Impact of agricultural farms on the environment of the Puck Commune: Integrated agriculture calculator – CalcGosPuck

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Background. Leaching of nutrients from agricultural areas is the main cause of water pollution and eutrophication of the Baltic Sea. A variety of actions in order to reduce nitrogen and phosphorus losses from agricultural holdings and cultivated fields have been taken in the past. Knowledge about the risk of leaching of nutrients has not yet reached many farmers operating in the water catchment area of the Baltic Sea.

Methods. The nutrient balance method known as "at the farm gate" involves calculating separate balances for nitrogen, phosphorus and potassium. After estimating all the components of the nutrient balance, the total balance for nitrogen, phosphorus and potassium is calculated. The data obtained is expressed as the ratio of total change (surplus) to the area of arable land on a farm. The nutrient usage efficiency on a farm is also calculated. An opinion poll was conducted in 2017 on 31 farms within the commune of Puck, which is approx. 3.6% of all farms located in this commune. Those farms have an area of from 5 to 130 ha (an average of 45.82 ha), including areas of arable land and grassland, which respectively range from 4.45 to 130 ha (an average of 30.79 ha) and from 0 to 53 ha (an average of 12.77 hectares).

Results. The average consumption of mineral nitrogen fertilizers, phosphorous and potassium nitrate per 1 ha of agricultural land (AL) in the entire population of the farms surveyed ranged within the levels of: 114.9 kg N•ha^{-1}AL, 9.3 kg P•ha^{-1}AL, and 22.9 kg K•ha^{-1}AL, respectively. Nitrogen surplus in the farms being analyzed ranged from -23.3 to 254.5 kg N•ha^{-1}AL, and efficiency in the usage of this component ranged from 0.40 to 231.3% . In the case of phosphorus surplus, it has been found that the average value for all farms was 5.0 kg P•ha^{-1} AL. The efficiency of phosphorus usage on farms was 0.4-266.5%.

Discussion. Individual nitrogen fertilizer consumption in the tested farms was higher than the average usage across Poland and in the Pomeranian Voivodeship, compared to the lower consumption of potassium fertilizers. Phosphorus fertilizer consumption was higher than in the Pomeranian Voivodeship, but lower compared to the entire country. Generally, on the basis of designated research indicators of farm pressures on water quality (such as livestock density in LU•ha^{-1}AL; ~~of~~ nitrogen fertilizers in kg N•ha^{-1}AL; consumption of phosphate fertilizers in kg P•ha^{-1}AL; nitrogen surplus in kg N•ha^{-1}AL; and phosphorus surplus in kg P•ha^{-1}AL) concentrations of total nitrogen and total phosphorus are obtained. CalcGosPuck will help to improve and plan fertilizer usage by farmers in order to obtain the best harvest policies, and to raise awareness.

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Abstract

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Generally, on the basis of designated research indicators of farm pressures on water quality (such as livestock density in LU·ha^{-1} AL; of nitrogen fertilizers in kg N·ha^{-1} AL; consumption of

phosphate fertilizers in kg P·ha^{-1} AL; nitrogen surplus in kg N·ha^{-1} AL; and phosphorus surplus in kg P·ha^{-1} AL) concentrations of total nitrogen and total phosphorus are obtained.

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Main article text

Introduction

Leaching of nutrients from agricultural areas is the main cause of water pollution and eutrophication of the Baltic Sea. A variety of actions in order to reduce nitrogen and phosphorus losses from agricultural holdings and cultivated fields have been taken in the past. Knowledge about the risk of leaching of nutrients has not yet reached many farmers operating in the water catchment area of the Baltic Sea.

Thanks to international cooperation in the field of water quality improvement, it was determined that the future focus should be on expanding knowledge and social awareness in a given country. There are relatively cheap and simple prevention measures, but not all of them have yet been implemented or entered into the list of 25 priority measures set out within the framework of the Baltic Compass project (Salomon E., Sundberg M., 2012). One of the reasons for this is that these measures should be worked out in practice by farmers based on their knowledge, and then adapted to the given farming conditions. (Ulén, Pietrzak, Tonderski, 2013.)

The farm is the basic organizational unit in agriculture and it produces food and raw materials for industry. Production involves a large number of nutrients, only a fraction of which are converted into animal and vegetable products. Some of the unused nutrients in production (surplus or lost nutrients) accumulate in the soil, or are lost to surface waters, drain water, groundwater, or to the atmosphere. Loss of nutrients has a negative economic impact (reduced production and higher cost of production inputs) and poses a threat to the environment. Nitrogen and phosphorus compounds are of special concern to the environment and are being lost through several pathways:

– surface runoff from soils
– subsurface flow and leaching within soils
– water and wind erosion (transport by water and wind of nitrogen and phosphorus compounds bound to soil particles)

– emissions of gaseous forms of nitrogen: ammonia, oxides of nitrogen (II and IV) and their deposition by atmospheric precipitation.

Nutrient losses are inevitable, but because of the environmental and the economic impacts on production they should be limited to the possible minimum. Therefore it is essential to create farm production conditions which ensure the effective management of nutrients. Drawing up a nutrient balance for a farm may be helpful in this context, performed by the "farm gate" method. Estimating nitrogen and phosphorus values in a nutrient balance can lead to many practical conclusions helping to reduce the impact of agricultural production on the environment and to improve the economics of farming. An example of the latter would be the results of more effective use of nutrients on a farm and lower expenditures on fertilizers and feeds. Therefore knowledge on how to estimate nutrient balances should be more widely disseminated, especially among skilled farmers and agricultural advisors (Pietrzak, 2013).

The research presented in this paper was made within the “WaterPUCK” project (“Modelling of the impact of the agricultural holdings and land-use structure located in the Puck Commune on the quality of water in the Bay of Puck – Integrated information and forecasting Service ‘WaterPUCK’”) (Dzierzbicka-Glowacka et al., 2018).

The project is focused on the determination of the current and future environmental status of the surface water and groundwater in the Puck Commune and its impact on the Bay of Puck environment (Fig. 1). The most significant sources of nutrients and pesticides for the environment are agriculture and surface structure usage, such as sewers or drainage ditches, therefore their impact on the environment will be estimated by compiling the recent knowledge, factoring in the essential in situ measurements, and using advanced modelling.

The web tools obtained within the project (service WaterPUCK with CalcGosPuck) will be developed in a way to take into account many innovative measures processes and models to serve as a good basis for "green economy" development, and could be implemented in other Baltic Sea catchment areas. This is in line with the objectives of European legislation, including the Water Framework Directive, the Marine Strategy Framework Directive and the Habitats Directive, as well as with the HELCOM Baltic Sea Action Plan and the strategic program of environmental protection for the Puck Commune.

The WaterPUCK service (Fig. 2) will include the following: a surface water model based on SWAT, a groundwater flow model based on Modflow, a 3D environmental model of the Bay of

Puck based on the "EcoPuckBay" POP code and an integrated agriculture calculator called "CalcGosPuck".

CalcGosPuck was formed as the first module of the WaterPuck service and is the one presented in this article. The agricultural practices defined in the model have the biggest effect on the amount of pollution that enters both the surface and the ground waters, and from a purely hydrological point of view on the amount of evapotranspiration as well. It should be underlined that the uncertainty included in the data provided by farmers is insignificant: the agrotechnological practices of farmers, in principle, have been captured in the scale of the commune of Puck, taking into account 31 farms of different types.

Material and methods

The general concept of nutrient balance on farms

The "at the farm gate" nutrient balance method usually involves calculating separate balances for nitrogen, phosphorus and potassium. The principle is the same for all three nutrients, with the exception that nitrogen balance sheets include more elements because a larger number of sources introduce nitrogen onto farms (e.g. legumes, deposition). The procedure balance of nutrients using the farm gate method has been described in detail by Pietrzak (2013). Preparation of the nutrient balance by the farm gate method involves determination of input and output streams on the farm (Fig. 3).

The masses of nutrients brought onto a farm in the form (income) is calculated by:

A: Amount of input in mineral fertilizers (own study based on data producers of mineral fertilizers)

B: Amount of input in purchased concentrated fodders (Mercik, 2002)

C: Amount of input in purchased bred animals (Fagerberg et al., 1993;Wrzaszcz, 2009; Rutkowska, 2010; Szewczuk, 2010)

D: Amount of input in natural fertilizers (manure) (Maćkowiak, 1997; Grabowski, 2009)

E: Amount of input in other purchased products (Fagerberg et al., 1993;Wrzaszcz, 200; Rutkowska, 2010; Szewczuk, 2010)

F: Amount of input in deposition (adopted for the Pomeranian Voivodeship)(IMGW)

G: Amount of symbiotically fixed nitrogen (Schmidtke, 2008; Høgh-Jensen et al., 2004)

H: Amount of nitrogen introduced by free-living soil microorganisms (Mazur, 1991)

Calculation of the amount of nutrients exports from the farm (Fagerberg et al., 1993; Wrzaszcz, 2009; Rutkowska, 2010; Szewczuk, 2010):

I: Amount of output nutrients in sold animal products

J: Amount of output nutrients in sold plant products

Estimating nutrient balance and usage efficiency

After estimating all the components of the nutrient balance, the total balance for nitrogen, phosphorus and potassium, and for all macronutrients combined, can be calculated. The data obtained can be expressed as a ratio of total change (surplus) to area of arable land on the farm. The nutrient usage efficiency on the farm can also be calculated. The use efficiency of nitrogen, phosphorus and potassium is the ratio: the amount leaving the farm/the amount entering the farm X 100%. The nutrient usage efficiency can be used to define the percentage of nutrients brought into the farm which are used directly for production.

