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Mineral Nitrogen as a Universal Soil Test to Predict Plant N Requirements and Ground Water Pollution – Case Study for Poland

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1. Introduction

Nearly whole (99,7%) territory of Poland, covering about 313 thousand square kilometers is situated in the Baltic Sea basin. This territory is drained by two big rivers Vistula and Odra and seven small rivers flowing directly to this sea. The load of about 145 Gg mineral nitrogen, originating mainly from the agricultural land is discharged yearly by polish rivers to Baltic Sea. Among all countries situated in this catchment Poland contributes in almost 26% to the pollution of Baltic Sea with biogenic substance, nitrogen. In the bulk, this is a serious contribution although calculated for one inhabitant (3,7 kg N per capita) and/or one area unit (4,6 kg N per ha) it belongs to the smallest among other Baltic countries. The big share of agriculture in this load results from the fact that agricultural land covers over 60% of the whole polish territory and constitutes almost 50% of this land in the entire Baltic catchment's. However, no wonder that Helsinki Commission and UE exert the pressure on our country for limiting the outflow of nitrogen, including the one from agriculture.

Natural farming conditions in Poland are poor, due to prevalence of light, sand- derived soils (60% very light and light soils) and unfavorable climate. The agriculture landscape originates from the period of glaciations. Due to the high diversity of the parent rocks and different geological and pedological processes, a substantial number of soil types and sub-types have developed in Poland. According to the Polish classification system there are 35 different soil types and 78 sub-types. The most common are brown soils, grey brown podsolic soils, rusty soils and podsolis soils (Terelak et al. 2000). A much smaller part of land is covered by chernozem soils, rendzina soils, black soils and alluvial soils. Unfertile and acid soils account for 50 to 65 percent of arable land. Soil acidity is linked with the low content of available phosphorus and magnesium and hence constitutes of one of the most limiting factors for soil productivity.

Rainfall mostly occurs during the summer months, and the average annual precipitation varies from 500 mm to 900 mm for the regions of Poland, depending on height above sea level and distance from the Baltic Sea. Average temperature ranges from 7,0 to 9,5 degrees of Celsius. The length of growing season is on average 220 days and is comparable to that in Scandinavian countries. From May to September evapotranspiration in Poland exceeds rainfall, resulting in a continuous water deficit, especially on light soil. Nevertheless, in the early spring the outflow of water from the soil profile is a common phenomena.

Overall, the natural conditions for crop production in Poland are by 30-40% worse in comparison for those in Western Europe. The efficiency of agricultural production is rather low (about 3,5 $t \cdot ha^{-1}$ cereal grain) but the consumption of nitrogen in mineral (about 65 kg $N \cdot ha^{-1}$) and organic (about 30 kg $N \cdot ha^{-1}$) fertilizers are comparable with most of the EU countries. As a consequence the balance of nitrogen is positive (about 50 kg $N \cdot ha^{-1}$) and the nutrient utilization efficiency is rather low (about 57%). To deal with the problems of nitrogen surplus in the country and bad management of nitrogen fertilizers, Ministry of Agriculture and Rural Development launched in late 90ties the program of soil monitoring for mineral nitrogen.

2. Mineral nitrogen test – the purposes and the needs

Mineral nitrogen, widely understood as the sum of NO_3^- and NH_4^+ ions, consists of a very small part in the total pool of soil nitrogen. Over 98% of all nitrogen present in soil is in organic forms, not available for plant roots until it is mineralized by microbes into inorganic forms. Mineral forms of nitrogen are very labile and prone to be lost through volatilization and leaching to the ground water. Thus, in the last years the content of mineral nitrogen (N_{min}) is commonly recognized as a soil test of nitrogen accessibility for crops and as an indicator for potential pollution of ground water with nitrogen compounds.
Van der Paauw (1963), researching the effects of residual nitrogen was the forerunner for investigations on inorganic N in the soil profile. Later, research in various countries led to N fertilization recommendations based on the linear relationship between N_{min} in the rooting zone of the crop at the beginning of vegetation and the optimum N fertilizer rate for the crop.
In the Netherlands, N fertilizer recommendations are the function of soil type, whereby "a" and "b" represent a coefficient of the linear relationship between recommendation and N_{min} accordingly to the equation (1):

$$N_{rec} = a - b \times N_{min} \quad (1)$$

(as cited in Van Cleemput et al. 2008). In Belgium, an N index method has been proposed. However, this index includes numerous factors, up to 18, as N mineralization, soil compaction, possible N leaching and is calculated as follows (2):

$$N \text{ index} = X_1 + X_2 + X_3 + \ldots + X_{16} + X_{17} + X_{18} \quad (2)$$

