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 remedial actions to reduce nitrogen and phosphorus losses from agricultural holdings and cultivated fields have been taken in the past. However, knowledge about the risk of nutrient leaching 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 (N), phosphorus (P) and potassium (K). After estimating all the components of the nutrient balance, the total balance for NPK is calculated and the data obtained is expressed as the ratio of total change (surplus) to the area of arable land on a farm. In addition, the nutrient usage efficiency on a farm is also calculated. An opinion poll was conducted in 2017 on 3.6 percent (n=31) of the farms located in commune of Puck. The total area of the farms including arable and grass land ranged from 5-130 ha with an average of 45.82 ha. The arable land was on average 30.79 ha ranging from 4.45-130 ha while the grassland averaged 12.77 ha and ranged from 0-53 ha.

Results. The average consumption of mineral fertilizer in the sample population of farms was 114.9 kg N, 9.3 kg P, and 22.9 kg K•ha^{-1}of agricultural land (AL), respectively. N balance in the sample farms being ranged from -23.3 to 254.5 kg N•ha^{-1}AL while nutrient use efficiency ranged from 0.40 to 231.3 percent. In comparison, P surplus in the sample farms was 5.0 kg P•ha^{-1}AL with the P use efficiency of 0.4-266.5 percent.

Discussion. Mean N fertilizer consumption in the tested farms was higher than the average usage across Poland and in the Pomeranian Voivodeship. However, mean consumption of potassium fertilizers was lower than mentioned averages. Mean P 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, concentrations of total nitrogen and total phosphorus were obtained. CalcGosPuck (an integrated agriculture calculator) will help to raise farmers' awareness about NPK flow on farm scale and to improve nutrient management.

1 **Impact of agricultural farms on the environment of the Puck**

2 **Commune: Integrated agriculture calculator – CalcGosPuck**

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Abstract

Background. Leaching of nutrients from agricultural areas is the main cause of water pollution
and eutrophication of the Baltic Sea. A variety of remedial actions to reduce nitrogen and
phosphorus losses from agricultural holdings and cultivated fields have been taken in the past.
However, knowledge about the risk of nutrient leaching 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 (N), phosphorus (P) and potassium (K). After estimating all the
components of the nutrient balance, the total balance for NPK is calculated and the data obtained
is expressed as the ratio of total change (surplus) to the area of arable land on a farm. In addition,
the nutrient usage efficiency on a farm is also calculated.

An opinion poll was conducted in 2017 on 3.6 percent (n=31) of the farms located in commune
of Puck. The total area of the farms including arable and grass land ranged from 5-130 ha with
an average of 45.82 ha. The arable land was on average 30.79 ha ranging from 4.45-130 ha while
the grassland averaged 12.77 ha and ranged from 0-53 ha.

Results. The average consumption of mineral fertilizer in the sample population of farms was
114.9 kg N, 9.3 kg P, and 22.9 kg K·ha^{-1}of agricultural land (AL), respectively.
N balance in the sample farms being ranged from -23.3 to 254.5 kg N·ha^{-1}AL while nutrient use
efficiency ranged from 0.40 to 231.3 percent. In comparison, P surplus in the sample farms was
5.0 kg P·ha^{-1}AL with the P use efficiency of 0.4-266.5 percent.

Discussion. Mean N fertilizer consumption in the tested farms was higher than the average usage
across Poland and in the Pomeranian Voivodeship. However, mean consumption of potassium
fertilizers was lower than mentioned averages. Mean P 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,
concentrations of total nitrogen and total phosphorus were obtained. CalcGosPuck (an integrated
agriculture calculator) will help to raise farmers' awareness about NPK flow on farm scale and to
improve nutrient management.

60 *Main article text*

61 **Introduction**

62 Leaching of nutrients from agricultural areas is the main cause of water pollution and

63 eutrophication of the Baltic Sea. A variety of remedial measures to reduce Nitrogen (N) and

64 Phosphorus (P) losses from agricultural holdings have been taken in the past. However,

65 knowledge about the risk of nutrient leaching has not yet reached many farmers operating in the

66 watershed areas of the Baltic Sea. Nevertheless, the growing international consciousness on the

67 need for water quality improvement has influenced the desire to expand knowledge and social

68 awareness of environmental implications of water quality worldwide. There are relatively cheap

69 and simple prevention measures (e.g., crop rotation, soil fertility analysis, separation of pastures

70 from water courses and reservoirs or systematic on-farm Advisory Services), but not all of them

71 have been implemented or entered into the list of 25 priority measures set out within the

72 framework of the Baltic Compass project (Salomon, Sundberg, 2012). One of the reasons for this

73 is that these measures should be worked out in practice by farmers based on their knowledge,

74 and then adapted to the given farming conditions (Ulén et al., 2013).

75 The farm is the basic organizational unit in agriculture and it produces food and raw materials for

76 industry. Production involves a large quantity of nutrients, only a fraction of which is converted

77 into animal and vegetable products. The surplus of the unused nutrients in production

78 accumulates in the soil, or are lost to surface waters, drain water, groundwater, or to the

79 atmosphere. The loss of nutrients is an economic cost in terms of reduced production obtained

80 with higher cost of inputs and poses a threat to the environment. N and P compounds are of

81 special concern in environmental quality management because they are lost through several

82 pathways such as surface runoff, subsurface flow and leaching within soils, water and wind

83 erosion, emissions of gaseous forms of N and their deposition by atmospheric precipitation

84 (Pietrzak, 2013).

85 Arguably, nutrient losses are inevitable; however, given their environmental and the economic

86 impacts on production and environmental quality, they should be kept below acceptable

87 minimum thresholds. Therefore, it is essential to create farm production thresholds to ensure

88 effective nutrient management. The "At the farm gate" method is one way to conduct a nutrient

89 balance for a farm. This method is a good educational and decision support tool in the area of

90 agricultural production activities, for such entities as farmers, agricultural advisors, agricultural

91   school and university teachers as well as employees of state and local government institutions

92   who are responsible for agri-environmental policy implementation. It is particularly important

93   for farmers and agricultural consultants and advisors cooperating with them. In this partner

94   system, the "At the farm gate" method is used as a measure that could potentially improve the

95   efficiency of fertilizer components management in an agricultural holding, which is a beneficial

96   factor for both economic and environmental reasons. Therefore, farmers and agricultural

97   advisors must be trained to acquire the knowledge and skills to estimate nutrient balances

98   (Pietrzak, 2013). However, there are best practices for increasing nutrient use efficiency in order

99   to reduce expenditure on fertilizers use and feed in commercial agriculture. These entail use of

100 computer programs to estimate nutrient balances in the farm especially for NP. In the United

101 Kingdom, for example, the software for calculating "At the farm gate" nutrient balance is

102 available free of charge for farmers and agricultural advisors as a module of the PLANET

103 (Planning Land Applications of Nutrients for Efficiency and the Environment) system (Farmgate

104 Nutrient Balance Help file). In Sweden, a computerized NPK balancing system called "Greppa

105 Näringen i.e. Focus on nutrients" was implemented on a large scale (Nilsson, 2016) and used by

106 farmers in cooperation with agricultural advisors on a voluntary basis and makes significant

107 impact (Jakobsson, 2012). Furthermore, in the United States, the application for balancing

108 fertilizer components on the farm was disseminated nationwide as part of the "Livestock and

109 Poultry Environmental Stewardship – LPES" program (Koelsch; Koelsch, Franzen, 2002).

110 The research presented in this paper was conducted as part of the project on modelling of the

111 impact of the agricultural holdings and land-use structure on quality of water in the Bay of Puck –

112 Integrated information and forecasting Service "WaterPUCK" (Dzierzbicka-Glowacka et al.,

113 2018).

114 The purpose of the project was to determine the current and future environmental status of

115 surface water and groundwater quality in the Puck Commune and its impact on the Bay of Puck

116 environment (Fig. 1). The most significant input of nutrients and pesticides in the environment

117 comes from agricultural source and surface structure usage e.g. sewers or drainage ditches.

118 Therefore, objective of the project was to estimate the impact of nutrient loading by compiling

119 the recent knowledge, factoring in the essential in situ measurements, and using advanced

120 modelling.

121

122 **Material and methods**

123 **Integrated agriculture calculator – CalcGosPuck**

124 The web tools obtained within the project (service WaterPUCK with CalcGosPuck) were

125 modified account for many innovative measures, processes and models to provide a basis for the

126 "green economy" development that could be implemented in other Baltic Sea catchment areas.

127 This is in line with the objectives of European legislation, including: i) the Nitrates Directive

128 (91/676/EEC), ii) the Water Framework Directive (2000/60/EC), iii) the Marine Strategy

129 Framework Directive (2008/56/EC) and iv) the Habitats Directive (92/43/EEC) as well as with

130 the HELCOM Baltic Sea Action Plan and the strategic program of environmental protection for

131 the Puck Commune.

132 The WaterPUCK service (Fig. 2) includes the following: a surface water model based on SWAT,

133 a groundwater flow model "GroundPuck" based on Modflow, a 3D environmental model of the

134 Bay of Puck "EcoPuckBay" based on the POP code and an integrated agriculture calculator

135 called "CalcGosPuck". The CalcGosPuck, presented in this paper, was developed as the first

136 module of the WaterPuck service. Data obtained from farms and defined in this model were used

137 to determine fertilizer components loads released from agricultural production to the

138 environment, including surface and groundwater.

