SELF-EVALUATION OF FARMS FOR IMPROVED NUTRIENT MANAGEMENT AND MINIMISED ENVIRONMENTAL IMPACT

Scientific Editors

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PREFACE

Nutrient leaching from agriculture is the main source of nutrient loads and eutrophication in the Baltic Sea. In the past, various actions have been taken to reduce nitrogen and phosphorus losses from farms and farmlands. However, knowledge about the risk of nutrient leaching has still not reached many farmers operating in the Baltic Sea catchment and wide-scale mitigation measures to prevent nutrient leaching have not begun to be implemented. There is thus an urgent need for further advisory action. The consensus in international co-operations on improving water quality is that future work should focus on knowledge building to country-specific conditions concerning suggested mitigation measures. A number of relatively cheap and simple measures are available, but few of these have been implemented to date or placed on the list of 25 priority measures set out in the Project Baltic Compass1). One of the reasons for this is that these measures must build on farmers' own knowledge in practice. Therefore, initiatives by farmers need to be stimulated and supported. At the same time, trust must be created between farmers and agricultural advisory services, with the advisors not regarded as the controlling authority. This handbook should be used along with the manual on systematic self-evaluation by farmers – primarily owners of medium-sized farms – supported by agricultural advisors in Poland.

The instructions contained in this handbook can be used as support for calculating nutrient balances "at the farm gate" (Chapter I), estimation of the risk of nitrogen leaching from fields on the farm (Chapter II), and estimation of the risk of leaching of phosphorus based on soil tests and intensity of fertilisation (Chapter III). Calculating the farm balance for nitrogen and phosphorus can lead to tangible suggestions for cost-effective reduction of the impact of agricultural production on aquatic environments through better and more efficient use of nutrients (Chapter IV).

This handbook also discusses selected measures that could minimise nutrient losses, including advanced, modern technologies and methods for dealing with problems of soil acidification and liming. Moreover, it outlines issues relating to the content of phosphorus in feeds for cattle and pigs and its utilisation by these livestock.

Evaluating the fields on the farm forms the basis for the discussion between the advisor and the farmer during a walk around the farm. Following this assessment, specific preventive measures to reduce the risk of nutrient losses can be selected. Some specialist technologies for wetlands and filters for reducing nutrient losses from farmyards can be introduced, as described in Chapter V.

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

I NUTRIENT BALANCE AT “FARM GATE"

Stefan Pietrzak

1.1. Introduction

The farm is the basic organisational unit in agriculture and it produces food and raw materials for industry. The production involves a large amount of nutrients, only a fraction of which are converted into animal and vegetable products. Part of the unused nutrients in the production (excess, surplus or lost nutrients) accumulate in the soil, 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 for the environment and are 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 with atmospheric precipitation.

Nutrient losses are inevitable, but because of the environmental impact and the economic impact on production they should be limited as much as possible. Therefore it is essential to create conditions for production on the farm that ensure effective management of nutrients. It may be helpful in this context to draw up a nutrient balance for the farm, performed by the “farm gate" method. Estimating nitrogen and phosphorus, in a nutrient balance can lead to many practical conclusions, helping to reduce the impact of agricultural production on the environment and improving the economics of farming. The latter is e.g. an effect from more effective use of the nutrients on the farm contributes to lower expenditure on fertilisers or feed. Therefore, knowledge of how to estimate a nutrient balance must be more widely disseminated, especially among skilled farmers and agricultural advisors.

The nutrient balance method "at farm gate" 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 bring nitrogen to the farm (e.g. legumes, deposition).

1.2. Overall concept of nutrient balance at farm level

Preparation of the nutrient balance by the "at farm gate" method involves determination of input and output streams on the farm (Figure I.1).

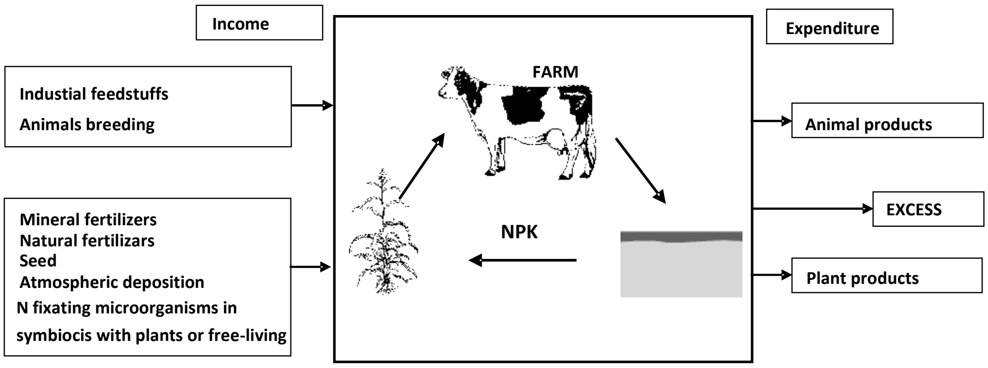


Figure I.1. Components of the "at farm gate" nutrient balance method.

Inputs are the masses of nutrients brought onto the farm in the form of:

1) Purchased materials:
   - mineral fertilisers
   - commercial feedstuffs
   - breeding and replacement animals
   - other agricultural inputs, for example, manure, straw, seed
2) Biological fixation by plant material (legumes and nitrogen)
3) Atmospheric deposition
4) Biological fixation in soil by non-symbiotic microorganisms (nitrogen).

Outputs are the masses of nutrients leaving the farm in the form of:

1) Products sold:
   - plant products (e.g. cereals, potatoes, sugar beet, oilseed, fruits, vegetables etc.)
   - animal products (live animal, milk, eggs, wool, etc.);
2) Random events, such as fallen animals, accidental crop destruction (e.g. by fire or flooding).

The difference between inputs and outputs is defined as the balance (surplus or deficit).

1.3. Nutrient inputs to the farm

1.3.1. Nutrients imported with purchased mineral fertilisers

The amount of nitrogen (N), phosphorus (P) and potassium (K) brought onto the farm in mineral fertilisers is calculated by multiplying the mass of each fertiliser purchased by the corresponding N, P or K ratio and adding up the figures for each nutrient (for an example, see Table I.1). If the data needed for the calculations regarding levels of N, P and K in fertilisers are lacking, they must be obtained from the literature or other sources such as the labels on fertiliser bags. The amounts of nitrogen, phosphorus and potassium in selected mineral fertilisers are given in Table I.2.

Table I.1. Calculating the amounts of nitrogen (N), phosphorus (P) and potassium (K) entering the farm in the form of purchased mineral fertilisers (A)

Name of purchased fertiliser	Mass purchased dt (a)	Content of N, P and K in the fertiliser (see Table I.2), kg/dt			Mass of N, P and K entering the farm in purchased fertiliser, kg		
		N (b)	P (c)	K (d)	N (a x b)	P (a x c)	K (a x d)
1. Example: 'polifoska 6'	15	6.0	8.7	24.8	90.0	130.5	372.0
2.							
3.							
4.							
Total A							

dt = decitonne = 100 kg.

1.3.2. Nutrients imported with purchased feedstuffs

A wide assortment of industrial feeds (all kinds of feed produced by the feed industry: a mixture of forage, protein concentrates, premixes, etc.) are available on the market and it would be difficult to make an inventory and obtain data giving their composition for all of these. For the preparation of a nutrient balance, use of data about the composition of the purchased feed as shown by the label on the packaging is recommended (such data can also be located on the Internet, where they are often published by manufacturers). The information on feed composition stated on the label includes the nitrogen content (but in an indirect way, estimated as crude protein, which can divided by a factor of 6.25 to give the N content) and the phosphorus content, but there is no information on the amount of potassium.

The content of crude protein and phosphorus in selected industrial compound feeds is given in Table I.3. The potassium content in industrial compound feed is on average [Mercik, 2002]:

- Compound feeds for calves: 1.30 kg K/dt
- Compound feeds for dairy cows: 1.20 kg K/dt
- Compound feeds for piglets and fattening pigs: 0.89 kg K/dt.

Table I.2. Content of nitrogen (N), phosphorus (P) and potassium (K) in various commercial mineral fertilisers

Fertiliser name	Content, kg/dt fertiliser		
	N	P	K
Agrofoska, root crops granulated	0.0	7.0	29.7
Agrofoska, cereal	0.0	10.5	19.8
Agrofoska, cereal - root crops granulated	0.0	9.2	26.4
Amofoska, spring granulated	10.0	3.9	9.9
Amofoska, with magnesium and boron	3.0	4.4	23.2
FAMP-4	12.0	2.4	4.9
FAMP–OZ	4.0	5.2	6.6
FAM–R	5.0	5.5	0.0
FAM–W	12.0	2.6	0.0
FAM–Z	3.0	6.3	0.0
Hydrofoska 21	21.0	3.5	9.1
Hydro Crop PK	0.0	12.0	29.0
Hydro Crop 6	6.0	14.0	26.0
Kemira Beta	13.6	0.0	11.6
Kemira Power 5	5.0	6.1	23.2
Kemira Power 8	8.0	8.7	24.9
Kemira Power 16	16.0	3.8	11.4
Kemira Power 21	20.6	2.7	9.6
Kemira Corn	6.0	8.7	23.2
Kemira KemiCAN	27.0	0.0	0.0
Kemira Optima 10	10.0	3.5	16.6
Kemira Optima 16	16.0	2.2	10.8
Kemira PK	0.0	4.8	16.6
Kemira Solanum	14.0	3.1	17.4
Luboplon 4	4.0	7.4	19.9
Luboplon B	3.0	5.7	20.7
Luboplon R	3.0	5.7	20.7
Lubofos 12 PK	0.0	12.0	20.0
Lubofoska (z borem)	4.0	5.2	10.0
Urea	46.0	0.0	0.0
Fertiliser phosphorus-potassium, magnesium	0.0	5.7	10.7
Fertiliser PK	0.0	5.9	11.1
Fertiliser PKMg – B	0.0	4.8	14.9
Polidap – ammonium phosphate	18.0	20.1	0.0
Polifoska 4	4.0	5.2	26.6

Table I.2 (contd.)

Fertiliser name	Content, kg/dt fertiliser		
	N	P	K
Polifoska 5	5.0	6.5	24.9
Polifoska 6	6.0	8.7	24.8
Polifoska 8	8.0	10.5	19.8
Polifoska 11	11.0	9.6	13.2
Polifoska 13	13.0	5.7	17.4
Polifoska 15	15.0	6.5	12.4
Polifoska 15 + Mg	15.0	6.5	12.4
Polifoska 17	17.0	7.4	14.0
Potafoska Mg + B	0.0	5.7	10.8
Polifosfat J	4.0	5.2	8.3
Polimag 305	5.0	7.0	19.8
Polimag 306	6.0	8.3	15.7
Polimag 309	7.0	7.4	9.9
Polimag 315	15.0	6.5	12.4
Polimap	12.0	22.7	0.0
RSM 32 – liquid urea-ammonium nitrate fertiliser	32.0	0.0	0.0
RSM 30 – liquid urea-ammonium nitrate fertiliser	30.0	0.0	0.0
RSM 28 – liquid urea-ammonium nitrate fertiliser	28.0	0.0	0.0
Ammonium sulphate	34.0	0.0	0.0
Calcium - ammonium nitrate	27.0	0.0	0.0
Saletrzak	27.5	0.0	0.0
Salmag B – saletrzak GM „B”	27.5	0.0	0.0
Salmag – saletrzak GM	27.5	0.0	0.0
Ammonium sulphate	21.0	0.0	0.0
Potassium sulphate	0.0	0.0	42.3
Granulated potassium salt	0.0	0.0	49.6
Powdery potassium salt	0.0	0.0	47.9
Superfosamon J	6.5	5.5	0.0
Superfosamon W	12.5	2.8	0.0
Granulated single superphosphate	0.0	8.3	0.0
Single superphosphate powdery	0.0	7.8	0.0
Magnesium superphosphate	0.0	6.9	0.0
Granulated triple superphosphate	0.0	20.1	0.0
Unifoska Mg + B	12.0	2.2	5.0
Unifoska W	8.5	3.7	7.1

Modified based on data from fertiliser manufacturers.

Table I.3. Content of crude protein and phosphorus in the various commercial compound feed products (given in %, = kg/dt)

Trade name of the commercial compound feed	Content	
	Crude protein	Phosphorus
Feeds for cattle		
Agrolac Gold (for calves)	21.00	0.51
Calve	17.96	0.51
Calve 25%	40.50	1.18
Opas	16.00	0.65
Opas plus	22.00	0.80
Opas ekstra	33.00	1.00
Krasula 15 economy	15.00	0.80
Krasula 18 economy	18.00	0.80
Krasula 20 economy	20.00	0.80
Krasula 15 standard	15.00	1.05
Krasula 18 standard	18.00	1.00
Krasula 20 standard	20.00	1.00
Krasula 15 plus	15.00	1.00
Krasula 18 plus	18.00	1.00
Krasula 20 plus	20.00	1.00
Feeds for pigs		
Osesek (milk replacer feed for piglets)	18.00	0.70
Piglet 1	18.50	0.53
Piglet 2	16.00	0.48
Piglet 1 Super	20.00	0.53
Piglet 2 Super	18.50	0.53
Piglet Odsadzenie 25%	40.00	1.29
Piglet Uniwersal 25–30%	39.50	1.09
Pigs Max with fish	42.00	1.15
Kaban	34.00	1.32
T-Komplet Happig	18.00	0.60
T-Komplet Start	17.60	0.60
T-Komplet Sprint	16.80	0.57
T-Komplet Finisz	14.50	0.55
T-Komplet Lacto	16.00	0.74
T-Komplet Pregio	13.00	0.68
Megavit Full 15–10%	40.40	1.50

Modified based on data from feed manufacturers.

Table I.3 (contd.)

Trade name of the commercial compound feed	Content	
	Crude protein	Phosphorus
Feeds for poultry		
Nioska	17.34	0.50
Concentrate 15% nioska	41.50	1.39
Broiler starter	21.30	0.60
Turkey 1 starter	23.85	0.68
Goose 1 starter	26.00	0.57
Mieszanka KB – 1 (complete for ducks)	20.00	0.57

Modified based on data from feed manufacturers.

The amount of nitrogen, phosphorus and potassium brought onto the farm in commercial feeds is calculated by multiplying the mass of each feed purchased by the corresponding content of N, P and K in the feed and adding up the figures for each nutrient (for an example, see Table I.4).

Table I.4. Calculating the amounts of nitrogen (N), phosphorus (P) and potassium (K) entering the farm in the form of purchased feeds (B)

Name of the purchased feed	Weight purchased, dt (a)	Content of N, P and K in the feed (for N and P content see Table I.3), kg/dt			Mass of N, P and K entering the farm in purchased feed, kg		
		N (b)	P (c)	K (d)	N (a x b)	P (a x c)	K (a x d)
1. Example: Kaban	20	N = 34/6.25 = 5.44	1.32	0.89	59.8	14.5	9.8
2.							
3.							
4.							
Total B							

1.3.3. Nutrients imported with purchased animals

The amount of nitrogen, phosphorus and potassium brought onto the farm in the form of purchased animals (breeding, replacement) is calculated by multiplying the mass of animals purchased by the corresponding contents of N, P or K in the particular category of animal (for an example, see Table I.5) and adding up the figures for each nutrient. The content of nitrogen, phosphorus and potassium in different categories of animals is given in Table I.20.

1.3.4. Nutrients imported with purchased organic fertilisers

The amount of nitrogen, phosphorus and potassium brought onto the farm as purchased organic fertilisers is estimated by multiplying the mass of organic fertilisers by the corresponding content of N, P or K in that type of organic fertiliser and adding up the figures for each nutrient (example, see Table I.6).

Table I.5. Calculating the amounts of nitrogen (N), phosphorus (P) and potassium (K) entering the farm in the form of purchased animals (C)

Category of animals	Mass purchased, dt (a)	Content of N, P and K in the animal body (see Table I.20), kg/dt			Mass of N, P and K entering the farm in purchased animals, kg		
		N (b)	P (c)	K (d)	N (a x b)	P (a x c)	K (a x d)
1. Example: dairy cows	11	2.50	0.74	0.17	27.5	8.1	1.9
2.							
3.							
4.							
Total C							

The content of nitrogen, phosphorus and potassium in various types of organic fertilisers is given in Table I.7. The values shown were determined from a large numbers of samples of these fertilisers tested in the period up to 1995. More recent data about the composition of different organic fertilisers from studies carried out in 2003-2005 in 17 regional chemical-agricultural stations in Poland are shown in Table I.8. As can be seen, these values differ from those reported in Table 1.7 and also differ from those in other earlier sources, probably because of changes in the diet of farm animals in recent years. However, they are less representative and therefore when drawing up the nutrient balance sheet for the farm, the values in Table I.7 should be used. The best situation as regards the accuracy of the calculations is when results of laboratory analyses on purchased organic fertilisers are available and if the farmer has these data available, they should be used for drawing up the balance.

Table I.6. Calculating the amounts of nitrogen (N), phosphorus (P) and potassium (K) entering the farm in the form of purchased manures (D)

Name of organic fertiliser	Mass purchased, dt (a)	Content of N, P and K in purchased organic fertiliser (see Table I.7), kg/dt fresh weight			Mass of N, P, and K entering the farm in purchased organic fertiliser, kg		
		N (b)	P (c)	K (d)	N (a x b)	P (a x c)	K (a x d)
1. Example: manure from pigs	300	0.89	0.36	0.69	267.0	108.0	207.0
2.							
3.							
4.							
Total D							

Table I.7. Content of nitrogen (N), phosphorus (P) and potassium (K) in various types of organic fertilisers according to analyses carried out prior to 1995

Type of organic fertilisers	Content, kg/dt		
	N	P	K
Manure from dairy cows	0.47	0.122	0.529
Manure from fattening cows	0.48	0.127	0.545
Manure from calves	0.60	0.140	0.611
Manure from cattle - in general	0.47	0.122	0.537
Manure from sows with piglets	0.52	0.201	0.570
Manure from fattening pigs	0.54	0.227	0.529
Manure from pigs - in general	0.53	0.205	0.570
Manure from horses	0.54	0.127	0.785
Manure from sheep	0.76	0.175	1.033
Urine from dairy cows	0.32	0.013	0.636
Urine from fattening cows	0.30	0.013	1.058
Urine from calves	0.36	0.013	0.446
Urine from cattle - in general	0.32	0.013	0.661
Urine from sows with piglets	0.23	0.013	0.273
Urine from fattening pigs	0.29	0.022	0.347
Urine from pigs - in general	0.28	0.017	0.339
Urine from horses 1)	0.47	0.002	0.463
Slurry from dairy cows	0.36	0.087	0.314
Slurry from fattening cows	0.31	0.087	0.289
Slurry from calves	0.31	0.070	0.289
Slurry from cattle - in general	0.34	0.087	0.306
Slurry from pigs - in general	0.43	0.144	0.190

1)Refers to urine stored for more than 12 weeks in airproof and waterproof tanks [Boratyński et al. 1988]. Modified based on MAĆKOWIAK [1997].

Table I.8. Content of nitrogen (N), phosphorus (P) and potassium (K) in organic fertilisers (fresh weight basis) according to analyses carried out in 2003-2005

Type of organic fertiliser	Origin	Content, kg/dt		
		N	P	K
Manure from pigs	Large farms	0.89	0.36	0.69
	Small farms	0.73	0.23	0.62
Manure from cattle	Small farms	0.69	0.38	0.58
Slurry from pigs	Large farms	0.32	0.07	0.20
	Small farms	0.28	0.05	0.22
Urine from pigs	Large farms	0.27	0.10	0.17
Slurry from cattle	Small farms	0.27	0.04	0.18
Urine from cattle	Total	0.21	0.02	0.18
Chicken manure	Large farms	2.36	0.91	1.62
	Small farms	2.20	0.99	1.22
Turkey manure	Large farms	2.41	1.27	1.56
	Small farms	2.63	1.29	1.72

Modified based on GRABOWSKI [2009].

1.3.6. Nutrients imported with other purchased materials

Other purchased products and materials containing fertiliser components include: roughages (e.g. hay, silage), protein feed (e.g. soy, rapeseed, bran), energy feed (such as cereal meal, beet pulp), seed material and straw. The amount of nitrogen, phosphorus and potassium brought onto the farm with these materials is calculated by multiplying the mass purchased (raw material) by the corresponding content of N, P and K (for an example, see Table I.9) and adding up the figures for each nutrient. The contents of nitrogen, phosphorus and potassium in other purchased agricultural production materials are presented in Tables I.10 and I.20.

