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Abstract

Problems with storage and management of manure from pig farming on the one hand and possibility to use the manure as a renewable source of fertilizer components on the other hand encourage seeking new effective methods of manure management. For reduction of odour emission and costs of storage and transportation as well as for proper preparation of the manure for further treatment, the material has to be separated into solid and liquid fractions. We worked out the new method providing treatment of pig manure by filtration.

Further processing of the after filtration sediment into mineral-organic fertilizers was the second stage of our research. In the sediment used for production of solid fertilizers moisture content and chemical composition were determined. Moreover, elementary analyses of P, Ca, Mg, S, K, N, C and H contents in the sediment were carried out. Due to utilization of sediments as fertilizers the tests determined content of available for animal's phosphates. In the after filtration sediments concentration of available nitrogen compounds, potassium, calcium, microelements and heavy metals were determined too.

The compositions of different type of fertilizers with use as main component of the after filtration sediments with proper microelements were proposed for such type cultivation as corn, crops, potatoes, beets, rape, root crops, leys and pastures and universal type phosphate fertilizer.

Keywords:

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Introduction

Considering the seasonal character of its use and huge amount of pig manure the substantial problem with the pig manure management is the development of a method for quick and efficient separation of manure slurry. Membrane filtration may be an effective method for separation of the pig manure into solid and liquid phase. In comparison to the original pig manure composition (Bary et al., 2000; Konieczny et al., 2011; Pieters et al., 1999) the application of filtration membranes allowed obtaining a significant decrease in nitrogen & phosphor compounds concentration, and COD in obtained permeate. However, filtration methods are mostly applied for this purpose (Sneath et al., 1988; Wolter et al., 2004; Zhang & Westerman, 1997).

Fertilizer properties of the pig manure were checked on acid and neutral soils. Influence of manures on corn cultivation was tested. It was noted that the manures occurred to be useful as sources for nutrients. Except that, the manures had a beneficial impact on soil properties including increase of pH, organic carbon content and digestible forms of phosphor and nitrogen compounds. However, the mass of obtained crops was higher when applying standard NPK fertilizers. After all, the application of the manures has a positive impact on soil microbiologic activity and secondary processes related to biochemical changes (Adeniyan et al., 2011; Mohan Kumar et al., 2011; Sánchez & González, 2005).

This study shows the results and suggested procedures for the management of after filtration sediments which develop as a result of the application of the filtration method for separation of the pig manure (Kowalski et al., 2012). The method allows applying processes such as pH control by phosphoric and sulphurous acids, precipitation by whitewash and by addition of double superphosphate and subsequent heating. Processing of the pig manure allows obtaining filtrate and after filtration sediment separated by filtration. The sediment was a raw material for the tests on production of mineral-organic fertilizers for agriculture. The pig manure sample were taken from one of Polish pig farms (Kowalski et al., 2012; Polish patent application, 2012). The analyses were based on the samples drawn each time in the same way and at the same place. Solid samples constituted the foundation for mineral-organic fertilizers with properties and composition selected appropriately to the type of cultivation in Poland. The selection of recipes was also based on potential physical and chemical properties of after filtration sediment.

Research Methodology

The present research utilized the pig manure taken between June 2011 and May 2012 from a piggery located near the town of Piła, Poland that produces piglets intended for fattening in other pig farms as well as sows for renewing the flock. The average monthly livestock statistics as to the type of animals were as follows: 1101 sows, 64 gilts, 2536 sucking piglets, 140 weaned piglets, 200 shoats, 160 porkers, in total 4201. Pig manure samples were taken from drain pipe carrying slurry from a piggery to a lagoon. Sampling was carried out each time using the same system and source of sample (Regulation, 2003). In the sample taken, the content of nitrogen, biochemical oxygen demand, chemical oxygen demand, phosphorus, potassium, calcium and dry mass was determined according to proper polish standards. Moreover, microbiological tests were performed on the analysed slurry to identify the bacilli of genus *Salmonella* and live eggs of parasites (PN-EN ISO 6579:2003).