139

140 **The general concept of nutrient balance on farms**

141 The "At the farm gate" nutrient balance method usually involves calculating separate balances

142 for NPK nutrient elements. The principle is the same for all three nutrients, with the exception

143 that the N balance sheets include more factors because of larger number of N nutrient sources

144 into the farms (e.g. legumes crops, deposition from the atmosphere). The procedure for

145 establishing balance of nutrients using the "At the farm gate" method has been described in

146 detail by Pietrzak (2013). Preparation of the nutrient balance using "At the farm gate" method

147 involves determination of input and output streams on the farm (Fig. 3).

148 The mass of nutrients imported onto a farm is calculated as the amount of input in: i) mineral

149 fertilizers (own study based on data producers of mineral fertilizers); ii) purchased concentrated

150 fodders (Mercik, 2002); iii) purchased bred animals (Fagerberg et al., 1993; Wrzaszcz, 2009;

151 Rutkowska, 2010; Szewczuk, 2010); iv) natural fertilizers (farm-produced or externally

152 purchased manure) (Maćkowiak, 1997; Grabowski, 2009); v) other purchased products

153   (Fagerberg et al., 1993; Wrzaszcz, 2009; Rutkowska, 2010; Szewczuk, 2010); vi) atmospheric

154   deposition (adopted for the Pomeranian Voivodeship) (IMGW); vii) symbiotically fixed nitrogen

155   (Schmidtke, 2008; Høgh-Jensen et al., 2004); viii) nitrogen introduced by free-living soil

156   microorganisms (Mazur, 1991); while the masses of nutrients exported from the farm are

157   calculated as the amount of output in sold animal and plant products (Fagerberg et al., 1993;

158   Wrzaszcz, 2009; Rutkowska, 2010; Szewczuk, 2010).

159

160   **Estimating nutrient balance and usage efficiency**

161   After estimating all the components of the nutrient balance, the total balance (surplus or deficit)

162   for N, P and K was calculated as a difference between inputs and outputs. The data obtained was

163   then expressed as a ratio of total change to area of agricultural land on the farm and the nutrient

164   usage efficiency on the farm was calculated. The use efficiency of NPK is the ratio of the amount

165   leaving the farm (outputs in plant and animal products, not including leaching, volatilization) to

166   the amount entering the farm (inputs) expressed as a percentage. The nutrient usage efficiency

167   was then used to define the percentage of nutrients brought into the farm, which are used directly

168   for production.

169   Analysis of the correlation between N and P surplus and selected elements of the balance of

170   these components was carried out using the STATISTICA 7 Soft. The nonparametric method of

171   calculating the Spearman rank correlation coefficient was used, because the data was not

172   normally distributed (Spearman, 1904).

173

174   **Farms in the Puck Commune**

175   **Agricultural lands and livestock production**

176   An opinion poll was conducted on 31 farms within the Commune of Puck, which is

177   approximately 3.6 percent of all farms in this Commune. The average area of the farms is 45.82

178   ha with a range of 5 to 130 ha including arable land. The average area of arable land is 30.79 ha

179   with a range of 4.45 to 130 ha while the mean area of grassland is 12.77 ha ranging from zero to

180   53 ha (Fig. S1).

181   Within the test area of the agricultural land, the majority of soils (90.3%, n=28) are medium -

182   Category III (21-35% content of particles with diameter less than 0.02 mm) (Jadczyszyn et al.,

183   2016). The soils in the remaining farms (9.7% n=3) include light texture soils (11-20% content)

184 (Fig. S2). The types and areas of the field-scale crops and grasslands in farms participating in the
185 WaterPUCK project are given in Fig. 4, and animal population, type, and the barn maintenance
186 systems are given in Table 1.
187 The profile of production systems in the study farms is presented in Table 2.
188 In the majority of farms (96.8%, n=30) the management system of livestock manure was the
189 slurry and solid manure system, in which animals are maintained in livestock buildings on a
190 shallow litter. An exception was the farm marked Code 29, where some of the young animals
191 (calves and heifers) were kept in deep leaf litter, and one small farm (Code 31) where all the
192 animals (calves and piglets) were kept in a deep barn, in a total of 1.3 of livestock unit (LU). The
193 livestock density was variable ranging from
194   a) $0.1 – 1.0$ LU·ha^{-1} on fourteen farms;
195   b) $1.1 – 2.0$ LU·ha^{-1} on nine farms; and
196   c) $2.1 – 3.0$ LU·ha^{-1} on two farms.
197 In the high density farms (c) the mass of nitrogen produced in natural fertilizers per hectare was
198 relatively high, with values ranging from 138 to 145 kg N·ha^{-1}. However, it did not exceed the
199 limit of land application of 170 kg N·ha^{-1} per year stated in the Nitrates Directive.
200 In a small portion of the farms (Codes: 9, 11, 20 and 23) involved in the production of milk and
201 beef livestock, animals have periodically been at pasture. The farm marked Code 27, which
202 breeds and raises horses, has also been using pastures.
203
204 **Crop rotation and after-crops**
205 Out of the Puck Commune farms surveyed, the vast majority of them (96.8%, n=30) practice
206 crop rotation. The most common (76.6%, n=23) kind of crop rotation was cereal rotation (the
207 share of cereal plants above 60%). The most distinctive types of cereal rotation were silage
208 maize-winter wheat-spring grain mixtures, winter wheat-spring wheat-winter wheat-oat and
209 spring barley-oat-spring grain mixtures-potatoes.
210 The most relevant rotation was field-corn cereal (above 60%), on 23 farms (76.7%).
211 Only 19.4 percent (n=6) out of all farms use after-crops (a later crop of the same year from the
212 same soil). In farms with additional vegetative cover two types of after-crops – catch crops and
213 mixed cropping (companion crops), have been equally preferred. These after-crops were in the

214 majority of cases (83.3%, n=5) incorporated in green manure. The cultivated area with after-

215 crops ranged from 14.4 to 35.7 percent of farms' total arable lands.

216

217 **Storage of natural fertilizers and silage**

218 In all sample farms all structures used for the storage of manure regardless of size meet the

219 requirements of Polish legislation "Action program aimed at reducing the outflows of nitrates

220 from agricultural sources" (J. of Laws, 2018 item 1339) for minimum distance of 20 meters from

221 wells, edges of waterways and reservoirs. Moreover, a large proportion (82.6%, n=19) of the

222 dung panels and tanks for manure are less than 14 years old. Thus, there is a high probability of

223 effectively stopping leachate of manure and slurry leakage (Fig. S3). In three farms manure was

224 stored directly on the ground, but the piles are located on flat terrain where the soil is neither

225 sandy nor waterlogged at a distance of more than 20 m from the edges of waterways and

226 reservoirs. However, one of the farms was obligated to have a slurry storage tank, due to the

227 litter-free system of keeping livestock. On this farm the current tank was made in 2013 and is

228 located at a distance of more than 20 m from the protected zones of water sources and water

229 intakes and the of the edges of reservoirs and waterways. In almost 50 percent of the farms

230 (n=16), the most common practice to store compacted silage is special plastic bales that limit the

231 risk of silage juice although, about 30 percent (n=9) silage is stored in field piles directly on the

232 grounds less frequently.

233

234 **Permitted dates to use natural fertilizers**

235 In accordance with the Polish law – Act of July 10, 2007 on fertilizers and fertilizing (J. of Laws,

236 2007 No. 147, item 1033), natural and organic fertilizers, in either liquid or solid form (manure,

237 liquid slurry, slurry), were allowed to be applied on field between March 1st and November 30th.

238 Permitted dates of solid manure use on arable lands and liquid natural fertilizers use (manure,

239 slurry) on permanent meadows with marked dates of fertilizer uses by farmers in the Puck

240 Commune are given in Figs S4 and S5, respectively.

241

242 **Results**

243 **Integrated agriculture calculator - CalcGosPuck**

244 In accordance with the "At the farm gate" concept method, the agriculture calculator

245 "CalcGosPuck" was developed. The CalcGosPuck calculator works as an independent

246 application designed to calculate the nutrient inputs and outputs, and then the surplus/deficit and

247 the nutrient use efficiency on a farm. The user gives the farm size and selects the required

248 province, input and output products for balance and gives their amount. CalcGosPuck works

249 properly (see the website www.waterpuck.pl in Service – Fig. 5).

250 One should enter specified data (Fig. 6) into the CalcGosPuck calculator in order to determine

251 inputs, outputs, NP surplus (or deficit) and the use efficiency of nutrients on the farm: i) the area

252 of agricultural land of the farm (in hectares) (Fig. 6a); ii) the province in which the farm operates

253 (Fig. 6b); iii) select indicators of what is imported onto the farm (mineral fertilizers, concentrated

254 fodder (mixed cattle feed, mixed pig feed, mixed poultry feed), purchased animal products,

255 natural fertilizers, other purchased plant products, by atmospheric precipitation, by legumes, and

256 fixed by soil microorganisms) (Figs. 6c); iv) select indicators of what is exported from the farm

257 (in animal and plant products sold) (Fig. 6d); v) give the amount of each selected indicator (Fig.

258 6e). After each parameter is selected, the basic data are automatically set down input, output,

259 surplus (or deficit = value with a minus sign) and the data related to the efficiency of the farm are

260 displayed in the top bar (Fig. 6f).

261

262 Case Study Application of the Calculator (on the example of a farm marked Code 9)

263 Step 1: Enter the area of agricultural land [in ha]: 70;

264 Step 2: Select the Voivodeship: Pomerania;

265 Step 3: Select inputs and their amounts:

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

267   － in energy and protein fodders: rape cake for animals = 240 dt, dried pulp = 150 dt,

268   post-extraction soya meal = 400 dt;

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

270 Step 4: Select outputs and their amount:

271   － animal products: milk = 3500 dt, dairy cattle = 35 dt.