The optimum N fertilization recommendation is calculated accordingly to the equation (3):

$$N_{rec} = a - b \times N \text{ index}, \quad (3)$$

where a and b depend on the cultivar and the destination of the harvested products (Vandendriessche et al., 1992). In France and United States of America, the N balance sheet method was developed. The theoretically recommended N fertilizer doses are based on the balance between the crop requirement minus the amount of N_{min} present before sowing plus the mineralization. The residual N_{min} in the soil profile at harvest to the mean rooting depth consists of the amount of mineral N that remains in the rooting zone after optimum N fertilization. The practical N fertilization recommendation can further be adjusted according to expected losses. The potential losses are estimated at between 5 and 20%, depending mostly on soil texture (Carter et al., 1974). This method has been applied also in China, with the following approach (4):

$$W_{input} = W_{output} - \Delta W - (W_n - W_{n+m}), \quad (4)$$

where W_{input} is the N requirement, W_{output} – N requirement of the target yield, ΔW – volatilized N (N mineralized + subsoil mineral N + dry deposition N + wet deposition N, W_n - N available before planting, W_{n+m} – N available after harvest (as cited in Van Cleemput et al., 2008).

In Western Europe, investigations on N_{min} as a soil test for fertilizers recommendations have started at the beginning of 1970s (Nommik 1966, Scharpf and Wehrman 1975) and in Poland in the beginning of 1990s (Fotyma 1995, 1996). Of course, for fertilizer recommendations, N_{min} test needs a calibration, e.g. critical value for crop nutrition has to be estimated. In pioneer German studies (Scharpf, 1977) by calibrating this test for fertilizer recommendations the simple principle "kilogram for kilogram" has been proposed. It means that each kilogram of mineral nitrogen in the soil profile reveals the fertilizer value equal to one kilogram of nitrogen applied in mineral fertilizers. In Polish approach (Fotyma, 1995) the effect of soil mineral nitrogen has been evaluated by using the N_{min} fertilizer replacement value (N_{min} RFV). RFV is a multiplying factor for the content of N_{min} to a given depth in the soil profile in order to obtain the equivalent amount of nitrogen in mineral fertilizers. When RFV value is equal to 1 then the principle "kilogram for kilogram" comes practically into force. This value depends on crop as well as on soil and climatic conditions and changes in the range 0,6 – 1,1 (Fotyma et al., 2007).

Similarly as in the case of all methods above, evaluation of RFV values is laborious and numerous data from experiments including at least 5-6 nitrogen rates are needed for the process. Moreover, the values reveal a strong variability depending on soil and climatic conditions thus results can be generalized only roughly. The lack of universality of RVF poses a serious drawback in direct application of the N_{min} soil test and since late 80ties, another approach gains in popularity. Allowing for the difficulty of evaluating RFV values for fertilizer recommendation, determination of these values has been substituted by establishing the classes of N_{min} content in the soil profile, like classes of available phosphorus and potassium. For such calibration of N_{min} test the results of soil monitoring for the content of mineral nitrogen offer a good solution.

In the late of 90s, N_{min} test starts to be used as a tool for predicting a risk of soil and water pollution by nitrates (Verhagen & Bouma 1997, Enckevort et al. 2002). Nitrates are easily leached down the soil profile to the ground water thus, for environment protection, the content and distribution of nitrates in the soil profile in autumn are of paramount importance. The EU Nitrate Directive (1991) precisely established its content in at 50 mg dm^{-3} NO_3 or 11,3 mg NO_3-N dm^{-3} of drinking water. This limit is a reference value for the soil ground water as well, though the ground water with an exception of shallow wells is not directly used for this purpose in general. However direct estimation of nitrate concentration in a ground water is a cumbersome and costly procedure. Therefore, it seems interesting to calculate this concentration based on nitrates content in the bulk of soil.

This paper is focused on the parameterization of N_{min} soil test both for fertilizer recommendation and environment protection, using numerous data from the soil monitoring program.