The samples of after filtration sediments were prepared according to our new pig manure treatment and filtration process. Each time prior to the commencement of mineralization process, the manure was thoroughly stirred, and then the phosphoric and sulphuric acids were added to the manure for obtaining pH value of ~5.5 and 3.0, respectively. After treatment with acids, the slurry was treated with 10% solution of lime milk for obtaining a pH value of ~8.5, then super phosphate in amount of 10% of the initial manure weight was added, and the mixture was second time neutralized with the use of lime milk. The resulting slurry was heated for ~55 minutes, cooled down to ~75°C, and filtered in the pressure filter (Kowalski et al. 2012; Polish patent application, 2012). As a result of filtration, light straw colour filtrate and sediment were obtained. The advantage of worked out technology is the method of incorporation in organic phase of the manure of 20-60% of crystalline phase. These resulted in high filtration rate with used pressure filters over 1000L/m^2/h and good quality of filtrate.

For laboratory tests, the pressure filter of volumetric capacity of 2000 mL manufactured by Sartorius was used. For Kjeldahl's method of nitrogen (PN-EN 25663:2001) determination in the manure and in the filtrate, DK6 mineralizer and equipment for distillation with steam, both manufactured by VELP, were used. Phosphorus content was determined with Nano colour UV/VIS spectrophotometer manufactured by Macherey-Nagel. For mineralization of samples for determination of Chemical Oxygen Demand (COD), M-9 mineralizer manufactured by WSL was used (PN-ISO 6060:2006). Content of macroelements (Ca, Mg, S, Al), heavy metals (As, Pb, Cd, Cr, Ni) and microelements (Cu, Zn, Mo, Fe, Mn) were determined using Inductively Coupled Plasma Atomic Emission (ICP-AE) spectrometer of OPTIMA 7300 DV type manufactured by Perkin Elmer. Potassium and calcium was determined with flame atomic absorption spectroscopy (FAAS), using an OPTIMA 7300 DV apparatus by Perkin Elmer. Content of mercury were determined with method of atomic absorption spectrometry using mercury analyser AMA-254 ALTEC with autosampler. The contents of C, H and N were determined with use of Perkin Elmer's PE 2400 analyser.

Phase composition of the sediments was made with use of Bruker AXS D8 Advance diffractometer, scope of angle: 2Θ/Θ, Goebl mirror in the primary beam, detector with dispersion of the X-radiation energy SOL-XE. In the samples with semi-quantitative analytical method the content of phases were determined using Rietveld method and semi-quantitative analysis software package RayfleX Autoquan version 2.6 – commercial and modified version of the software package BGMN.

Chemical analyses of the fertilizers included determination of (Regulation, 2003):

- Total content of phosphoric compounds by extraction of phosphor from the fertilizer using the mixture of nitric and sulphuric acids;
- Content of phosphoric compounds soluble in formic acid by determination of extracted phosphor soluble in 2% formic acid;
- Content of phosphoric compounds soluble in citric acid by determination of extracted phosphor soluble in 2% nitric acid;
- Content of phosphoric compounds soluble in ammonium citrate by determination of extracted phosphor soluble in ammonium citrate at 65°C (pH = 7).

Determination of pH, organic content, organic carbon, nitrogen, and potassium was done using a method for compost testing (Regulation, 2003). TKN, for researches on fertilizers, was determined applying a method for reduction of nitrates to ammonia in acid environment in the presence of powdered chromium and distilling off ammonia from alkaline solution (PN-Z-15011-3:2001). The methods designed for composts (Regulation, 2003), which are substances with huge amount of organic compounds, and methods for water quality testing (PN 93/C-87085) were also applied. The content of TKN up to 10 mg in analytic sample may be determined.

Ammonia nitrogen was determined using distillation method with final acid-base titration in accordance with standard (PN-75/C-04576/15). Dry mineralization excluding flux was applied for testing of the pig manure. The mineralization was carried out according to (Regulation, 2003). K_2O analyse was carried out by flame atomic absorption photometry in accordance with the standard (PN-ISO 9964-2:1994). The determination of calcium content (after sample mineralization) was made according to (Regulation, 2003).