272 Step 5: Results of the calculations (Fig. 6f):

273   Budget:

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

275	Outputs:	N: 1977.50 kg;	P: 375.90 kg;	K: 530.95 kg;
276	Surplus:	N: 9018.50 kg;	P: 233.10 kg;	K: 115.00 kg;
277	Efficiency:	N: 17.98%;	P: 61.72%;	K: 82.20%.

278

Consumption of natural fertilizers

279

280 The average consumption of mineral NPK ha^{-1}in the study area ranged within the respective

281 levels of: 114.9 kg N, 9.3 kg P, and 22.9 kg K·ha^{-1} AL. On the individual farms, consumption of

282 the components listed was highly variable with a range $0 - 232.6$ kg N·ha^{-1} (Fig. 7); $0 - 31.2$ kg

283 P·ha^{-1} (Fig. 8) and $0 - 159.6$ kg K·ha^{-1} (Fig 9).

284

Environmental aspects of fertilizer usage

285

286 With regard to the conditions of fertilizers application, it was determined that:

287   – On 29 out of the 31 tested farms (93.5%), the annual dosages of nitrogen fertilizers

288   (mineral, natural, organic) were divided into parts during the growing season, usually

289   into three in case of arable lands and two fertilizations of permanent meadows.

290   – On 19 farms (61.3%) have arable land on parcels with steep slopes (more than 10%). On

291   16 out of them (84.2%) the general rules of fertilizer usage on steep slopes were taken. In

292   only two agricultural holdings (10.5%) the rules have not been followed. In cases of

293   parcels with a slope of more than 10%, cultivation treatments have been carried out in a

294   direction transverse to the slope leaving the ridge up the slope.

295   – On 2 farms (6.5%) fertilizers were applied on field in situations when the soils was

296   flooded, covered by snow or frozen to a depth of 30 centimeters, and during rainfall.

297   Municipal sewage sludge has not been used in areas of special flood hazard, temporarily

298   flooded and swampy areas, or on high permeability areas on any of the farms.

299   – On the majority of the tested farms (87.1%, n=27), there were agricultural lands located

300   at a distance of less than 50 meters from the edges of waterways and lakes. On the other

301   hand, on most of them (63%, n=17) in the areas close to waterways or reservoirs,

302   fertilization has not been used. In 6 cases (22.2%) fertilization has been used at a

303   distance less than 20 meters from the edges of waterways and lakes.

304   – Records of agricultural treatments containing information about dates and doses of

305   fertilization were being kept on 23 agricultural holding (74.2%). On the remaining 7

306   farms (22.6%) agro-technical practices were not documented and on one – there were no

307   data.

308   –   Only one of the analyzed farms (3.2%) kept records of natural fertilizers disposal

309   (agreement for sale of any surpluses).

310   –   Nitrogen balance estimation and fertilization plans were being developed on 20 (64.5%)

311   of all the farms. In remaining ones, there were either no balance sheets and fertilization

312   plans or there was no information about that.

313

314 The Surplus and Use Efficiency of Nitrogen, Phosphorus and Potassium

315 Nitrogen balances on the analyzed farms ranged from -23.3 to 254.5 kg $N \cdot ha^{-1}$ AL while N use

316 efficiency ranged from 0.40 to 231.3 percent (Fig. 10). The lowest efficiency, 0.4 percent, was

317 observed in the horse-breeding farm (Code 27) while the highest level, 231.3 percent, was

318 recorded in the sole plant production farm (Code 17). The average nitrogen surplus in all 31

319 farms was 120.6 kg $N \cdot ha^{-1}$ AL while efficiency of this component use was 31.8 percent.

320 In the case of phosphorus, the average P surplus/deficit value for all farms was 5.0 kg $P \cdot ha^{-1}$ AL

321 (Fig. 11) with a farm range of -17.11 to 28.7 kg $P \cdot ha^{-1}$ AL (Fig. 11). The average P use efficiency

322 was 66.2 percent while on farms ranged from 0.4 to 266.5 percent.

323 Potassium balances and use efficiency on study farms ranged from -54.1 to 159.8 kg $K \cdot ha^{-1}$ AL

324 and from 1.5 to 432.3%, respectively (Fig. 12). The average K surplus value was 10.8 kg $K \cdot ha^{-1}$

325 AL while average K use efficiency was 62.2%.

326 With regard to all agricultural holdings, in general structure of N inputs the largest amounts came

327 from mineral fertilizers (65%) and purchased concentrated fodder (17.7%). The next order was

328 as follows: legumes (6.3%), atmospheric precipitation (5.1%), soil microorganisms (4.2%) and

329 others (0.6%). In structure of N outputs, the largest amount was nitrogen sold in plant products

330 (62.3%) while the remaining N part (37.7%) was sold in animal products.

331 In P balance, the order of the largest proportions of P input was mineral fertilizers (63%),

332 purchased concentrated fodder (32.7%), atmospheric precipitation (2.5%), others (1.6%), while P

333 was output in sold plant (57.4%) and animal products (32.7%).

334 As with N and P, in K balance the order of inputs was mineral fertilizers (79.4%), purchased

335 concentrated fodder (10.6%), atmospheric precipitation (9.1%) and others (0.9%). In structure of

336 K outputs sold, plant products (77.4%) predominated over animal products (22.6%).

337

Discussion

339   Impact of agricultural farms on the environment of the Puck Commune caused by dispersion of

340   fertilizer components, was determined by a set of natural and anthropogenic factors conditioning

341   the activities of these farms. Undoubtedly, the most important factors were those that concerned

342   the use of mineral fertilizers. Nitrogen fertilizers consumption in the tested farms was higher

343   than average usage across Poland and in the Pomeranian Voivodeship, compared to the lesser

344   consumption of potassium fertilizers (Table 3). Phosphorus fertilizers consumption was higher

345   than in the Pomeranian Voivodeship, but lower compared to the entire country. Most of the

346   farms of the Puck Commune used N fertilizers in doses of 50-100 (35.5%, n=11) and 100-150

347   kg $N \cdot ha^{-1}$ AL (the same) while P fertilizers in doses of 10-15 kg $P \cdot ha^{-1}$ AL (32.3%, n=10) and 5-

348   10 kg $P \cdot ha^{-1}$ AL (25.8%, n=8). In case of K fertilizers, the largest two groups of farms (35.5%,

349   n=11) used them in doses of 0-20 and 20-40 kg $K \cdot ha^{-1}$ AL. $N : P_2O_5 : K_2O$ ratio in average fertilizer

350   dose for all farms was 1.0:0.19:0.24 (what means that for every 1 kg of N only 0.19 kg of P_2O_5

351   and 0.24 kg of K_2O were applied). These proportions may raise some doubts in the light of the

352   general recommendations of crop fertilization. According to them, 1.00:0.50:0.98 proportions

353   are recommended for fertilization that is sustainable for field crops in Polish soil conditions and

354   1.00:0.46:0.68 for permanent grassland (Kucharska et al., 1996). It should be also emphasized

355   that in conditions of wrong N:P:K ratios in fertilizers usage there may occur some disturbances

356   in process of N acquirement by plants and increased losses of this component, causing

357   environmental hazards.

358   Considering the environmental aspects of fertilizer usage, it can be concluded that the majority

359   of farms in the Puck Commune used the correct approach in mineral fertilizers management

360   (e.g. dividing doses, not using fertilizers in high-risk conditions, observing rules for fertilizer use

361   on slopes, no fertilizers in proximity to surface water, keeping agro-technical practices records).

362   However, in most of farms there were natural conditions that could create increased fertilizers

363   losses during their application, especially in which arable lands were located in steep-slope areas

364   (more than 60% of all farms). On such plots, surface runoff could be formed, delivering

365   nutrients from land to watercourses and water reservoirs. Therefore, this could lead to their

366   eutrophication (Andraska, Bundy, 2003; Miller et al. 2011). Therefore, the higher fertilizers

367 doses were used, the greater could be the loss of nutrients by surface runoff (Thayer, 2011;

368 Smith, Jackson, Pepper, 2001).

369 NP and K in mineral fertilizers constituted the largest shares in total components input brought

370 onto the analyzed farms from outside (on average, 65.0, 63.0 and 79.4 percent, respectively).

371 Moreover, the relationship between N, P and K content in mineral fertilizers and their surplus

372 generated by farms has a strong positive correlation (Table 4-6).The average N and K surplus

373 had also a statistically significant positive impact on purchased concentrated fodder while in

374 case of average P surplus this relationship did not occur. These two sources frequently

375 determine the N surplus size estimated by "At the farm gate" method (Pietrzak, 2009; Kupiec,

376 2011).

377 In addition to purchased fertilizers and concentrated fodder, the factors that had a significant

378 impact on the results of N, P and K balances were sold plant products as well as sold animal

379 products – it was an inverse relationship. In the N and P cases, there were also significant

380 positive correlations between surpluses of these nutrients and their outputs in sold animal

381 products. With regard to K balances, no such relationships were found.

382 The average N surplus in farms of the Puck Commune was 120.6 kg N·ha^{-1} AL while the

383 average P surplus was at a level of -5.0 kg P·ha^{-1} AL (values of these indicators were

384 characterized by a considerable variety among the surveyed farms). According to various

385 authors works (Godinot et al., 2015; Olofsson, 2015), the levels of N and P surplus determined

386 using farm scale nutrient balance are closely related to their business profile – the largest NP

387 surplus are generated on farms focused on animal production.