3. Materials and methods

The monitoring program for the content of mineral nitrogen has been launched by the Polish Ministry of Agriculture and Rural Development in 1997. Soil samples have been collected in fixed sites all over the country, twice a year – in spring and autumn to the depth of 90 cm in 0-30, 30-60 and 60-90 cm layers. Soil samples were frozen, and the content of N_{min} was determined in each layer by the colorimetric method in 1% extract of K_2SO_4. The content of N_{min} was expressed in mg NO_3-N and NH_4- N·kg^{-1} soil dry matter and recalculated into kilogram of N_{min} in a given soil layer per ha, called further N_{min} amount. Additionally, at the beginning of this project in all monitoring sites, soil texture has been determined. The technical part of the program, including soil sampling and analysis was entrusted to 17 agrochemical laboratories supervised by the Ministry. The results of analysis were collected in the central database at the Institute of Soil Science and Plant Cultivation – National Research Institute in Puławy, processed statistically and reported in due course.

Fig. 1. Localization of the monitoring sites in Poland

In this paper, the results for soil samples, collected from about 5100 sites, in the years 1997-2006 are presented as the first stage of the monitoring program. The total number of samples (records) in the data base is about 95000. Each record includes data for three soil layers and two forms of mineral nitrogen NH_4-N and NO_3-N. The monitoring sites were established on arable land, randomly distributed all over Poland (Fig 1). The distribution of obtained data concerning concentration and content of N_{min} was far from normality. Therefore, the median value was used as a characteristic of a mean and percentile as a measure of date distribution. The preliminary statistical analysis shows the significant dependence of N_{min} content on the soil texture. For this reason, the normative of mineral nitrogen were calculated for each of four textural soil groups: very light (up to 10% of particles below 0,02 mm, light (11 - 20% of particles below 0,02 mm, medium (21-35% of particles below 0,02 mm and heavy (above 35% of particles below 0,02 mm). Similarly, to five classes of soil reaction and P, K, and Mg content officially used in Poland, five intervals of N_{min} content were proposed. Each following interval contains 20% of ordered observations and thus five classes of N_{min} were distinguished - very low, low, medium, high and very high.

4. Results

4.1 Content of mineral nitrogen forms in soil profile

The content of mineral forms of nitrogen has been presented in table 1. The quantity of nitrates and ammonia strongly depends on soil texture, the soil layer and a period of soil sampling. The content of nitrates in soil are higher in autumn than in spring and increases from the very light to heavy soils. The content of nitrate in the upper soil layer is higher in autumn than in spring while the reverse is true for the deepest soil horizon. Ammonia content does not practically differ between the sampling periods and soil textural groups and NH_4 – N is much more evenly distributed in the soil profile irrespective of the season and soil texture. Generally, nitrates content is higher than the content of ammonia.

N form	Soil layer cm	Spring				Autumn			
		Soil texture				Soil texture			
		very light	light	medium	heavy	very light	light	medium	heavy
N_{min}	0 - 30	6,4	7,6	8,4	9,0	8,7	10	10,6	11
	30 -60	3,8	5,5	6,1	7,1	4,7	5,4	6,1	6,6
	60 -90	3,4	5,1	4,8	5,4	3,3	4,2	4,0	4,3
NO_3 - N	0 - 30	3,3	4,4	5,5	6,5	5,6	7,1	7,8	8,3
	30 -60	2,0	3,5	4,0	5,2	2,9	3,7	4,1	4,9
	60 -90	1,9	3,4	3,2	3,8	2,0	2,7	2,5	2,8
NH_4 - N	0 - 30	2,7	2,5	2,2	1,8	2,4	2,2	2,0	1,6
	30 -60	1,4	1,4	1,5	1,3	1,4	1,2	1,4	1,1
	60 -90	1,1	1,3	1,1	1,2	1,0	1,1	1,1	1,0

Table 1. Median of mineral nitrogen forms in soil profile depending on soil layer, soil textural group and sampling period in mg N· kg^{-1} soil

4.2 Total amount of mineral nitrogen in soil

For practical purposes, the content of mineral nitrogen, expressed in mg N ·kg^{-1} soil has been recalculated into the nitrogen amount expressed in kg N · ha^{-1} using standardized value of soil density for selected textural soil groups. Generalized values of soil density for each soil textural group as well as a conversion factor used for recalculation of N content into N amount are presented in table 2.