1.3.7. Nutrient inputs with atmospheric precipitation

The amount of nitrogen, phosphorus and potassium brought onto the farm with atmospheric precipitation is calculated by multiplying the agricultural area of the farm by the load of N, P and K per hectare of atmospheric precipitation (for an example, see Table I.11). The amount of nutrients deposited with atmospheric precipitation are given in Table I.12. In fact, the amount of nutrients added with atmospheric precipitation is larger than stated in Table I.12, because they are brought with dry precipitation, but there are no monitoring data on quantitative deposition of nutrients by that pathway. According to available data, dry deposition of nitrogen in 2011 was on average for Poland 1.15 kg/ha (calculation by the EMEP - European Monitoring and Evaluation Programme) [SZCZEPAŃSKI (ed.) 2013].

Table I.9. Calculating the amounts of nitrogen (N), phosphorus (P) and potassium (K) entering the farm in the form of other purchased products (E)

Name of purchased product	Mass purchased, dt (a)	Content of N, P and K in fresh weight of product (raw material) (see Tables I.10 and I.20), kg/dt			Mass of N, P and K entering the farm in purchased product (raw material)		
		N (b)	P (c)	K (d)	N (a x b)	P (a x c)	K (a x d)
1. Example: Beet pulp	200	0.23	0.01	0.09	69.0	3.0	27.0
2.							
3.							
4.							
Total E							

Table I.10. Content of nitrogen (N), phosphorus (P) and potassium (K) in selected energy and protein feedstuffs

Name of feedstuff	Content, kg/dt		
	N	P	K
Soya seeds	7.20	0.63	2.08
Rape cakes[1)]	5.90	1.20	1.35
Rapeseed meal	5.62	1.15	1.71
Soya cakes[1)]	7.10	0.63	2.00
Wheat bran	2.26	1.06	1.34
Rye bran	2.29	1.02	1.23
Dry beet pulp	1.44	0.09	0.55
Wet beet pulp	0.23	0.01	0.09

[1)] Created during processing the seeds, as a by-product during oil extrusion. Used in animal feed. Modified based on data from MERCIK (red.) [2002], FAGERBERG. [1993], Workshop[1992].

Table I.11. Amounts of nitrogen (N), phosphorus (P) and potassium (K) entering the farm in the form of atmospheric precipitation (F)

Region	Area of agricultural land, ha (a)	Load of N, P and K in atmospheric deposition (see Table I.12), kg/ha			Mass of N, P and K entering the farm with atmospheric precipitation, kg		
		N (b)	P (c)	K (d)	N (a x b)	P (a x c)	K (a x d)
Example:	59	12.01	0.362	2.04	708.6	21.4	120.4
Total F							

Table I.12. Atmospheric deposition inputs of nitrogen (N), phosphorus (P) and potassium (K) in Poland in 2011.

Province	Amount, kg/ha/year		
	N_{tot}	P_{tot}	K
Dolnośląskie	10.36	0.268	2.24
Kujawsko-pomorskie	9.05	0.308	1.66
Lubelskie	10.71	0.307	1.90
Lubuskie	10.00	0.375	1.77
Łódzkie	8.83	0.238	1.90
Małopolskie	12.52	0.295	4.36
Mazowieckie	12.01	0.362	2.04
Opolskie	10.72	0.293	2.96
Podkarpackie	14.08	0.457	2.65
Podlaskie	11.49	0.620	1.87
Pomorskie	9.75	0.397	2.63
Śląskie	10.12	0.318	3.09
Świętokrzyskie	10.67	0.284	2.94
Warmińsko-mazurskie	9.15	0.301	1.59
Wielkopolskie	11.38	0.507	2.57
Zachodniopomorskie	11.77	0.514	2.31
Poland	10.85	0.378	2.30

Modified based on LIANA et al. (data for provinces)and IMGW (data for whole country).

1.3.8. Inputs of nitrogen from legumes

Nodule bacteria of the *Rhizobium* genus fix atmospheric nitrogen by symbiotic co-existence with legume plants, transform it into ammonia (NH_3) or amino acid (glutamine) and transfer it to the plant cells, where it is stored in the biomass (green parts and roots). The plants in turn supply the bacteria with carbon compounds and provide a habitat in which they can grow.

The nitrogen symbiotically fixed by legumes grown in monoculture is stored in their stems, leaves and roots. It also concentrates in senesced parts of plants and can be transferred to the soil as a consequence of rhizodeposition[1)] (Figure I.2). In mixed grass-legume swards, part of the nitrogen taken up by legumes from the atmosphere can be used by the grass. This transfer of nitrogen occurs in soil and also via grazing animals that leave manure on the pasture. The amount of molecular nitrogen symbiotically fixed by legumes depends on the species concerned and yield, as well as on soil and climate conditions.

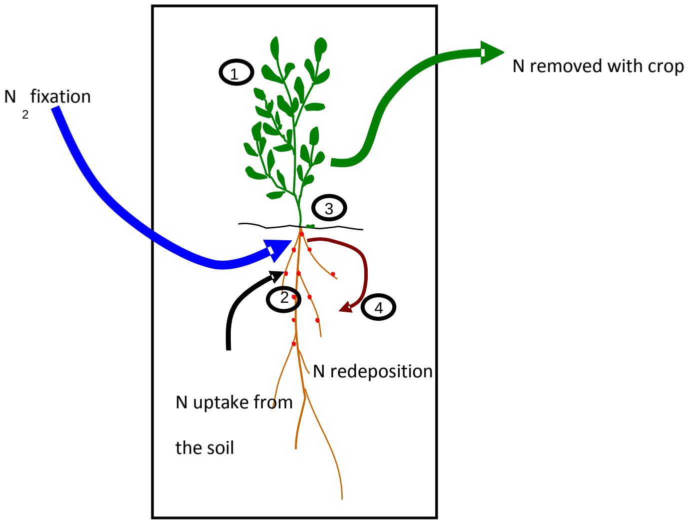


Figure I.2. Flux of nitrogen in a legume crop. *1:* Aboveground plant parts; *2:* roots; *3:* wilted plant parts; *4:* organic matter released from roots to the soil during rhizodeposition. Modified from SCHMIDTKE [2008].

[1)] Rhizodeposition – release of organic compounds from living roots to soil during the vegetation of the plant.

Table I.13. Calculating the amount of nitrogen (N) entering the farm through fixation of atmospheric nitrogen by legumes (G)

Type of plant	Cultivated area1), ha (a)	Yield of green parts2), t/ha (b)	Amount of symbiotically fixed N in green parts (see Tables I.14 and I.15), kg/t (c)	Mass of symbiotically fixed N entering the farm, kg (a x b x c)
1. Example: Yellow lupin	2	15	5.1	153
2. Example: Two-year mixed 20:80 red clover:grass ley	1.3	30 x 0.20 (share of clover)	10.2	79.6 ≈ 80
3.				
4.				
Total G				

1) Area of each legume species grown.

2) Yield of aerial parts of each legume species fresh weight) or seeds (yield of aerial plant parts grown in mixed leys with grass can be estimated as: yield of green mass of the mixture x proportion of legume).

3) Amount of nitrogen fixed by the legume species per tonne of green aboveground biomass or seeds according to Tables I.14 and I.15.

Table I.14. Amount of nitrogen (N) fixed by legume arable crops cultivated for green manure and seed production

Plant	Amount of N fixed by plants per:		Method of estimation [source]
	kg N/t aboveground biomass	kg N/t seeds	
In the main crop			Based on the amount of N in biomass of legumes cultivated as the main crop for a green manure (during the phase after deposition of pods before ploughing) [GORALSKI 1967], the symbiotic N fixation coefficient [MAZUR 1991] and the amount of N transferred to soil during rhizodeposition [SCHMIDTKE 2008]
– yellow lupin	5.1	–	
– pea	5.2	–	
– serradella	5.3	–	
In cultivation for seeds			Adapted from SCHMIDTKE [2008]
– green pea	–	40.5	
– vetch beans	–	60.0	
In intercrops			Estimation based on amount of N in biomass of legumes cultivated as aftercrops for green manure [GORALSKI 1967; IUNG 1973], the symbiotic N fixation coefficient [MAZUR 1991] and amount of N transferred to soil during rhizodeposition [SCHMIDTKE 2008]
– yellow lupin	6.1	–	
– pea	5.0	–	
– serradella	4.3	–	
– winter wetch (wsiewka)	5.0	–	

Modified based on data from the literature.

The amount of nitrogen assimilated by nodule bacteria in all legumes on the farm can be estimated from the area of each legume crop cultivated, the yield of aboveground plant parts obtained and a factor for symbiotic nitrogen fixation (for an example, see Table I.13).

Data collected from around the world indicate that symbiotic Rhizobium bacteria fix approx. 30-40 kg N per tonne in the aboveground plant parts of legumes [PEOPLES et al. 2009]. This factor can be used for simplified estimation of nitrogen inputs to the farm by legumes.

Table I.15. Total amount of nitrogen (N) fixed by monoculture perennial legumes and mixed legume:grass leys (kg N/t aboveground biomass)

Cultivated area	Land use	Amount of N_2 fixed by plants in :	
		Clay soil	Sandy soil
One-year or two-year lucerne in monoculture	Hay	7.4	6.2
One-year or two-year red clover in monoculture		8.2	6.8
One-year or two-year mixed white clover:grass ley		17.2	14.2
One-year or two-year mixed red clover:grass ley		10.2	8.8
More than two-year mixed white clover:grass ley		15.0	11.8
One-year or two-year mixed white clover:grass ley	Grazing	16.8	14.4
One-year or two-year mixed red clover:grass ley		9.6	8.4
More than two-year mixed white clover:grass ley		13.0	10.6

Modified based on HØGH-JENSEN et al. [2004].

1.3.9. Inputs of nitrogen from soil microorganisms

Over 150 species of bacteria live in the soil. Some of these bacteria have the ability to fix atmospheric nitrogen, the most well-known being *Azotobacter* sp. and *Clostridium* sp. The amount of nitrogen fixed in the soil by microorganisms is influenced by their physiological characteristics but also by: soil pH, nutrient availability, soil moisture content, temperature, soil oxygen content and amount of available carbohydrates and other organic compounds. Mineralisation of humus and post-harvest residues and roots is a source of energy for the nitrogen fixation process. The amount of nitrogen fixed by microorganisms present in different types of soil is given in Table I.16.

Table I.16. Amount of nitrogen (N) fixed by microorganisms present in different types of soil

Soil	Amount of N fixed, kg N/ha/year
Podozolic soil	7.5–9.5
Grey forest soil	18.9–24.5
Black soil (chernozem)	35.0–42.0
Chestnut soil	19.0–24.0
Serozem	19.0–24.0
Mean value for Poland	10.0

Modified based on MAZUR [1991, after Beresteckim 1988].

Publications describing the amount of nitrogen fixed by non-symbiotic microbes present in soil in Central Europe are rare. Such research has been carried out only on a small scale in Poland. On basis of available data, it can be assumed that nitrogen non-symbiotically fixed in arable land in Poland is approx. 8-25 kg N/ha per year. The lower value refers to sandy soils and the higher value is typical for clayey soils [MAZUR 1991, after Berestecki 1984]. The most frequently cited figure in international literature is that the maximum amount of nitrogen fixed by free-living soil microbes is approx. 20 kg N/ha per year [CSIRO 2006].

The amount of nitrogen introduced into the environment by non-symbiotic microbes can be calculated by multiplying the area of arable land on the farm by a factor characterising the amount introduced by these microbes (for an example, see Table I.17).

Table 1.17. Calculating the amount of nitrogen (N) entering the farm through fixation of atmospheric nitrogen by free-living soil microbes (H)

Area of arable land on the farm, ha (a)	Amount of N introduced by soil microbes fixing N_2 (see Table I.16), kg/ha (b)	Mass of N entering the farm with non-symbiotic microbes, kg (a x b)
Example: 59	10	590
Total H		

1.4. Nutrient exports from the farm

1.4.1. Nutrient exports with sales of agricultural products

The amount of nitrogen, phosphorus and potassium leaving the farm in the form of agricultural products sold on the market[2)] can be calculated by multiplying the amount of plant and animal products sold by their corresponding N, P and K content and adding the figures obtained for each nutrient (for example, see Tables I.18 and I.19)

The amount of nitrogen, phosphorus and potassium potentially leaving the farm as a result of accidental events (unpredictable and non-dependent on human will) should be added to the mass of agricultural products sold. Accidental losses include e.g. dead animals and loss of crops as a result of fire or flooding, where nutrients leave the farm. The amount of nutrients involved can be calculated by multiplying the mass of agricultural products lost due to accident by the corresponding amount of N, P and K, as calculated for products sold (Table I.19). The amounts of nitrogen, phosphorus and potassium in different agricultural products are given in Table I.20.

[2)] agricultural products are products derived from farming and fishing, as well as products of first-stage processing directly related to these productsAccordance to Annex I Treaty establishing the European Community (OJ. No C 235, 24.12.2002),

Table I.18. Calculating the amount of nitrogen (N), phosphorus (P) and potassium (K) leaving the farm in animal products sold (I)

Type of product	Mass sold, dt (a)	Amount of N, P and K in the product (see Table I.20), kg/dt			Mass of N, K and K leaving the farm with the product, kg		
		N (b)	P (c)	K (d)	N (a x b)	P (a x c)	K (a x d)
1. Example: slaughter pigs	22	2.60	0.46	0.22	57.2	10.1	4.8
2.							
3.							
4.							
Total I							

Table I.19. Calculating the amount of nitrogen (N), phosphorus (P) and potassium (K) leaving the farm in plant products sold (J)

Type of product	Mass sold, dt (a)	Amount of N, P and K in the product (see Table I.20), kg/dt			Mass of N, P and K leaving the farm with the product, kg		
		N (b)	P (c)	K (d)	N (a x b)	P (a x c)	K (a x d)
1. Example: winter wheat	15	1.82	0.32	0.43	27.3	4.8	6.5
2.							
3.							
4.							
Total J							

Table I.20. Amount of nitrogen (N), phosphorus (P) and potassium (K) in different types of agricultural products

Type of product	Amount, kg/dt per product		
	N	P	K
Plant products			
Winter wheat (grain)	1.82	0.32	0.43
Spring wheat (grain)	1.82	0.32	0.43
Triticale (grain)	1.80	0.36	0.46
Barley (grain)	1.71	0.35	0.43
Rye (grain)	1.59	0.30	0.42
Oat (grain)	1.77	0.29	0.44
Grain mixtures (grain)	1.80	0.35	0.43
Millet (grain)	2.00	0.65	0.50
Maize (grain)	1.4	0.27	0.44
Silage maize	0.381	0.061	0.664
Colza (seed)	3.50	0.60	0.80
Legumes (seed), average	3.33	0.39	1.04
Green pea (seed)	3.50	0.36	1.00
Seeds from seed crops (grass, legumes)	2.00	2.00	3.00
Sugar beet (root)	0.21	0.029	0.27
Sugar beet (leaves)	0.37	0.03	0.41
Potatoes (tuber)	0.35	0.05	0.48
Vegetable (average)	0.33	0.035	0.31
Fruit (fresh)	0.12	0.02	0.20
Apple	0.08	0.01	0.12
Soft fruits	0.22	0.03	0.17
Grass ley for green forage	0.41	0.06	0.39
Legumes (e.g. clover, lucerne) for green forage	0.56	0.06	0.38
Hay from grass (85% of dry mass)	2.00	0.26	2.00
Hay with 25% clover and 75% grass (85% of dry mass)	2.10	0.26	2.05

Table I.20 (contd.)

Type of product	Amount, kg/dt per product		
	N	P	K
Hay with 75% clover 25% grass (85% of dry mass)	2.30	0.26	2.15
Clover hay (85% of dry mass)	2.40	0.26	2.20
Lucerne hay (85% of dry mass)	2.50	0.26	2.30
Silage (25% dry weight)	0.36	0.07	0.45
Straw – rye	0.58	0.11	1.00
Straw – wheat	0.66	0.11	1.06
Straw – triticale	0.61	0.11	1.03
Straw – barley	0.73	0.11	1.20
Straw – oat	0.71	0.14	1.51
Straw – corn	0.80	0.20	1.79
Straw – olefin plant (colza)	0.72	0.13	1.68
Animal products			
Milk	0.54	0.10	0.15
Eggs	1.94	0.20	0.125
Wool	13.40	0.04	1.82
Slaughter cattle (weight after slaughter)	2.70	0.55	0.22
Animals – live weight			
Horses (100–900 kg)	2.50	0.74	0.17
Dairy cattle (550 kg)	2.50	0.74	0.17
Fattening beef animals (550 kg)	2.50	0.74	0.17
Heifers	2.50	0.74	0.17
Calves (60 kg)	2.50	0.74	0.17
Sows (180 kg)	2.60	0.46	0.22
Slaughter pigs (110 kg)	2.60	0.46	0.22
Piglets (25 kg)	2.60	0.46	0.22
Sheep	2.50	0.74	0.17
Lambs (40 kg)	2.50	0.74	0.17
Poultry (1.5–6 kg)	2.70	0.60	0.29
Fur animals	3.07	0.47	0.26
Vegetables			
Broccoli	0.35	0.078	0.415
Beet above-ground part	0.24	0.048	0.407
Beetroot	0.30	0.065	0.415
Onion	0.20	0.044	0.166
Horse radish	0.69	0.096	0.623
Chicory	0.25	0.044	0.415
Squash	0.20	0.039	0.249
Garlic	0.34	0.057	0.216

Table I.20 (contd.)

Type of product	Amount, kg/dt per product		
	N	P	K
Endive	0.20	0.026	0.307
Dwarf kidney bean	0.40	0.065	0.249
Runner bean	0.30	0.035	0.224
Fennel	0.25	0.031	0.407
Green pea (yield 10 t/ha fresh mass)	0.16	0.074	0.332
Green pea (yield 5 t/ha fresh mass)	1.10	0.109	0.332
Kale	0.50	0.070	0.457
Kohlrabi	0.30	0.044	0.374
Cauliflower	0.35	0.052	0.332
Brussels sprouts	0.33	0.105	0.498
White cabbage	0.30	0.044	0.266
Red cabbage	0.30	0.035	0.291
Italian cabbage	0.35	0.052	0.332
Chinese cabbage	0.20	0.044	0.291
Dill	0.35	0.031	0.315
Sweetcorn	0.25	0.065	0.440
Carrot	0.20	0.044	0.374
Gherkin	0.20	0.044	0.415
Paprika	0.30	0.035	0.291
Parsnip	0.35	0.087	0.498
Parsley (yield 20 t/ha fresh mass)	0.50	0.065	0.664
Parsley (yield 30 t/ha fresh mass)	0.40	0.087	0.540
Tomatoes	0.18	0.031	0.291
Leek	0.30	0.044	0.332
Turnip	0.15	0.031	0.332
Garden radish	0.20	0.031	0.332
Radish	0.15	0.031	0.315
Garden lettuce	0.20	0.044	0.332
lettuce fragile	0.20	0.031	0.315
ceberg lettuce	0.20	0.026	0.266
Other (lollo) lettuce	0.20	0.031	0.315
Root celery	0.30	0.087	0.498
Chive	0.40	0.044	0.249
Asparagus	0.35	0.065	0.291
Spinach	0.40	0.061	0.581

Modified based on: Vegetables: GRZEŚKOWIAK [2006 after Schweder et al. 1998], other products: different sources, mainly FAGERBERG et al. [1993], Workshop [1992], WRZASZCZ [2009], RUTKOWSKA [2010], SZEWCZUK [2010].

Table I.21. Calculating changes in the amount of nitrogen (N), phosphorus (P) and potassium (K) stocks present on the farm in mineral and organic fertilisers over the year

Type of fertiliser	Mass, dt		Amount of N, P and K in the fertiliser (see Tables I.2 and I.7), kg/dt			Changes in the amount of N, P and K in the fertiliser over the year, kg		
	Start of year (1 I) (a)	End of year (31 XII) (b)	N (c)	P (d)	K (e)	N c·(b–a)	P d·(b–a)	K e·(b–a)
1. Example:	7	1	5.0	7.0	19.8	–30	–42	–118.8
2.								
3.								
4.								
Total (L)								

1.4.2. Changes in nutrient stocks on the farm

While estimating the nutrient balance for a farm, changes in the amount of nutrients in resources for agricultural production and in ready-to-sell products (e.g. fertilisers, fodder), between the start and end of the year should be taken into account. These changes are determined by comparing differences between the amount of N, P and K accumulated in stocks at the start and the end of the year. To estimate changes in the amounts of nitrogen, phosphorus and potassium accumulated in fertilisers, feed and livestock on the farm, one should:

- calculate the difference in mass of these production resources between the start and end of the year
- multiply the change in mass obtained for each resource by the corresponding amount of N, P and K (see Tables I.21-I.23).