388 The broad majority of farms in the Puck Commune (80.6%, n=25) was focused on livestock

389 production, in particular, milk and beef (48%, n=12), only pork (24%, n=6), only beef (8%, n=2),

390 beef and pork production (24%, n=6) and horse breeding (4%, n=1).Comparing study farms

391 average N surplus, it can be concluded that its value was smaller in relation to a similar category

392 of French farms (Table 7), while compared to Swedish farms, it was at comparable level (Table

393 8).Comparable in level to farms in Sweden was also an average P surplus calculated for all

394 surveyed farms in the Puck Commune. In view of the fact that in Sweden huge attention to

395 reducing the losses of nutrients from agriculture is paid, especially due to need of counteracting

396 Baltic Sea eutrophication, it seems that N and P surplus generated by farms of the Puck

397 Commune can be considered acceptable in the context of their impact on the environment.

398   The average surplus of K – a component regarded as neutral for the environment – in study farms

399   was 10.8 kg K·ha^{-1} AL. The level of this surplus was 28% lower than in K balance found in other

400   researches undertaken in Poland on a comparable group of farms (in terms of number of farms and

401   their specialization of production), but located in a region with more intensive agriculture (Kupiec,

402   2015).

403   With regard to the presented results of nitrogen, phosphorus and potassium balance, it should be

404   noted that they might be affected by some uncertainty associated to method of obtaining results

405   for their preparation, based on interviews with farmers. Therefore, it is right to postulate that

406   keeping records on agro-technical practices or nutrient booking containing necessary information

407   for balance sheets preparation should be implemented (in particular records on purchased

408   fertilizers and concentrated fodder as well as sold agricultural products) (Kupiec, Zbierska,

409   2008).Apart from purely cognitive values of nutrient balance results, they have an educational

410   significance in shaping farmers' awareness. This meaning is widely articulated in many sources

411   and can be expressed in the form of the following opinions and statements:

412   ° The "At the farm gate" nutrient balance method is a basic and simple way to increase

413   knowledge and farmers' awareness about nitrogen, phosphorus and potassium flow - to

414   and from a farm, - creating a starting point for discussion on how to use these components

415   efficiently on farm scale and on impact of NPK and their incomplete use on farm

416   economics as well as the environment (Nilsson, 2013);

417   ° Nutrient balance enables farmers to easily review NPK flow at farm gate level by

418   calculating the amount of nutrient imported and exported to the farm. Thanks to that, a

419   well-prepared nutrient balance can help the farmer to evaluate and improve their nutrient

420   management which can contribute to lower operating costs of the farm by showing the

421   actual amount of nutrients needed for production (Nutrient balance; Farmgate Nutrient

422   Balance Help file PLANET);

423   ° Farm gate nutrient balances are a useful tool to compare farms and farm systems as well

424   as to identify high-risk areas where a lot of nutrients is gathered and hotspots for nutrient

425   emissions (Ramnerö, 2015);

426   By calculating the nutrient balances at farm gate level, based on the principles of farmers'

427   voluntary participation and through their dialogue with the advisory institutions, an agreement

428   may be achieved – in order to reduce NPK surpluses and to increase farm profit (Olofsson,

429   2014).

430   In the light of the above, preparation of tool called Integrated agriculture calculator –

431   CalcGosPuck within the WaterPUCK project is well grounded and fully justified. Its

432   dissemination may contribute to broadening farmers' knowledge on correct nutrient management

433   and fertilizer on farm scale and thus reduce environmental pressure exerted by agricultural

434   activities.

435

436   **Conclusion**

437   The environmental impact of study agricultural holdings in the Puck Commune (which can be

438   taken as representatives of the entire collectivity in this commune) was mainly related to the

439   amount of mineral nitrogen and phosphorus fertilizers consumption in these farms as well as

440   practices and conditions of their use. The mean N fertilizers consumption per 1 ha of agriculture

441   land in the study area was significantly higher in comparison to their average unit usage in

442   Poland, while the mean consumption of P fertilizers was slightly lower than the national average.

443   At the time of application these fertilizers, the recommendations for reducing their

444   environmental impact were considered. The amount of purchased N, P and K fertilizers had a

445   significant impact on the results of nutrient balances estimated by the "At the farm gate" method.

446   The results of nutrient balances showed, in particular, that average N, P and K surplus generated

447   by the analyzed farms ranged within the respective levels of 120.6 kg N, 5.0 kg P and 10.8 kg

448   $K \cdot ha^{-1}$ AL. Comparing nutrient surplus amount in agricultural holdings of the Puck Commune to

449   similar farms and farm systems, e.g. in countries with well-developed agriculture, such as France

450   and Sweden, average N and P surplus in study area can be assessed as moderate while average K

451   surplus as being in the range of its average values typical for farms in Poland.

452   Notwithstanding the above, the results of estimated NPK balance well showed their practical

453   dimension. In this regard, it should be indicated that estimating N, P and K values in a nutrient

454   balance can lead to many practical conclusions helping to reduce the impact of agricultural

455   production on the environment and to improve the farming economy. An example of the latter

456   would be the results of more effective use of nutrients on a farm and lower expenditures on

457   fertilizers and feeds. Therefore, knowledge on how to estimate nutrient balances should be more

458   widely disseminated, especially among farmers and agricultural advisors. Helpful role in this

459 area can play program developed within the WaterPUCK project called "Integrated agriculture

460 calculator - CalcGosPuck". CalcGosPuck works as an independent application to calculate the

461 pollution emission from agricultural holdings to the environment, including surface and

462 groundwater, but it also can serve to calculate the nutrients' distribution over agricultural areas.

463

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467

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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.

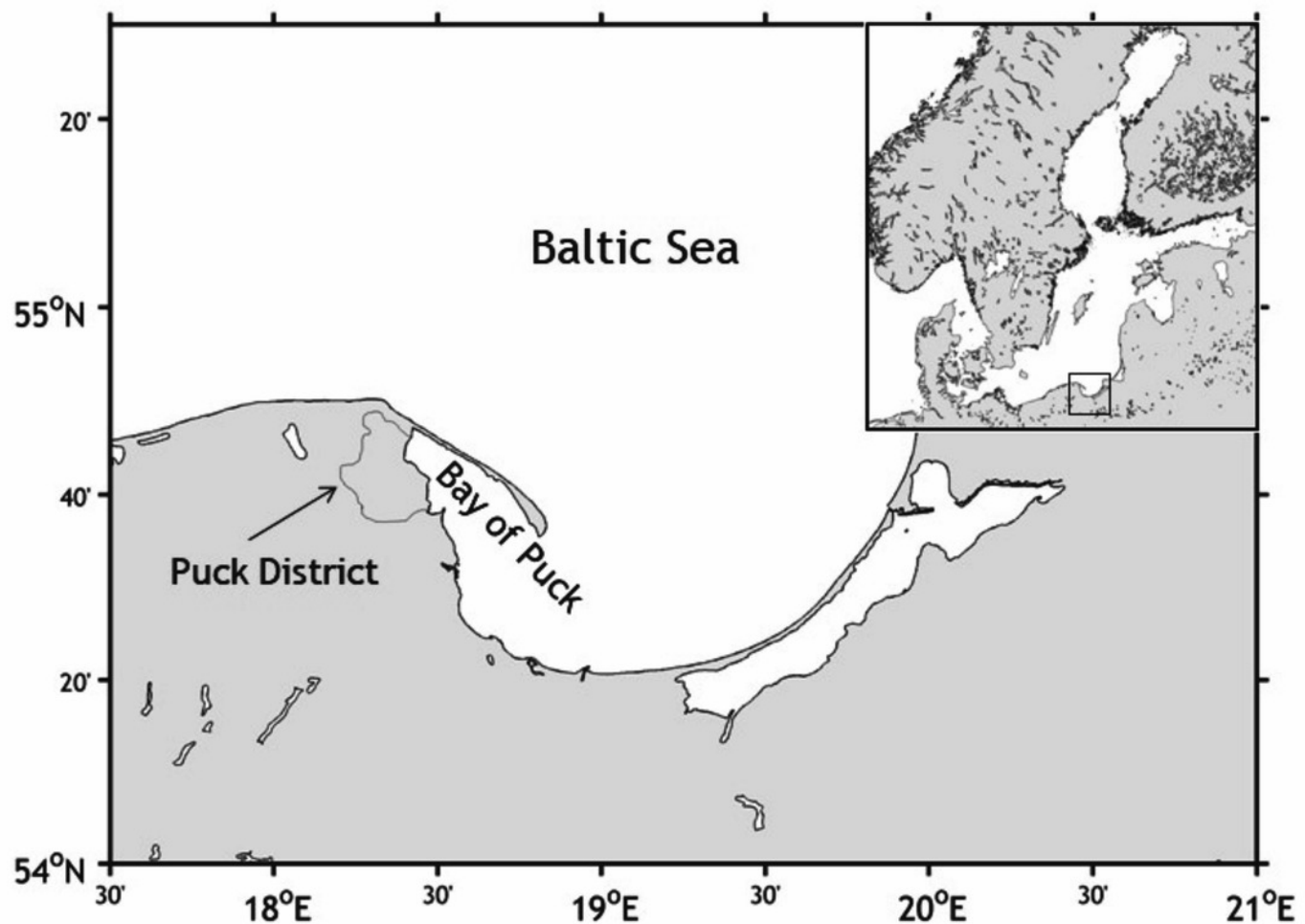



Figure 2

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.