Soil texture	Soil density [kg ·m^{-3}]	Conversion factor for 30 cm soil layer* (rounded)
Very light	1533	4,6
Light	1500	4,5
Medium	1433	4,3
Heavy	1300	3,9

* kg N ·30cm = mg N ·kg^{-1} soil x W

Table 2. Soil density depending on soil textural classes

The tables 3 – 5 shows general statistics for the central tendency and the scatter of the data, in the form of percentiles for amounts of N_{min} and amounts of NO_3 – N. Nitrate nitrogen is the form mostly preferred by plants and simultaneously very prone to leaching to the ground and open waters. Three soil layers, or rather profiles 0-30 cm, 0-60 cm and 0-90 cm have been distinguished. Fertilizer recommendations are usually based on the mineral nitrogen amount in these profiles with the preference for 0-60 cm and/or 0-90 cm profiles. The most interesting is the soil profile 0-90 cm which is explored by the roots of common crops. The difference in the amounts of nitrates in this profile between autumn and spring periods of soil sampling was further considered as nitrogen losses to the underground water. In the soil profile 0 - 90 cm (table 5) the median quantity of N_{min} amounted to 65 – 95 kg N ha^{-1} in spring and 79-96 kg N ha^{-1} in autumn. The quantity of NO_3 – N ranged from 35 – 69 kg N ha^{-1} in spring and 52 -72 kg N ha^{-1} in autumn. The amount of nitrates and total mineral nitrogen increased from the very light soils towards heavy ones. The difference between the N_{min} and NO_3 –N amounts in spring and autumn periods of soil sampling diminished in the same direction.

Characteristics	Spring				Autumn			
	Soil texture				Soil texture			
	Very light	Light	Medium	Heavy	Very light	Light	Medium	Heavy
Number of samples	10784	19585	8718	8710	10821	19584	8792	8016
Median	29,0 (14,7)	33,3 (19,8)	34,8 (22,9)	35,1 (25,3)	39,1 (26,2)	44,5 (32,4)	45,0 (33,5)	43,7 (33,5)
20% - percentile	18,8 (7,36)	22,0 (10,3)	22,5 (12,3)	22,6 (14,0)	23,5 (12,4)	27,4 (16,3)	26,8 (17,0)	25,7 (17,2)
40% - percentile	25,3 (11,9)	29,7 (16,2)	30,6 (19,1)	30,4 (21,4)	34,0 (21,1)	38,7 (26,5)	38,6 (27,6)	37,0 (27,1)
60% - percentile	33,1 (17,9)	37,8 (23,8)	40,3 (27,2)	40,2 (29,6)	45,1 (31,7)	51,7 (38,7)	52,7 (40,8)	50,3 (40,6)
80% - percentile	45,5 (28,0)	52,2 (35,5)	55,6 (39,9)	55,8 (42,5)	63,9 (48,7)	72,4 (58,0)	74,8 (59,9)	72,9 (62,0)
100% - percentile	105 (74,0)	108 (79,2)	112 (82,4)	111 (83,5)	143 (119)	145 (126)	146 (126)	145 (128)

Table 3. Statistical characteristics of N_{min} and N-NO_3 (in parenthesis) amounts in the soil profile 0-30 cm for soil textural groups and sampling date (kg N· ha^{-1})

Characteristics	Spring				Autumn			
	Soil texture				Soil texture			
	Very light	Light	Medium	Heavy	Very light	Light	Medium	Heavy
Median	47,8 (25,3)	58,5 (36,6)	64,8 (44,3)	67,1 (19,5)	62,1 (41,4)	71,1 (51,3)	74,3 (54,8)	73,3 (56,9)
20% - percentile	30,3 (12,4)	37,8 (18,9)	41,6 (23,8)	42,9 (26,3)	38,2 (20,2)	43,7 (27,0)	44,7 (28,0)	44,1 (29,6)
40% - percentile	41,4 (20,2)	51,3 (30,2)	56,6 (36,9)	59,0 (41,7)	53,8 (34,0)	61,4 (42,4)	64,1 (45,3)	63,2 (47,6)
60% - percentile	55,2 (30,8)	67,0 (44,1)	73,9 (52,2)	76,8 (58,9)	71,7 (50,1)	81,9 (61,5)	86,5 (65,3)	85,6 (68,2)
80% - percentile	77,7 (49,2)	93,7 (67,7)	103 (77,5)	106 (84,3)	102 (76,1)	116 (92,2)	122 (98,2)	122 (104)
99% - percentile	187 (139)	196 (157)	202 (167)	203 (171)	235 (208)	247 (218)	248 (221)	247 (223)