Farms in the Puck Commune.

Cultivation and their area.

An opinion poll was conducted on 31 farms within the Commune of Puck, which is approx. 3.6% of all farms in this commune. Those farms have an area of from 5 to 130 ha (an average of 45.82 ha) including areas of arable land and grassland, respectively from 4.45 to 130 ha (an average of 30.79 ha) and from 0 to 53 ha (an average of 12.77 hectares) (Fig. S1).

Within the test area of the agricultural land, medium soils defined as category III comprise the majority: 90.3% (28 farms). These are sandy clay, light clay, silty clay, and silts. The remaining 9.7% (3 farms) of the soils includes light soil (Fig. S2). The types and areas of the field-scale crops and grasslands in farms participating in the WaterPUCK project are given in Fig. 4, and animal population, type, and the barn maintenance systems are given in Table 1.

The main profile of the animal production of farms participating in the project is:

- production of milk and beef livestock on 12 farms – 39% of the total number of all farms,
- production of pork livestock on 6 farms – 19% of the total,
- production of pork and beef livestock on 4 farms – 13% of the total,
- production of beef livestock on 2 farms – 7% of the total,
- farming and horse breeding on 1 farm – 3% of the total.

In the decisive majority of farms the management system of livestock manure was the slurry and solid manure system, in which animals are maintained in livestock buildings on a shallow litter.

An exception was the farm marked code 29, where some of the young animals (calves and heifers) were kept in deep leaf litter, and one small farm (code 31) where all the animals (calves and piglets) were kept in a deep barn, in a total of 1.3 LU.

The livestock density fell within a wide range of values: on 14 farms it ranged from 0.1 to 1.0 $LU \cdot ha^{-1}$; on 9 farms it ranged from 1.1 to 2.0; and only 2 farms had values from 2.1 to 3.0 $LU \cdot ha^{-1}$.

In those two farms the mass of nitrogen produced in natural fertilizers per hectare was relatively high, with values ranging from 138 to 145 kg $N \cdot ha^{-1}$. Under unfavourable farming conditions, within the meaning of the principles of the Nitrates Directive, it could have already been a potential environmental hazard.

In a small portion of the farms (9, 11, 20 and 23) involved in the production of milk and beef livestock, animals have periodically been at pasture. The farm marked code 27, which breeds and raises horses, has also been using pastures.

Crop rotation and after-crops on the farm

Out of the Puck Commune farms surveyed, the vast majority of them (30) practice crop rotation (96.8%). The most common kind of crop rotation was cereal rotation (the share of cereal plants above 60%).

The most relevant rotation was field-corn cereal (above 60%), on 23 farms (76.7%).

Only 6 (19.4%) out of all the farms cultivated after-crops. On farms that have been using after-crops the two types of the after-crops, catch crops and mixed cropping (companion crops), have been equally preferred. These after-crops were in the majority of cases (83.3%) incorporated in green manure. The cultivated area of after-crops amounted to from 14.4 to 35.7% of the farms' total arable surface.

Storage of natural fertilizers and silage

In all the surveyed farms from Puck commune all structures used for the storage of manure, smaller and larger, meet the requirements for distance from wells, edges of waterways and reservoirs. Moreover, 19 (82.6%) dung panels and tanks for manure are relatively new (made after 2004), therefore there is a high probability of effectively stopping leachate of manure and slurry leakage (Fig. S3).

- On three farms manure is being stored directly on the ground, but the piles are located on flat, not sandy and not waterlogged areas, at a distance of more than 20 m from the edges of waterways and reservoirs.
- One of the farms (3.2%) is obligated to have a slurry storage tank, due to the litter-free system of keeping livestock in. On this farm the current tank was made in 2013 and is located at a distance of more than 20 m from the protected zones of water sources and water intakes and the of the edges of reservoirs and waterways.
- On16 of the surveyed farms (51.6%) the most common practice to store compacted silage is special plastic bales that limit the risk of silage juice. Less frequently observed, on only 9 farms (29%), is silage storage in field piles directly on the ground.

Permitted dates to use natural fertilizers

In 2017, in accordance with the law dated 10 July 2007 on fertilizers and fertilization, natural and organic fertilizers, in either liquid or solid form (manure, liquid slurry, slurry), were allowed to be used from March 1st to November 30th. Permitted dates of solid manure use on arable lands and liquid natural fertilizers use (manure, slurry) on permanent meadows are given in Figs S4 and S5, respectively.

Results

Integrated agriculture calculator - CalcGosPuck.

In accordance with the "at the farm gate" concept method, the agriculture calculator “CalcGosPuck” was developed. The CalcGosPuck calculator works as an independent application designed to calculate the income and expenditure, and then the surplus and the efficiency of a farm. The user gives the farm size and selects the required province, input and output products for balance and gives their amount. CalcGosPuck works properly (see the website www.waterpuck.pl in Service .– Fig. 5)

One should enter the following data into the CalcGosPuck calculator (Fig. 6), in order to determine revenue, expenditure, surplus (or deficiency) and the efficiency of the farm:

- give the area of agricultural land of the farm (in hectares) (Fig. 6a);
- select the province in which the farm operates (Fig. 6b);
- select indicators of what is introduced onto the farm (mineral fertilizers, concentrated fodder (mixed cattle feed, mixed pig feed, mixed poultry feed), purchased animal products, natural

fertilizers, other purchased plant products, by atmospheric precipitation, by legumes, and fixed by soil microorganisms) (Figs. 6c)

- select indicators of what is removed from the farm (in sold animal products and in sold plant products) (Fig. 6d)
- give the amount of each selected indicator (Fig. 6e)

After each parameter is selected, the basic data are automatically set down: income, expenditure, surplus (or deficiency = value with a minus sign) and also the data related to the efficiency of the farm, which are displayed in the top bar. (Fig. 6f).

An examples presented below for the following situations:

Select parameters:

Area of agricultural land – 70 ha (9th farm),

Province – Pomerania

Inputs and their amounts:

– in mineral fertilizers: urea =100 dt, ammonium nitrate = 50 dt,

– in concentrated fodder:

- mixed cattle feed: –
- mixed pig feed: –
- mixed poultry feed: –

– in natural fertilizers: –

– in energy and protein fodders: rape cake for animals = 240 dt, dried pulp = 150 dt, post-extraction soya meal = 400 dt;

– by legumes: –

– in other plant and animal products: maize (grain) =120 dt, heifers 15 dt;

– by soil microorganisms: 8 $kg \cdot ha^{-1} \cdot year^{-1} \cdot 70$ ha (area) (here, we have adopted a fixed value of 8 $kg \cdot ha^{-1} \cdot year^{-1}$ in all cases)

Outputs and their amount:

– animal products: milk = 3500 dt, dairy cattle = 35 dt,

– plant products: –

After the parameters have been selected, the screen will illustrate the results of the calculator (Fig. 6f):

Budget:

Inputs: N: 10996.00 kg; P: 609.00 kg; K: 645.95 kg

Outputs: N: 1977.50 kg; P: 375.90kg; K: 530.95 kg

Surplus: N: 9018.50 kg P: 233.10 kg; K: 115.00 kg

Efficiency: N: 17.98 %; P: 61.72 %; K: 82.20% .

Consumption of natural fertilizers

The average consumption of mineral nitrogen fertilizers, phosphorous and potassium nitrate per 1 ha of agricultural land in the entire population of the farms surveyed ranged within the respective levels of: 114.9 kg N·ha^{-1} AL, 9.3 kg P·ha^{-1} AL, and 22.9 kg K·ha^{-1} AL. On the individual farms consumption of the components listed ranged widely, as: nitrogen: from 0 to about 232.6 kg·ha^{-1} (Fig. 7); phosphorus: from 0 to about 31.2 kg·ha^{-1} (Fig. 8); and potassium: from 0 to 159.6 kg·ha^{-1} (Fig 9.).

The surplus and efficiency of nitrogen and phosphorus usage

Nitrogen surpluses on the analyzed farms ranged from -23.3 to 254.5 kg N·ha^{-1} AL, and efficiency in the usage of this component ranged from 0.40 to 231.3% (Fig. 10). The lowest efficiency, of 0.4%, was found in the farm with code 27, breeding horses; next, the level of 4.5%; and finally the highest level of 231.3%, in the farm with code 17, dealing solely with plant production. The average nitrogen surplus in 31 farms, in relation to their total agricultural area, was 120.6 kg N·ha^{-1} AL.

In the case of phosphorus surplus, it has been found that the average value for all farms was 5.0 kg P·ha^{-1} AL (Fig. 11). On each individual farm it ranged from 17.11 to 28.7 kg P·ha^{-1} AL. Efficiency in the phosphorus usage on farms was at a level of 0.4-266.5%.