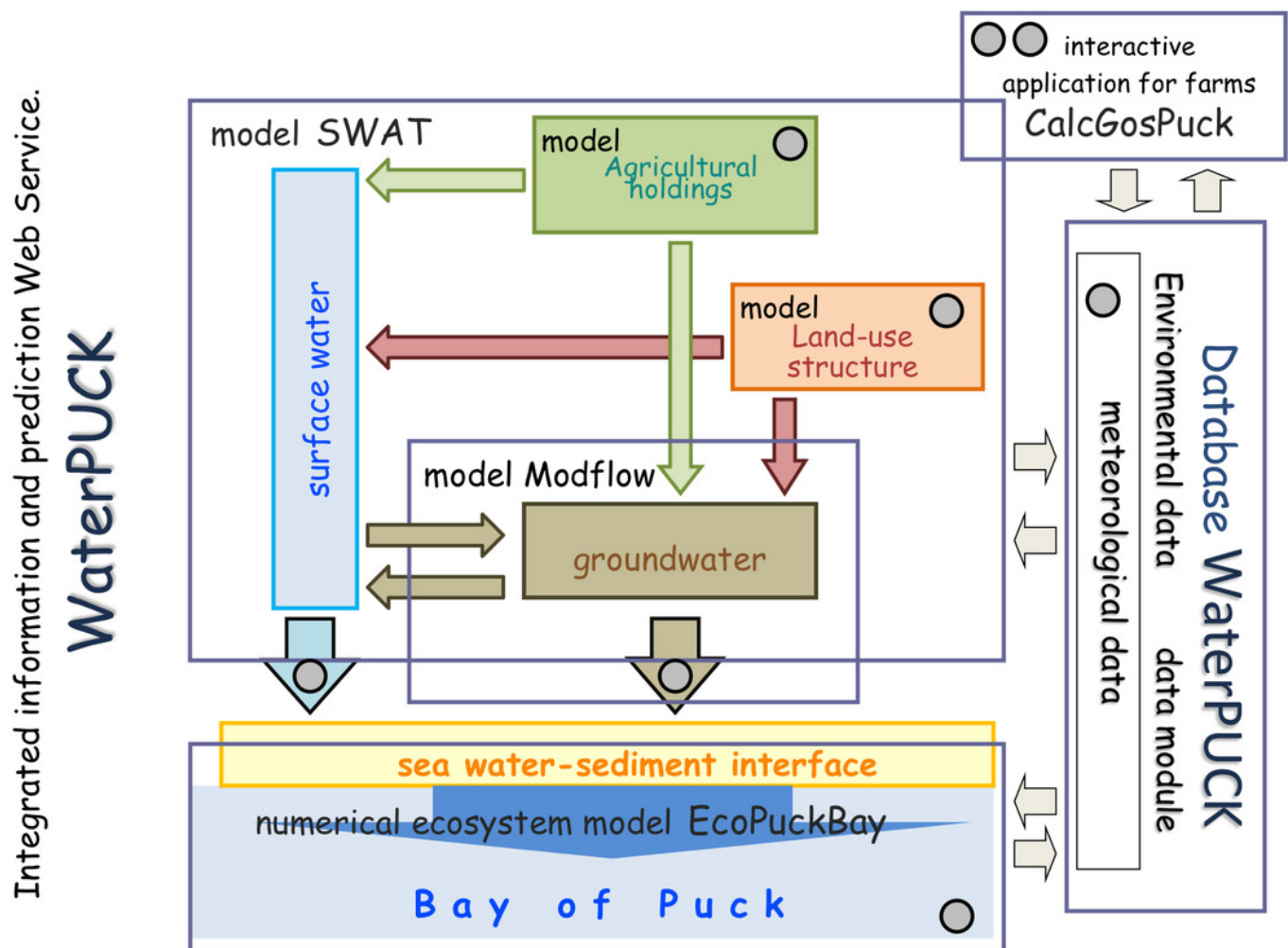



Figure 3

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

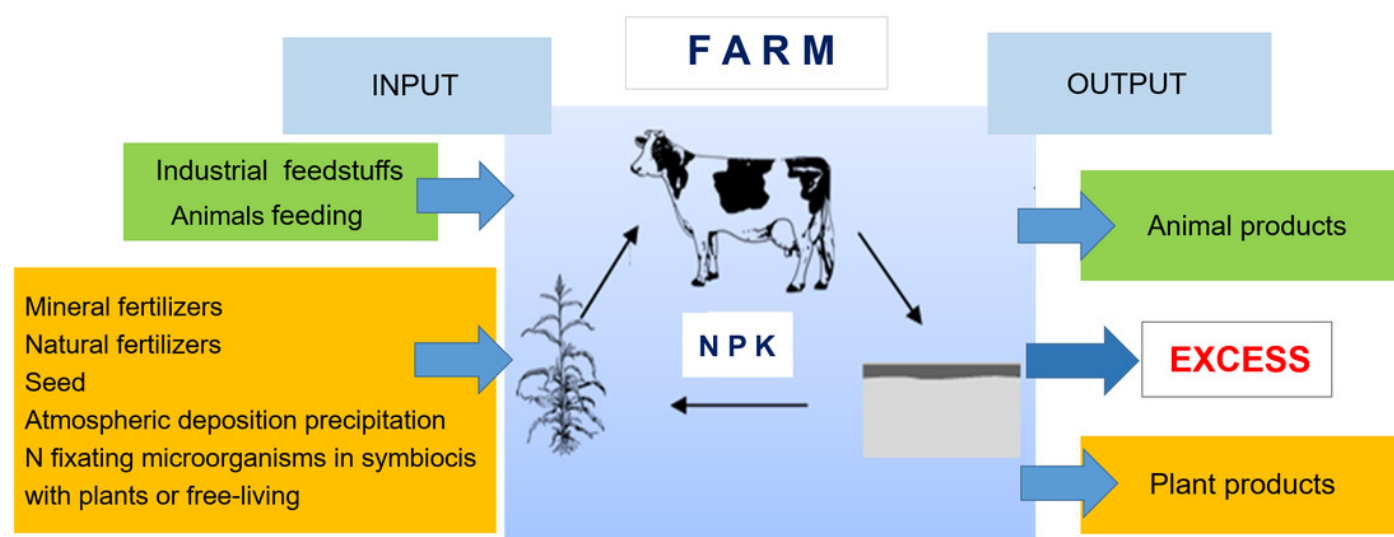



Figure 4

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

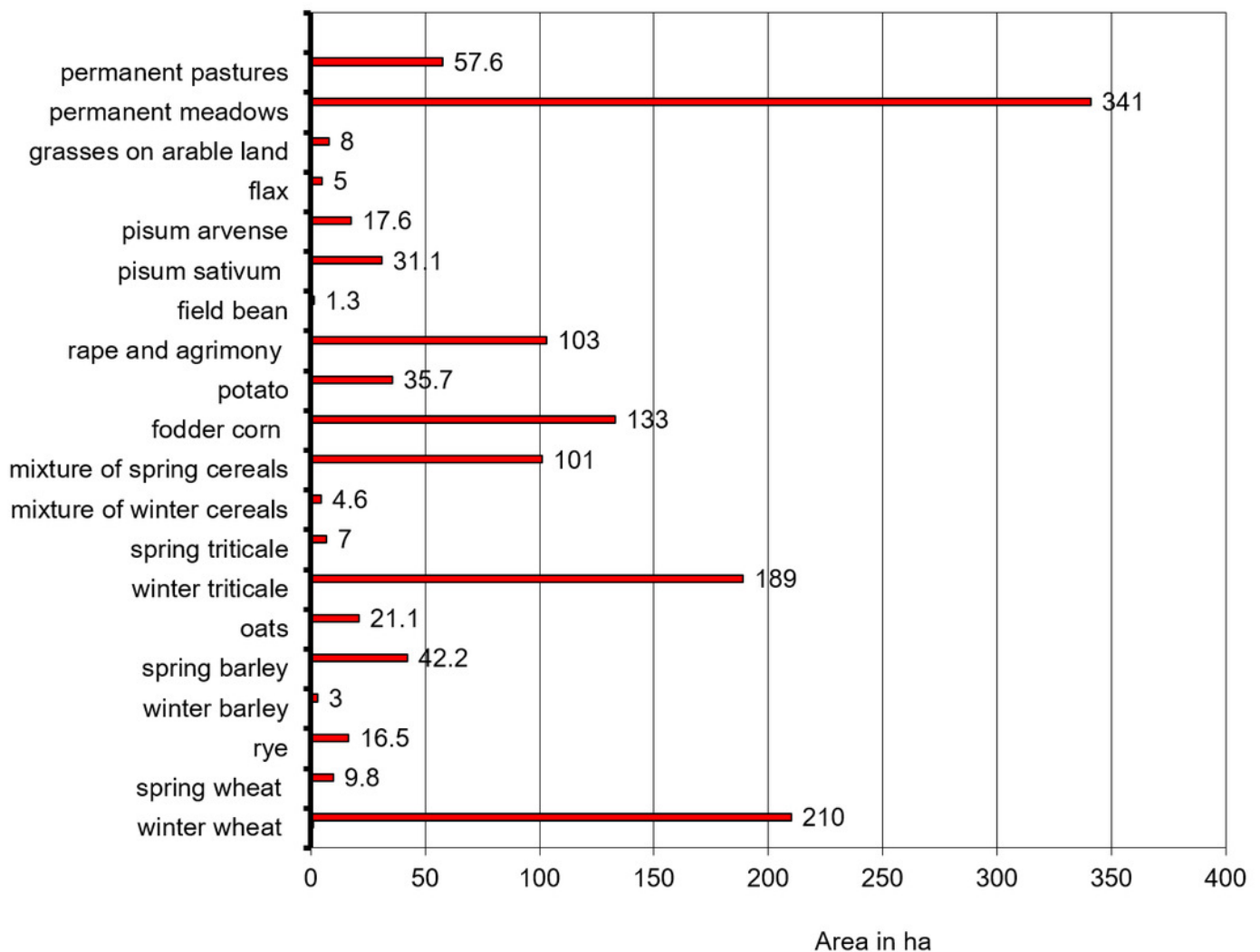



Figure 5

The selection page of the CalcGosPuck agricultural's calculator

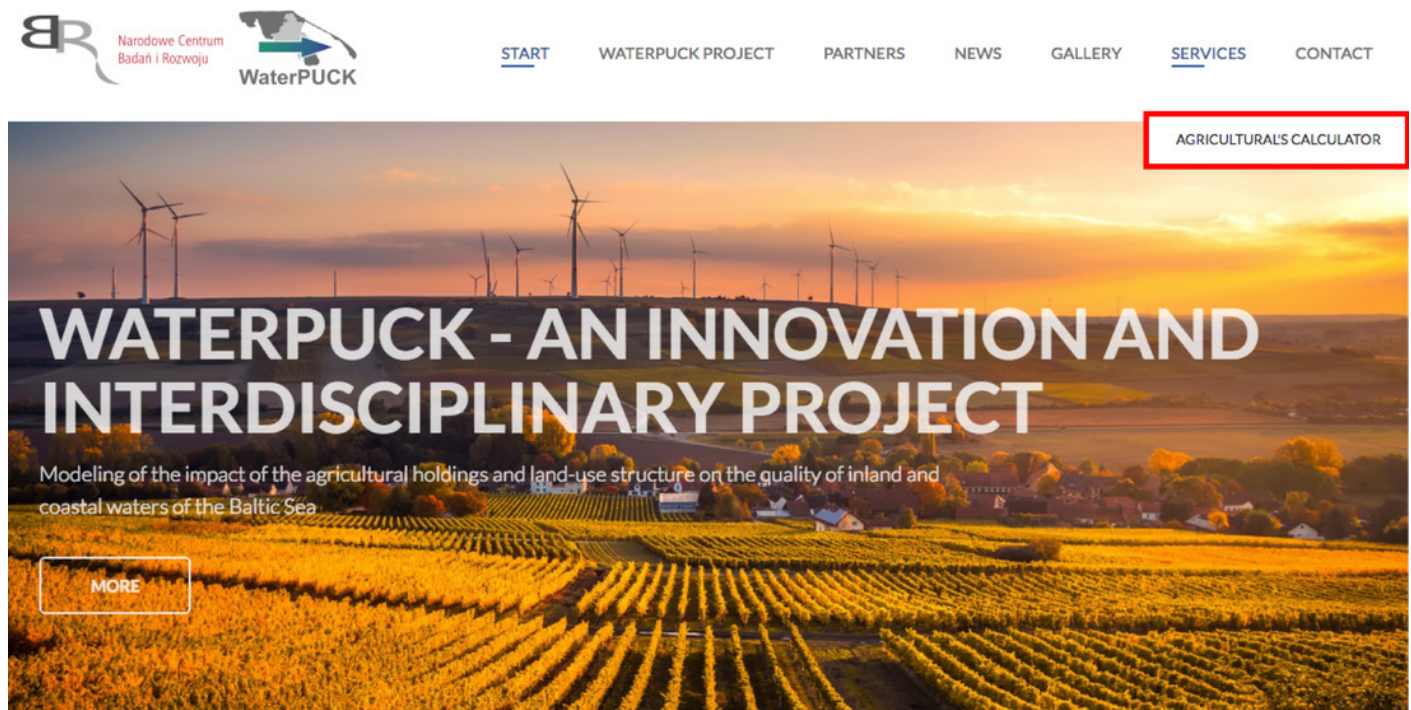



Figure 6

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**

e

name	amount [dt]
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
FAM – R"

×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.