Test Results and Discussion

Analyses of all the batches of pig manure have been juxtaposed in Table 1. Table 2 shows the analysis of chemical composition of the after filtration sediments used for production of solid fertilizers. Table 3 includes phase composition of sediments. The content of available forms of phosphorus in the after filtration sediments was tested on account of the use of sediment as fertilizer (Table 4). Table 5 shows the content of nitrogen and potassium fertilizers in filtration residue. Table 6 shows the content of lime fertilizers. Table 7 shows the test results of the content of lime in filtration residue. The content of minor elements in filtration residue is shown in Table 8. The statistical assessment of the content of major and minor elements (including heavy metals) in fertilizers was carried out in order to determine mean value of the content of nutrients in filtration residue which was selected for the determination of the content of fertilizers formed on its basis. The test results are shown in Table 8.

Table 1. *The results of pig manure tests*

Determined parameter	Pig manure symbol						
	GW1	GW2	GW3	GW4	GW5	GW6	GW7
N (mg/dm^3)	7972	2956	3960	9180	6310	4315	4125
BOD (mg/dm^3)	41400	2620	12240	18800	38200	9400	38800
COD (mg/dm^3)	98300	8760	36880	60900	112800	23650	103350
P (mg/dm^3)	1810	224	784	1770	1590	795	1290
K* (%)	6.92	11.8	6.8	2.84	2.84	2.56	1.81
Ca* (%)	2.3	2.32	3.86	2.35	2.69	3.94	2.9
Dry mass (%)	9.48	1.0	1.7	8.0	8.24	3.9	4.83
Salmonella group bacilli (amount/L)	not detected	not detected	not detected	not detected	not detected	not detected	not detected
Parasite eggs (amount/L)	absent	absent	absent	absent	absent	absent	absent

*content expressed as dry mass

Table 2. *Results of after filtration sediment analyses (% of dry mass)*

Determined element	Batch symbol						
	GW1	GW2	GW3	GW4	GW5	GW6	GW7
N	1.225	1.18	0.925	1.61	1.78	1.365	1.14
C	19.68	21.49	23.42	19.00	18.36	18.32	22.55
K	0.29	0.21	0.19	0.39	0.52	0.31	0.34
Mg	0.52	0.54	0.50	0.59	0.51	0.55	0.56
P	8.05	10.05	10.96	8.75	7.74	8.34	9.27
S	1.50	1.53	1.57	1.89	2.47	1.65	1.93
C	13.255	13.56	10.775	15.81	16.875	18.7	14.32
H	2.3	2.325	2.05	2.75	2.44	2.67	2.61

Table 3. *Phase composition of the after filtration sediment*

Phase content (%)	Batch symbol						
	GW1	GW2	GW3	GW4	GW5	GW6	GW7
Amorphous phase	42.4 ± 2.8	44.5± 1.5	28.1± 3.3	53.7± 2.2	47.6± 2.5	50.8± 1.1	31.0± 5.7
$Ca_5(PO_4)_3(OH)$	38.1± 1.2	38.20± 0.67	46.6± 1.5	22.5± 1.3	33.0± 1.2	30.01± 0.56	61.7± 1.1
$CaSO_4 \cdot 2H_2O$	2.38± 0.44	2.30± 0.23	2.72± 0.51	2.52± 0.28	4.89± 0.35	3.79± 0.18	-
SiO_2	0.246± 0.043	0.337± 0.024	0.539± 0.058	0.838± 0.048	-	-	-
$CaHPO_4$	3.06± 0.44	5.89± 0.30	8.71± 0.66	3.31± 0.33	2.41± 0.28	2.67± 0.17	7.28± 0.66
$CaSO_4 \cdot 0.5H_2O$	1.18± 0.21	1.43± 0.12	1.26± 0.21	0.76± 0.13	-	-	-
$CaPO_3(OH) \cdot 2H_2O$	1.11± 0.25	0.60± 0.14	0.66± 0.29	0.92± 0.18	-	-	-
$Ca_{18}Mg_2H_2(PO_4)_{14}$	11.47± 0.64	6.75± 0.31	11.4± 0.1	15.41± 0.68	12.02± 0.68	12.73± 0.32	-

Table 4. *The content of various forms of the soluble phosphorus in the after filtration sediments*