Changes in stocks can mean an increase of the amount of nutrients (positive value) or a decrease (negative value). The result can be defined as the increase or decrease in N, P and K resources. If there has been an increase in nutrients in fertilisers, feed or livestock for the year, the values relating to the increase should be subtracted from the calculated inflow of each nutrient. If there has been a decrease in nutrients in production resources, the values relating to the decrease should be subtracted (denoted with a minus sign) from the calculated outflow of each nutrient. The corrected inflows and outflows of nutrients should be used to calculate the final balance for the farm.

Table I.22. Calculating changes in the amount of nitrogen (N), phosphorus (P) and potassium (K) stocks present on the farm in feedstuffs over the year (concentrate, green feed, roughage, maize) (Example: rapeseed meal)

Type of feed	Mass, kg		Amount of N, P and K in the feedstuff (see Tables I.3 and I. 20), kg/dt			Changes in the amount N, P and K in the feedstuff over the year, kg		
	Start of year (1 I) (a)	End of year (31 XII) (b)	N (c)	P (d)	K (e)	N c·(b–a)	P d·(b–a)	K e·(b–a)
1. Example:	2	10	5.62	1.15	1.71	45.0	9.2	13.7
2.								
3.								
4.								
Total (M)								

1.4.3. Estimating nutrient balance and use 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 figures obtained can be expressed as ratio of total change (surplus) to area of arable land on the farm. Nutrient use efficiency on the farm can also be calculated (see Table I.24). The use efficiency of nitrogen, phosphorus and potassium is the ratio: Amount leaving the farm/Amount entering the farm x 100%. Nutrient use efficiency can be used to define the percentage of nutrients brought onto the farm that is used directly for production.

Table I.23. Changes in the amount of nitrogen (N), phosphorus (P) and potassium (K) stocks present on the farm in livestock over the year (Example: slaughter pigs)

Category of animal	Weight, dt		Amount of N, P and K in the animal (see Table I.20), kg/dt			Changes in the amount of N, P and K in the animals over the year, kg		
	Beginning of the year (1 I) (a)	End of the year (31 XII) (b)	N (c)	P (d)	K (e)	N c·(b–a)	P d·(b–a)	K e·(b–a)
1. Example:	550	440	2.60	0.46	0.22	–286.0	–50.6	–24.2
2.								
3.								
4.								
Total (Q)								

Own elaboration.

Table I.24. Calculating the overall balance for nitrogen (N), phosphorus (P) and potassium (K) and their use efficiency on the farm

No.	Specification	Figure from previous tables	Amount of the component, kg		
			N	P	K
1	**Nutrient inputs**				
2	Amount of inputs in mineral fertilisers	A			
3	Amount of inputs in purchased feeds	B			
4	Amount of inputs in purchased animals (for breeding)	C			
5	Amount of inputs in organic fertilisers	D			
6	Amount of inputs in other purchased materials and resources	E			
7	Amount of inputs in deposition	F			
8	Amount of symbiotically fixed nitrogen	G		X	X
9	Amount of nitrogen introduced by soil microorganisms	H		X	X
10	**Total inputs (2-9)**				
11	**Nutrient outputs**				
12	Outputs in animal products sold	I			
13	Outputs in plant products sold	J			
14	**Total outputs (12–13)**				
15	**Changes in stocks**				
16	Change in nutrient stocks in mineral and organic fertilisers over the year	L			
17	Change in nutrient stocks in feeds over the year (Green fodder, roughage, maize)	M			
18	Change in nutrient stocks in livestock over the year	Q			
19	**Total change in nutrient stocks (16–18)**				
20	**Inputs corrected for increase in nutrient stocks (difference: 10–19)**				
21	**Outputs corrected for decrease in nutrient stocks (difference: 14–19)**				
22	**Surplus/deficit (difference: 20–21)**				
23	**Surplus/deficit in kg/ha (ratio: 22/arable land on the farm)**				
24	**Nutrient use efficiency, % (ratio: 21/20 x 100)**				

1.5. Example of farm balances

The most significant surplus of nutrients generally occurs on farms specialising in animal production. This has been well proven at national and international level, e.g. a survey based on 186 farms in France found that the average nitrogen surplus on farms with intensive pig and poultry production was 392 and 532 kg/h and year, respectively. On dairy and beef cattle farms the nitrogen surplus was 152 and 256 kg/ha and year, respectively. However, on farms dedicated to plant production (maize and root vegetables), the nitrogen surplus was only 28 kg/ha and year (Figure I.3)

In Polish conditions, the surpluses of nutrients originating from animal farms are lower than in countries with highly developed agriculture. Nonetheless, the surpluses of nutrients are still significant, particularly on farms with exclusively or mainly fattening pig production. On specialist pig farms surveyed in the Wielkopolska region, the N and P surplus was 392 and 96 kg/ha respectively, while on predominantly pig farms in the same region the corresponding values were 219 and 71 kg/ha, respectively (Table I.25).

On farms with cattle production the N and P surpluses are usually lower. A surplus of 123 kg N/ha and 13 kg P/ha was recorded in three typical types of farms specialising in dairy production in Podlasie, the area with the highest concentration of dairy cattle in Poland (Table I.26).

On the farms with exclusively or predominantly pig or dairy production, higher N and P surpluses were noted than on farms with mixed production. In fact, the higher the proportion of plant production on the farm, the lower the N and P surplus (Tables I.25 and I.26). This confirms that farms with mixed production have a lower impact on the environment than farms specialising in animal production.

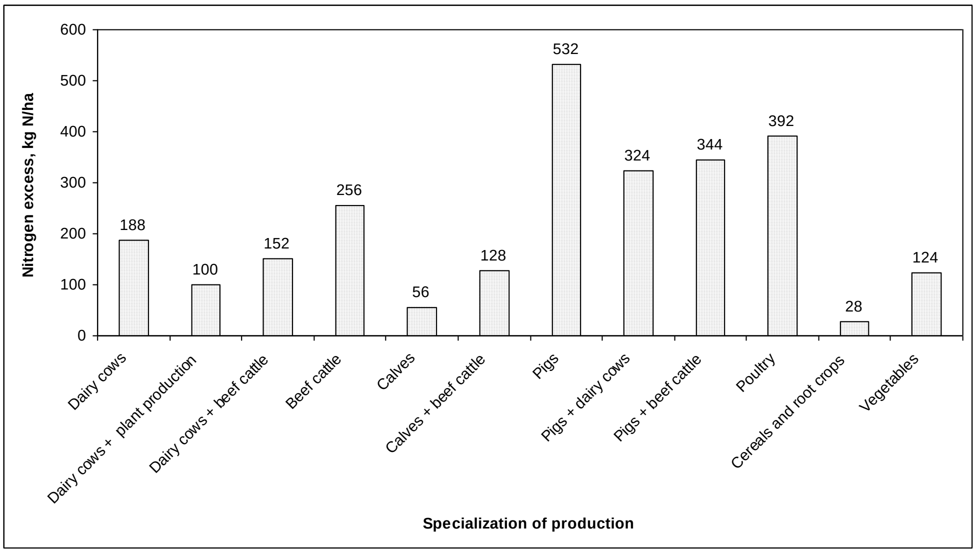


Figure. I.3. Nitrogen surplus on different types of farms in northern France. Modified after SIMON, LE CORRE [1992].

Table I.25. Mean nitrogen (N) and phosphorus (P) inputs, outputs and surplus and use efficiency on three farms with different intensity of pig production in Wielkopolska, Poland

Parameter	Form of production on the farm					
	Pig production, exclusively1)		Pig production, mainly2)		Pig production + arable)	
	N	P	N	P	N	P
Inflows, kg/ha/year						
- mineral fertilisers	67.8	21.1	123.6	43.8	102.7	22.1
– mixtures and concentrates	321.2	111.2	85.9	28.1	35.3	11.6
– maize for feed	318.8	63.2	103.9	21.4	0.0	0.0
– seed	4.0	0.8	1.8	0.3	2.4	0.5
– animals (breeding stock)	1.5	0.6	1.4	0.2	0.4	0.1
– free-living microorganisms	10.0	–	10.0	–	10.0	–
– atmospheric deposition	18.0	–	18.0	0.0	18.0	–
Total inflows, kg/ha	741.3	196.9	344.6	93.8	168.8	34.3
Outflows, kg/ha/year						
– slaughter pigs	256.6	45.4	91.2	16.1	29.8	5.3
– manure	92.3	55.4	–	–	–	–
– sugar beet	–	–	13.5	2.6	21.1	4.1
– olefin plant (colza)	–	–	20.8	4.0	–	–
– sweetcorn	–	–	–	–	4.5	0.9
– maize	–	–	–	–	9.5	1.9
Total outflows, kg/ha	348.9	100.8	125.5	22.7	64.9	12.2
Surplus, kg/ha	**392.4**	**96.1**	**219.1**	**71.1**	**103.9**	**22.1**
Use efficiency, %	47.1	51.2	36.4	24.2	38.4	35.6
Farm area, ha	13		38		119	

1) Nutrient outflows production with slaughter pigs and organic fertilisers.

2) Nutrient outflows with over 70% slaughter pigs and some plant production.

3) Nutrient outflows with approx. 45% slaughter pigs and 55% plant products.

Source: PIETRZAK [2002] based on data from KCDRRiOW department in Poznań.

On farms with animal production, the main factors determining the surplus of nutrients are purchased fertilisers for forage production and purchased concentrate feeds. On this type of farm, concentrates are usually introduced to the balance in significant amounts, which also increases the concentration of nutrients on the farm. On the Polish farms with predominantly or exclusively pig production discussed above, the amounts of nitrogen and phosphorus inputs with purchased commercial feeds and feed maize were higher than the amounts introduced with mineral fertilisers (Table I.25). Only a small proportion of the nutrients in feed can be transformed into milk or meat produced and the remainder are released by the animals in manure. This is the most significant and direct source of nutrient losses from agriculture.

Table I.26. Mean nitrogen (N) and phosphorus (P) inputs, outputs and surplus and use efficiency on four farms with dairy production in Podlasie, Poland

Parameter	Form of production on the farm			
	Dairy production[1] (average results from five consecutive years for three farms)		Dairy production + plant production (average results from five consecutive years for one farm)	
	N	P	N	P
Inflows, kg/ha/year				
- mineral fertilisers	108.1	14.1	88.6	14.2
- concentrate feed	12.8	3.9	7.5	2.3
- roughage	4.7	0.5	1.8	0.2
- straw	0.1	0.01	0.2	0.0
- animals	-	-	0.2	0.1
- legumes[2]	2.3	-	3.9	-
- free-living microorganisms	10.0	-	10.0	-
- atmospheric deposition	10.6	-	10.6	-
Total inflows, kg/ha	148.6	18.6	122.8	16.8
Outflows, kg/ha/year				
- grains	0.3	0.1	15.4	2.9
- potatoes	0.6	0.1	1.1	0.2
- sugar beet	-	-	8.8	1.8
- milk	22.1	4.4	13.9	2.6
- cattle	3.0	1.0	1.6	0.4
Total outflows, kg/ha	26.0	5.6	40.8	7.9
Surplus, kg/ha	**122.6**	**12.9**	**82.0**	**8.9**
Use efficiency, %	17.5	30.3	33.2	47.0
Surplus, kg/m^3 milk	29.3		31.1	

[1] Only farms with nutrient outflows with animal products or with small contribution by plant products were considered. [2] Without legumes in the sward. Source: PIETRZAK [2005].

II ESTIMATING NITROGEN LEACHING FROM INDIVIDUAL FIELDS

Helena Aronsson, Barbro Ulén

2.1 Introduction

Nitrogen leaching may differ greatly from one field to another within a farm and therefore the leachate from every field should be estimated as part of a risk assessment. Climate, soil and the agricultural management on every field are decisive factors for the magnitude of the leaching. The basis for estimations of nitrogen leaching is that there are factors which are vital for the leaching level in every cropping year. In reality, there are a huge number of factors that affect leaching, but in order to make an approximate estimation, some of these are chosen as key factors. Based on Swedish experiences, the following are key factors:

1. The crop in the preceding cropping year and crop cover during autumn/winter.
2. Time of tillage.
3. Manure or compost addition, especially in autumn.
4. Intensity (loads) of manure and mineral fertiliser.

This chapter describes methods for estimating nitrogen leaching from different areas of the farm. Similar estimates are used by advisors in Sweden. Tables used for the calculation are based on work by HOFFMANN et al. [1999] and ARONSSON and TORSTENSSON [2004], by making some modifications appropriate to the situation in Poland.

In addition to those factors, nitrogen leaching is controlled by factors relating to the natural conditions on the farm. Consequently, a ‘basic leaching’ value (A in Table II.1) is used in the estimations and this is equal to the leaching from a conventional cereal crop (e.g. oats and spring barley) without any manure addition, balanced fertilisation and with tillage in mid-autumn. This basic leaching varies depending on precipitation, other climate factors, soil and type of production.

There is no consideration of variations in precipitation and drought in the estimate, but every year is regarded as 'normal'. Statistical values of normal yields for the region are used in estimates of the basic leaching to avoid the effect of specific weather conditions which might result in abnormal harvest levels.

In spite of these uncertainties, there is an important aim with the calculations. The purpose is not to estimate the exact leaching from a specific farm. Instead, the calculations help to give a comprehensive overview of the farm when a farmer is going through the calculations. They provide a clearer idea of the factors that are most important for the nitrogen losses from the particular farm, and possible measures which should be taken to provide the largest reduction in losses.

This method of estimating nitrogen leaching was developed using results supported financially by the Federation of Swedish Farmers [HOFFMANN et al. 1999]. The aim of the project was to develop a method of supporting farmers in activities related to the reduction of nitrogen leaching. The calculations presented were later adopted by the Swedish Board of Agriculture and used in the computer programme *Stank in Mind*, developed for the needs of agricultural advisory services.

2.2. The method for estimating nitrogen leaching

2.2.1. Description of the method

Annual crops have different lengths of growing period, from about September 1 of year I to August 31 of year II. The growing season of the crop starts when the crop is harvested and preparations are made for the next crop. Nitrogen leaching starts with harvest in early autumn of the previous cropping season, and continues during winter and spring. However, leaching is mainly a result of actions taken during the preceding cropping season.

When calculating leaching of nitrogen from a field, one should therefore take into account the following;

- The crop that was grown on the field during the summer before leaching starts in autumn.
- The fertilisation to the crop and soil tillage for the new crop.

In order to let the years be of equal length, it is assumed that season includes all crops cultivated in the period from about September 1 in year I to August 31 in year II for comparison purposes.

Figure II.1. Crop, tillage and application of organic fertilisers in 2013 affecting the leaching of nitrogen in the main drainage season October 2013 – April 2014; Source: Aronsson, unpublished.

Table II.1. Factors to be used when calculating approximate annual N leaching from agricultural fields

Field No.	Factor								
	A	B	C	D	E	F	G	H	I
	Basic leaching kg/ha	Crop factor	Soil tillage	Modified leaching kg/ha = A·B·C	Manure application (autumn or spring)	Fertilisation intensity	Total leaching, kg/ha = (D·E)+F	Field area, ha	Total leaching kg =G·H
1									
2									
3									
4									
5									

Basic leaching (A), taking into account the type of soil and climate of the region. A is multiplied by a crop factor (B) and a soil tillage factor (C) to get the level of leaching (D). When multiplied by a factor for leaching from the manure and the date of its application (E), then the effect of fertilisation intensity (F) is added. Finally, the total leaching per hectare (G) is multiplied by the field area (H) to give the total amount leached from each respective field (I). A*B*C = D; (D*E) + F = G; G*H = I

Source: Hoffman et al., [1999]; Aronsson and Torstensson [2004].

For every field, go through the four key factors that are described on the following pages and put in a value for each factor and field in Table II.1. It is a good idea to have the harvest level for the previous year and the fertilisation plan available. As you fill in the table, you will surely encounter problems. You may find that the division into different classes is very rough, or lack options for your particular circumstances. Then you should choose the most appropriate figure based on own judgment or on the material available, or make a selection from the available data in the literature, the internet, etc.

Table II.2. Basic leaching (kg N/ha) with different amounts of precipitation (mm) and from different soil types

Precipitation	Leaching depending on the soil type			
	sandy soil	loamy soil	clay soil	organic soil
500–700	30	20	15	30
700–1000	40	30	20	40

Source: Hoffman et al., [1999]; Aronsson and Torstensson [2004].

2.2.2. Basic leaching with the impact of climate – factor A

The soil and climate are very important for nitrogen leaching. Table II.2 illustrates how leaching can vary depending on climate and soil conditions. This so-called ‘basic leaching’ represents nitrogen leaching in conventional cereal cultivation without manure supply and with the first autumn tillage made just after harvest. It is based on research carried out in the region of Götaland, in southern Sweden. Select the soil texture class that best represents your field. If a field is located just between two soil classes, you can still make an estimate of the basic leaching from the field. The amount of leaching you get for a field (kg/ha) is the basic leaching (A in Table II.1).

2.2.3. Effect of the crop in the previous crop year – factor B

Leaching of nitrogen occurs during the autumn and winter, i.e. in the beginning of each cropping year. It is largely a result of the actions taken during the previous cropping year. Hence, it is also the previous year's crop that primarily affects the leaching level. However, if a new crop is sown in autumn this will reduce leaching, and must be included. In Table II.1, insert the key factor (given in Table II.3) for the crop that was on the field on July 1 in the previous year, and if a crop is sown in autumn choose a combination for this. The crops that generate more leaching than cereals during subsequent cropping year, e.g. potato and oilseed, have a factor larger than 1.0 in Table II.3. Similarly, the crops that provide opportunities for reduced leaching, such as sugar beet, are given a factor lower than 1.0. Not all types of crops are included.

Table II.3. Factor to use when accounting for the leaching effect of the crop in the previous year (based on conditions in Götaland, Sweden)

Crop in the previous year	Factor
Cereal	1.0
Cereal followed by winter wheat	0.9
Cereal followed by winter oilseed	0.8
Oilseed	1.2
Oilseed followed by winter wheat	1.1
Cereal and oilseed with undersown catch crops	0.7
Cereal and oilseed with catch crops sown after	0.9
Cereal with undersown ley (grass and legumes)	0.7
Finalising ley without ploughing	0.6
Ley ploughed in early autumn	2.0
Ley ploughed in mid-autumn (October-December)	1.9
Potato	1.7
Potato followed by catch crop	1.2
Sugar beet (tops ploughed down)	0.9
Pea and bean	1.3
Special case when ploughing down ley: If the ploughing in spring took place before sowing in, the leaching will increase and the above factor for the crop from Table II.3 should be multiplied by a factor of 1.5 before being placed into Table II.1.	1.5

Source: HOFFMAN et al., [1999]; ARONSSON and TORSTENSSON [2004].

Table II.4. Factors to estimate effect of soil tillage on nitrogen leaching

Soil tillage	Factor
In early autumn (August-September)	1.0
Late autumn (October-December)	0.8
No tillage in the autumn	0.7

Source: ARONSSON and HOFFMAN [1999]; ARONSSON and TORSTENSSON [2004].

Table II.3 cannot be viewed separately to indicate the leaching of different crops and not all crops are included. Some crops, such as forage, fallow, sugar beet and catch crops, are combined with estimates of a tillage factor (Table II.4) for delayed tillage or no tillage, which reduce the leaching even further. The data from the sources is somewhat reworked in light of this.

If a short-term grassland (ley) was ploughed down in the spring, before the introduction of a new crop, this should be paid special attention (see special case given in Table II.3). Factors for ploughing down the ley are based on the assumption that the best time for ley is late autumn and spring. When estimating the effect from ploughing down the ley, all leaching is assumed to occur during one leaching, but in reality the enhanced leaching may be seen for some years. Leys with only grass contain less nitrogen than mixed leys. Ploughing down a grass ley is therefore likely to affect the leaching less than indicated for leys with grass and legumes in Table II.3.

2.2.4. Effect of soil tillage – factor C

Soil mixing stimulates the release of nitrate-nitrogen, especially if the tillage is done early in the autumn. Accordingly, delayed or no tillage in the autumn reduces leaching. Therefore insert a factor from Table II.4 that represents the effect of the tillage operation in the previous year and multiply by factors A and B in Table II.1. If a perennial crop is cultivated in the field, such as forage, use the factor "no-tillage in the autumn”. Please observe that for potatoes and sugar beet, the harvesting

2.2.5. Effect of manure – factor E

If manure is applied in autumn, some of the ammonium-nitrogen will contribute to the leaching. In addition, both plant-available nitrogen and organically bound nitrogen are added with manure and the latter will subsequently be released, not always synchronised with the crop uptake. Therefore, nitrogen leaching from a field that receives manure will always be somewhat increased, especially after application during autumn (and assigned more than a factor of 1.0). Slurry, which has a higher content of ammonium than solid manure, will cause a higher risk of leaching (Table II.5). Solid manure and slurry spread in the spring will also contribute somewhat to leaching. The leaching will be slightly higher than using only mineral fertilisers in balanced doses.