The correlation between nitrogen and phosphorus surplus and selected elements of the balance of these components

Analysis of the correlation between nitrogen and phosphorus surplus and selected elements of the balance of these components was carried out using the STATISTICA 7 program. The nonparametric method of calculating the Spearman rank correlation coefficient was used, because the data being compared did not have a normal distribution.

A positive correlation was found between nitrogen surplus and nitrogen being brought in with mineral fertilizers, between nitrogen being brought in with feeds and nitrogen share in the animal production sold, and a negative correlation with nitrogen usage effectiveness. In addition, there was a directly proportional relation between nitrogen being brought in with feeds and N livestock production sold, and an inverse proportional relation between nitrogen usage effectiveness and the nitrogen share in the animal production sold (Table 2).

With regard to the phosphorus surplus, with the exception of the lack of its correlation with the phosphorus in feeds, a similar type of relation between the analyzed factors has been identified, as in the case of nitrogen surplus (Table 3).

Discussion

Consumption of mineral fertilisers in the farms surveyed, in Poland and in the Pomeranian Voivodeship

The individual nitrogen fertilizers consumption on the tested farms was higher than average usage across Poland and in the Pomeranian Voivodeship, compared to the lesser consumption of potassium fertilizers (Table 4). Phosphorus fertilizers consumption was higher than in the Pomeranian Voivodeship, while being lower compared to the entire country.

Environmental aspects of fertilizer usage

- On 29 out of the 31 tested farms (93.5%), the annual dosage of nitrogen fertilizers (mineral, natural, organic) is divided into parts for individual field-scale crops during the growing season. In the case of arable lands, it is most common to divide them into three parts. The most common practice used for permanent meadows is two fertilizations in the growing season.
- 19 farms have arable land on parcels with steep~~er~~ slopes (~~a grade of~~ more than 10%), which represents more than 61% of all farms involved in the study. The general rules of fertilizer usage on steep slopes were taken into account on most of these farms (16 responses, representing 84.2%). In only two cases the rules have not been followed. In cases of parcels with a slope of more than 10%, cultivation treatments have been carried out in a direction transverse to the slope leaving the ridge up the slope.
- 2 farms (6.5% of all replies) applied fertilizers on flooded soils, covered in snow, frozen to a depth of 30 cm, and during rainfall. Municipal sewage sludge has not been used in areas of special flood hazard, temporarily flooded and swampy areas, or on high permeability areas on any of the farms.
- On the majority of the farms tested (87.9%), there are agricultural lands located at a distance of less than 50 m from the edges of waterways and lakes. On the other hand, on most of them (almost 63% of responses) in the areas close to waterways or reservoirs, fertilization has

not been used. In 6 cases (22. 2%) fertilization has been used at a distance less than 20 m from the edges of waterways and lakes.

- Records of agricultural treatments, containing information about due dates and doses of fertilization are being kept on 23 farms, representing 74.2% of all farms. On the remaining 7 farms, no agricultural records are kept. There are no data concerning one farm.
- Only one of the analyzed farms keeps documentation for the disposal of natural fertilizers (agreement for sale of any surpluses).
- Plans for balancing of nitrogen and fertilization are being developed on 64.5% of all the farms. As far as the remaining 11 farms are concerned, balance sheets and plans are not being developed, or there is no information about that.

Conclusion

- Both the need and importance to create nutrient balances "at the farm gate" in agricultural holdings - isare widely articulated in many sources. One can meet find such recommendations in this area such – as the following:
  - The balance of the farm gate nutrients is a basic and simple way to increase knowledge and awareness about the flow of nutrients flow - to and from the a farm, - creating a starting point for discussion on how to efficiently efficiency to use these components in a farm and on their impact onboth – on both the environment and on the economics of the farm (Nilsson, 2013).
  - Nutrients Balance allows enables a farmer to easily review their flow in their farm. This allows to checking whether too many nutrients are being brought into onto the farm, - in the means of production, – coming from the purchases. Thanks to that, a well-prepared nutrients balance can contribute to lower the operating costs of the farm by showing the actual amount of nutrients needed for production (Nutrient balance).
  - Nutrient Balance "at the farm gate" is helpsful to determine if there are opportunities to improve the management of the nutrients on the farm (Farmgate Nutrient Balance Help file PLANET).

By calculating the nutrients balances on the farm, based on the principles of farmers' voluntary participation and through their dialogue with the advisory institutions, the an agreement may be achieved – in order to reduce NPK surpluses and to increase farm income of the farms. (Olofsson, 2014).

- Mineral fertilization on sustainable farms should be considered as supplementary to organic fertilization. The basis for sustainable fertilization is defining, as precisely as possible, the amount of natural fertilizers available on a farm and the amount of nutrients they contain.
- The program's other function is the assessment of fertilization's impact on the environment by controlling the balance of ingredients designated by the "at the farm gate" method (Pietrzak,2013). A positive value indicates that the supply of nutrients (N, P, K) on a given field exceeds their intake with crops. A negative value means that the intake by plants is higher than the supply of components.

CalcGosPuck works as an independent application to calculate the discharge of pollution from agricultural holdings into the surface and groundwater, but it also can serve to calculate the nutrients' distribution over agricultural areas and estimate the processes impacting the productivity of the usage of fertilizers at different sites.

Generally, on the basis of designated research indicators of agricultural pressures on water quality, such as livestock density in LU·ha^{-1} AL, consumption of nitrogen fertilizers in kg N·ha^{-1} AL, consumption of phosphate fertilizers in kg P·ha^{-1} AL, nitrogen surplus in kg N·ha^{-1} AL, phosphorus surplus in kg P·ha^{-1} AL, concentrations of total nitrogen and total phosphorus are obtained.

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References

Dzierzbicka-Głowacka L., Janecki M., Dybowski D., Szymczycha B., Obarska-Pempkowiak H., Wojciechowska E., Zima P., Pietrzak S., Pazikowska-Sapota G., Jaworska-Szulc B., Nowicki A., Kłostowska Ż., Szymkiewicz A., Galer-Tatarowicz K., Wichorowski M., Białoskórski M., Puszkarczuk T. 2019. *A new approach for investigating the impact of pesticides and nutrient flux from agricultural holdings and land-use structures on the coastal waters of the Baltic Sea.* Polish Journal of Environmental Studies Vol. 29, No 5, 2019. DOI: 10.15244/pjoes/92524 (on-line 2018) (in press)

Fagerberg B., Salomon E., Steineck S. 1993.*The computer program NPK-FLO*. Uppsala. Swedish University of Agricultural Sciences. Department of Crop Production Science – Internal Publications, **9,** pp. 47.

Farmgate Nutrient Balance Help file PLANET, version 3.0 pp. 1-16. Available on the Internet:http://www.planet4farmers.co.uk/PlanetWebsiteTutorialsFiles%5CHelpEngland%5CPLANET%20v3%20Farmgate%20Nutrient%20Balance%20Help.pdf

Grabowski J. 2009.*Chemical composition of mineral fertilizers*. Białystok. OSCh–R: http://www.oschrbialystok.internetdsl.pl/pdf/nawozy_naturalne.pdf (in Polish)

Grześkowiak A.*Fertilization of vegetables in the field cultivation* : http://www.polifoska.pl/module-Publikacje-action-Nawozenie-file-content_ 83.html.html (in Polish).

Høgh-Jensen H., Loges R., Jørgensen F.V., Jensen E.S., Vinther F.P. 2004.*An empirical model for quantification of symbiotic nitrogen fixation in grass--clover mixtures*. Agricultural Systems, **82**:181–194.

Maćkowiak C. 1997.*Organic fertilizers in farms and their influence on the environment*. Przysiek. ODR, pp. 21 (in Polish).

MazurT. 1991. *Nitrogen in arable soils*. Warszawa, Polish Scientific Publishers.., pp. 1-239 (in Polish).

Mercik S. 2002.*Agricultural chemistry. Theoretical and practical basics.* Collective work. Warszawa. SGGW Publisher. pp. 1-287 (in Polish).

Nilsson C. 2013. Farm gate nutrient balance. The report prepared within the Baltic Deal project.

Nutrient balance. Available on the internet: http://www.balticdeal.eu/measure/nutrient-balance/.

Olofsson S. 2014. The setup for the voluntary nutrient balances in Sweden. Tema: Miljø 84 Obligatory or voluntary nutrient balances? Plantekongres – produktion, plan og miljø s. 350-351,

Pietrzak S. **2013**.*Preparation of nutrients balance with the method "at the gate of the farm*, In Ulén., Pietrzak s., Tonderski k. (eds), *Farms' self- evaluation in the fields of: nutrients' management and the environmental conditions' analysis*. Institute of Technology and Life Sciences in Falenty, Poland, pp. 1-99 (in Polish).

Rutkowska A. 2010.*Determination of the- AlgaPlant and AlgaminoPlant - growth promoters' impact on the yield green maze mass on green fodder.* Research report. Puławy.

