280-288. https://doi.org/10.1016/j.agee.2009.04.025

Owen, J. J., & Silver, W. L. (2015). Greenhouse gas emissions from dairy manure management: a review of field-based studies. Global Change Biology, 21(2), 550-565. https://doi.org/10.1111/gcb.12687

Palese, A. M., Persiani, A., D'Adamo, C., Pergola, M., Pastore, V., Sileo, R., Ippolito, G., Lombardi, M. A., & Celano, G. (2020). Composting as manure disposal strategy in small/medium-size livestock farms: Some demonstrations with operative indications. Sustainability, 12(8), 3315. https://doi.org/10.3390/su12083315

Pastuszak, M., Kowalkowski, T., Kopiński, J., Doroszewski, A., Jurga, B., & Buszewski, B. (2018). Long-term changes in nitrogen and phosphorus emission into the Vistula and Oder catchments (Poland)—modeling (MONERIS) studies. Environmental Science and Pollution Research, 25, 29734-29751. https://doi.org/10.1007/s11356-018-2945-7

Peplinski, B. (2022). Regional determinants of agricultural production development in Poland. Annals of the Polish Association of Agricultural and Agrobusiness Economists, 24(1), 225-242. https://doi.org/10.5604/01.3001.0015.7353

Petersen, R. J., Blicher-Mathiesen, G., Rolighed, J., Andersen, H. E., & Kronvang, B. (2021). Three decades of regulation of agricultural nitrogen losses: Experiences from the Danish Agricultural Monitoring Program. Science of The Total Environment, 787, 147619. https://doi.org/10.1016/j.scitotenv.2021.147619

Petersen, S. O. (2018). Greenhouse gas emissions from liquid dairy manure: Prediction and mitigation. Journal of Dairy Science, 101(7), 6642-6654. https://doi.org/10.3168/jds.2017-13301

Petersen, S. O., Blanchard, M., Chadwick, D., Del Prado, A., Edouard, N., Mosquera, J., & Sommer, S. G. (2013). Manure management for greenhouse gas mitigation. Animal, 7(s2), 266-282. https://doi.org/10.1017/S1751731113000736

Pietrzak, S. (2013). *Bilansowanie składników nawozowych i gospodarowanie nawozami naturalnymi, a ochrona jakości wody.* https://cdr.gov.pl/images/wydawnictwa/2013/2013-bilansowanie-skladnikow-nawozowych-i-gospodarowanie-nawozami-naturalnymi-a-ochrona-jakosci-wody.pdf (in Polish).

Pietrzak, S., & Nawalany, P. (2008). Wpływ długo-i krótkotrwałego składowania obornika na gruncie na zanieczyszczenie gleby i wody związkami azotu. Woda-Środowisko-Obszary Wiejskie, 8(2b), 117-126. https://www.itp.edu.pl/old/wydawnictwo/woda/zeszyt_24_2008/artykuly/pietrzak.pdf (in Polish).

Pietrzak, S., Rossa, L., Marcinkowski, T., & Wojcieszak, Ł. (2018). Przestrzenna i czasowa zmienność stężenia azotanów w płytkich wodach gruntowych w miejscu lokalizacji polowej pryzmy obornika. Inżynieria Ekologiczna, 19(5), 75-82. https://doi.org/10.12912/23920629/95272 (in Polish).

Pietrzak, S., Urbaniak, M., & Majewska, Z. (2018). Budowa i wstępna ocean składowiska obornika z podłożem denitryfikacyjnym. Zagadnienia Doradztwa Rolniczego, 94(4), 58-72. https://bibliotekanauki.pl/articles/2049677 (in Polish).

Regulation of the Council of Ministers from 31 January 2023 on the Program of measures to reduce water pollution by nitrates from agricultural sources and to prevent further pollution. Journal of Laws 2023, item 244. https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20230000244 (in Polish).

Report from the Commission to the Council and the European Parliament on the implementation of Council Directive 91/676/EEC concerning the Protection of Waters against Pollution Caused by Nitrates from Agricultural Sources Based on Member State Reports for the Period 2008–2011, Pub. L. No. 52013DC0683 (2013). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52013DC0683

Romaniuk, W., & Wardal, J. W. (2006). Techniczne uwarunkowania przechowywania i uzdatniania nawozów naturalnych. Nawozy i nawożenie, 8(4), 61-79. (in Polish).