Form of the soluble P – average (% of P_2O_5 in dry mass)	Batch symbol						
	GW1	GW2	GW3	GW4	GW5	GW6	GW7
P soluble in the mixture of mineral acids HNO_3:H_2SO_4	13.92	13.54	18.32	11.50	9.98	8.37	10.33
P soluble in 2% citric acid	4.77	5.20	5.71	4.73	4.52	4.20	5.43
P soluble in 2% formic acid	6.46	6.30	6.37	5.57	5.45	4.94	6.29
P soluble in neutral ammonium citrate solution	3.21	3.26	3.43	2.34	1.52	3.17	3.92
P soluble in water	0.77	0.35	0.50	0.51	0.54	0.31	0.61

Table 5. *The content of nitrogen and potassium in the after filtration sediments*

Batch symbol	Sample number	Content (% of mass)		
		N_{total}	$N_{ammonia}$	K_2O
GW1	1	0.50	0.21	0.16
	2	0.40	0.21	0.18
	3	0.45	0.20	0.17
	average	0.45	0.21	0.17
GW2	1	0.42	0.22	0.14
	2	0.54	0.22	0.15
	3	0.56	0.21	0.12
	average	0.51	0.22	0.14
GW3	1	0.50	0.21	0.16
	2	0.40	0.21	0.18
	3	0.45	0.20	0.17
	average	0.45	0.21	0.17
GW5	1	0.21	0.26	0.21
	2	0.24	0.23	0.20
	3	0.24	0.27	0.21
	average	0.23	0.25	0.21
GW6	1	0.21	0.26	0.21
	2	0.24	0.23	0.2
	3	0.24	0.27	0.21
	average	0.23	0.25	0.21
GW7	1	0.30	0.18	0.17
	2	0.35	0.19	0.15
	3	0.30	0.20	0.19
	average	0.32	0.19	0.17

Table 6. *The content of calcium in the after filtration sediments*

Batch symbol	Sample number	Content (% of mass)			
		Ca_{total} *	CaO_{total} *	Ca_{total} **	CaO_{total} **
GW1	1	14.89	20.84	14.26	19.96
	2	15.01	21.02	15.32	21.45
	3	14.92	20.89	14.72	20.61
	average	14.94	20.92	14.77	20.67
GW2	1	6.85	9.59	6.87	9.62
	2	6.98	9.77	6.98	9.77
	3	6.58	9.22	6.91	9.68
	average	6.80	9.52	6.92	9.69
GW3	1	12.65	17.71	12.37	17.31
	2	11.90	16.66	12.31	17.24
	3	12.52	17.52	12.47	17.46
	average	12.35	17.30	12.38	17.34
GW5	1	8.18	11.46	7.85	10.99
	2	7.85	10.99	7.89	11.05
	3	7.45	10.43	7.92	11.08
	average	7.83	10.96	7.88	11.04
GW6	1	11.77	16.48	11.57	16.20
	2	11.57	16.20	11.50	16.11
	3	12.24	17.14	11.62	16.26
	average	11.86	16.60	11.56	16.19
GW7	1	12.24	17.13	11.03	15.44
	2	11.90	16.67	11.18	15.65
	3	11.64	16.29	11.13	15.59
	average	11.93	16.70	11.11	15.56

* Manganometric determination of extracted calcium following precipitation in the form of oxalate ** Determination of magnesium by complexometry

Table 7. *Content of microelements and heavy metals in the after filtration sediments*

Batch symbol	GW1	GW2	GW3	GW5	GW6
Element	Content of element (mg/L), (result ± uncertainty for k=2)				
As	5.5±0.8	4.5±0.7	7.0±1.0	5.6±0.8	3.6±0.5
B	26±4	23±3	22±3	28±4	24±4
Cd	2.6±0.4	2.6±0.4	3.4±0.5	2.0±0.3	1.7±0.2
Cr	50±8	52±8	71±11	36±6	32±5
Cu	32±5	42±6	37±6	22±3	24±4
Fe	884±133	892±134	980±450	742±111	880±132
Hg	0.020±0.003	0.018±0.003	0.027±0.004	0.015±0.002	0.016±0.002
K	1650±330	1130±230	1170±230	1670±250	1940±390
Mn	86±13	97±14	80±12	77±12	65±10
Mo	0.77±0.12	0.89±0.13	0.95±0.14	0.76±0.12	0.50±0.08
Ni	4.6±0.7	3.5±0.5	4.4±0.7	3.2±0.5	3.1±0.5
Pb	1.4±0.3	1.1±0.2	1.7±0.2	1.0±0.2	1.70±0.2
S	7730±1550	8240±1650	9820±1550	8040±1610	10500±2100
Zn	186±28	216±32	218±33	155±23	130±20