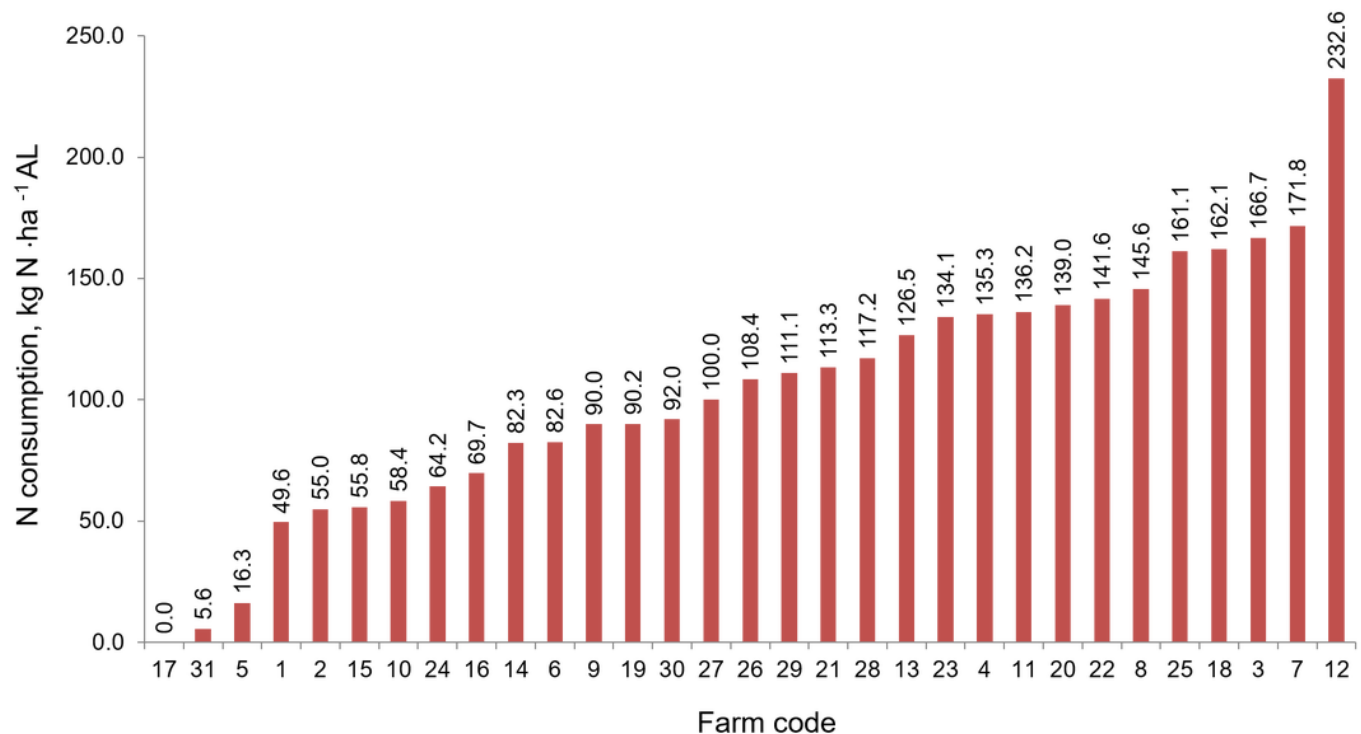



Figure 8

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

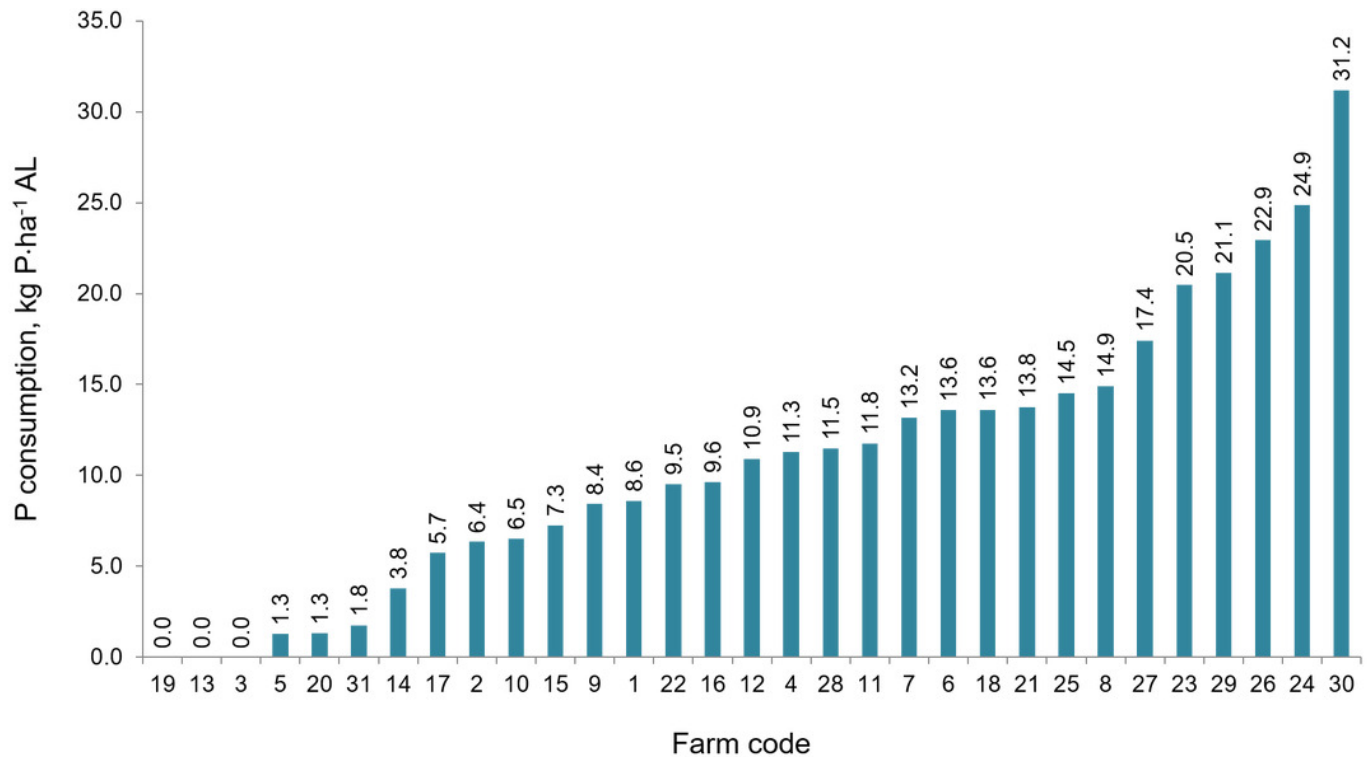



Figure 9

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

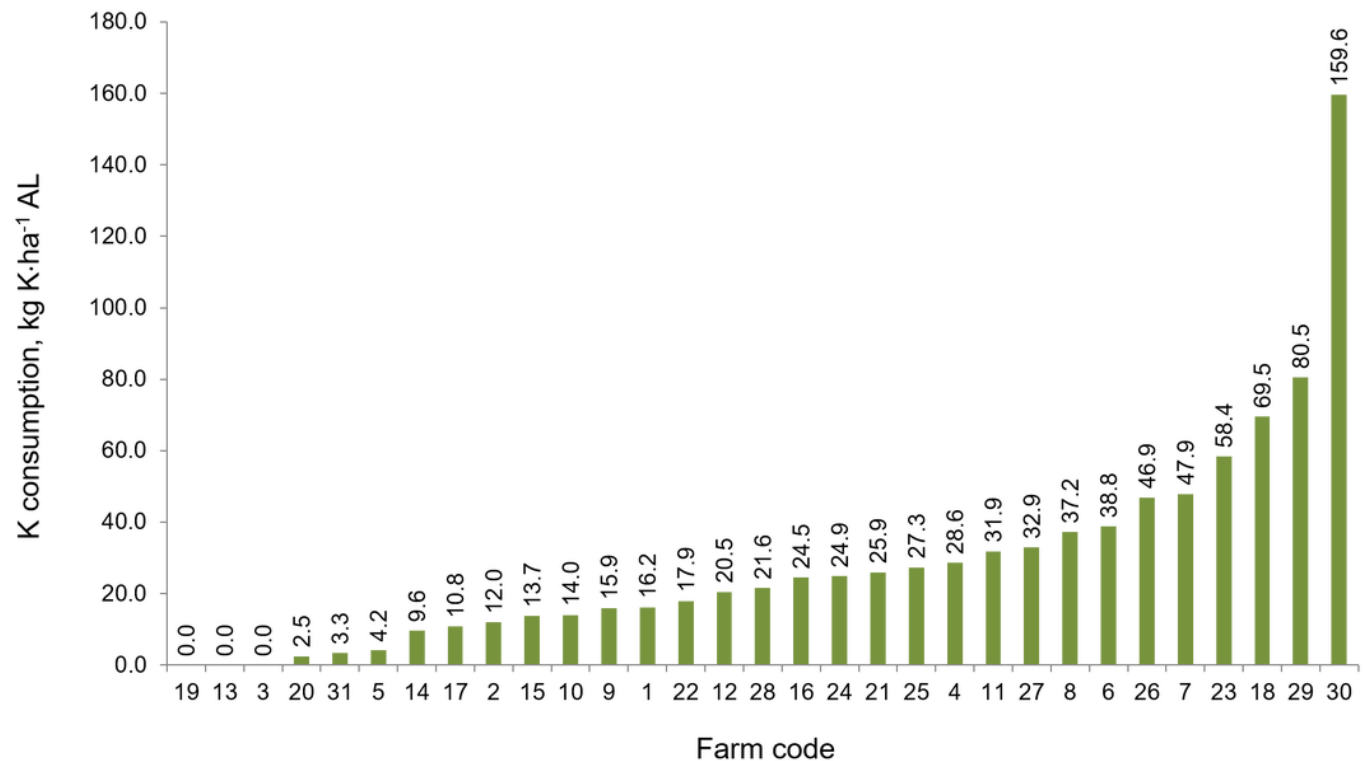



Figure 10

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

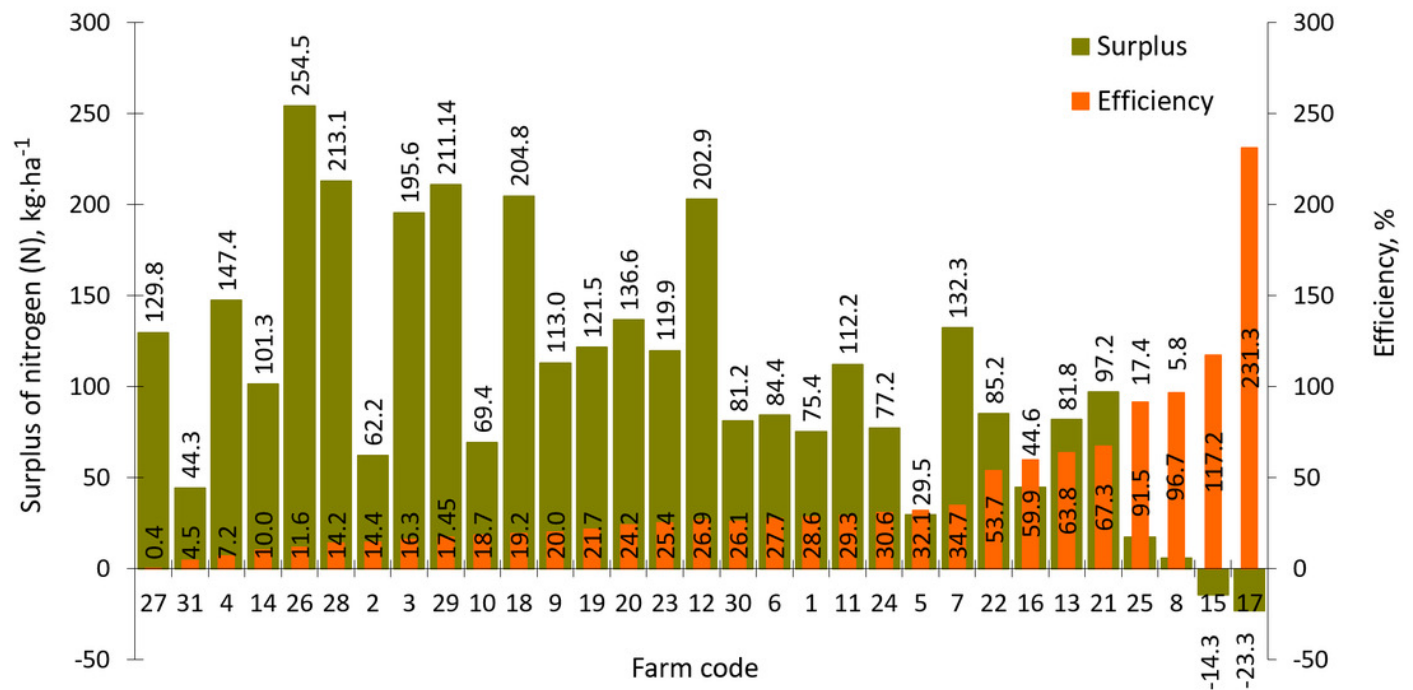



Figure 11

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

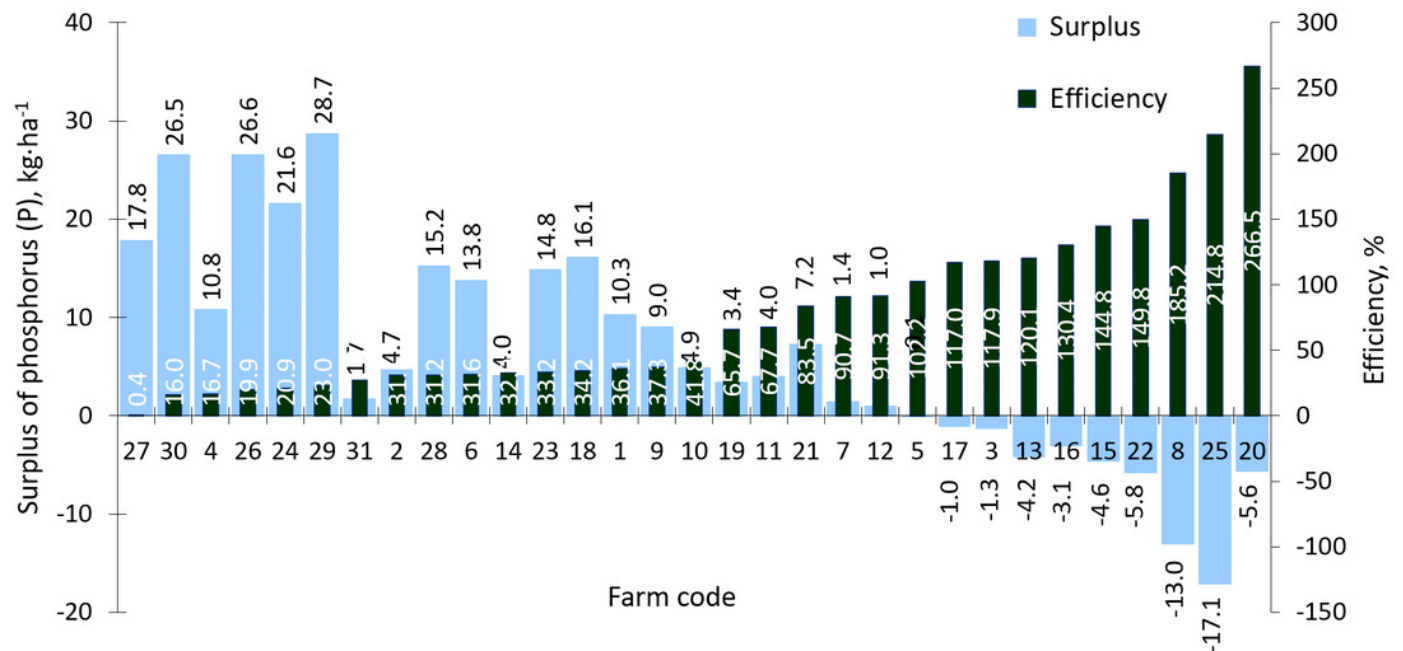
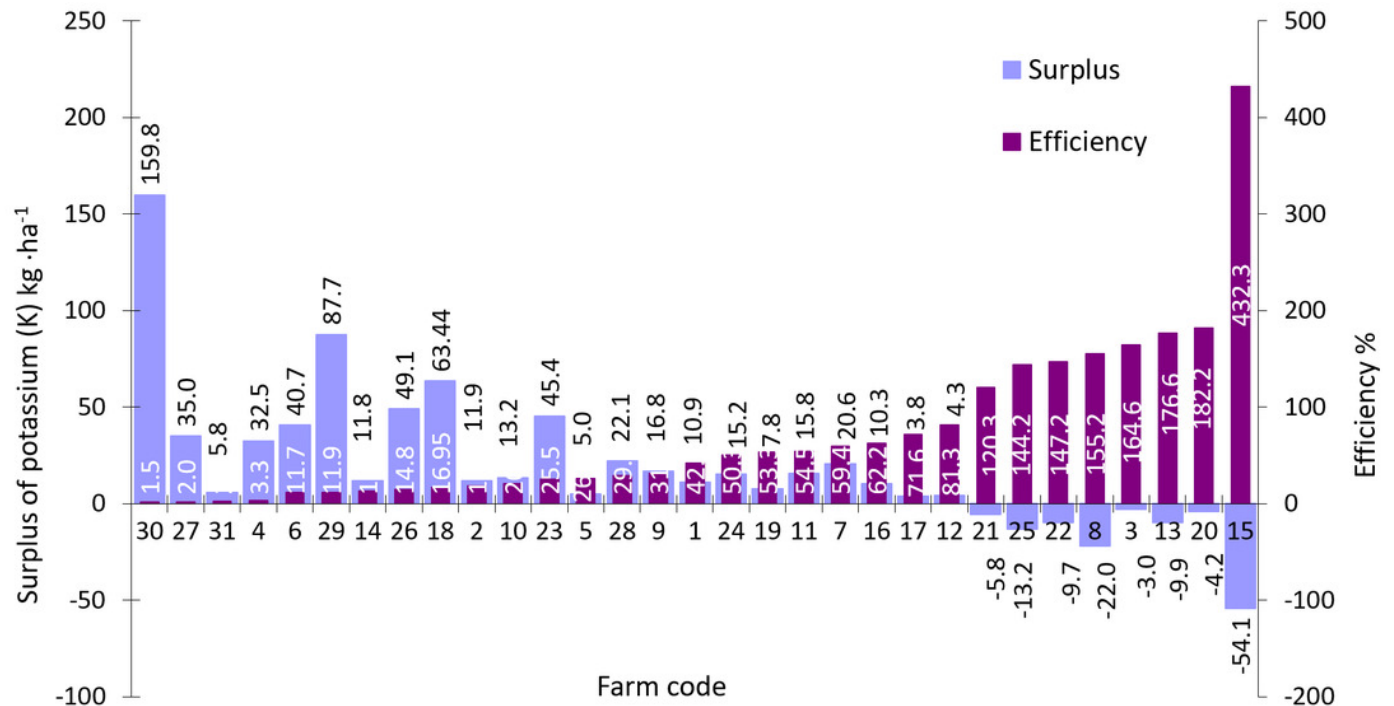



Figure 12

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

Animal population, type and the maintenance system in study farms of Puck Commune.

Farm Code	Farm area (in ha)	Profile of the animal production	Stocking density		Production of nitrogen in natural fertilizers		
			LU	LU ha $^{-1}$	Animals maintanance system	kg N	kg N ha^{-1}
1	48	milk and beef livestock	51.3	1.1	shallow litter	2308	48
3	81	milk and beef livestock	85.6	1.1	shallow litter	3843	48
4	17.3	beef and pork livestock	18.4	1.1	shallow litter	495	27
5	51.5	beef and pork livestock	15.4	0.3	shallow litter	917	18
6	16	milk and beef livestock.	14.3	0.9	shallow litter	772	48
7	38.2	beef livestock	21.2	0.6	shallow litter	723	19
9	70	milk and beef livestock	70.3	1.0	shallow litter	3192	46
10	29.5	milk and beef livestock	47.3	1.6	shallow litter	1899	64
11	18	beef and pork livestock.	8.3	0.5	shallow litter	422	24
13	43	pork livestock	52.4	1.2	shallow litter	3402	79
14	10.5	pork livestock	2.9	0.3	shallow litter	214	28
15	100	milk and beef livestock	61.6	0.7	shallow litter	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 litter	6527	54
20	45	beef livestock.	34.4	0.8	shallow litter	1171	26
21	15	pork livestock.	45.0	3.0	shallow litter	2073	138
22	62	milk and beef livestock	36.6	0.6	shallow litter	1603	26
23	36	milk and beef livestock	24.0	0.7	shallow litter	1095	30