Rutting, T., Aronsson, H., & Delin, S. (2018). Efficient use of nitrogen in agriculture. Nutrient cycling in agroecosystems, 110(1), 1-5. https://doi.org/10.1007/s10705-017-9900-8

Sapek, A., & Sapek, B. (2006). Wpływ składowania nawozów naturalnych na jakość gleby w zagrodzie wiejskiej. Zeszyty Problemowe Postępów Nauk Rolniczych, 512(2), 491-502. https://agro.icm.edu.pl/agro/element/bwmeta1.element.agro-article-a5856713-fc90-4cb7-a10d-dd6768795708/c/491-502.PDF (in Polish).

Śleszyński, J. (2022). Normative ecological economics as a condition for sustainable development. Economics and Environment, 4(83), 8-19. https://doi.org/10.34659/eis.2022.83.4.516

Smurzyńska, A., Dach, J., Dworecki, Z., & Czekała, W. (2016). Emisje gazowe podczas gospodarki gnojowicą. Inżynieria i Ochrona Środowiska, 19(1), 109-125. https://doi.org/10.17512/ios.2016.1.9 (in Polish).

Soliwoda, M., Wieliczko, B., & Kulawik, J. (2020). Gospodarka w cyklu zamkniętym a zrównoważenie agrobiznesu. Zagadnienia Ekonomiki Rolnej / Problems of Agriculture Economics, 362(1), 3-13. https://doi.org/10.30858/zer/110742

Sommer, S. G., & Knudsen, L. (2021). Impact of Danish livestock and manure management regulations on nitrogen pollution, crop production, and economy. Frontiers in Sustainability, 2, 658231. https://doi.org/10.3389/frsus.2021.658231

Sørensen, P., Bechini, L., & Jensen, L. S. (2019). Manure management in organic farming. In U. Köpke (Ed.), *Improving Organic Crop Cultivation* (pp. 179-209). London: Burleigh Dodds Science Publishing. https://doi.org/10.1201/9781351114578

Sørensen, P., Thomsen, I. K., & Schröder, J. J. (2017). Empirical model for mineralisation of manure nitrogen in soil. Soil Research, 55, 500-505. https://doi.org/10.1071/SR17018

Stoś, K., Rychlik, E., Woźniak, A., & Ołtarzewski, M. (2022). Red and processed meat consumption in Poland. Foods, 11(20), 3283. https://doi.org/10.3390/foods11203283

Sun, Y., Hu, C., & Lyu, L. (2022). New sustainable utilization approach of livestock manure: Conversion to dual-reaction-center Fenton-like catalyst for water purification. NPJ Clean Water, 5(1), 1-8. https://doi.org/10.1038/s41545-022-00200-2

Sutton, M. A., Howard, C., Reis, S., Abalos, D., Bracher, A., Bryukhanov, A., Condor-Golec, R. D., Kozlova, N., Lalor, S. T. J., Menzi, H., Maximov, D., Misselbrook, T., Raaflaub, M., Sanz-Cobena, A., von Atzigen-Sollberger, E., Spring, P., Vallejo, A., & Wade, B. (2015). Country case studies. In S. Reis, C. Howard & M.A. Sutton (Eds.), *Costs of Ammonia Abatement and the Climate Co-Benefits* (pp. 169-231). Dordrecht: Springer Netherlands.

Szalińska, E., Orlińska-Woźniak, P., & Wilk, P. (2018). Nitrate vulnerable zones revision in Poland – Assessment of environmental impact and land use conflicts. Sustainability, 10(9), 3297. https://doi.org/10.3390/su10093297

Szymańska, E. (2012). Produkcja żywca wieprzowego w zrównoważonym rozwoju rolnictwa. Zagadnienia Ekonomiki Rolnej / Problems of Agricultural Economics, 332(2), 89-103. https://bibliotekanauki.pl/articles/879235 (in Polish).