IUNG-PIB p. 10. (in Polish)

Salomon E., Sundberg M. 2012.*Implementation and status of priority measures to reduce N and P leakage.* Summary of country reports: www.balticcompass.org

Schmidtke K. 2008.*How to optimise symbiotic nitrogen fixation in organic crop rotations,* In. Organic agriculture in Asia. ISOFAR Conference. 13-14 March 2008. Dankook University, Republic of Korea: http://orgprints.org/13272/01/13272.doc

Schweder P., Kape E.-H., Brick M. 1998. *Düngung Hinweise und Richtwerte für die landwirtschaftliche Praxis – Leitfaden zur Umsetzung der Düngever¬ordnung. Mecklenburg-Vorpommern.* Ministerium für Landwirtschaft und Naturschutz pp.1-226. (in German)

Szewczuk Cz. 2010.*Before you sell the straw – the balance of nutrients*. Agricultural News Poland **9:**http://www.wrp.pl/zanim-sprzeda%C5%BC-s%C5%82om%C4%99-%E2%80%93-bilans-substancji-od%C5%BCywczych (in Polish)

Ulén B., Pietrzak S., Tonderski K., 2013. *Farms' self- evaluation in the fields of: nutrients' management and the environmental conditions' analysis.* Institute of Technology and Life Sciences in Falenty, Poland, pp. 1-99 (in Polish).

Wrzaszcz W. 2009. *Nutrients Balance and the balance sheet of organic matter in individual farms. The research on the socially sustainable agriculture.* T7. multi-annual program 2005-2009. The economic and social conditions for the development of Polish food economy after Polish accession to the European Union. Warsaw, Poland, IERiGŻ-PIB pp. 1-98 (in Polish).

Figure 1

Map of the study area: Puck District and Bay of Puck.

The Bay of Puck, southern Baltic Sea is an example of a region that is highly vulnerable to anthropogenic impact. Therefore, it has been included into Natura 2000.

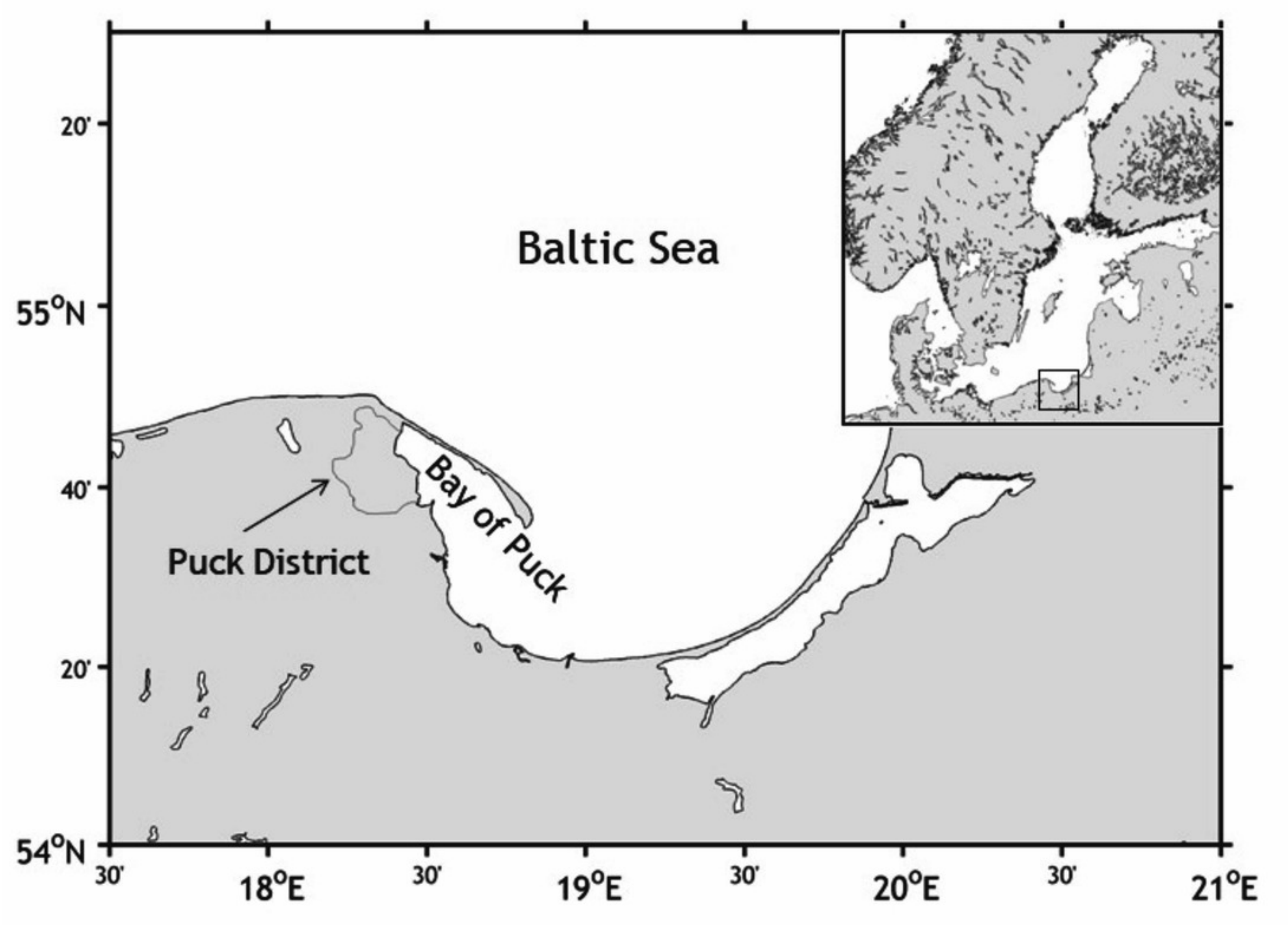

Figure 2

The shame of the WaterPUCK Service.

Integrated information and prediction Service WaterPUCK includes surface water model (based on SWAT Soil and Water Assessment Tool), groundwater flow model (based on Modflow code), 3D environmental model of the Bay of Puck EcoPuckBay (based on the POP code and 3D CEMBS model of the Battic Sea) and integrated agriculture calculator called "CalcGosPuck" plus large Database WaterPUCK.

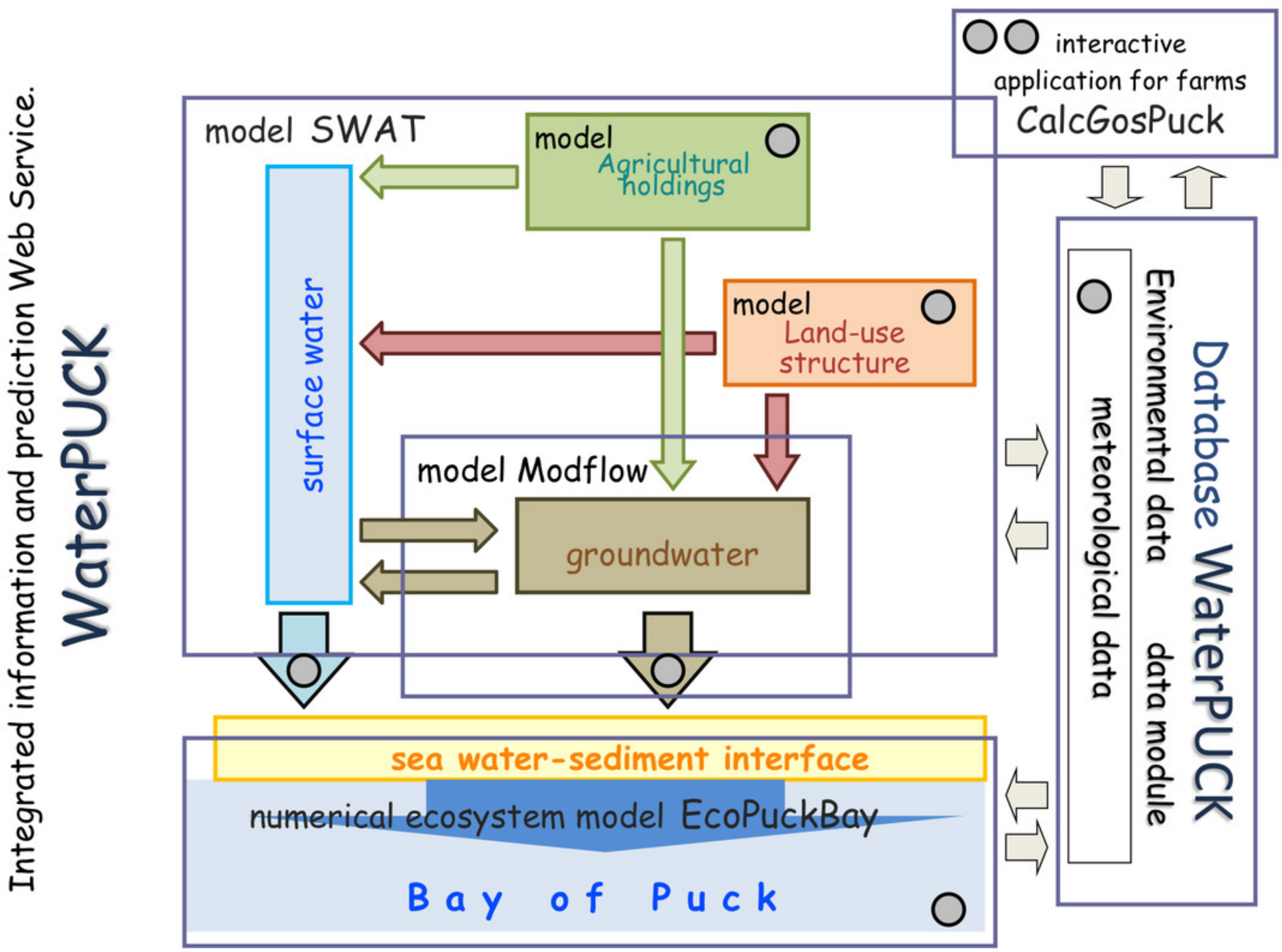

Figure 3

Schema of the nutrient balance method "at the farm gate"; own elaboration (Pietrzak 2013).