Urine may be comparable to mineral nitrogen fertilisers in ammonium form, since it consists predominantly of nitrogen available to plants. Urine from livestock with possible small amounts of faeces and/or water contains an average of 1-3% dry matter.

Field studies have shown about 10% greater leaching from soils where manure has been added than from soils with only mineral fertilisers. This is due to the mineralisation of organic nitrogen in the manure, which is released after the growing season. Litter manure, and compost, contains almost only organically bound nitrogen. Nitrogen release from litter can be slower than from both solid manure and slurry and therefore it is probably most advantageous for low N leaching to spread the litter and compost in the autumn rather than in spring. However, the various rules that exist regarding allowable timing for manure spreading should be strictly followed.

Table II.5. Factor for additional nitrogen leaching losses compared with basic leaching depending on manure type[1)]

Type of manure	Factor depending on the time of fertilisation	
	Autumn	spring
Solid manure	1.15	1.1
Slurry	1.30	1.1

[1)] Based on an application rate of 20–40 t/ha.

Source: HOFFMAN et al. [1999]; ARONSSON and TORSTENSSON [2004].

2.2.6. Effect of fertilisation intensity – factor F

When a field is fertilised with manure or mineral fertiliser in balance with the crop needs, nitrogen leaching can be assumed to be small, but as soon as there is an overdose, leaching increases. However, the overdose is not necessarily intended. A severe summer drought, for example, means that the small crop cannot fully make use of the nitrogen introduced with fertilisers during the spring and early summer.

When estimating whether a field received too much nitrogen or not, and if so how much, start with the nitrogen available to the crop remaining from the previous growing season, and add the total amount of mineral nitrogen applied with fertilisers and/or manure in the current crop year. Compare the amount of applied nitrogen with the recommended nitrogen rate for the crop yield commonly achieved from the field. Agriculture's "Guidelines for Fertilizing and Liming" is a good source for normal values. The applied amount of nitrogen is the sum of mineral fertiliser and the expected fertiliser value of any manure applied to the crop. If the actual amount of nitrogen is higher than recommended, you should check in Table II.6 how much more leaching you can expect from the field, and add this amount in Table II.1 to get a final value of leaching per hectare (G). Depending on which crop you are cultivating and which practice you use, this final leaching (G) will be higher or lower than the basic leaching.

Complete losses of nitrogen for a field are calculated by multiplying the total leaching of G (kg/ha) in Table II.1 by the surface area of the field.

Table II.6. Estimated extra nitrogen leaching (kg/ha) above recommended dose for normal yields for different soil types

Estimated extra N leaching due to higher than optimum fertilisation kg N/ha	Factors depending on soil type			
	sandy soil	loamy soil	clay soil	organic soil
10–20	3	2	2	3
20–30	6	4	4	6
30–40	10	5	5	10
40–50	16	7	7	16
50–60	22	8	8	22

Source: HOFFMAN ET AL., [1999]; ARONSSON and TORSTENSSON [2004].

III ESTIMATING THE RISK OF PHOSPHORUS LEACHING FROM INDIVIDUAL FIELDS BASED ON SOIL SURVEYS AND FERTILISATION

Barbro Ulén

Phosphorus losses from fields are much smaller than the nitrogen losses, but are still more important for the life in waters. The mean phosphorus leaching from arable land in Poland has been estimated at 0.4 kg ha year^{-1}, and the majority of this reaches the Baltic Sea [HELCOM 2012]. Phosphorus leaching shows large spatial variation and may differ widely between, or even within, fields on a farm. The leaching is difficult to estimate, and therefore risk factors for leaching are often discussed rather than absolute amounts. Important factors controlling the risk of phosphorus leaching are soil type, climate and the agricultural management, e.g. soil tillage, crops, fertilisation and the long-term build-up of soil phosphorus content due to excessive manure or mineral fertilisation.

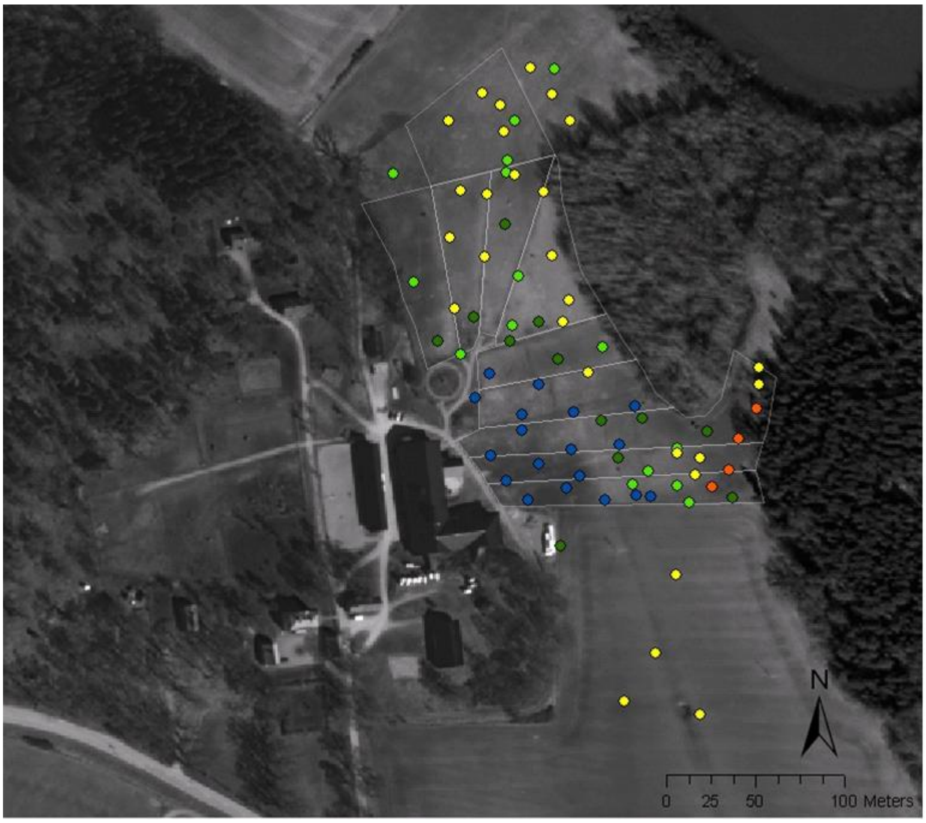
Based on the results of laboratory experiments, this chapter presents the relative risk of phosphorus leaching from the soil, depending on the phosphorus soil concentration [SVANBÄCK et al. 2013]. The phosphorus content in the soil is converted to the corresponding results of soil phosphorus status by the Egner-Riehm method (used in Poland) [ERIKSSON et al. 2013].

Soils are usually classified based on the soil phosphorus pentoxide (P_2O_5) content, measured with chemical extraction, and five phosphorus (P) status classes (as determined by Egner-Riehm chemical extraction) are used (Table III.1). The soil phosphorus status is important for crop yields, but may also be a decisive factor for the leaching risk (Figure III.1). The reason for this is that the available sorption sites where phosphorus could be attached in the soil become saturated when large amounts of phosphorus are added. This affects the extent to which more phosphorus can attach to the soil particles, but also the risk of leaching.

Table III.1. Classification of soil phosphorus (P) status according to concentration of phosphorus oxides (P_2O_5) determined with the Egner-Riehm method (chemical extraction)

Soil P class	Status	Content mg P_2O_5/kg soil
I	Very low	<50
II	Low	51–100
III	Medium	101–150
IV	High	151–200
V	Very high	>200

Source: MERCIK [2002].



Soil phosphorus content:

🔴 – very low 🟡 – low 🟢 – medium 🟢 – high 🔵 – very high

Figure III.1. Example of soil mapping with marked results for plant-available phosphorus.

The relationships between soil phosphorus content and yield, and between soil phosphorus content leaching, are different for every soil. However, a general conclusion is that in order to get a satisfactory yield, soils with low phosphorus status (<100 mg P_2O_5 kg soil^{-1}) need to be fertilised, while soils with phosphorus contents around class III (120 mg P_2O_5 kg soil^{-1}) give satisfactory yields even without fertilisation, and the risk of high phosphorus leaching is still low at this level.

In soils with a P status of class IV and V, the relative yields seldom increase due to the high phosphorus delivery, but there may be an obvious risk of more phosphorus leaching (Figure III.2). Based on Swedish laboratory measurements, the risk of phosphorus leaching for many soils may increase 3- to 4-fold when reaching soil P class IV compared with class III (Table III.2). At contents above 200 mg P_2O_5 kg soil^{-1} (class V), it is definitely not recommended to add more phosphorus fertiliser either in mineral or manure form. Instead, it is recommended to let the crops make use of the soil phosphorus reserves and to slowly decrease the risk of leaching by exploiting this phosphorus store.

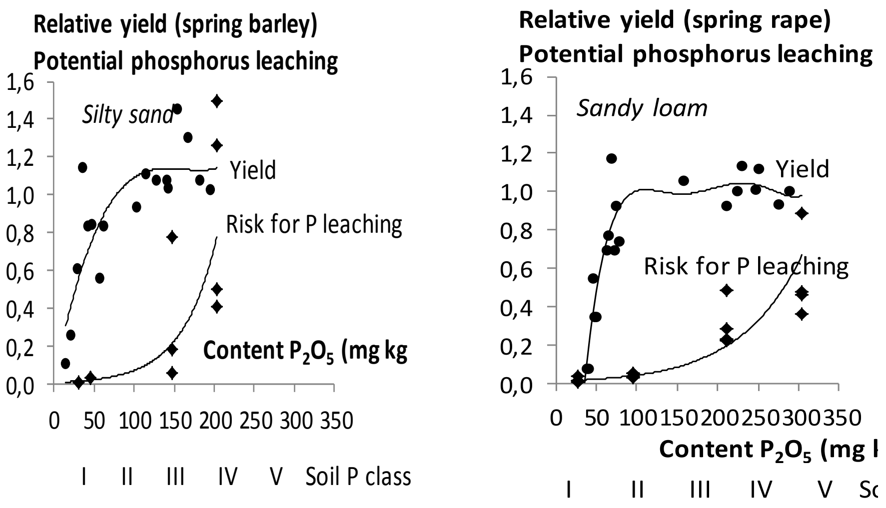


Figure III.2. Relative yield (compared with balanced fertilisation with equal addition to the soil as removed with the crop) in two of the Swedish long-term fertilisation experiments [EDHE 2012]; relative estimated risk of phosphorus leaching is based on the concentration of phosphorus in soils from the same site locations in leaching experiments in the laboratory [Svanbäck et al. 2013]; yields based on the results of the Swedish long-term experiments by EDHE [2012].

Table III.2. Potential risk of phosphorus leaching with three typical types of soils in Sweden according to their soil phosphorus class. This risk generally escalates in soils with higher P status

Soil P class	Soil type (and pH)		
	silty sand (5.8)	sandy loam (7.5)	clay (6.6)
I	0.01	0.01	0.01
II	0.02	0.02	0.02
III	0.1	0.04	0.3
IV	0.4	0.15	0.8
V	>0.8	>0.25	>2.0

Own work based on the concentration of phosphorus in surface run-off under the experimental conditions using artificial rain. Relative estimated risk of phosphorus leaching estimated from measured phosphorus concentrations in leachate in laboratory experiments from the same sites (Svanbäck et al., 2013). Yields are based on results from Swedish long-term experiments (Edhe, 2013).

Apart from the soil P status, the leaching is also affected by single applications of fertilisers or manure, especially if the soil is wet and the application is followed by heavy rain or snowmelt. The risk of phosphorus leaching after application of manure generally increases with increasing phosphorus content in soil (Table III.3). This is illustrated in Figure III.3. Consequently, it is very important to avoid applying high loads of manure on soils with a high soil P status.

Table III.3. Potential risk of phosphorus leaching (expressed as the concentration of P in mg/dm^3) before and after recent application of manure, estimated on the basis of laboratory tests with artificial rain (mean values for the three soil types indicated in Table III.2)

Phosphorus soil class	Potential risk of P leaching		Increased leaching risk with the manure
	Without use of manure	With use of manure	
I	0.01	0.02	0.01
II	0.02	0.05	0.03
III	0.15	0.5	0.36
IV	0.45	1.4	0.95
V	>1.00	>3.2	>2

Risk of leaching after the application of manure (expressed as the difference in concentration P) generally increases with increasing phosphorus content in soil (mg P/dm^3).

Source: Svanbäck et al., [2013].

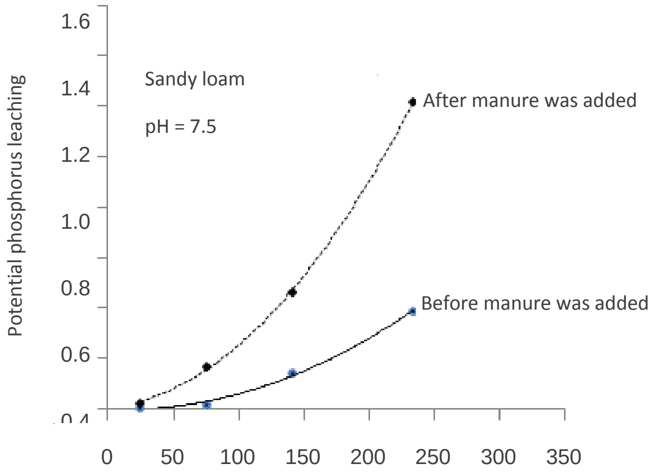


Figure III.3. Schematic diagram for one soil demonstrating the risk of phosphorus leaching depending on the phosphorus in the soil after application of cattle manure. Source: own study based on data from Sveriges lantbruksuniversitet and educational material from the Swedish Board of Agriculture.

IV FIELD EVALUATION ON-FARM AND MEASURES FOR IMPROVED NUTRIENT MANAGEMENT

Barbro Ulén, Stefan Pietrzak

4.1. Introduction

The first step in a self-evaluation procedure is to systematically compile all information that the farmer has about cultivation methods, use of technology and field conditions, and make a risk assessment of nutrient losses to water. These data and items such as soil maps, topographical maps and other types of information are collected and used for identification of e.g. ditches along field borders and for estimation of the distances from the farm to open ditches and streams. On these maps, field observations of water-saturated areas in the fields can be entered. More numerous and detailed observations from single fields can be noted in an Excel spreadsheet directly in a computer.

In the assessment of risk factors for phosphorus and nitrogen losses, the risks can be divided into four groups:

(1) Conditions in the farmyard and in animal houses, including feeding system of the animals.

(2) Field-specific characteristics including soil acidification, existence of open ditches and tile-ditches within the field.

(3) Agriculture, including cultivation, crop rotations, application of manure and mineral fertilisers and tillage.

(4) Conditions relating to the protection of surface waters; ditches and streams.

The observations may include:

- Livestock (type of animal production), type of system, storage of manure, and form of manure (solid, bedding, semi-liquid manure, slurry)
- The farmyard design (manure storage system and method of draining rainwater (storm water)
- Composting and manure storage on the fields (where, how long, how much and often?)

The second step in evaluating the risk of unnecessary losses of nitrogen and phosphorus is a "walk" on the farm together with the advisor to discuss different options to mitigate the risk. In the risk assessment, there is no quantification of nutrient losses, or any cost estimates for mitigating the leaching. The information from the individual farms is private information shared between farmers and advisors and is not reported to the authorities or third parties. Observations in the field may include:

- Grazed areas: Animal density, access to stream banks, any trampling effects etc.
- Individual fields: Soil type, topography, water-saturated areas in the field, groundwater level, location of drainage ditches or field ponds etc.
- For individual fields also: Cultivation data, type of crops etc. Yields
- Stream areas (grazing cattle, bank erosion close to streams)
- Ecological conditions (storks, groups of trees, open water)

4.2. Farmyard and farm buildings

4.2.1. Manure storage

Runoff from the farmyard and leachate from livestock buildings increase nutrient losses, especially in those farms where manure is stored directly on the ground in the yard (Figure IV.1). Manure should be stored on a solid concrete pad with an impervious floor and with side discharge channel and a reservoir to collect leachate (Figure IV.2). The pad base must have a slope to divert the effluent to a collection tank for urine and leachate. By diverting the polluted water to the urine tank, the risk of nutrient losses can be reduced. Wastewater from the milk room may also be diverted to the urine tank (if it is not treated together with wastewater from the household). The water from the tank and the urine can be spread on the fields as a fertiliser. It is recommended that the capacity of manure tanks (and other tanks) provide storage for natural fertilisers for a minimum of 6 months. In contrast, storage of manure on fields close to animal houses year after year is a waste of nutrients and makes the actual area a high-risk spot for nutrient leaching.

During storage of manure, its characteristics (pH, dry matter content) change depending on e.g. external temperature and storage time. For stored solid manure, especially if composting proceeds at high temperatures, NH_3 losses can be high. If the bedding material includes peat, such losses can be reduced.

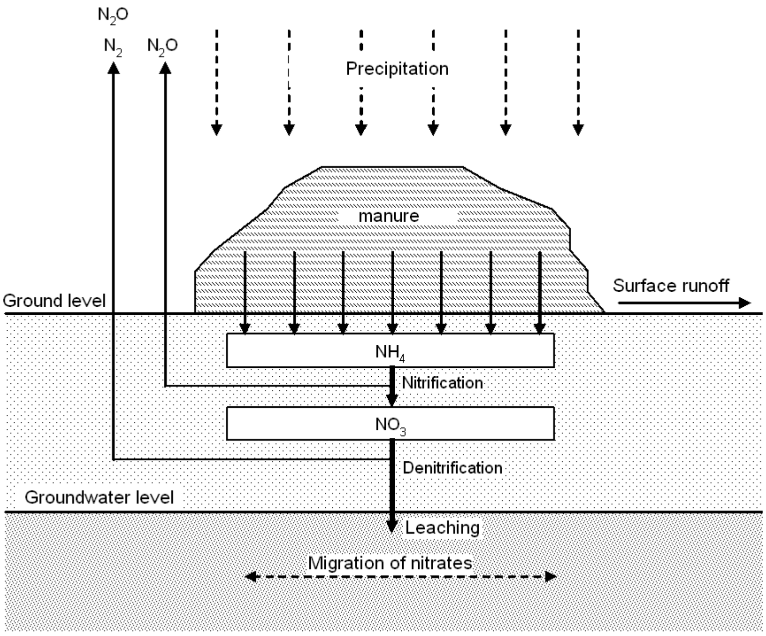


Figure IV.1. Mechanisms for transport of phosphorus and nitrogen to waters situated directly on the ground. Source: PIETRZAK [2013].

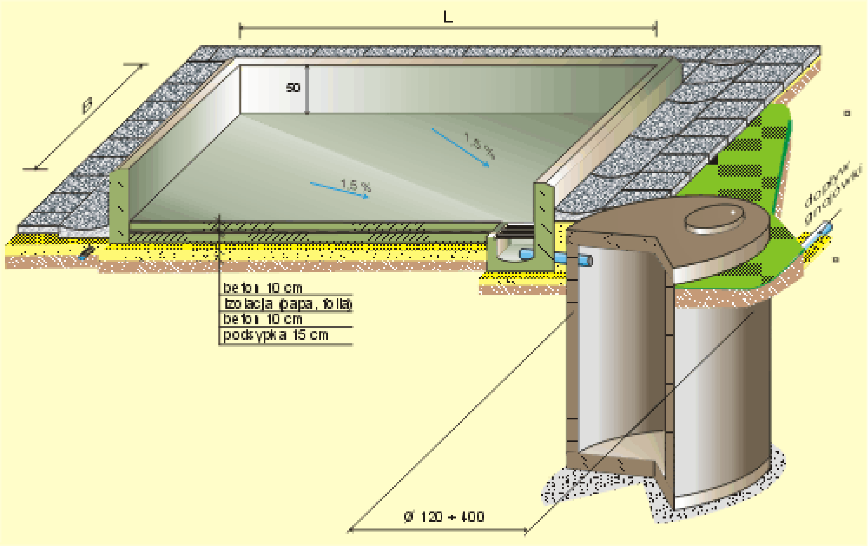


Figure IV.2. Manure floor with a tank to collect leachate. Source: ITP-GCB Tylicz.