Table 4. Statistical characteristics of N_{min} and $N\text{-}NO_3$ (in parenthesis) amounts in the soil profile 0-60 cm for soil textural groups and sampling date (kg N· ha^{-1})

Characteristics	Spring				Autumn			
	Soil texture				Soil texture			
	Very light	Light	Medium	Heavy	Very light	Light	Medium	Heavy
Number of samples	10924	19902	8844	8024	10913	19829	8867	8068
Median	65,3 (35,3)	81,4 (52,5)	90,9 (62,2)	94,8 (69,4)	79,3 (52,4)	89,7 (63,9)	95,4 (68,0)	96,3 (72,5)
20% - percentile	40,8 (17,0)	51,3 (26,5)	57,7 (33,1)	59,7 (36,7)	48,8 (26,2)	55,1 (33,3)	57,7 (35,5)	57,3 (37,4)
40% - percentile	56,6 (28,4)	70,7 (42,7)	79,4 (51,9)	82,3 (57,7)	69,0 (43,2)	77,5 (52,8)	82,4 (56,5)	82,7 (60,1)
60% - percentile	75,8 (43,7)	93,6 (62,9)	104 (73,9)	109 (82,0)	92,0 (63,0)	104 (76,2)	110 (81,8)	111 (87,3)
80% - percentile	107 (69,4)	131 (96,3)	145 (108)	150 (119)	132 (95,6)	148 (115)	159 (124)	157 (131)
99% - percentile	261 (196)	283 (223)	292 (234)	298 (236)	307 (253)	32 (267)	324 (271)	324 (273)

Table 5. Statistical characteristics of N_{min} and $N\text{-}NO_3$ (in parenthesis) amounts in the soil profile 0-90 cm for soil textural groups and sampling date (kg N· ha^{-1})

Numerous factors, apart from the soil texture, influenced the amount of mineral and nitrate nitrogen in soil and differences between the autumn and spring period of soil sampling. In spring, the quantity of nitrogen is affected mainly by crop grown in the previous year, while in autumn by crops grown in this particular year (Table 6). The preceding and actually grown crops have been classified by means of cluster analysis into three groups differing in the amount of N_{min} and NO_3 – N left in the soil. Cluster of crops reflects not only the type of particular crop but the agro technical measures for this crop as well, influencing the amount of mineral nitrogen in the soil. Sugar beet, potato and sometimes rape and maize are grown on farmyard manure. Leguminous crops assimilate nitrogen from the atmosphere and for intensive cereals and rape, high doses of mineral nitrogen are being commonly applied. Another factor influencing the amount of mineral and nitrate nitrogen in the spring period and the difference of these amounts between spring and autumn period is the winter precipitation. This factor will be discussed in the following part of the paper.

Cluster	Soil layer					
	0-30 cm		0-60 cm		0-90 cm	
	N_{min}	NO_3-N	N_{min}	NO_3-N	N_{min}	NO_3-N
I Intensive cereals, rape, sugar beet, maize, potatoes, leguminous crops and mixture with grasses, vegetables, grassland	Spring					
	35,7	22,7	63,8	42,2	87,1	59,5
	Autumn					
	46,3	34,7	76,7	57,4	99,4	72,7
II Extensive cereals, non-leguminous fodder crops, field grasses	Spring					
	31,3	17,7	50,0	28,0	65,7	37,3
	Autumn					
	36,2	22,4	56,2	35,6	70,6	43,6
III Set aside, bushes, forests	Spring					
	23,5	9,75	39,5	16,0	51,5	22,0
	Autumn					
	25,0	14,0	39,0	15,5	51,0	24,0

Table 6. Amounts of mineral and nitrate nitrogen in spring for clusters of preceding crops and in the autumn for crops grown in the particular year [kg N· ha^{-1}]

The largest amount of mineral nitrogen in soil has been revealed after intensive cereals (winter wheat and triticale), winter rape, row crops fertilized with manure (sugar beet, potato, vegetables and leguminous crops in a pure stand and with a mixture with grasses. The smallest quantity has been found after extensive cereals (rye, oats, cereal mixtures, non-leguminous fodder crops, grasses and on set aside land. Almost the same regularities appeared in the samples collected in autumn. The greatest differences in N_{min} and NO_3 – N quantities between autumn and spring period of soil sampling appeared in the cluster I. The quantities of nitrogen after crops of cluster III between autumn and spring periods of soil sampling in soil layers 0-60 and 0-90 cm were practically the same.