Szymańska, E., Mroczek, R., & Tłuczak, A. (2023). Conditions of changes in the regional specialization of animal production in Poland. Acta Scientiarum Polonorum. Oeconomia, 22(2), 73-86. https://doi.org/10.22630/ASPE.2023.22.2.13

Thorsøe, M. H., Andersen, M. S., Brady, M. V., Graversgaard, M., Kilis, E., Pedersen, A. B., Pitzén, S., & Valve, H. (2022). Promise and performance of agricultural nutrient management policy: Lessons from the Baltic Sea. Ambio, 51(1), 36-50. https://doi.org/10.1007/s13280-021-01549-3

Velthof, G. L., Lesschen, J. P., Webb, J., Pietrzak, S., Miatkowski, Z., Pinto, M., Kros, J., & Oenema, O. (2014). The impact of the Nitrates Directive on nitrogen emissions from agriculture in the EU-27 during 2000–2008. Science of the Total Environment, 468, 1225-1233. https://doi.org/10.1016/j.scitotenv.2013.04.058

Venkatachalam, L. (2007). Environmental economics and ecological economics: Where they can converge? Ecological Economics, 61(2-3), 550-558. https://doi.org/10.1016/j.ecolecon.2006.05.012

Wagner, S., Angenendt, E., Beletskaya, O., & Zeddies, J. (2017). Assessing ammonia emission abatement measures in agriculture: Farmers' costs and society's benefits–A case study for Lower Saxony, Germany. Agricultural Systems, 157, 70-80. https://doi.org/10.1016/j.agsy.2017.06.008

Wasilewski, J. (2005). Rodzaje gnojowni i ich lokalizacja w zagrodach wiejskich na Pomorzu Zachodnim. Inżynieria Rolnicza, 9(4), 339-347. http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-c65a26d9-7006-4996-a12f-b97b7cae016a (in Polish).

Webb, J., Sommer, S. G., Kupper, T., Groenestein, K., Hutchings, N. J., Eurich-Menden, B., Rodhe, L., Misselbrook, T. H., & Amon, B. (2012). Emissions of ammonia, nitrous oxide and methane during the management of solid manures. In E. Lichtfouse (Ed.), *Agroecology and strategies for climate change* (pp. 67-107). London: Springer. https://doi.org/10.1007/978-94-007-1905-7

Wierzbicki, K., & Krajewski, K. (2004). Kierunki rozwoju infrastruktury technicznej obszarów wiejskich w Polsce. Woda-Środowisko-Obszary Wiejskie, 4(12), 9-20. https://www.itp.edu.pl/old/wydawnictwo/woda/Zeszyt_12_2004/artykuly/WierzbickiKrajewski.pdf (in Polish).

Wrzaszcz, W. (2012). Prośrodowiskowe praktyki rolne w świetle deklaracji respondentów objętych systemem FADN. Roczniki Naukowe Stowarzyszenia Ekonomistów Rolnictwa i Agrobiznesu, 14(5), 208-214. https://rnseria.com/seo/article/119506/pl (in Polish).

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POTRZEBA ROZBUDOWY INFRASTRUKTURY DO PRZECHOWYWANIA NAWOZÓW NATURALNYCH W POLSCE W ODNIESIENIU DO WYMOGÓW NOWEGO PROGRAMU DZIAŁAŃ NA RZECZ WDRAŻANIA DYREKTYWY AZOTANOWEJ

STRESZCZENIE: Celem przeprowadzonych badań było ustalenie potrzeb w zakresie zwiększenia infrastruktury do przechowywania nawozów naturalnych w Polsce w grupach gospodarstw rolnych wydzielonych na podstawie liczebności stad zwierząt. Wykorzystują jednostkowe danych GUS za pomocą metody bilansowej oszacowano niedostosowanie infrastruktury do nowych wymagań prawnych w zakresie przechowywania nawozów naturalnych. Ustalono, że spełnienie norm zawartych w nowym programie działań obowiązującym w kraju na podstawie dyrektywy azotanowej wymagać będzie budowy lub rozbudowy płyt obornikowych o powierzchni 2 539,6 tys. m^2, nowych zbiorników o pojemności 3 437,2 tys. m^3 oraz pokrycia istniejących o pojemności 3 170,6 tys. m^3. Łącznie koszty inwestycji oszacowano na kwotę 5 907 913,40 tys. zł, tj. około 1,4 miliarda euro. Obowiązujące od 1 stycznia 2025 roku wymogi dla większości podmiotów przyniosą daleko idące zmiany prowadząc do koncentracji zwierząt w bardzo dużych stadach i pogłębienia rejonizacji produkcji. Wskazano zarówno na korzystne jak również negatywne skutki tego procesu dla środowiska przyrodniczego.

SŁOWA KLUCZOWE: gospodarstwa z produkcją zwierzęcą, przechowywanie nawozów naturalnych, płynne nawozy naturalne, wpływ na środowisko, przepisy prawa