Rainwater can cause leakage of nutrients from manure piles. A roof (Figure IV.3) may reduce ammonia losses from manure storage sites. The roof keeps rainwater out, which can prevent nutrient leakage from the manure floor if it has insufficient or lacking drainage leading to a collection tank.

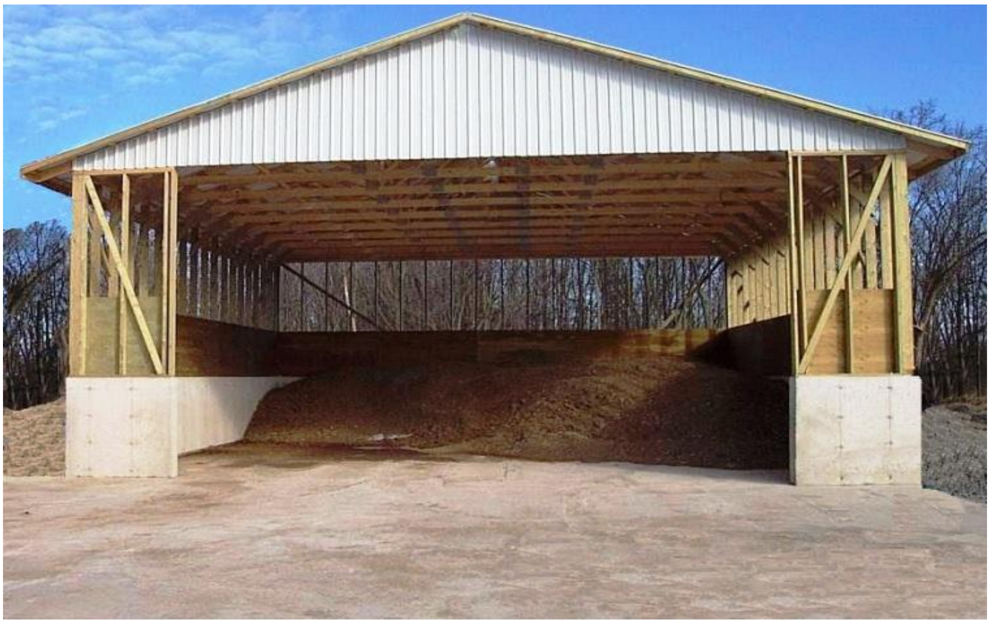


Figure IV.3. A covered manure store reduces ammonia emissions to the atmosphere and eliminates losses of leachate to groundwater. Source: Hilborn, LEBEAU [2013].

In the animal house, some ammonium emissions can be avoided by keeping the area clear of manure and urine. In cowsheds and pigsties with bedding, it is recommended that a larger amount of straw be used for bedding, to ensure rapid drainage of urine into the tank and to keep drinking water supplies and troughs in good condition to avoid water leakage.

4.2.2. Management of water on the farmyard

Poor water management on the farm contributes to the formation of large amounts of contaminated water (Figure IV.4) The risk of nutrient losses on the farm can be reduced through appropriate management of water in the yard, for example, consuming only the necessary amount of water for washing machines, livestock buildings and equipment and storing wastewater in sealed containers. Waste of clean water can arise when filling spreaders, overflows, pumps running by mistake etc. Poorly designed rain gutters and pipes cause any farmyard water to be diluted and larger volumes to be managed. A pond may be built to capture nutrients lost from the farmyard (see Chapter V). Such ponds can also act as a barrier to prevent liquid from any leakages or breaks in the slurry tank and spills of manure from running to open ditches and streams. Another option is to arrange some kind of barrier to prevent spills reaching surface waters. Manure tanks located less than 100 m from a lake or a stream may have a rampart as an extra precaution to keep the manure volume contained in the tank.

Figure IV.4. Polluted water flowing out of the farmyard. Photo by Bob Embleton.

4.3. Adaptive feeding of animals

4.3.1. Reducing dietary phosphorus and nitrogen intake

Balanced feeding provides an opportunity to ensure animal health and production requirements, while minimising negative impacts on the environment. Farm animals are often fed with more than the recommended dose of phosphorus and nitrogen in order to avoid any risk of a reduction in production. This additional ‘safety margin’ can comprise up to 30-50% of the nutritional requirements on some farms. This can lead to excessive losses via the faeces of major and trace nutrients, contributing to the pollution of soil. Therefore, a proper balance of nutrients in the feed is a key way to ensure animal health and adequate production, while minimising the negative impact on the environment and lowering production costs.

Table IV.1. Utilisation Efficiency of phosphorus and nitrogen from feed in fattening pigs and in relation to age

Category of pigs	Utilisation phosphorus %	Utilisation nitrogen %
Piglets	14	18
Slaughter pigs	39	47

Own calculations based on data from Swedish University of Agricultural Sciences.

A low efficiency of utilisation of nutrients in livestock production systems is inevitable, since only a small proportion of the nutrients ingested are actually retained. The efficiency of utilisation of these components depends on the species of animal. In relation to nitrogen, conversion efficiency is approximately 13-28% for dairy cows, 5-13% for sheep and 4-10% for beef cattle. The actual utilisation of nitrogen and phosphorus also depends on the age of the animal, as exemplified for pigs in Table IV.1.

Reproductive status is also important: more phosphorus and nitrogen are retained in sows during lactation than in dry sows.

Changing the diet to reduce the environmental impact means reduced cost. Commercial feeds are often based on least-cost formulation, which oversupplies nutrients because cheaper raw materials often have a poorer balance of amino acids and a lower digestibility. On-farm mixing of rations from arable crops produced on-farm, as well as crop residues or rejects from vegetable production, often form an important part of livestock diets. However, these feed components also need management and analysis of nutrient content and dietary value to improve nutrient use efficiency. A helpful tool for reducing phosphorus and nitrogen in the diet of animals is computer feeding programmes. They allow balancing and optimisation of feed formulations for farm animals according to their living and productive needs.

Reducing phosphorus in the diet is especially important since faecal phosphorus represents about 95-98% of total phosphorus excreted. Only about 1% is excreted via urine, and 1% via sweat and cell debris. The relationship between intake of phosphorus and the content in the faeces is shown in Figure IV.5. By adjusting the phosphorus content of feedstuffs and increasing the phosphorus use efficiency in livestock production, the amounts of excreted phosphorus in the manure will decrease. Recommended dietary levels of phosphorus to meet dairy cow requirements have successively decreased over the past 50 years. Diseases associated with phosphorus deficiency in cows are extremely rare. Studies in several countries (USA, Canada and Sweden) indicate that dairy cows are more likely to be fed phosphorus in excess than in deficit. In a Swedish study, non-lactating cows had higher phosphorus concentrations in faeces than lactating cows (Table IV.2), which indicated that the cows were over-fed with phosphorus [Ögren, 2013].

All types of manure usually contain a large amount of phosphorus and less nitrogen in relation to the requirements of plants.

Table IV.2. Faecal total phosphorus content (TP) (g/kg DM) and proportion of inorganic P fractions (P_{inorg}) to TP in the faeces of cows during lactation and non-lactation

Phase of the cow's production cycle	TP content g/kg DM	Proportion P_{inorg} to TP %
Lactation	7.0	49
Non-lactation	7.6	57

Source: ÖGREN [2013].

Non-lactating cows grazing on pasture probably do not need feeding mineral supplements with phosphorus at all, apart from cows in late pregnancy. Dairy cow excreta spread on growing pasture are utilised by the growing plants and may not be an environmental problem. However, if the pastures have a poor vegetation cover and if the soil is compacted by trampling animals, the risk of phosphorus losses increases considerably.

Monogastric animals (pigs and poultry) have a different bacterial flora to ruminants and cannot themselves produce phytase, so bound phosphorus in the form of phytate is unavailable to them. Therefore in addition, these animals are usually fed a mineral phosphorus supplement. This leads to large amounts of non-digestible phosphorus being excreted. The digestible content varies widely between different feed types (Table IV.3). The basis for feeding pigs is feedstuffs with varying phosphorus content (in the range 3-12 g/kg dry feed) and varying availability. The highest content of phytate is found in cereal grains (from 55 to 77%), oilseeds and leguminous plants. A feed supplement with synthetic phytase for pigs reduces the need for addition of mineral phosphorus. Phytase increases the availability of phosphorus in the feed and can reduce the total content of phosphorus in the feed without affecting the production. After the application of phytase, the mineral phosphorus content in feed for pigs can be reduced by 30%.

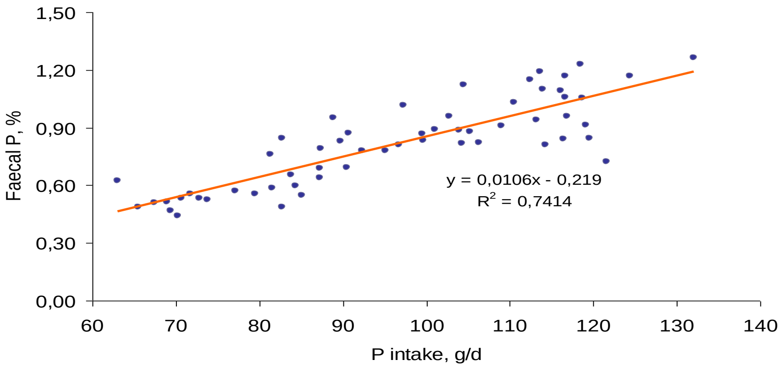


Figure IV.5. Relationship between phosphorus (P) intake and faecal P in lactating dairy cows [Wu et al., 2001].

4.3.2. Wet feeding and fermentation

Feed for pigs is best utilised as wet feed (feed component or compound feed mixed with water) and more nutrients are retained in the body. Wetting of the pig feed shortly prior to feeding activates endogenous phytase (the enzyme which increases the availability of phosphorus bound in cereals). Fermentation occurs naturally and endogenous phytase is activated after some time if wet, thereby reducing or even eliminating the need for mineral phosphorus supplementation. This means that pig production units with wet feed systems should be able to utilise feed with a lower P content than normally recommended (Figure IV.6). As a result, the body should be able to utilise feed with a lower phosphorus content than normally recommended. For feed that has not been heat-treated,

Table IV.3. Total content, digestible (not heat-treated) and excreted phosphorus (P) in different kinds of dry fodder for pigs

Fodder	P content (%)	Digestible P (%) in feed		Excreted P (%) in relation to the total amount of P in the feed	
		Pellets	Meal	Pellets	Meal
Barley	0.5	0.1	0.2	72	68
Fish meal	39.1	32.8	30.1	16	23
Lupin (white)	3.8	1.1	1.9	70	50
Lucerne	22.4	4.7	4.5	79	80
Maize	0.1	0.3	0.3	72	72
Molasses from beet	5.4	0.9	1.1	84	80
Oats	0.8	0.2	0.3	69	68
Pea	0.9	0.4	0.4	61	53
Potato pulp[1)]	1.9	–	1.5	–	20
Rapeseed meal	9.6	7.0	3.1	37	68
Rape cake	8.1	2.9	2.5	41	32
Rye	0.5	0.2	0.2	64	70
Triticale	0.5	0.2	0.2	63	70
Soya bean	4.0	2.2	1.3	45	68
Wheat meal[2)]	0.9	0.4	0.3	60	70
Wheat bran[3)]	1.1	1.0	0.3	81	75
Sunflower	4.1	–	0.8	–	19

[1)] Potato pulp - a by-product of the extraction of potato starch. The wet pulp is a mixture of potato skins and pulp and due to the high moisture content (87%) and extensive chemical composition (starch 4.8%, vegetable fibre 4.9%, proteins 0.5%), it is unstable and susceptible to numerous infections by microflora.

[2)] Wheat - a by-product of flour manufacture, obtained from screened grains of wheat. It consists mainly of fragments of the outer skins, and of particles of grain from which less has been removed than wheat bran.

[3)] Wheat bran - a by-product of flour manufacture, obtained from screened grains of wheat; consists mainly of fragments of the outer skins and of particles of grain. Source: Department of Animal Nutrition, SLU, modified.

mixing the feed with water approx. two hour before feeding to pigs can also substantially increase the digestibility (by up to 25%), thereby reducing or even eliminating the need to supplement with mineral phosphorus. One experiment found that wetting of cereal pellets for 2.5 hours before feeding causes the body to excrete from a few to several percent less phosphorus with faeces and urine. However, the fermentation can be difficult to manage and hygiene problems occur.

4.3.3. Phase feeding

Livestock at different growth stages or stages of the reproductive cycle have different optimum nutritional requirements. Grouping livestock on the basis of their feed requirements allows more precise formulation of individual rations. This increases the animal's nutrient use efficiency and results in reduced excretion of nitrogen and phosphorus in fresh animal faeces and urine.

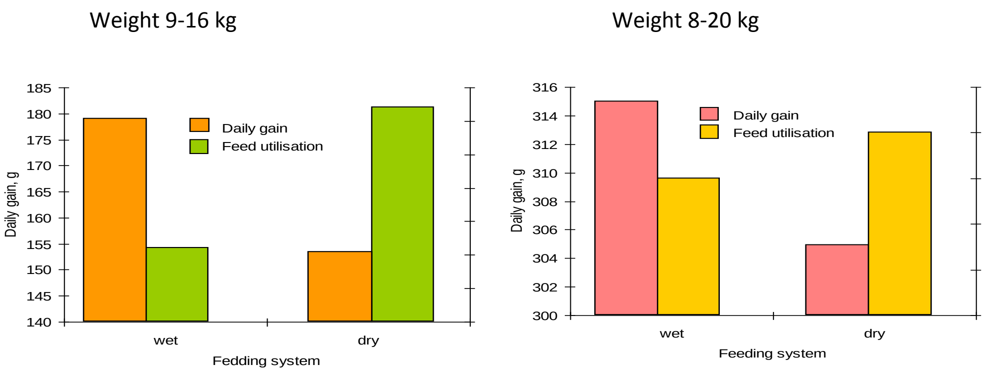


Figure IV.6. Fattening of piglets - effect of wet and dry feeding systems (daily weight gain and feed utilisation) in a) piglets weighing between 9-16 kg; and b) piglets weighing between 8-20 kg. [Milewska, 2009]; based on [Nielsen et al., 1983].

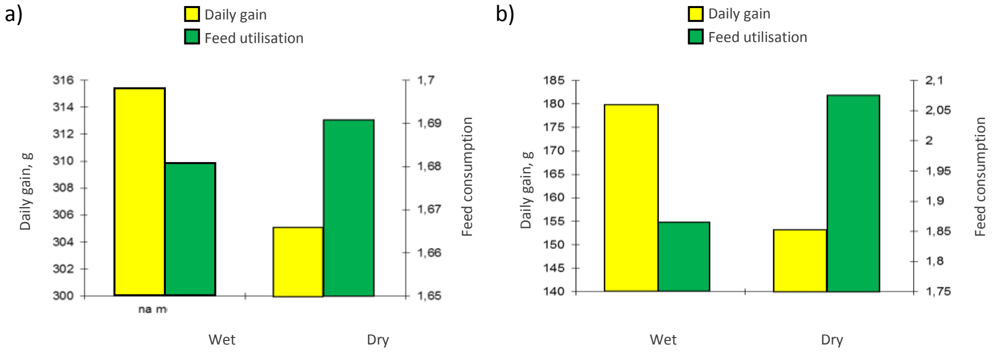


Figure IV.7. Effect of feeding system used for piglets weaned at 5 weeks of age on the results of rearing for: a) piglets weighing between 9-16 kg; b) piglets weighing between 8-20 kg. Own study based on: MILEWSKA [2009] and NIELSEN et al. [1983].

Table IV.4. Nitrogen excretion by pigs with 1-phase and 4-phase feeding

Specification	Excretion (kg N) in pig under					
	1-phase feeding	4-phase feeding				
	Added lysine relative to protein content in the diet,%					
	5.0	5.0	5.5	6.0	6.5	7.0
Nitrogen uptake	6.3	5.66	5.14	4.72	4.35	4.04
Nitrogen retention	2.29	2.26	2.26	2.26	2.26	2.26
Nitrogen excretion	4.01	3.4	2.88	2.45	2.09	1.78
Nitrogen excretion ratio,%	100	85	72	61	52	44

Source: POTKAŃSKI [1997], after KRICHGESSNER et al. [1994].

In pig feeding, the fattening period can be divided into four consecutive sub-periods (feeding phases). In any of these periods the level of phosphorus and protein in feed can be closely adapted to the needs. The percentage of protein in the feed for growing pigs can also be reduced together with their growth due to the decreasing animal demand for protein. At the same time, addition of lysine may be used to improve the quality of the protein. According to some studies, phase fattening and supplementation with lysine reduce the protein requirement in the feed and can reduce nitrogen excretion by pigs. This is only 44% of that obtained with one-phase feeding when the addition of lysine is 7% (Table IV.4). One study showed that four-phase feeding complemented with 7% lysine reduced the excretion of nitrogen for fattening pigs by up to 56% compared with feeding a single-phase system containing 5% lysine (Table IV.4).

4.4. Other relevant field characteristics

4.4.1. Acid soil and liming

The soil nitrogen, phosphorus and potassium content and use efficiency by the crop depend on the soil pH. With a soil pH below 4.5, the absorption of nitrogen and phosphorus is much lower (Figure IV.8). At low pH, much of the phosphorus is bound to iron, aluminium and manganese, and at high pH it is bound to calcium in the soil. In very acid soils (pH<4-5), phosphorus availability for plants is considerably reduced and aluminium ions may even dissolve into the water and become toxic to plants and soil organisms (Figure IV.9). The nitrification process is blocked at low soil pH with anaerobic conditions, and more nitrogen is leached or lost to the air. Acid soils often have low yields, which can lead to a reduction in soil organic content and to long-term deterioration in soil fertility. This also means low removal of nutrients with the crop and a higher risk of nutrient leaching in the long run. Therefore liming is important both to sustain the productivity and reduce the leaching.

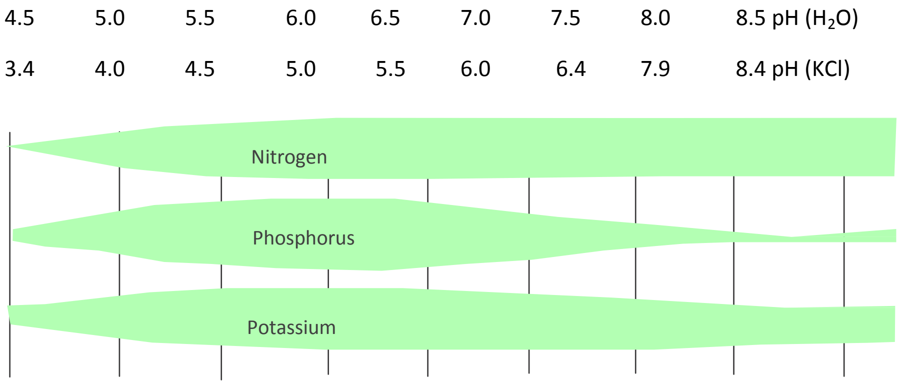


Figure IV.8. Schematic diagram of nitrogen, phosphorus and potassium availability for the crop at different pH in the soil (measured either in water or KCl); Source: DOCK GUSTAVSSON et al. [2004].

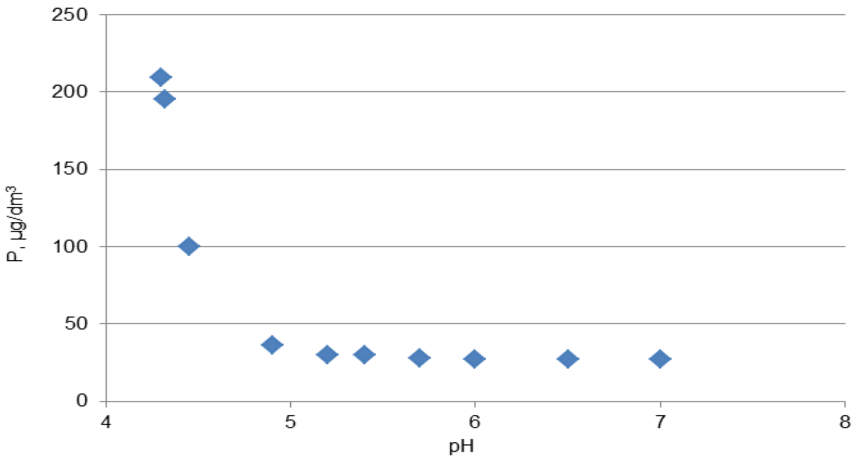


Figure IV.9. Amount of phosphorus (P) extracted from a Swedish soil at different pH. The experiments were carried out as batch experiments where pH (measured in H_2O) was adjusted with addition of acid or base. Source: ERIKSSON, A-K pers. comm. 2014.