Table 8. *The statistical analysis of the content of fertilizer components in filtration residue*

Determination	Unit	Determination of the residue						Mean value	SD
		GW1	GW2	GW3	GW5	GW6	GW7		
N_{total}	% of mass	0.45	0.51	0.45	0.23	0.23	0.32	0.37	0.12
$N_{ammonia}$	% of mass	0.21	0.22	0.21	0.25	0.25	0.19	0.22	0.024
P_2O_5 soluble in HNO_3:H_2SO_4	% of mass	13.92	13.54	18,32	9.98	8.37	10.33	12.41	3.61`
P_2O_5 soluble in 2% citric acid	% of mass	4.77	5.20	5.71	4.52	4.20	5.43	4.97	0.57
P_2O_5 soluble in 2% formic acid	% of mass	6.46	6.30	6.37	5.45	4.94	6.29	5.97	0.63
P_2O_5 soluble in ammonium citrate	% of mass	3.21	3.26	3.43	1.52	3.17	3.92	3.09	0.81
P_2O_5 soluble in water	% of mass	0.77	0.35	0.50	0.54	0.31	0.61	0.51	0.17
K_2O	% of mass	0.17	0.14	0.17	0.21	0.21	0.17	0.18	0.027
CaO	% of mass	20.8	9.61	16.13	11.0	16.4	17.32	15.21	4.17
B	mg/kg	26	23	22	28	24	no	25	2.4
Cu	mg/kg	32	42	37	22	24	no	31	8.5
Fe	mg/kg	884	892	980	742	880	no	876	85
Mn	mg/kg	86	97	80	77	65	no	81	12
Mo	mg/kg	0.77	0.89	0.95	0.76	0.50	no	0.77	0.17
Zn	mg/kg	186	216	218	155	130	no	181	38
As	mg/kg	5.5	4.5	7.0	5.6	3.6	no	5.2	1.3
Cd	mg/kg	2.6	2.6	3.4	2.0	1.7	no	2.5	0.65
Hg	mg/kg	0.02	0.018	0.027	0.015	0.016	no	0.019	0.0048
Pb	mg/kg	1.4	1.1	1.7	1.0	1.7	no	1.4	0.33

The content of the filtration residue is approximately similar to the content of single superphosphate. Basing on the tests, phosphor included in the residue (approx. 12.4%) is mainly non-soluble in water. The content of calcium in the sediment (approx. 15.2%) is also high. The content of outstanding major and minor elements shall be supplemented with mineral additives. The content of heavy metals is within limits determined by the standard for fertilizers (Regulation, 2003).

Solid mineral-organic fertilizers based on processed pig manure residue were tested with special attention to demand for fertilizing domesticated plants (Czuba & Mazur, 1988; Finck, 1982; Katyal & Randhawa, 1983): corn, cereals, potatoes, beets, rape, leguminous plants, and grasslands.

Corn is mainly cultivated for silage or grains. Its demand for fertilizers is above-average. Satisfactory harvest includes 120 kg of nitrogen, 90 kg of P_2O_5, 130 kg of potassium, approx. 40 kg of calcium, and 30 kg of magnesium per hectare, with significant amount of essential minor elements including zinc, copper, manganese and iron.

Demand of crops for fertilizers depends on richness of soils, organic matter mineralization and remains of forecrop. The dosages of nitrogen fertilizers are as follows [kg N/ha]: 55-145 for winter and spring wheat, 65-155 for triticale, 70-130 for rye, 35-105 for spring barley, 45-95 for oat. All cereals, excluding rye, are sensitive for nitrogen and phosphor deficiency in soils demanding a significant dosage of both elements. Depending on crops to be expected and the content of available fertilizer in soils, it is necessary to fertilize fields with 25-80 kg/ha of P_2O_5 and 40-125 kg/ha of K_2O. Wheat, triticale and barley show huge sensitivity to acid reaction of soils. Their growth after liming is significant. Magnesium influence is particularly effective on light soils. Recommended dose for magnesium lime or magnesite deacidification should be within 120-160 kg/h of MgO. 20-40 kg/ha of MgO is applied to available magnesium supplement fertilization. In case of major elements, crops positively respond to zinc, copper and manganese fertilization.