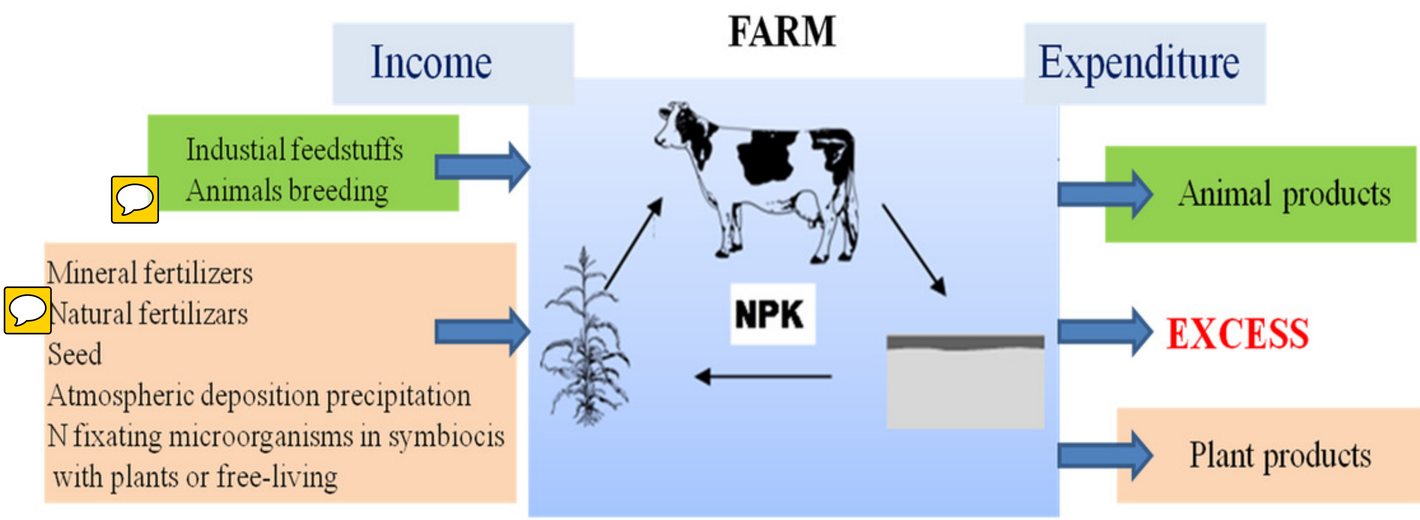

Figure 4

Type and area of arable land or grassland in farms participating in the WaterPUCK project.