Liming (Figure IV.10) has a general positive effect on the soil and on crop growth in several ways. A good lime status benefits root development and nutrient uptake, through increased availability of soil phosphorus. The increase in pH causes the gradual release of available phosphorus, thus increasing its utilisation from fertilisers and soil. As a result of liming, phosphorus intake increases in some plants, for example 2– to 3-fold in maize, by about 60% in oats and by about 10–20% in clover [Hołubowicz-Kliza, 2006].

Figure IV.10. Field liming. Photo. M. Robinson.

In addition, improved soil structure affects plant uptake and may reduce the need for fertiliser. Thus, liming aims to ensure that nutrients are utilised efficiently and also reduces the leaching risk. Liming also accelerates organic matter decomposition and nitrification, which proceed most efficiently when the soil pH is slightly acidic or neutral. By improving soil aeration, liming improves the decomposition of organic matter and nitrification. Liming also contributes to better nitrogen intake by plants in the form of ammonium. Regulation of soil pH from very acid to slightly acidic or neutral also improves the growth of nitrogen-fixing bacteria. Bacteria in the soil are generally favoured instead of fungi. This is very important, because such bacteria bind free nitrogen from the air and contribute to better nitrogen uptake by plants. Using magnesium (Mg)-containing lime products might be cheaper than applying Mg as fertiliser and is preferable to sandy soils with low humus content. Magnesium deficiency can appear at levels below 80-150 mg extractable MgO kg soil^{-1}.

Lime can be divided into three groups according to calcium content or its form (Table IV.5.)

- Containing calcium oxide - CaO or hydroxide - $Ca(OH)_2$,

- Containing calcium carbonate - $CaCO_3$,

- Containing calcium oxide and carbonate - CaO + $CaCO_3$.

Table IV.5. Calcium fertilisers which can be used for de-acidification of soils

Group	Name of product	Chemical compound	Content CaO, %
I	Quicklime	CaO	60–80
	Calcium carbide residue	$Ca(OH)_2$	65–70
II	Agricultural milled limestone	$CaCO_3$	45
	Chalk fertiliser		45
	Meadow chalk (meadow lime)		40
	Agricultural marl		15–40
	Soda lime[1)]		40–50
	Cellulose lime[1)]		40
	Sulphuric acid lime from ore [1)]		35
	Production lime (flotation) [1)]		40
	Sugar factory lime[1)]		15–30
III	Agricultural mixed lime	$CaO + CaCO_3$	50
	Agricultural fine lime		45–50

[1)] An industrial residue.

Source: KRZEBIETKE, BENEDYCKA [2006], modified.

Products containing quicklime (CaO) or slaked lime $Ca(OH)_2$ as the active component (Groups I and III in Table IV.5) are most suitable for soils with a high clay content or compacted clay soils with structural problems, since this lime improves the structure. Quicklime in particular reacts quickly and equilibrates with clay components of the soil. The lime strengthens the bonds between the soil particles, and the soil aggregates are stabilised. Later, the soil structure is strengthened by several slower reactions. Swedish field experiments have shown that lime applied on soil heavy loam has a positive impact on the structure and improves the strength of soil aggregates, which in turn decreases phosphorus leaching significantly. This type of lime should be applied under dry conditions and be carefully incorporated into the soil.

Products containing crushed limestone ($CaCO_3$) are more suitable for sandy soils. This lime operates more slowly but for longer, and therefore the pH change occurs gradually.

In order to estimate the lime effect in an acid soil, one should know both the organic content and the soil type, since this determines the amount of lime needed for achieving a certain pH. Acid soils can primarily be limed up to approx. 6.5, but peat soil never to more than pH 5-5.5 (pH measured with Swedish method, which gives higher values than the Polish method). Depending on soil type, the amount needed varies between 1 and 14 ton CaO per ha (Table IV.6).

Table IV.6. Lime requirement (expressed as milled lime with 50% CaO per ha) in order to increase soil pH by 0.5 units within the range 5.0-6.5

Organic matter content %	Amount of lime for application to a soil with a clay content of (%)					
	<5 sandy soil	5–15 clayey soil	15–25 loamy soil	25–40 clay soil	40–60 heavy clay soil	>60 very heavy clay soil
<2	1	2	4	6	8	9
2–3	2	3	5	7	9	10
3–6	3	4	6	8	10	11
6–12	5	6	8	10	12	14

Source: Swedish Board of Agriculture.

It should also be borne in mind that the lime products may contain heavy metals such as cadmium and lead, addition of which to soil is regulated by law (Table IV.7).

Table IV.7. Maximum permissible content of cadmium and lead in lime used in agriculture in Poland

Component	Maximum permissible concentration in lime	
	Limestone, mg/kg CaO	Calcium-magnesium lime, mg/kg CaO + MgO
Cadmium	8	15
Lead	200	600

Source: Rozporządzenie Ministra Rolnictwa [2008].

4.2.4. Other characteristics

The crop itself affects soil physical and chemical properties. Fields with high soil phosphorus status can pose high risks for phosphorus losses. Therefore, manure should not be applied on fields (or parts of fields) with the highest P soil classes (see Chapter III).

Ponded (standing water) on the field may have several causes. It may be due to impaired soil permeability as a result of soil compaction (Figure IV.11). The water flow within the field is highly affected in a negative way by compaction, with more channelised water flows. This has a negative effect on plant growth and yield. Ponded water also increases the risk of phosphorus dissolving both into the soil solution and into the ponded water above the soil. Another risk of long-term wet soil is the risk of reducing conditions developing, which means that soil phosphorus can be dissolved very rapidly. Such conditions may occur after rainfall or snowmelt on frozen ground, or heavy rainfall in summer thunderstorms.

Figure IV.11. Ponded water resulting from wheel tracks after passage of agricultural machinery. Photo: John Poyser.

For compacted soils (especially clay soils) it is important to try to eradicate the plough pan, e.g. BY DEEP PLOUGHING. One should also maintain all open ditches but be careful when dredging. This should be done under low-water conditions and without removing all vegetation.

Surface runoff (Figure IV.12) occurs as a result of impaired permeability of the soil or upward pressure from groundwater and follows heavy rainfall or snowmelt on frozen ground. Water can also run (not necessarily visibly) from areas located higher in the landscape, primarily from compacted areas at forest edges. The absence of ‘back ditches’ around the fields can thus be a major risk factor for phosphorus losses. More or less lateral flow water (non-visible) can also take place, e.g. on top of a thick so-called plough pan. Erosion of the field can take place both on the soil surface and within the soil. Visible erosion (turbid water) can usually be seen above soils with a high content of clay and silt, but can also occur in the soil pores where the water is flowing fast and is ‘channelised’. In drained fields with old malfunctioning drainage systems, the risk of phosphorus leaching increases. Maintaining the drainage system (if any) and repairing broken pipes etc. is important to reduce nutrient runoff and nutrient leaching.

Figure IV.12. Surface runoff from a field after a heavy rainstorm. Photo: Lynn Betts.

4.5. Crops

4.5.1. Vegetation cover in the autumn and winter

An efficient way of reducing plant nutrient losses from arable land during autumn and winter is to keep the land under vegetative cover (green land) during this period, particularly in areas with light soils and a mild climate. Both permanent and temporary grasslands generally have low nutrient losses. Cultivation of temporary grass or legume/grass crops in the crop rotation can reduce nitrogen and phosphorus leaching and surface run-off losses, as well as soil erosion, compared with only annual crops in the crop rotation.

Growing intercrops (former name: catch crops) is an opportunity to reduce nitrogen leaching instead of leaving the soil without cover during autumn and winter. Intercrops are fast-growing plants that can be sown simultaneously with the main crop or just after sowing of that main crop (Figure IV.13). When the main crop is harvested, which is in late summer and autumn, the intercrop has an established root system ready to take up nitrogen from the soil during late summer and autumn. Nitrogen that could otherwise have been leached is then taken up and incorporated into plant biomass. Intercrops/catch crops work best where the need is greatest, i.e. on soils prone to nitrogen leaching and when there is accumulation of leachable nitrogen in the soil in autumn.

Figure IV.13. White mustard as stubble intercrop. Photo: L. Zimny.

Intercrops should be ploughed down as late as possible in the autumn or early spring. The choice of plant species used as an intercrop depends on climate and soil conditions.

Depending on soil conditions in Poland, the recommended crops are:

a) For soils of lower fertility: yellow lupin, serradella, Phacelia and rye.

b) For soils of medium fertility: pea fodder (field peas), sunflower, blue lupin, white mustard, radish oil and vetch.

c) For fertile soils: beans, vetch, rape and turnip rape.

Please note that rotations composed mainly of cereals may have a negative impact on the structure of the soil, and grasses and legumes increase the organic matter content, which is especially important in clayey soils.

4.5.2. Temporary grassland (leys) and long-term grassland

Both long-term and short-term grassland can be effective in reducing nutrient losses (Figure IV.14). Pastures or mixtures of legume-grass plants used in a short rotation can reduce phosphorus and nitrogen in runoff and leaching compared with annual crops. Grasslands can be both extensively and intensively managed.

Low input grazing-based meat production is often practised on land where alternative land use is restricted and where the grazing may contribute to the maintenance of high species diversity of the wild flora and fauna. The external nutrient inputs are generally small, as are the area stocking rates and productivity.

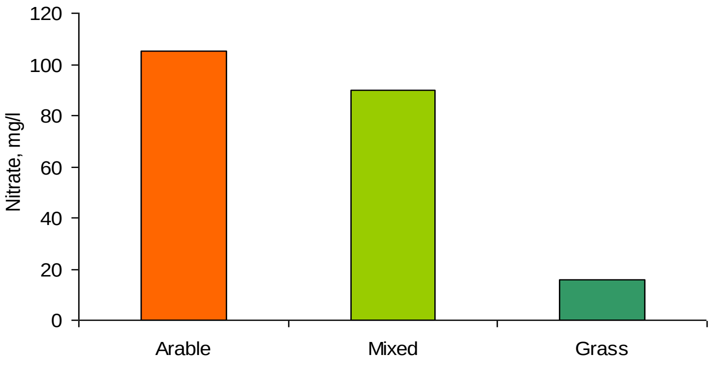


Figure IV.14. Nitrate concentrations in water from arable land within nitrate-vulnerable zones of particular concern regarding nitrate leaching in England, winter 2005-2006. Source: LORD et al., [2006] (ADAS).

In contrast, forage and grazing-based meat or milk production can have a ten-fold higher nitrogen input, corresponding to the application of 200–400 kg nitrogen per hectare and year, and a high productivity. Long-term continuity of grassland also improves the carbon storage in the soil. Temporary grassland contributes to soil and water protection, but regular ploughing and conversion to arable crops is crucial due to potential discharge of nitrogen after the ploughing and adverse effects on the development of biodiversity.

Obtaining a favourable impact on the environment through long-term grass crops requires proper management. Maintaining perennial grass is beneficial due to the conservation of biodiversity and carbon storage in the soil.

Both permanent and temporary grasslands generally have low nutrient losses (Figure IV.14). Cultivation of temporary grass or legume/grass crops in the crop rotation can reduce nitrogen and phosphorus leaching and surface run-off losses, as well as soil erosion, compared with only annual crops in the crop rotation.

Grassland can be both extensively and intensively managed. Low input grazing-based meat production is often practised on land where alternative land use is restricted and where the grazing may contribute to the maintenance of high species diversity of the wild flora and fauna. The external nutrient inputs are generally small, as are the area stocking rates and productivity. Forage and grazing-based meat or milk production can have 10-fold higher nitrogen inputs, corresponding to the application of 200-400 kg nitrogen per hectare and year, and high productivity. Long-term continuity of grassland also improves carbon storage in the soil. Temporary grassland contributes to soil and water protection, but ploughing and conversion of grassland to arable is risky due to potential discharge of the nitrogen accumulated in the grassland.

4.6. Application of mineral fertilisers and manure to the right places at the right time

4.6.1. General principles of fertilisation

Applying excessive loads of nitrogen or phosphorus to the soil with mineral fertilisers always involves a greater risk of nutrient losses than if the application rate is adapted to the current needs of the crop. In addition, it means a waste of money. The aim should be to match the plant needs for nutrients by accurate fertilisation. In organic soils (20% organic matter), both the crop availability and the mobility of nutrients in the soil are higher than for corresponding mineral soils and the application rate of fertiliser can often be lower than to mineral soils. Nitrogen fertilisation is restricted to 170 kg/ha in the EU nitrate-sensitive zones, but for most crops greater loads should not be given in other areas either because of the risk of losses.

Animal density (livestock units (LIU)/ha) is a measure of the number and type of animals kept on a farm in relation to the arable area available for spreading their manure (RAMIRAN, 2010). It is used to avoid excess application of phosphorus with manure on a farm. The content of phosphorus and nitrogen in the manure must be considered in the fertiliser plan in order to adjust the need for mineral fertilisers for the crop requirements and to avoid excessive application.

Sampling and analysing phosphorus and nitrogen in manure provides valuable information and the effect of manure can be valued in the fertilisation plan. Manure characteristics can vary widely. Stored and composted manure usually has a lower proportion of directly plant-available nitrogen (NH_4-N + NH_3-N) relative to total nitrogen content than e.g. slurry (liquid manure).

Sampling and analysing phosphorus, calcium, magnesium and potassium in arable soil provides information on soil fertility concerning these nutrients, which should be considered in the fertilisation plan in order to avoid excessive fertiliser applications or declining soil fertility. Mineral soil nitrogen may be sampled and analysed as well, but since it varies greatly within the year (Figure IV.15), soil samples should be taken and analysed just before the planned fertilisation.

The fertiliser plan describes fertiliser and manure recommendations based on the soil analysis and crop requirements. The fertiliser plan (outlined in Figure IV.15) should be made for each crop in each field before any nitrogen or phosphorus fertiliser is applied. The balanced plan also includes sustainable management advice on optimum use of fertilisers for different crops.

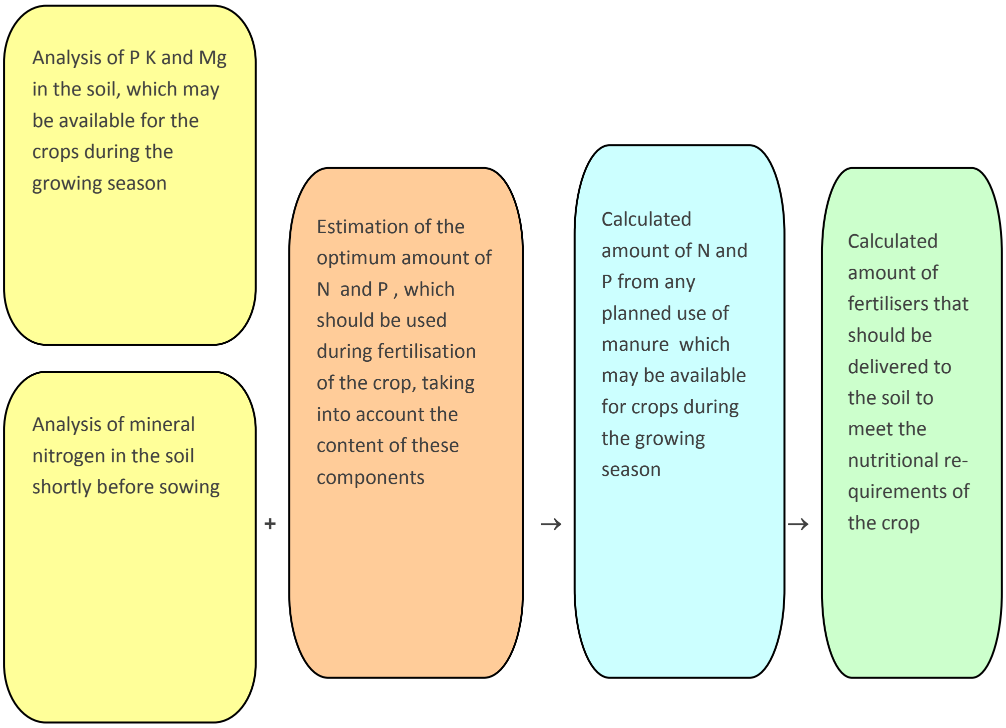


Figure IV.15. The sequence of actions necessary to draw up a fertiliser plan.

4.6.2. General rules for manure application

Compared with mineral fertilisers, applying high loads of manure not adapted to the needs of the current crop always involves an increased risk of nutrient losses. Therefore, high doses of manure should always be avoided.

Losses of ammonia to the air under different conditions and the proportion of organically bound nitrogen which becomes available to plants during the growing season are difficult to predict. Due to this uncertainty, the exact use efficiency of manure and compost is uncertain. However, with analysis of the content of the farm's own manure, the application can be better adapted to the needs of the crop.

The risk of leaching increases when manure is applied in large quantities to the same field year after year. Therefore spreading the manure evenly on the farm is very important, even if transport distances are long. Repeat manure addition to the same field year after year should be avoided. Organic soils (>20% organic matter) need special precautions. For such soils, the amount of manure can be reduced.

When composting in the field, this should be done within the field where the compost is planned to be spread. Mixing the material and keeping the composting time short is a way to reduce the nitrogen losses to the air.

Spreading manure in late autumn can pose a risk of nutrients, phosphorus in particular, being discharged to watercourses during intensive water flow events. Spreading of manure should not be carried out on water-saturated soil. Avoid applying much manure on sloping land prone to surface runoff and be careful on clay soils with visible cracks. When applying manure rich in nitrogen, the recommendations given in Table IV.8 must be followed.

Table IV.8. Recommendations for the use of manure-rich nitrogen (usually in the form of liquid manure slurry)

Situations where it is appropriate to spread	Situations where spreading should be avoided
In spring before sowing cereals	In autumn before sowing winter cereals
In the growing crop in the spring (slurry)	In early autumn before sowing a spring crop
In growing grass, even in autumn (slurry)	Before fallow, especially in autumn
In crops with a long growing season	For plants with a short growing season, after which there is no intercrop (catch crop), such as potatoes
In crops that are followed by a catch crop	

4.6.3. Avoiding use of mineral fertilisers and manure in high-risk areas

High-risk areas are areas particularly exposed to a high risk of rapid transport of solutes or suspended material to watercourses (Figures IV.16, IV.17, IV.18). High-risk areas are most evident for phosphorus, but exist also for nitrogen. Fields with a significant slope, with cracking soil over field drains and with drain pipes leading directly to streams, are clear examples of high-risk areas where manure and mineral fertiliser application should be restricted. Repeated application of phosphorus mineral fertilisers and manure to these areas causes a further increase in the surplus phosphorus content in soil and increases the risk of losses. Wherever possible, high inputs of all kinds of potential pollutants to these areas should be avoided.

Special attention should be paid to excessive use of phosphorus fertiliser on fields with a phosphorus content beyond the agronomic optimum range (see also Chapter III). Balancing P inputs with crop intake, ceasing P application to soils with high soil P status and the amount of P supplied as mineral fertilisers and in the form of manure should all be taken into account together (Figure IV.19). It should be noted that the reduction in phosphorus reserves in soil is slow and gradual. No general decline is apparent even after at least 10 years of low application of manure or fertiliser.

Figure IV.16 Cracking soil. Photo: Z. Kowalewski.

Figure IV.17. Field adjacent to ditch with eroded stream bank. Photo: P. Nawalany.

Figure IV.18. Soil erosion. Photo: Walter Schmidt.

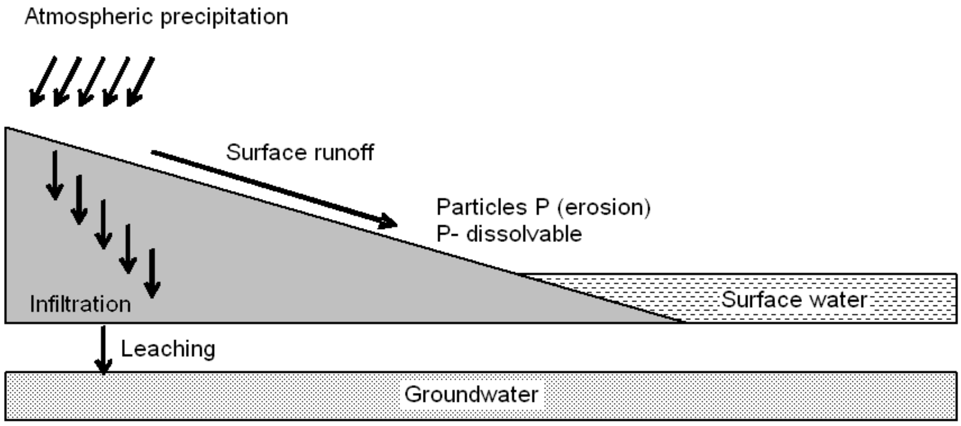


Figure IV.19. Processes for phosphorus transport to water. Source: Lory [1999], modified.