Mineral fertilization of potatoes is closely dependent on harvest purpose. Seed-potatoes demand rich fertilization with phosphor and potassium ($N:P_2O_5:K_2O=1:1.2:1.6$), however 40 kg/ha of nitrogen fertilization is applied. Edible potatoes are obtained from soils fertilized with average high nitrogen & potassium content and rich phosphor & magnesium content ($N:P_2O_5:K_2O= 1:1.6:1.8$) with 80-100 kg/ha of nitrogen dose. Fodder potatoes demand rich fertilization with nitrogen and potassium ($N:P_2O_5:K_2O=1:1.5:2$) for 120 kg/ha of nitrogen dose. Magnesium used on potato farms plays a significant role in carbohydrates synthesis and takes part in energy-related management of the plants. Demand of potatoes for major elements is huge. Particularly, they are sensitive for deficiency in available zinc, boron and manganese.

Sugar beet takes huge amounts of fertilizer components. It is confirmed that nitrogen dosages of up to 160 kg N per hectare have a positive impact on this plant. An amount of phosphoric fertilizers for beets equals to 80-130 kg of P_2O_5 per hectare. It is beneficial to apply a major dose of phosphor in autumn for ploughing as it creates favourable conditions for growth of roots when surface phosphor is not available. Sugar beets demand huge amounts of sodium. For this reason, it is advantageous to apply 40 or 50 grade potassium salts, which contain NaCl additive, or potassium derivatives such as kainite. Sugar beets positively respond to liming applied with parallel magnesium supply. In case of major elements, sugar beets are sensitive to deficiency of boron, manganese, copper, molybdenum and zinc.

Rape highly requires nitrogen, phosphor, calcium, magnesium, sulphur, boron, copper, manganese and zinc fertilization. It is advantageous to divide fertilization into autumn dose, up to 40 kg/ha and spring dose, 100-160 kg N per hectare. Phosphor fertilization is efficient with 60-120 kg of P_2O_5 per hectare and 80-180 kg/ha of potassium. Rape growth is efficient with nitrogen dosage of even 300 kg/ha, but it causes a decrease in agricultural and physiological efficiency of such enormous nitrogen dosages. Considering high sensitivity to acid reaction of soils, rape positively responds to lime and magnesium fertilization. Requirement for major elements is in excess of 1,5-2 times more than in case of cereals. Boron, copper and manganese fertilization is particularly important.

Considering leguminous plants, lupine, pea and broad bean are mainly cultivated. Having in mind that these plants coexist with module bacteria (Rhizobium), they do not require mineral nitrogen fertilization. It is assumed that nitrogen fertilization up to 30 kg/ha is sufficient. Principally, nitrogen fertilization helps plants decrease energy consumption (depletion of carbohydrates for nitrogen bonding) and seems to be efficient. For example, in case of broad bean growth in such conditions, efficiency of 80-90 kg/ha nitrogen fertilization was confirmed. Leguminous plants are particularly sensitive to phosphor and potassium deficiency and they respond with significant growth when fertilized with mentioned elements. 40-45 kg of P_2O_5 per hectare and 110-120 kg of K_2O per hectare should be applied on average soils. These plants shall be cultivated on neutral-reaction or light-acid-reaction soils. It is disadvantageous to cultivate the plants on soils directly after liming (the most profitable is liming for forecrop or a year before cultivation). Yellow lupine may be cultivated few years after liming. Leguminous plants are highly sensitive to deficiency of molybdenum, boron and copper.