24	7.24	pork livestock	5.42	0.8	shallow litter	349	48
26	118	milk and beef livestock.	45.5	0.4	shallow litter	4716	40
27	19	farming and horse breeding	24.7	1.3	shallow litter	836	40
28	38	milk and beef livestock	41.9	1.1	shallow litter	1828	48
29	16.5	milk and beef livestock	34.9	2.1	deep/ shallow litter	2385	145
30	5.0	pork livestock	6.4	1.3	shallow litter	398	80
31	13	beef and pork livestock.	1.3	0.01	deep litter	70	5

The profile of production systems in the study farms in the Puck Commune.

[1]no livestock production (plant production only)

Production System	No. of Farms	Proportion of Total (%)
Milk and Beef	12	38.7
Pork only	6	19.4
Pork and Beef	4	12.9
Beef only	2	6.5
Horse Breeding	1	3.2
None[1]	6	19.4

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

*CSO 2018. Means of production in agriculture in the 2016/2017 farming year - updated tables. Warszawa. Central Statistical Office. Available online:: https://stat.gov.pl/obszary-tematyczne/rolnictwo-lesnictwo/rolnictwo/srodki-produkcji-w-rolnictwie-w-roku-gospodarczym-20162017,6,14.html (in Polish).

Area	Mineral fertilizers consumption. kg·ha⁻¹ AL			
	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**

The relationship between the surplus of N and selected factors.

Correlation Spearman ranks order, marked (in red) correlations are significant - with p < 0.05.

	Surplus N (kg·ha⁻¹)	Efficiency (%)	Nitrogen in mineral fertilizers (kg·ha⁻¹)	Nitrogen in feeds (kg·ha⁻¹)	N share in the sold animal production (%)	N share in the sold plant production (%)
Surplus N (kg·ha⁻¹)	1.00					
Efficiency (%)	-0.58	1.00				
Nitrogen in mineral fertilisers (kg·ha⁻¹)	0.57	0.04	1.00			
Nitrogen in feed (kg·ha⁻¹)	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	
N share in the sold plant production (%)	-0.36	0.53	0.20	-0.64	-1.00	1.00

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The relationship between the P surplus and selected factors.