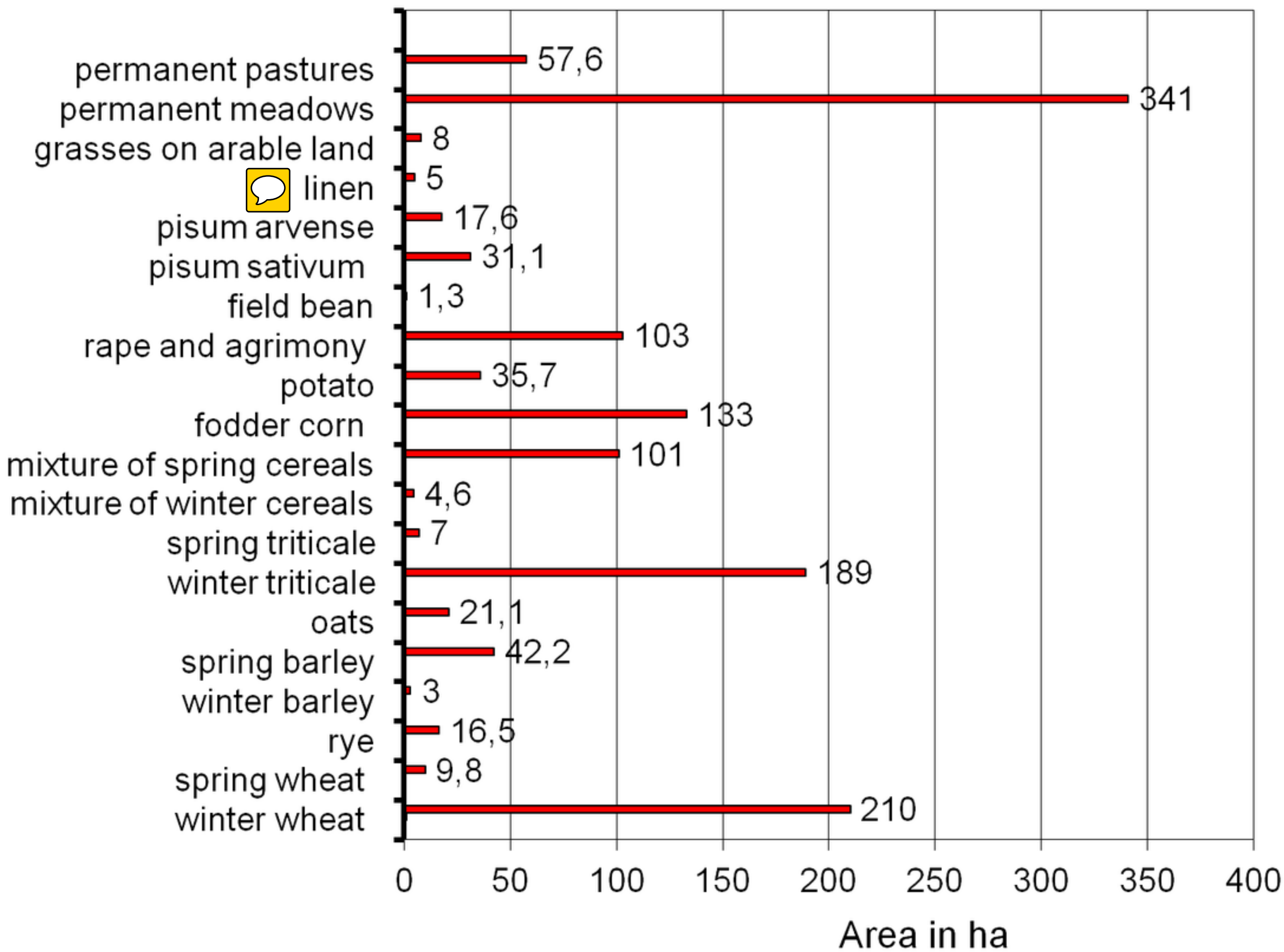

Figure 5

The selection page of the CalcGosPuck agricultural's calculator

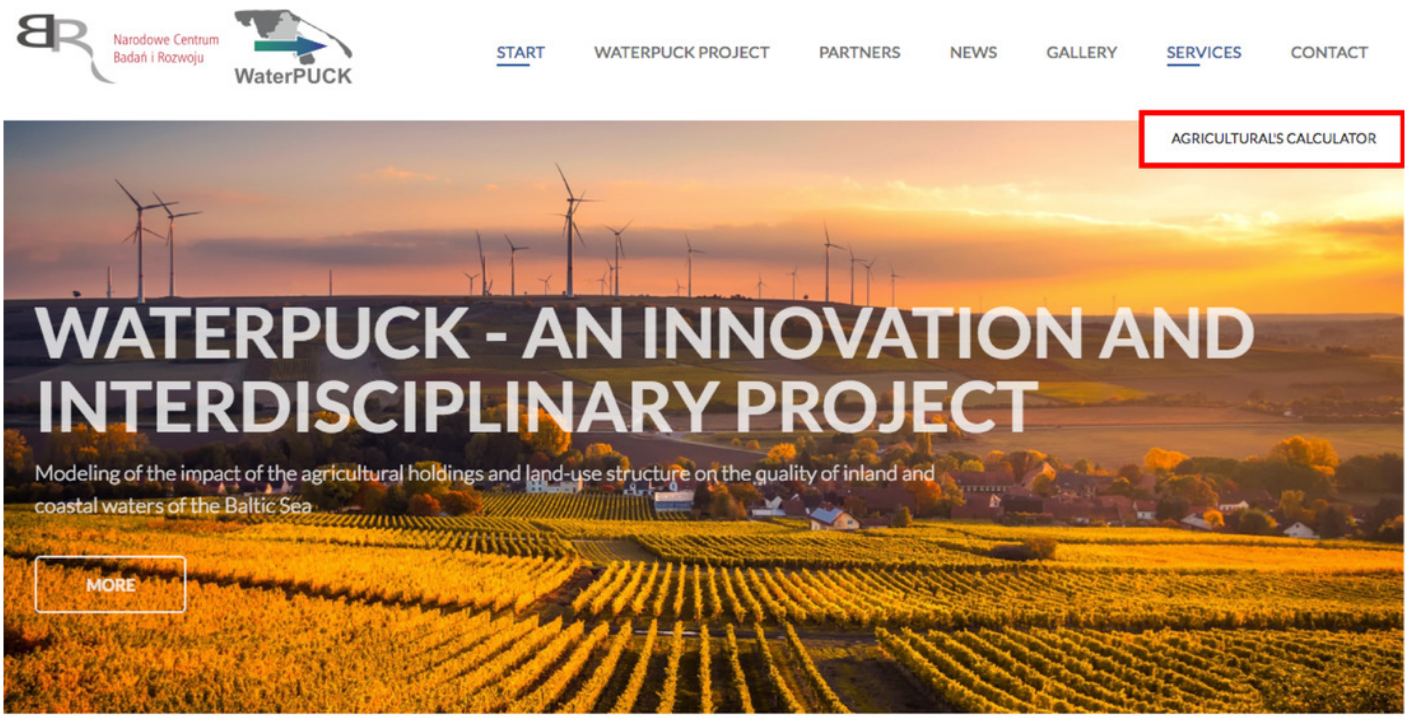

Figure 6

Calculating nutrients balance in farm. Choose parameters for farm.

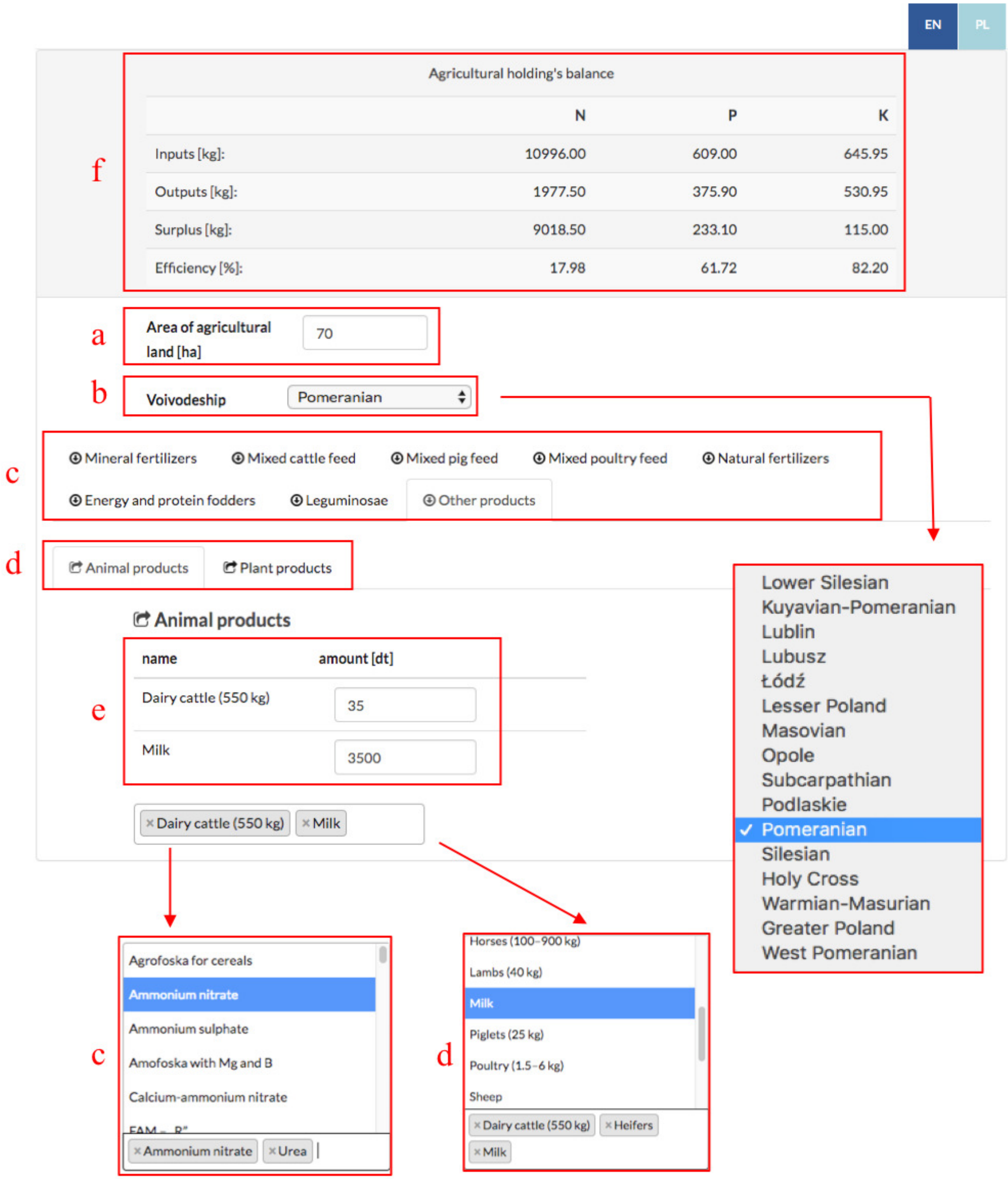
EN
PL
Agricultural holding's balance
N
P
K
Inputs [kg]: 10996.00 609.00 645.95
Outputs [kg]: 1977.50 375.90 530.95
Surplus [kg]: 9018.50 233.10 115.00
Efficiency [%]: 17.98 61.72 82.20
f
a
Area of agricultural land [ha]
70
b
Voivodeship
Pomeranian
c
Mineral fertilizers
Mixed cattle feed
Mixed pig feed
Mixed poultry feed
Natural fertilizers
Energy and protein fodders
Leguminosae
Other products
d
Animal products
Plant products
Animal products
name
amount [dt]
e
Dairy cattle (550 kg)
35
Milk
3500
× Dairy cattle (550 kg)
× Milk
Lower Silesian
Kuyavian-Pomeranian
Lublin
Lubusz
Łódź
Lesser Poland
Masovian
Opole
Subcarpathian
Podlaskie
Pomeranian
Silesian
Holy Cross
Warmian-Masurian
Greater Poland
West Pomeranian
c
Agrofoska for cereals
Ammonium nitrate
Ammonium sulphate
Amofoska with Mg and B
Calcium-ammonium nitrate
× Ammonium nitrate
× Urea
d
Horses (100–900 kg)
Lambs (40 kg)
Milk
Piglets (25 kg)
Poultry (1.5–6 kg)
Sheep
× Dairy cattle (550 kg)
× Heifers
× Milk

Figure 7

The consumption of nitrogen fertilizers in individual farms in farms participating in the WaterPUCK project.

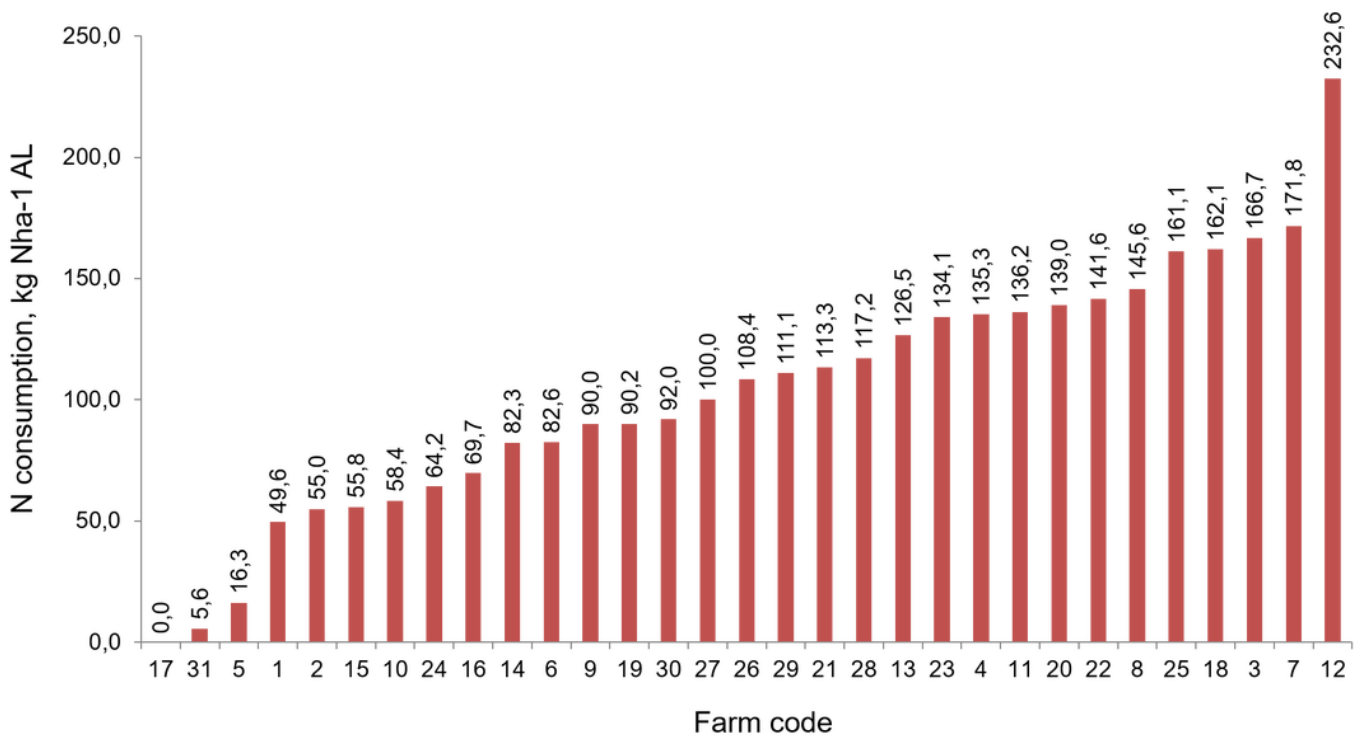

Figure 8

The consumption of phosphorus fertilizers in the individual farms in farms participating in the WaterPUCK project.