Meadow and pasture lichen respond extensively to nitrogen fertilization. A dosage even up to 400 kg per hectare give rise to harvest, but agriculture efficiency of dosages exceeding 240 kg/ha is unsatisfactorily. Greater dosages of nitrogen cause changes in botanical composition of pasture. The distribution of grass (cock's-foot, Yorkshire fog, rough-stalked meadow-grass) is then increased while the distribution of legume and herbs decreases. Phosphor and nitrogen fertilization has an impact on productivity of grasslands, composition of pasture and the quality of green mass. Application of up to 60 kg of P_2O_5 and 150 kg of K_2O on each type of soil is well-founded. Except that, bigger dosages of phosphor fertilizers cause an increase in phosphor content and have a positive impact on mineral composition of hay. For this reason, it is advantageous not to decrease phosphor fertilization. Potassium overdose causes excessive increase of the content of this element while magnesium consumption becomes limited. Grasslands liming is less significant, but magnesium fertilization is substantial on account of depletion of this element in soils and deterioration in the amount and quality of harvests. It is advantageous to apply magnesium sulphate or potassium and magnesium fertilizer up to 100 kg/ha each 2 or 3 years. Magnesium content in hay should not be lower than 0.25% of mass fraction of Mg in dry mass. An increase of interest in sodium fertilization has been noted on account of nutritive value of grasslands feedstuff. The content of sodium in grassland plants is limited to 0.15% of Na in dry mass. Deficiency of this element has an impact on development of tetany, losing appetite, licking disease, and anxiety in animals. Sodium fertilization is more advantageous than application of mineral lick containing this element as it improves tastiness of feedstuff and better eating up of plants. High nitrogen fertilization causes increase in major elements consumption from soils, especially of Cu, Mn, Zn, Fe. Depending on the content of these elements in soils, it is recommended to use them as fertilizers.

9 fertilizer recipes were named on the basis of filtration residue, test results and analysis of types of cultivations & applications of fertilizers obtained from these residues. They are specified in Table 9.

Table 9. *The nominal characteristic of the content of nutrient components in the worked out manure-based fertilizers*

No.	Purpose	Component ratio $N:P_2O_5:K_2O:MgO$	Minor elements (% of mass)
1.	Corn cultivated for grains and silage on all stations	1 : 0.8 : 1 : 0.4	Cu - 0.1; Zn - 0.2
2.	Cereals cultivated on magnesium low content soils	0.6 : 1 : 1 : 0.5	Cu - 0.1; Mn - 0.2; Zn - 0.1
3.	Cereals cultivated on phosphor low content soils	0.4 : 1 : 1 : 0.4	Cu - 0.1; Mn - 0.2; Zn - 0.2
4.	Potatoes on all stations	0.8 : 1 : 1 : 0.3	B - 0.1; Mn - 0.2; Zn - 0.2
5.	Beetroot on all stations	1 : 1 : 1 : 0.5	B - 0.2; Cu - 0.1; Mn - 0.2
6.	Rape on all stations	1 : 1 : 1 : 0.4	B - 0.2; Cu - 0.2; Mn - 0.3
7.	Leguminous plants on all stations	0.3 : 1 : 1 : 0.4	B - 0.2; Cu - 0.1; Mn - 0.2
8.	Meadows and pastures	1.2 : 1 : 1 : 0.3	Cu - 0.1; Mn - 0.2; Zn - 0.1
9.	All-purpose fertilizer for phosphor and major elements hungry soils	0.5 : 1 : 1 : 0.2	B - 0.1; Cu - 0.1; Mn - 0.2 Mo - 0.01; Zn - 0.2

Conclusions

Considering quantitative factor for mineral fertilizer, the pig manure may not be fully, directly and sensibly used in agriculture industry. Technologies for processing it in a way enabling partly return of obtained purified waters for farming purposes are tested.

Filtration residue, enriched in inorganic phosphoric compounds and other nutrients for plants, which may be used to obtain solid multi-component mineral-organic fertilizers, is formed during tests for processing of the pig manure carried out with an application of mineral acids and fertilizing components.

Applied procedures for purification of the pig manure had a significant impact on chemical composition of filtration residue which contains vast quantity of common inorganic phosphoric elements (average 12.4% of P) with limited number of these elements in compounds soluble in neutral ammonium citrate and water. The content of lime (average 15.2%) in residue is also high. The content of outstanding major and minor elements shall be supplemented with mineral additives. Heavy metals content falls within limits determined by the European standard for fertilizers.