Correlation of the Spearman ranks order, marked (in red) correlations are significant - with p < 0.05.

	Surplus P (kg·ha^{-1})	Efficiency (%)	Phosphorus in mineral fertilizers (kg·ha^{-1})	Phosphorus in feeds (kg·ha^{-1})	P share in the sold animal production (%)	P share in the sold plant production (%)
Surplus P (kg·ha^{-1})	1.00					
Efficiency (%)	-0.91	1.00				
Phosphorus in mineral fertilisers (kg·ha^{-1})	0.57	-0.43	1.00			
Phosphorus in feed (kg·ha^{-1})	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	
P share in the sold plant production (%)	-0.44	0.44	0.12	-0.51	-1.00	1.00

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The relationship between the K surplus and selected factors.

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

	Surplus K, kg·ha⁻¹	K efficiency, %	K in mineral fertilizers, kg·ha⁻¹	K in feeds, kg·ha⁻¹	K in sold animal products, kg·ha⁻¹	K in sold plant products, kg·ha⁻¹
Surplus K, kg·ha⁻¹	1.00					
K efficiency, %	-0.81	1.00				
K in mineral fertilizers, kg·ha⁻¹	0.65	-0.41	1.00			
K in feed, kg·ha⁻¹	0.36	-0.19	0.01	1.00		
K in sold animal products, kg·ha⁻¹	0.26	-0.06	0.02	0.52	1.00	
K in sold plant products, kg·ha⁻¹	-0.52	0.62	0.14	-0.40	-0.48	1.00

Mean surplus N and N-efficiency in nine farming system categories in France (based on: Godinot et al., 2015).

	Farming system categories								
	Beef cattle	Beef cattle and crops	Beef cattle and pigs	Crops	Crops and milk	Milk	Milk and pigs	Pigs	Poultry
Number of farms	47	35	13	24	53	299	36	30	20
Surplus N (kg N·ha^{-1} AL)	228	128	448	141	124	245	420	852	377
N-efficiency (%)	11.6	30.4	17.5	41.7	27.9	16.9	21.9	23.5	26.8

Farm gate balances of conventional farms in southern Sweden (based on: Olofsson, 2015).

	Type of farms		
	Crop	Dairy	Pig
Number of farms	965	976	204
Surplus N (kg N·ha^{-1} AL)	45	143	104
Surplus P (kg P·ha^{-1} AL)	-1.4	4.7	7.6