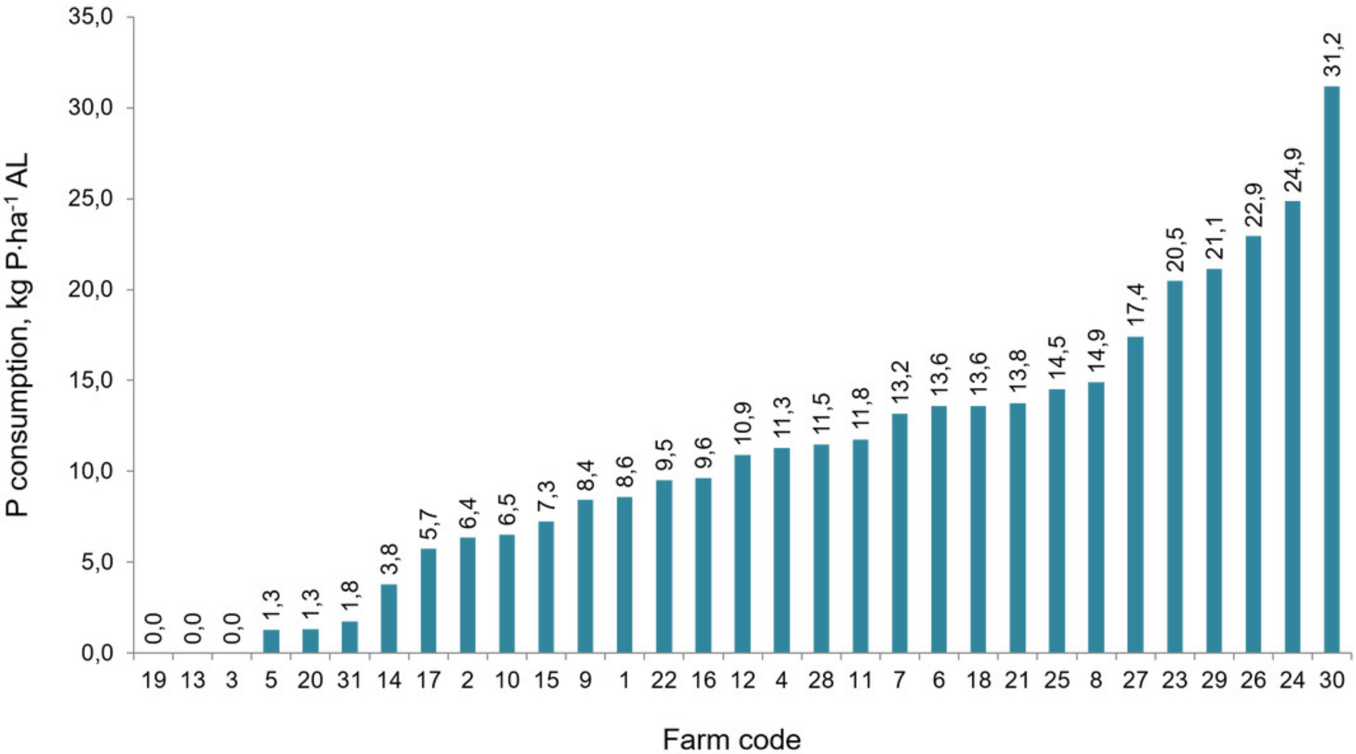

Figure 9

The consumption of potassium fertilizers in the individual farms in farms participating in the WaterPUCK project.

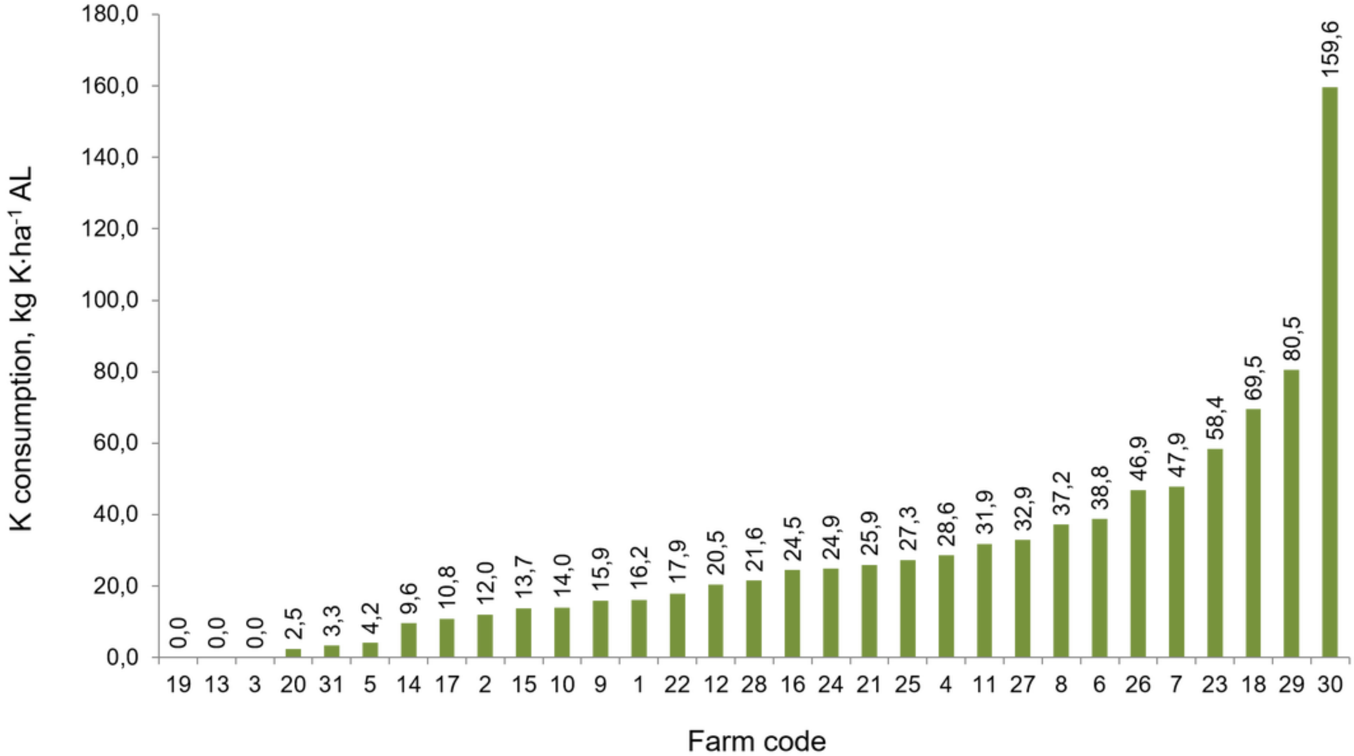

Figure 10

Surplus and efficiency of nitrogen (N) use in farms participating in the WaterPUCK project.