Basing on filtration residue from the pig manure purification process, a group of mineral-organic fertilizers including minor elements, for fertilizing corn, cereals, potatoes, beets, rape, root vegetables, meadows and pastures, and all-purpose fertilizer were obtained.

Literature

Adeniyan O.N., A.O. Ojo, O.A. Akinbode & J.A. Adediran (2011). 'Comparative study of different organic manures and NPK fertilizer for improvement of soil chemical properties and dry matter yield of maize in two different soils'. *Journal of Soil Science and Environmental Management* 2(1): 9-13.

Bary A.I., C.G. Cogger & D.M. Sullivan (2000). *Fertilizing with manure*. Washington State University, PNW 0533.

Czuba R. & T. Mazur (1988). *Impact of fertilization on the quality of crops*. Warszawa: PWN. [In Polish].

Finck A. (1982). 'Fertilizers and Fertilization. Introduction and Practical Guide to Crop Fertilization'. Verlag Chemie Weinheim, Deerfield Beach, Florida, Basel.

Katyal J.C. & N.S. Randhawa (1983). Micronutrients. FAO Fertilizer and Plant Nutrion Bulletin, No.7. FAO, United Nations, Roma.

Konieczny K., A. Kwiecińska & B. Gworek (2011). 'The recovery of water from slurry produced in high density livestock farming with the use of membrane processes'. *Separation and Purification Technology* 80(3): 490-498.

Kowalski Z., A. Makara, J. Hoffmann & K. Hoffmann (2012). 'Obtaining of NPK type fertilizers from the pig manure using cleaner production methods'. Research report from realization of grant No 14-0003-10/2010. Cracow University of Technology. [Not published].

Mohan Kumar A.B., N.C. Narase Gowda, G. Raviraja Shetty & M.N. Karthik (2011). 'Effect of Organic Manures and Inorganic Fertilizers on Available NPK, Microbial Density of the Soil and Nutrient Uptake of Brinjal'. *Research Journal of Agricultural Sciences* 2(2): 304-307.

Pieters J.G., G.G.J. Neukermans & M.B.A. Colanbeen (1999). 'Farm-scale membrane filtration of sow slurry'. *Journal of Agricultural Engineering Research* 73(4): 403-409.

PN-EN 25663:2001. The quality of water – Determination of total nitrogen by Kjeldahl method – Method used after selenium mineralization. The method of nitrogen determination called Kjeldahl method.

PN-EN ISO 6579:2003. Microbiology of food and animal feeding stuffs - Horizontal method for the detection of Salmonella spp.

PN-ISO 9964-2:1994. Water quality – Determination of sodium and potassium - Part 2: Determination of potassium by atomic absorption spectrometry.

PN-ISO 6060:2006. Water quality – Determination of the chemical oxygen demand.

PN-Z-15011-3:2001. Compost obtained from municipal wastes – Determination of: pH, organic substance content, organic carbon, nitrogen, phosphor and potassium.

PN-75/C-04576/15 – Determination of ammonia nitrogen in waste water residue.

PN 93/C-87085. Artificial fertilizers – Determination of NPK by distillation method.

Polish patent application (2012). P. 400044.

Regulation (UE) No 2003/2003 of the European Parlament and the council of Europe as of October 13 2003 for fertilizers (Journal of Laws L 304 as of 21.11.2003).

Sánchez M. & J.L. González (2005). 'The fertilizer value of pig slurry. I. Values depending on the type of operations'. *Bioresource Technology* 96(10): 1117-1123.

Sneath R.W., M. Shaw & A.G. Williams (1988). 'Centrifugation for separating piggery slurry 1. The performance of a decanting centrifuge'. *Journal of Agricultural Engineering Research* 39(2): 181-190.

Wolter M., S. Prayitno & F. Schuchardt (2004). 'Greenhouse gas emission during storage of pig manure on a pilot scale'. *Bioresource Technology* 95(3): 235-244.

Zhang R. & P. Westerman (1997). 'Solid-liquid separation of animal manure for odour control and nutrient management'. Applied Engineering in Agriculture 13(5): 657-664.