4.6.4. Avoiding the use of mineral fertilisers and manure in high-risk periods

The timing of application of fertilisers and manure is a key factor in achieving high efficiency of nutrient use (Figure IV.20). Fertilisers and manure should not be used in times and conditions when the nutrients, especially nitrogen, are vulnerable to leaching to groundwater or when phosphorus may be transported via (not necessary visible) lateral flows to surface waters. This applies especially to the winter period, but also to other periods, depending on soil type, rainfall intensity and soil cover. As a precaution, one should never add mineral phosphorus on frozen ground and, if possible, avoid all kinds of fertilisation before heavy rain events, as these can lead to losses. Fertiliser and manure should never be applied when the soil is frozen and covered with snow (Figure IV.21, IV.22), even when there has been periodic warming.

The relationship between the amount of nitrogen uptake by plants and content in soil mineral nitrogen available for crops is shown graphically in Figure IV.20. The diagram visualises nitrogen uptake by the crop and soil mineral nitrogen and the lack of synchronicity that usually follows. Nitrogen uptake is rapid in spring and summer periods. When the need for fertiliser inputs has been correctly estimated, the concentrations of mineral nitrogen in the soil are small by late summer. However, once the growth of plants slows down and then stops (in July for cereal crops) soil mineral nitrogen increases as a result of natural soil mineralisation. The nitrogen present in the soil in autumn which is not taken up by a new crop (e.g. a catch crop) poses a risk of leaching in autumn [ADAS, 2007].

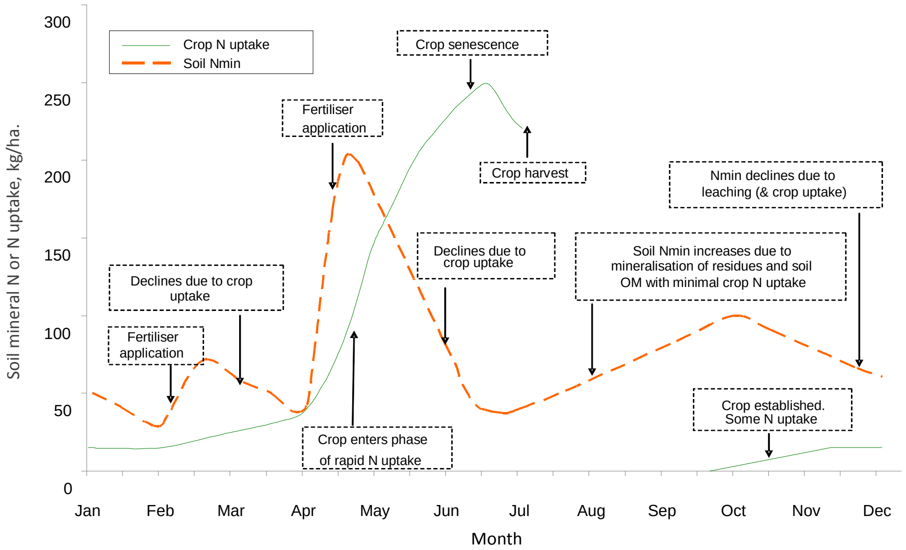


Figure IV.20. Example of the dynamics of changes in soil nitrogen content over time, showing the risk of leaching and synchronisation between supply of mineral nitrogen in the soil and its uptake by plants. Source: ADAS [2007].

Figure IV.21. Manure should not be applied when the soil is frozen. Photo: Ra Boe.

Figure IV.22. Manure applied to snow-covered field poses a high risk of leaching and transport to watercourses during the thaw. Source: Brenneman [undated].

4.6.5. Simultaneous seeding and fertilising with the same machine

Simultaneous seed drilling and mineral fertilisation with the same machine (combi-drilling) involves placing seed and fertiliser in one work operation. (Figure IV.23). A seed drill with normal distance between the seed coulters is equipped with coulters for mineral fertiliser placed between alternate rows in front of the seed coulters. The fertiliser coulters place the mineral fertiliser a few centimetres deeper than the seeds.

Band placement of fertilisers with a combidrill allows the overall rate of fertiliser in the field to be reduced, and added nutrients are used with higher efficiency. Placement of fertilisers down in the rows provides good conditions for germinating plants to get access to the nutrients. In addition to time savings and better nutrient use efficiency, combidrilling reduces the competition for plant nutrients from weeds and reduces the risk of nutrient surface runoff. Phosphorus in fertilisers binds quickly to soil particles and is thus less exposed to leaching.

The recommended nitrogen dose for a particular yield level can be reduced by 10 kg N/ha if combidrilling is used. Leaching is probably reduced by 1–2 kg N/ha compared with other fertilisation techniques.

Figure IV.23. Equipment for simultaneous sowing of seeds and fertilisers (combi-drilling). Source: Nilsson [2005].

4.6.6. Application of manure

Manure should be evenly distributed on the surface of the field and quickly covered with soil. Spreading should ensure uniform and accurate scattering of each type of manure, both fresh and composted. Uniformity of distribution is important to provide an assurance that all parts of the field plants have good access to nutrients. It is also important for minimisation of the environmental risks. Unfortunately, many manure spreaders (especially older models) work unevenly, and larger doses of fertiliser are placed directly behind the spreader than to the sides of the machine (Figure IV.24).

Uniform spreading of manure means that there are no parts of the field poorly or excessively coated, allowing uniform uptake of nutrients by plants. Manure should be spread only by means of spreaders in good condition and designed for a specific type of manure spreading. Most important is the quality of the manure spreader adapter. Adapters are used with the axis of the drum set horizontally or vertically (number of drums may be 2, 3 or 4). There are also technical solutions with drum and side discharge. Examples of different spreaders are shown in Figure IV.25.

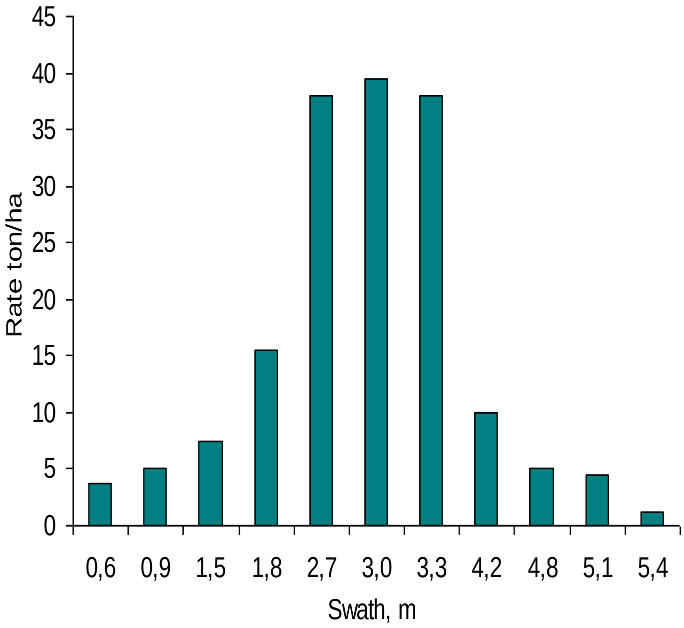


Figure IV.24. Distribution of the width of strips (swaths) from a single pass of a rear-discharge dry manure spreader. Adapted from: LORIMOR [2000].

Figure IV.25. Manure spreaders for rear and side spreading. Photos: LORIMOR [2000].

Manure (and mineral fertiliser) should be completely covered with soil so that the nutrients can be maximally utilised by plants. Covering the soil is usually done during a separate operation. Manure should quickly be covered by the soil after the spreading, because ammonia losses occur immediately after the execution of this procedure. To reduce emissions of ammonia by shortening the residence time of the slurry on the surface of the field, it is recommended to till the soil within six hours after application. The most effective way to cover the manure applied into the soil is by ploughing. However, this kind of tilling takes time and in some cases, use of a spring cultivator or disc harrow may be more effective. Slurry injection equipment also effectively cover manure by the soil (Figures IV.26, IV.27).

Figure IV.26. Liquid manure applicator for shallow injection of liquid manure. Photo: P. Nawalany.

Covering manured soil effectively reduces ammonia emissions. Most losses occur within a few hours after spreading of fertiliser on the surface of the field. Therefore, it is recommended to incorporate the manure into the soil within 24 hours. In order to reduce the losses, the manure should be completely covered with a layer of soil. This is often difficult to achieve in the case of certain types of slurry. Manure should also be immediately covered with soil by ploughing or other tillage in order to prevent losses of nutrients due to runoff or erosion and to preserve as much of the nutrients as possible for the crop.

Figure IV.27. Application of manure with an applicator for deep injection. Photo: Werktuigendagen.

4.7. Ploughing and other soil tillage

4.7.1. Ploughing at different times of the year

Time of ploughing has a significant impact on the process of nitrogen mineralisation in the soil and the amount of nitrogen leaching. Autumn tillage of the soil, due to the prevailing warm and humid conditions and the lack of growing plants, actively enhances the process of mineralisation in the soil and increases the risk of nitrogen losses. Later, in the winter, accumulated nitrogen is transported from the soil profile to watercourses (Figures IV.28, IV.29).

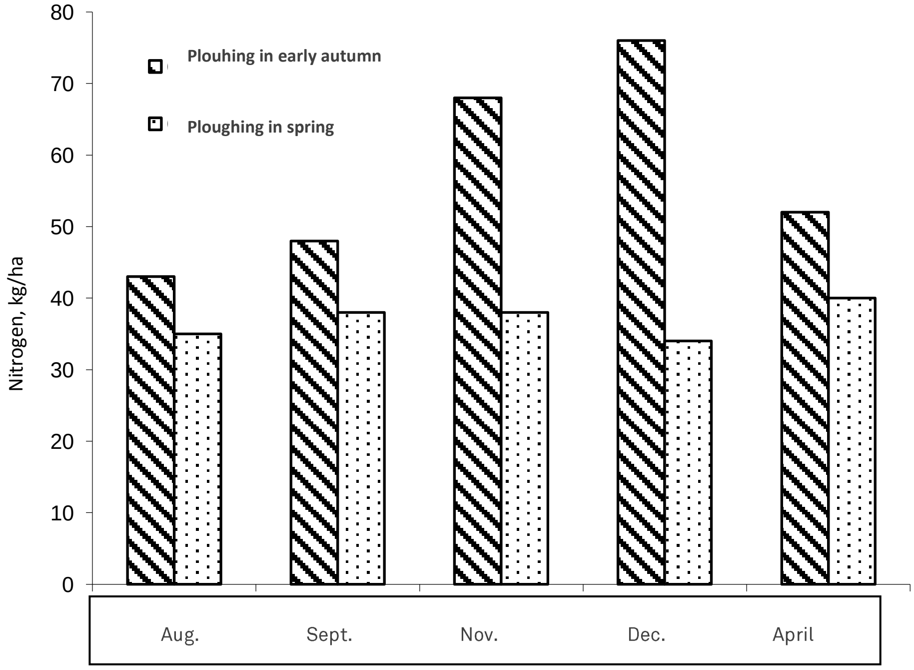


Figure IV.28. Soil mineral N content at harvest (August) in September, November December and in April in the following spring. Source: STENBERG et al. [1999].

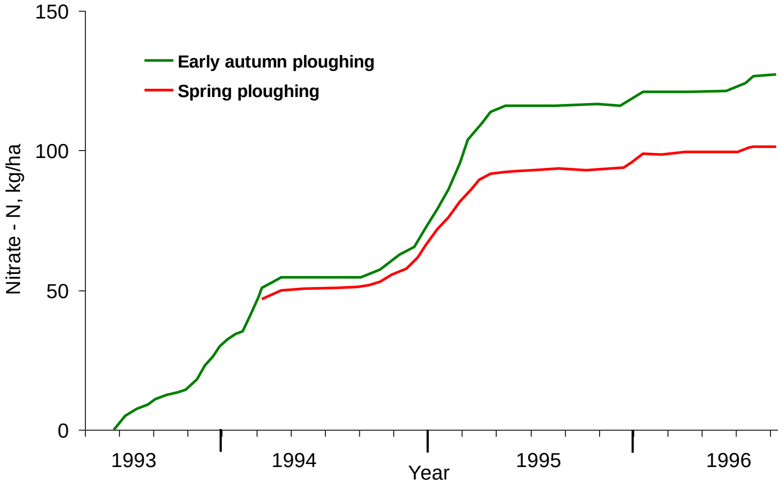


Figure IV.29. Cumulative nitrate leaching (kg/ha) depending on the time of ploughing. Modified based on STENBERG et al. [1999].

If the cultivation of the soil (e.g. discing) after harvest of spring crops is postponed until late October or if no stubble cultivation is performed, the risk of nitrogen leaching is reduced. This is particularly important for crops with residues rich in nitrogen, for example, oilseed or leguminous plants.

Delayed autumn tillage is suitable in many soils, but most important for those with a clay content below 25%, with respect to nitrogen leaching. However, if late tillage causes soil compaction, it may have a negative impact on succeeding crops and also increase the risk of phosphorus losses. Delayed tillage can reduce crop yields and contribute to the spread of weeds. Delayed cultivation can therefore increase the demand for the use of chemicals for weed control, because the growth of weeds can be significant during autumn. Use of a catch crop (intercrop) can reduce this problem.

For spring crops, soil tillage is preferably done in spring and not in autumn, since this poses less risk of mineralised nitrogen leaching in winter. The soil types dominant in areas of Poland such as Pomorskie and Mazowieck are generally suitable for spring tillage, and shortly after spring sowing, the growing spring crops retrieve soil nitrogen. However, spring tillage can cause delays in work and problems with suitable preparation of the soil for cultivation, especially when there are a lot of crop residues from the previous year.

The risk of phosphorus losses is also greater when ploughing is carried out in the autumn compared with spring, since the soil surface is without a protective plant cover. Therefore, shallow tillage (only cultivator) can be used in the spring, preferably as early as possible, at the beginning of the season. Autumn ploughing may be occasionally necessary, to reduce the risk of soil compaction. Compaction is especially problematic in areas where wet clay soils are common. In clay soils all tillage should (if possible) be carried out when the surface soil is relatively dry. Another possibility to avoid smearing and compaction of the soil is keeping the wheels of the tractor ‘on-land’. Visible rills on the fields should be removed as soon as possible and the tractor with heavy equipment may be driven on special tramlines.

Autumn ploughing also allows earlier sowing of spring crops when additional tillage is required before drilling. For medium to heavy soils, delayed tillage can cause burn of the young seedlings. Reducing the risk of nitrogen leaching due to delaying or postponing the autumn crop to the spring also gives a risk of hazards associated with the use of plant protection products. The pros and cons should therefore be carefully considered when deciding to postpone ploughing in the spring.

4.7.2. Reduced tillage

The traditional system of soil cultivation based on ploughing and other mechanical treatments changes the natural soil structure, dries the soil and accelerates the mineralisation of organic matter. Loss of organic matter after 20 years of intensive ploughing can sometimes be as high as 50% (Figure IV.30). Reducing soil tillage can reduce mineralisation of organic matter in soil, which contributes to the reduction in nitrate leaching.

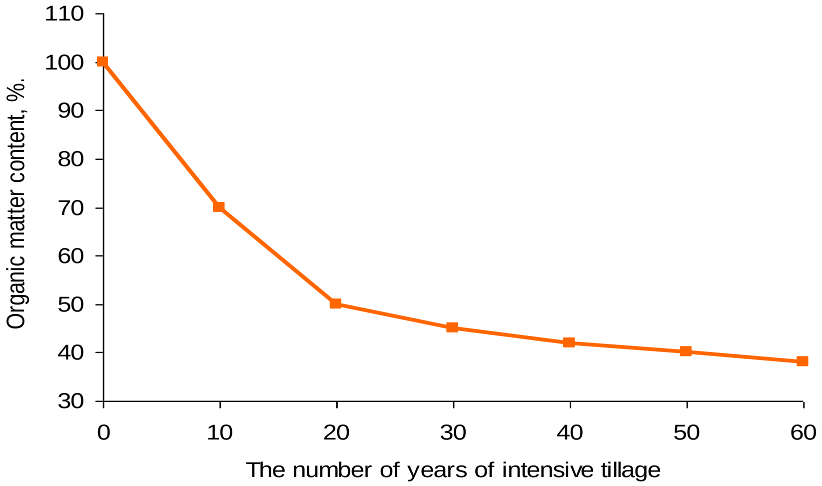


Figure IV.30. Changes in the content of organic matter depending on duration of intensive cultivation in terms of decades. Source: SMAGACZ [2011] based on KINSELLA [1995].

In relation to tillage system, two alternative systems can be identified: a) conservation tillage (ploughless) with direct drilling with just minimal disturbance of the soil (Figure IV.31) and b) shallow tillage with a cultivator or disc harrow without the use of a plough. The latter operation usually occurs to a depth of 10–12 cm with a cultivator with rigid legs (grubber), or a rotary or disc cultivator and without inverting the soil.

When direct-drilling seeds, it is necessary to use special drills, usually with disc tines. In a no-tillage system, seeds are drilled into the soil usually directly after harvest of the previous crop. Tillage using disc harrows or cultivators or aggregates for direct sowing (no-till system system) protect the organic matter in the soil.

Figure IV.31. Equipment for direct drilling. Photo: Gene Alexander.

4.8. Conditions close to the stream

4.8.1. Grazing animals close to the stream

Giving animals access to streams means that soil is trampled down and becomes susceptible to erosion (Figure IV.32). It also means that water quality can be impaired by grazing animal excreta. Therefore, do not allow grazing animals in a strip along the watercourse or into streams to drink water and instead fence cattle out (Figure IV.33). The preferred solution in the vicinity of watercourses and water reservoirs is the use of a forage harvesting and pasture land management system on grassland.

Figure IV.32. Cattle drinking directly from rivers and reservoirs can lead to faecal contamination.
Photo: Keith Evans.

Figure IV.33. Pasture should be fenced off from streams to prevent contamination by animals.
Photo: Tim McCabe.

4.8.2. Buffer zones

Buffer zones are uncultivated areas between fields and water courses, main ditches, ponds, lakes or bays. Buffer zones comprise a permanent plant cover of dense grass or other vegetation (Figure IV.34). The zones are situated on former agricultural land. The vegetation should be kept dense and plants should be established if needed for maintenance. It is recommended that the width ranges from 5 to 20 m. In order to obtain an EU grant, the strips cannot be cropped, fertilised or sprayed with herbicides and pesticides. The buffer zone should be increased to more than 6 m for sloping stream banks or when the land along the stream edge has a concave dip where water can concentrate before reaching the stream (not necessarily visible as water rills or standing water).

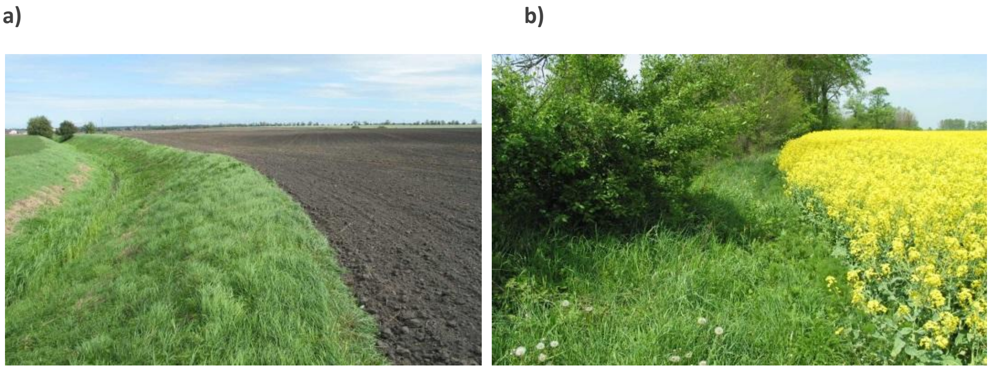


Figure IV.34. Buffer zones: a) with grass (photo: M. Śmietanka, D. Śliwiński), and b) complex vegetation (photo: Z. Miatkowski).

Buffer zones reduce the velocity of surface water run-off and decrease losses of soil material, phosphorus and other pollutants, including pesticides. They also reduce the risk of leaching of pesticides into the aquatic environment. Buffer zones are particularly important in areas at risk of erosion. They can also be placed in water intake protection zones and around areas with a high groundwater level. The ability to reduce pollution by buffer zones depends on: the width of the zone, gradient, soil type, plant cover, hydrological and meteorological conditions.