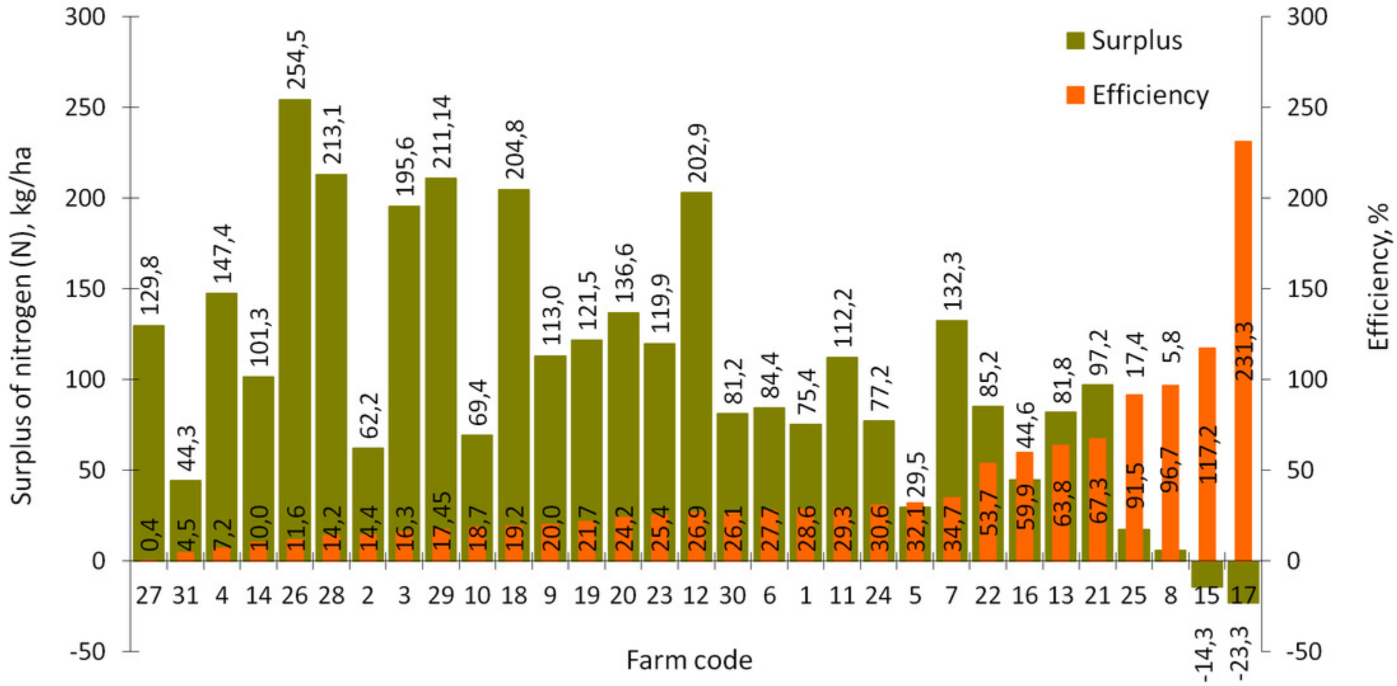

Figure 11

Surplus and efficiency of phosphorus (P) use in farms participating in the WaterPUCK project.

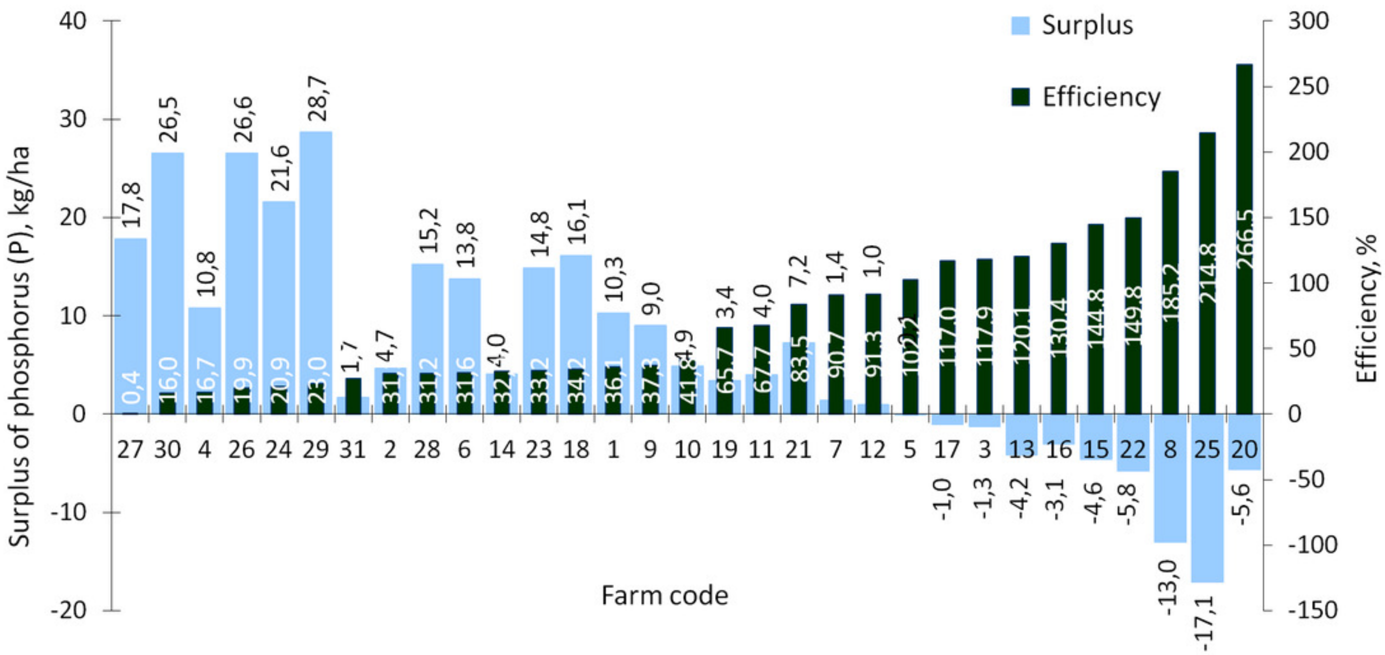

Table 1(on next page)

Animal population, type and the maintenance system in the barn.

Farm Code	Farm area (in ha)	Profile of the animal production	Stocking density		Production of nitrogen in natural fertilizers		
			DJP	DJP/ ha	Animals maintanance system	kg N	kg N/ha
1.	48	milk and beef livestock	51,3	1,1	shallow liter	2308	48
3.	81	milk and beef livestock	85,6	1,1	shallow liter	3843	48
4.	17,3	beef and pork livestock	18,4	1,1	shallow liter	495	27
5.	51,5	beef and pork livestock	15,4	0,3	shallow liter	917	18
6.	16	milk and beef livestock.	14,3	0,9	shallow liter	772	48
7.	38,2	beef livestock	21,2	0,6	shallow liter	723	19
9.	70	milk and beef livestock	70,3	1,0	shallow liter	3192	46
10.	29,5	milk and beef livestock	47,3	1,6	shallow liter	1899	64
11.	18	beef and pork livestock.	8,3	0,5	shallow liter	422	24
13.	43	pork livestock	52,4	1,2	shallow liter	3402	79
14.	10,5	pork livestock	2,9	0,3	shallow liter	214	28
15.	100	milk and beef livestock	61,6	0,7	shallow liter	2662	30
18.	77,5	pork livestock.	67,6	0,8	litter free	4449	56
19.	120	milk and beef livestock	148,6	1,2	shallow liter	6527	54
20.	45	beef livestock.	34,4	0,8	shallow liter	1171	26
21.	15	pork livestock.	45,0	3,0	shallow liter	2073	138
22.	62	milk and beef livestock	36,6	0,6	shallow liter	1603	26
23.	36	milk and beef livestock	24,0	0,7	shallow liter	1095	30
24.	7,24	pork livestock	5,42	0,8	shallow liter	349	48
26.	118	milk and beef livestock.	45,5	0,4	shallow liter	4716	40
27.	19	farming and horse breeding	24,7	1,3	shallow liter	836	40
28.	38	milk and beef livestock	41,9	1,1	shallow liter	1828	48
29.	16,5	milk and beef livestock	34,9	2,1	deep / shallow liter	2385	145
30.	5,0	pork livestock	6,4	1,3	shallow liter	398	80
31.	13	beef and pork livestock.	1,3	0,01	deep litter	70	5

Table 2 (on next page)

The relationship between the surplus of N and selected factors.

Correlation Spearman ranks order, marked correlations are significant - with $p < 0.05$.

	Surplus N [kg/ha]	Efficiency [%]	Nitrogen in mineral fertilizers [kg/ha]	Nitorgen in feeds [kg/ha]	N share in the sold animal production [%]	Area [ha]
Surplus N [kg/ha]	1,00					
Efficiency [%]	-0,58	1,00				
Nitrogen in mineral fertilisers [kg/ha]	0,57	0,04	1,00			
Nitrogen in feed [kg/ha]	0,48	-0,18	0,03	1,00		
N share in the sold animal production [%]	0,36	-0,53	-0,20	0,64	1,00	
Area [ha]	0,25	-0,01	0,24	0,20	-0,01	1,00

Table 3 (on next page)

The relationship between the P surplus and selected factors.

Correlation of the Spearman ranks order, marked correlations are significant - with $p < 0.05$.

	Surplus P [kg/ha]	Efficiency [%]	Phosphorus in mineral fertilizers [kg/ha]	Phosphorus in feeds [kg/ha]	P share in the sold animal production [%]	Area [ha]
Surplus P [kg/ha]	1,00					
Efficiency [%]	-0,91	1,00				
Phosphorus in mineral fertilisers [kg/ha]	0,57	-0,43	1,00			
Phosphorus in feed [kg/ha]	0,33	-0,10	-0,04	1,00		
P share in the sold animal production [%]	0,44	-0,44	-0,12	0,51	1,00	
Area [ha]	-0,24	0,31	-0,35	0,22	-0,07	1,00

Table 4(on next page)

Consumption of mineral fertilizers (calculated on the pure ingredient) per 1ha of agricultural land in the marketing year of 2016/2017.

Area	Mineral fertilizers consumption, kg·ha-1 UR			
	Total (NPK)	Nitrogen (N)	Phosphorus (P)	Potassium (K)
Poland*	121,6	79,4	10,3	31,9
Pomeranian Voivodship*	121,1	82,8	8,8	29,5
Farms surveyed – average	**147,1**	**114,9**	**9,3**	**22,9**