4.3 Application of N_{min} test for fertilizer recommendations

A very serious and still unsolved problem is how to include the results of N_{min} or NO_3 – N test into nitrogen fertilizer recommendations. Generally, two approaches can be considered: quantitative and qualitative. The most straightforward quantitative approach is to express the content of N_{min} in kg· ha^{-1} and to relate its amount to the amount of nitrogen from fertilizers. Based on this approach the simple model has been developed in Europe:

$N_{fer} = N_{crop} - N_{min}$ *RFV, where: N_{fer} - optimal rate of fertilizer nitrogen, N_{crop} – crop nitrogen requirement, RVF- N_{min} replacement value. As has been already pointed out Wehrman et al. (1986) assumed that RVF value is equal to 1, while in Polish investigations this value depends on crop as well as on soil and climatic conditions and changes in the range 0,6 – 1,1 (Fotyma et al., 2007). The lack of universality of RVF poses a serious drawback in quantitative application of the N_{min} soils test and since late 80ties qualitative approach gains popularity. This particular approach to soil test of mineral nitrogen has been implemented in Germany (Muller & Gorlitz 1986, 2000) and lately in Poland (Fotyma, 2010, Rutkowska & Fotyma, 2009). The first step in qualitative approach is to calibrate the soil test. Calibration is commonly understood as establishing the test critical value or several classes corresponding to the expected efficiency of a given nutrient. The classical method is to calibrate the soil test against plant indices in the series of field experiments carried on the soil differing in the test values. This is a very cumbersome and expensive procedure practically not applied any further. In Poland N_{min} soil test has been calibrated using the data from monitoring program providing representative data for different natural and agronomic conditions in the country.

The five test classes for mineral and nitrate nitrogen correspond to the percentiles of these forms in soils of different texture (Table 7). Each following interval contains 20% of ordered observations and thus five classes of N_{min} and NO_3-N were distinguished - very low, low, medium, high and very high nitrogen content. Five calibration classes have been chosen in order to comply with the numbers of availability classes for other nutrients, officially used in Poland.

Soil texture	Form of nitrogen	Class of content (percentile interval) kg $N_{min} \cdot ha^{-1}$				
		Very low 0-20%	Low 20-40%	Medium 40-60%	High 60-80%	Very high 80-100%
Very light	NO_3-N	to 17	18-28	8-11	29-44	over 70
	N_{min}	to 41	42-57	58-76	77-107	over 108
Light	NO_3-N	to 26	27-43	44-63	64-96	Over 96
	N_{min}	to 58	59-79	80-104	105-145	over 132
Medium	NO_3-N	to 33	36-52	53-74	75-108	over 109
	N_{min}	to 58	59-79	80-104	105-145	over 146
Heavy	NO_3-N	to 37	38-58	59-82	83-119	over 120
	N_{min}	to 60	61-82	83-109	110-150	over 151

Table 7. Classes of the mineral nitrogen N_{min} and nitrate nitrogen NO_3-N in spring in the soil profile 0-90 cm

Soil test for NO_3 – N seems to be more suitable for fertilizer recommendations than N_{min} test. This is because nitrates are directly available for plants. Total amount of N_{min} includes also NH_4 – N form, but NH_4^+ cation is preferred only by some specific group of plants, and besides undergoes the sorption on the soil colloids. The calibration figures are given for the soil profile 0-90 cm. For technical reasons soil sampling is sometimes limited to the depth of 0-60 cm. However data obtained from the monitoring program showed the close correlation between the amounts of mineral nitrogen in the two soil layers 0-60 and 0-90 cm.

Classes of N_{min} quantity in spring corresponds in reverse order to the classes of crop nitrogen requirements In the class of very low mineral nitrogen content, crop requirements are the highest and vice versa. In fertilizer recommendations if the content of N_{min} or NO_3–

N in the spring falls in "medium " class farmer is enhanced to stick to the standard N rate and its common splitting pattern. If the N_{min} content proved to be "very low" or "low" then the standard 1st rate of nitrogen fertilizer should be increased and applied as early as possible. The reverse is recommended when mineral nitrogen content is "high" or "very high". Usually for deep rooting and/or winter crops the content of N_{min} in the soil profile 0 – 90 cm and for shallow rooting and/or spring sown crops the content of N_{min} in the soil profile 0-60 cm is taken into consideration. Thus, this qualitative approach to mineral nitrogen soil test makes it at present rather as an auxiliary tool for nitrogen recommendations system. The calculation of standard nitrogen dose is still in foreground. This problem lies however outside the scope of this paper and is discussed elsewhere (Jadczyszyn, 2000, 2009).