Buffer zones that are sufficiently wide and positioned at a suitable location can be very effective in nutrient retention (Table IV.9). Their effectiveness also depends on the species composition of plants. Grass-covered zones are effective in retaining slurry, but they are less effective in nitrogen removal than tree-lined zones.

Table IV.9. Efficiency of buffer zones for removal of contaminants depending on the type of vegetation present

Type of vegetation	Removal efficiency, %		
	Nitrogen	Phosphorus	Sediment
Trees and shrubs	48–74	36–70	70–90
Grass	4–70	24–85	53–97
Trees, shrubs and grass	75–95	73–79	92–96

Based on a study by: HAWES, SMITH [2005].

The banks of watercourses should be stabilised and covered with vegetation. Ploughing and other agricultural practices on the edge of watercourses increase the risk of erosion of the banks. The erosion rate increases when the banks are steep and when there are sharp bends in the stream or ditch. Clogged culverts, restrictions to the flow in the stream or damage to equipment designed to reduce the flow of water increases the risk of erosion. In the case of dredging, the likelihood of erosion of the bottom increases, especially when all plant material is removed.

4.8.3. Denitrifying wall

A wall for denitrification is a measure to reduce nitrogen in subsurface waters or in drainage water which has left the field. This involves the water passing through a barrier that is designed to provide good conditions for denitrification. This can take the form of trenches with a depth of about 1.0-1.5 m and a width of 1.5 m, filled with a mixture of soil and fibrous organic material (usually sawdust) perpendicular to the direction of flow of subsurface waters (Figure IV.35). The sawdust can act as carbon source for denitrifying bacteria.

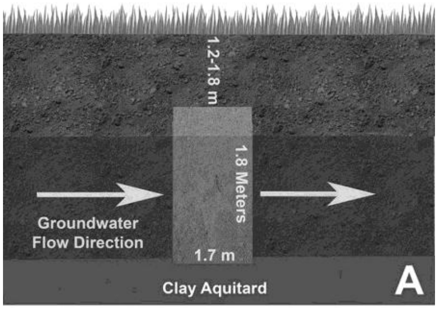


Figure IV.35. Denitrifying wall. Source: SCHMIDT, CLARK [2012], modified.

V WETLANDS AND SORPTIVE FILTERS FOR REDUCING NUTRIENT LOSSES FROM FIELDS AND FARMYARDS

Karin Tonderski, Pia Kynkäänniemi, Karin Johannesson, Barbro Ulén

5.1. Introduction

The runoff from farmyards can contain large amounts of nutrients that will be discharged to surface or ground water unless taken through a system for treatment. This is particularly true for runoff from yards on farms with animals, where feed and manure droppings are easily washed off during rainfall events, and can result in high concentrations of phosphorus, organic matter (measured as COD) and bacteria (Table V.1). By constructing a wetland to collect the runoff from the farmyard (Figure V.1), it is possible to achieve much better quality of this water before it leaves the farm. On many farms in Poland, there may already be a small pond or wetland to which the runoff is flowing. Those ponds and wetlands can serve as important first steps in the treatment and removal of nutrients and soil from the farmyard runoff and should be preserved and maintained.

Table V.1. Examples of minimum, mean and maximum for contamination indicators of stormwater discharged from a farmyard in Mazowia, Poland, and mean values for farmyard runoff in the Annestown/Dunhill catchment, Ireland

Parameter	Cattle farm in Falenty, Poland			Farmyard runoff, Ireland
	Min	Mean	Max	Mean
Ammonium nitrogen (mg $N\text{-}NH_4$/l)	0.18	0.81	3.45	64
Nitrate nitrogen (mg $N\text{-}NO_3$/l)	0.74	2.86	4.43	2.6
Nitrite nitrogen (mg $N\text{-}NO_2$/l)	0.04	0.13	0.44	n.d.
Dissolved reactive phosphorus (mg /l)	2.20	5.51	9.90	10
Chemical oxygen demand (mg O_2/l)	24	66	289	1908
Psychrophilic bacteria (tot number/cm^3)	$7.7 \cdot 10^3$	$5.8 \cdot 10^6$	$2.8 \cdot 10^7$	–

Source: RUSSEL, ROSSA [2012] for Polish data, DEHLG [2010] for Irish data.

Constructed wetlands, as well as existing ponds and natural wetlands, can intercept runoff and transform and store sediment and nutrients found in farmyard runoff. They can also have additional benefits such as nutrient recovery and increased water storage with irrigation possibilities, depending on the size of the wetland. In addition, the biodiversity is increased, as wetlands are habitats for many amphibians and birds. One example is the stork population, which is largely dependent on such wet habitats for its long-term survival.

An important characteristic of a constructed wetland is the establishment of emergent (Figure V.2) and submerged wetland plant species. The plants play a very important role in the wetland, since they take up nutrients as they grow. However, more importantly, they improve the filtration and adsorption of particles in the water and act as surfaces for the growth of water treatment microorganisms. Dead plant parts provide energy for some of the microorganisms that transform nitrogen in the water into nitrogen gas, and plants growing under the water release oxygen, which is beneficial to other organisms.

Figure V.1. Example of a constructed wetland downstream from a farmyard in Ireland. Photo: Harrington.

The capacity for nutrient reduction in wetlands varies, sometimes greatly, within and between years depending on a number of factors such as the weather during the year and how fast the water leaves the wetland. It is generally accepted that constructed wetlands retain 20-90% of the nitrogen load and 25-90% of the phosphorus load. One of the main factors determining the level of treatment is achieved is the load of nutrients, i.e. the size of the wetland relative to the amount of water and nutrients running off from the farmyard annually. This is further discussed in the section ‘Size of the wetland’.

5.2. Treatment processes

In a treatment wetland, there are a number of different processes that contribute to water treatment. Soil particles settle out as the water velocity decreases when the water flows into the wetland. Plant stems further contribute to the filtration of soil particles and their roots stabilise the sediment and may decrease the resuspension of particles that can otherwise occur during extreme flow events.

Organic matter is decomposed by microorganisms, both in the water and in the bottom sediments. Live and dead plant stems and leaves provide important surfaces on which the microorganisms grow and form biofilms where most of the decomposition takes place. The total surface area available for microbial activity in the soil and the overlying dead plant material (litter or detritus) is extremely high in wetlands.

Another important characteristic of wetlands is that they provide both *anaerobic and aerobic micro-environments*, which are favourable for nitrogen removal. In aerobic environments, e.g. on the surface of submersed plants, *nitrifying* bacteria convert ammonium to nitrate. Nitrate ions diffuse into anaerobic environments in litter layers and sediments, where anaerobic bacteria decompose dead plant parts and thereby convert nitrate ions to nitrogen gas, *denitrification*. In this sequential N removal process, nitrification is typically the rate-limiting step due to low oxygen availability in many parts of the wetland ecosystem. In runoff from animal farmyards, where quite a lot of ammonium can be expected, it is important to try to design the wetland with this in mind, promoting oxygenation in parts of the wetland area. One way of doing this is to establish submerged plants in the deeper sections of the wetland, as those *release oxygen* to the water during their photosynthesis. If the topography allows construction of level differences between compartments in the wetland, this would also promote oxygenation.

Figure V.2. A constructed wetland for water treatment . Photo: Linda Flyckt.

Phosphorus is often bound to soil particles and hence removed by *settling* of those particles. In farmyard runoff, much of the phosphorus can occur in soluble form, which is mainly removed by *plant uptake* and *sorption processes*. Phosphate is easily sorbed to *iron and aluminium oxides and hydroxides* in the wetland sediment, and may also be *co-precipitated* with *calcium carbonate* in water with alkaline pH.

To achieve low P concentrations on an annual basis in the wetland outlet, plants would need to be harvested, as most of the P is released when the plants die in the autumn. Alternatively, the wetland area should be very large to retain the phosphorus in the accumulating plant parts that are not entirely decomposed. A third alternative is to add a filter with a sorptive material at the wetland outlet, to capture the phosphate that has not been taken up or adsorbed to the wetland sediments (see paragraph V.5).

5.3. Size of the wetland

When designing a wetland to treat runoff, the volume and area of the wetland are among the most important factors for efficient treatment. The wetland must be large enough to allow for a considerable reduction in the water velocity and thus settling of particles in the water. At the same time, this is favourable for biological and chemical treatment processes. Sometimes the landowner is also interested in other functions, such as water storage for irrigation, that also require large volumes and this will be beneficial for the treatment effect.

There is no strict guideline for the desirable retention time, but it can generally be stated that the larger the wetland, the better the water quality achieved. Depending on which chemical variable is in focus (e.g. nitrogen, phosphorus or soil particles), the area requirement will vary. Efficient removal of soil and particles can be achieved on a smaller area than removal of soluble ammonium and nitrate, whereas efficient removal of soluble phosphate requires the largest wetland area if no P-sorptive material is added. For example, in Ireland, with annual rainfall of 750-1200 mm, the recommendation is that the wetland should be 1.3 times the size of the farmyard itself to achieve efficient removal of soluble phosphate (<1 mg/l P in the wetland outlet) in runoff from animal farm yards [MUSTAFA et al. 2009]. However, if the goal is to achieve reasonable removal of soil particles and nitrogen, the wetland size can be considerably smaller. A general size recommendation for wetlands constructed to significantly reduce the concentrations of nitrogen in runoff from agricultural land is that they should be at least 2% of the catchment area in regions with rainfall of 500-700 mm per year [BRASKERUD and HAUGE, 2008]. Urban stormwater ponds are dimensioned for a retention time of 1-3 days to achieve good settling of soil particles and considerably lowered concentrations of particles in the outlet water [PERSSON, 1998]. At a dimensioning maximum rainfall of 20 mm per day, a 5000 m^2 farmyard would require a 0.5 m deep wetland of 200 m^2 to achieve a theoretical retention time of one day.

Since rainfall varies considerably, dimensioning should be based on knowledge of the maximum rainfall expected in the area and the frequency with which this occurs. It is common to use e.g. the maximum rainfall occurring every two years as a basis for dimensioning stormwater systems.

5.4. Design of a treatment wetland for farmyard runoff

The effectiveness of treatment depends on the hydrological and biological parameters of the artificial wetlands. If possible, a wetland for water treatment should have an elongated shape, with the length *at least* twice the width of the wetland. This contributes to a good distribution of the water over the entire surface, and hence good opportunities for all treatment processes to take place.

A constructed wetland should provide heterogeneous water regimes and environments. For treatment of farmyard runoff, it is advisable to create a deep (>1.5 m) section at the inlet to allow for settling of soil particles before the water passes further into the wetland. By doing this, most of the soil particles will settle close to the inlet, which makes it easier to remove them when the wetland has filled up with soil. This first deeper section should be around 20% of the total wetland area. The rest of the wetland should be kept shallow (<0.5 m) to allow for establishment of emergent vegetation, which has several important treatment functions, as mentioned above (Figure V.3).

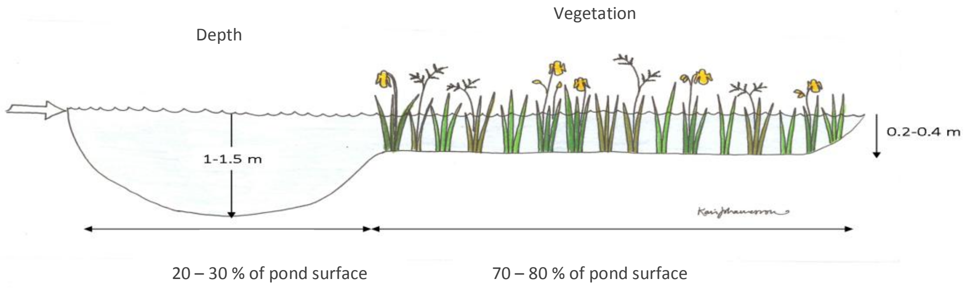


Figure V.3. A constructed wetland for farmyard runoff should be designed with a deeper inlet section where particles can settle and later be removed. The shallower section allows for plant establishment and both filtering and biological and chemical treatment processes. Source: K. Johannesson, LINKÖPING UNIVERSITY.

If a large wetland area is created, it is a good idea to vary the water depth in sections perpendicular to the main water flow (Figure V.4), as deeper sections help to counteract any channel flow of the water that might occur during extreme runoff events when the water velocity is very high. If the topography of the area allows, levees can be constructed to separate the wetland into sub-compartments (Figure V.5). Such levees should be protected against erosion by geotextile and stones. Erosion protection measures should be considered in all parts where the water velocity may become particularly high during high rainfall events.

The edges of the wetland should have a maximum slope of 1:3 to minimise the risk of erosion and people or animals slipping and falling into the wetland. In sensitive soil areas, it may be advisable to cover the edges at and under the water level with an erosion-protection material, and sow the edges above the water level with suitable plant species.

Plants should be established in the shallow sections of the wetlands. This can be done by digging up plants from a nearby stream or lake and transferring them to the wetland. Care must be taken not to use protected species or dig in sensitive or protected aquatic ecosystems.

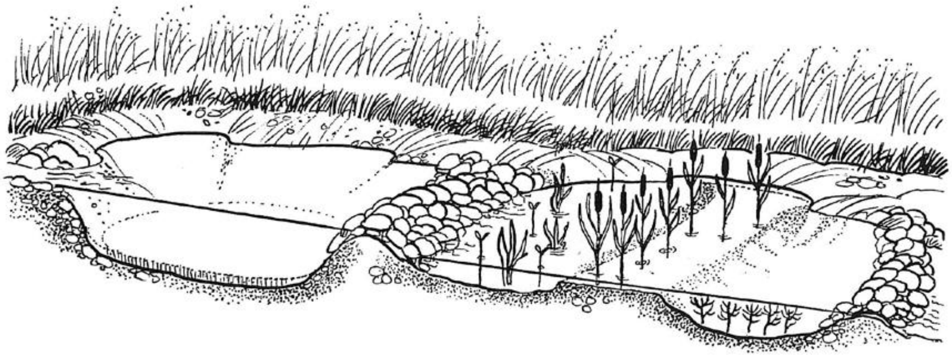


Figure. V.4. The water depth in the shallow part of the wetland can be interspersed with deeper sections perpendicular to the main water flow direction in order to create a more varied ecosystem and improve the water distribution over the wetland area. Picture source: Braskerud & Hauge, Bioforsk FOKUS 2008.

Figure V.5. Example of a wetland with levees that separate the deeper inlet section from the following, shallower wetland areas. Photo: P. Kynkäänniemi, SLU.

The plants should be planted perpendicular to the main water flow in order for the distribution of water to be as even as possible. By planting rather than allowing for spontaneous plant establishment, it is possible to establish desirable species, for example from an aesthetic perspective. Any species that can grow in standing water of about 0.4 m deep and that does not form tufts can be chosen. By mixing different species and avoiding dominant and very productive plants such as reed (*Phragmites australis*), the risk of damage due to insects or plant diseases is reduced.

The treatment efficiency can be further improved by allowing for fluctuating water levels in the wetland. If the wetland has its maximum volume at the onset of rainfall, the retention time will be lower than if a certain empty storage volume can be accommodated and the water level is allowed to rise during the first flush of the runoff. It is possible to create such storage volumes by designing the outlet with two outlet levels (Figure V.6), where the lower sets the minimum water level in the wetland and only allows for a lower discharge than expected during heavy rainfall, and the upper sets the maximum water level with an outlet that allows for maximum expected storm discharge.

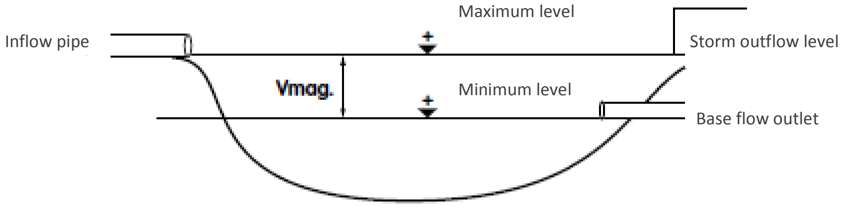


Figure V.6. Schematic diagram of a wetland outlet that allows for fluctuating water levels. The minimum water level is set by the base flow outlet. During intensive rainfall, the water level in the wetland rises until it reaches the storm outfall level that allows for the maximum discharge. Source: PERSSON, WEISNER [2002].

5.5 Filters for phosphorus sorption

Wastewater from farmyards occasionally has high concentrations of dissolved phosphorus and organic matter, particularly on farms with animals. To achieve a low concentration of dissolved phosphorus in farmyard runoff, quite a large wetland needs to be constructed. An alternative way of lowering the concentrations is to add a filter after the wetland. There are various types of filter materials that can be used to reduce nutrients and particles in water, from sand to products based on lime or lightweight aggregates (Figure V.7).

Sand filters can reduce particles and particulate-bound phosphorus, but if dissolved phosphorus is to be reduced, a reactive material is needed. Phosphorus-binding material contains calcium, iron or aluminium and perhaps residues such as slag from steel production, fly ash from power plants or calcium-rich shell sand. In Norway, lightweight aggregates have proven efficient in wastewater treatment plants. Many of the filter materials that have been tried and are in use have the ability to chemically bind dissolved phosphorus, but also to increase the removal of particles through aggregation of the smallest particles. Filter materials are used in many European countries to treat wastewater from single houses and small villages.

Figure V.7. The filter material Polonite, used for sorption of dissolved phosphorus in agricultural stream water. Photo: K. Tonderski, POMinnO Sp.zo.o.

However, the variable water flow from farmyards is a major challenge for the use of filters to adsorb phosphorus. The capacity of filter materials to adsorb phosphorus in runoff from agricultural fields is currently being tested in e.g. in Sweden, Denmark and Poland (Figure V.8). The filter material is kept in a well, cartridge or cassette to facilitate replacement when the sorption capacity has become saturated. The saturated filter material can be returned to farmland as a phosphorus fertilizer.

To prevent the filter material from freezing in winter, the cassettes should be buried below frost depth. The design of sorption filters to treat the outlet from farmyard wetlands with variable water flow should meet the following criteria:

- The water should be spread evenly over the filter material in order to avoid channel flow. The particle size of the granules should be optimal to get as good and even percolation of water as possible. If the levels allow, it is also possible to design the filter with upward flow instead of downward flow.

- The water must have sufficient contact with the filter material. High flows can flush out the phosphate and particles that have previously been adsorbed in the filter, and also reduce the binding capacity due to short contact time. This may be avoided by installing a bypass structure that diverts some of the water away from the filter at high flows.

There is also a risk of suspended matter and organic matter clogging the filter and of the filters being saturated with phosphorus. This is less of a problem when the filter is installed at the outlet of a wetland with reasonable size, as most of the particles will have settled in the wetland.

In the laboratory, the phosphorus can be bound to a solid matrix, of calcium granules or iron oxide, at an amount of 10 g P/kg granules, but this requires the water to be in contact with the granules for at least 30 minutes [Ekstrand et al., 2011]. In practice, the capacity is only half of that. In Poland, Merox (Hyttö) sand, Polonite and Filtralite®P are being studied in field experiments with runoff from agricultural fields (Figure V.9). The filter materials are placed in wells or ditches downstream from small ponds, and the phosphorus removal varies between 19 and 49 %, depending on the material.

Figure V.8. A cassette with shell sand installed in a drainage well in Denmark to investigate the phosphate sorption capacity of the material. Photo: K. Tonderski, POMInnO Sp.zo.o.

Figure V.9. Well with filter material receiving agricultural water. Photo: Piotr Nawalang.

There is a risk that the precipitated phosphorus will be released as the filter ages and the pH and calcium concentration become lower. Therefore it is important to remember that the filter only provides temporary storage of phosphorus.

Depending on the amount of filter material in the cartridge/cassette and the size of the ditch, the water is diluted more or less quickly and the pH is lowered. The filter material must be changed frequently, one to twice a year, in order to ensure a satisfactory effect. The phosphorus-rich filter material can be returned to farmland. Fertiliser effect and soil capacity (structural improvements) are currently being investigated. The preliminary finding from a short-term study at SLU is that the filter materials neither improved nor reduced grain yield, but the investigation was too short (only five weeks) to allow any real conclusions on phosphorus availability in the long term to be drawn.

Advantages and disadvantages of applying filters with absorbent material for the purification of runoff from farmyards and fields are listed in Table V.2.

Table V.2. Advantages and disadvantages of applying filters with absorbent material

Advantages	Disadvantages
Provide additional benefits after a wetland/pond	A larger area is needed if placed after a wetland
Small land area is required for the filter	High filter material consumption
Increases the removal of dissolved phosphorus	Maintenance (material replacement) is needed
	Relatively high installation costs

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