4.4 Application of N_{min} soil test for environment protection

Agriculture in Poland is a main source for the leaching of nitrates to groundwater and surface waters. It is estimated that in the Baltic catchment over 60% of nitrogen in the riverine outflow originates from the diffuse sources. The diffuse outflow, as well as point sources are considered the main sources of nitrogen discharged by the Vistula and Oder rivers, the two out of seven largest rivers feeding the Baltic Sea. Fertilizer recommendations alike the problem is how to include the mineral nitrogen soils test in predicting the potential threat for ground water by excess of nitrates. It is clear that main losses of nitrate to ground water took place in winter and early spring periods due to the outflow of excess of water. Therefore, for environment protection, the content and distribution of nitrate in the soil profile in autumn are of paramount importance. On the base of data gathered from the soil monitoring program carried on in Poland since 1997, the threat from nitrate excess has been qualitatively assessed. The five classes of nitrate content in the soil profiles 0-90 cm and 60-90 cm corresponding to its pentiles distribution were distinguished (Table 8).

Soil texture	Depth cm	Class of nitrate content kg $N-NO_3$ ha^{-1}					
		Very low	Low	Medium	High	Very high	Median
Very light	0-90	≤27	27-43	44-62	63-94	≥97	52
	60 - 90	≤24	5-7	8-11	12-20	≥42	9
Light	0-90	≤233	34-53	54-76	77-115	≥116	64
	60 - 90	≤24	5-8	9-13	14-23	≥54	10
Medium	0-90	≤237	38-59	60-85	85-131	≥125	71
	60 - 90	≤25	6-9	10-15	16-27	≥60	12
Heavy	0-90	≤240	41-61	62-88	89-134	≥132	74
	60 - 90	≤26	7-10	11-17	18-30	≥62	13

Table 8. The classes of nitrate content in autumn depending on the depth in the soil profile

The low content of NO_3-N in the very light and light soils and the medium one in medium and heavy soils are proposed in Poland as the threshold ranges of soil threatening with excess of nitrogen. These limits are roughly 40 kg $N-NO_3$ ha^{-1}, and 60 kg $N-NO_3 \cdot ha^{-1}$ for the very light/ light and medium/ heavy soils, respectively. Similar limits were established in few European countries as well. In Belgium the limit is set at 90 kg $N-NO_3 \cdot ha^{-1}$ in the soil layer 0-90 cm, in Germany at 45 kg $N-NO_3 \cdot ha^{-1}$ in mineral soils and at 90 kg in organic soils. The validity of our approach was confirmed by comparing the amounts of nitrates in autumn and spring periods (Table 9). It results from the table 7 that by low content of nitrate in the very light/light soils and medium one in the medium/heavy soils the losses of nitrates from the soil profile 0-90 cm in winter period are negligible.

Class of NO_3 – N in autumn	kg NO_3–N ha^{-1} in 0-90 cm	Soil texture			
		Very light	Light	Medium	Heavy
Very low	autumn	16	22	24	24
	spring	21	33	40	44
	difference	+5	+11	+16	+20
Low	autumn	34	43	45	49
	spring	31	46	54	60
	difference	-3	+3	+11	+11
Medium	autumn	52	64	68	73
	spring	36	53	65	71
	difference	-16	-11	-3	+2
High	autumn	76	92	99	107
	spring	43	62	72	81
	difference	-33	-30	-27	-26
Very high	autumn	132	156	166	172
	spring	51	72	84	92
	difference	-81	-72	-82	-79
Average for the soil	autumn	52	64	68	74
	spring	34	51	61	69
	difference	-18	-13	-7	-5

Table 9. Reserves of nitrates in autumn and following spring depending on the nitrate classes in autumn

4.5 Simulated nitrates concentrations in ground water

As has been already mentioned, for environment protection the key point is concentration of nitrate in the drinking water, which in fact originates from ground water and not the content of nitrate in the bulk of soil. The EU Nitrates Directive has stated the limit in drinking water to 50 mg· dm^3 NO_3^- or 11,3 mg· dm^3 NO_3 – N. However direct estimation of this concentration is laborious and difficult. The most prone to leaching processes are nitrate in the deeper soil layers being in contacts with ground water, particularly in the periods of water saturation to full soils water capacity. Soil saturation to full water capacity in the depth 0-30 cm and 30-60 cm occurs only in the early spring but the subsoil nearly through the whole vegetation period. In the paper the indirect method for estimation the safe limit of nitrate content in the bulk of soil by comparison with calculated nitrate concentration in the soil water at the depth 0 -30, 30 – 60 and 60-90 cm was proposed, using the following formulas (5) and (6):

$$\text{Concentration (mg N-NO}_3\ \text{dm}^{-3}) = \text{content (mg N-NO}_3\ \text{kg}^{-1}) *R, \quad (5)$$

$$\text{and } R=1/(W/D), \quad (6)$$

where: W – soil water content in dm^3 dm^{-3} (v/v), D- soil bulk density in kg· dm^{-3}
The soil water content W at this point depends on soil texture. Standard W values for soil saturation to full water capacity and D values for soil categories in Poland are given in table

10 (Fotyma, & Ślusarczyk, 1992). The simulated concentration of nitrates in the soil layer 0-30, 30-60 and 60-90 cm are presented in Table 11.

Soil texture	Soil bulk density $G \cdot dm^{-3}$ D	Soil water capacity v/v, $dm^3 \cdot dm^{-3}$ W(1)	Soil water capacity v/w, $dm^3 \cdot kg^{-1}$	Conversion factor **R**	Coefficient $\mathbf{W_z}$(2)
Very light	1,533	0,125	0,082	12,40	2,65
Light	1,500	0,174	0,116	8,62	1,91
Medium	1,433	0,291	0,203	4,93	1,14
Heavy	1,300	0,433	0,331	3,02	0,77

1) coefficient to recalculate the content of nitrates in bulk soil into nitrate concentration in soil solution
2) coefficient to recalculate the quantity of nitrates in the soil layer of 30 cm into concentration of nitrates in soil water

Table 10. Soil parameters for recalculation the content of nitrate in the bulk of soil to its concentration in soil solution assuming soil saturation to full water capacity

Soil texture	Soil layer 0-30 cm		Soil layer 0-30 cm		Soil layer 0-30 cm	
	autumn	spring	autumn	spring	autumn	spring
Very light	66,5	37,0	33,3	28,2	22,2	20,9
Light	59,6	36,3	29,4	28,5	21,6	27,6
Medium	37,9	26,1	19,7	19,2	11,3	18,8
Heavy	25,4	19,0	13,9	15,4	8,2	10,9
Average	48,2	30,5	23,4	22,2	13,8	16,3

Table 11. Simulated concentration of nitrates in the soil layer 0-30, 30-60 and 60-90 cm under assumption that the soil is saturated to full water capacity

The quantity of nitrates decreased from very light to heavy soils, which results in differences in their soil water capacity. Concentrations NO_3- N both in autumn and spring period diminish down the soil profile, independently of the soil texture. Except the heavy soils, the concentration of nitrates in the upper soil layer is strongly on behalf the autumn period in the intermediate soil layer still on behalf of autumn and in subsoil on behalf of spring period with except of the light soil. As a consequence of that, the downward movement of nitrates in the winter period with the water soaking into the soil profile occurs. Besides, the data in Table 13 indicate, that part of nitrates translocated from the upper soil layers is retained by the subsoil, particularly in medium and heavy soils. However, the remaining part is leached in soil profile below the rooting zone and potentially dispersed to the ground water.
In the monitoring program, soil samples to the depth 0-90 cm have been collected thus the concentration of nitrates below 90 cm can be simulated only. It has been assumed that the total quantity of lost NO_3 – N during the winter period can be found in the depth of 90-120 cm and that the soil texture on this depth is the same as in subsoil. Hence, the quantity of nitrates expressed in kg $N \cdot ha^{-1}$ removed to the soil layer 90-120 cm can be recalculate into nitrates concentration expressed in mg NO_3- N mg dm^3 in soil water using the coefficient W_z (Table 10). The value of W_z coefficient decreases from very light towards heavy soils as a result decreasing in the water capacity. For example, if the value of W_z is 2,67, it means (Table 12) that 1 kilogram NO_3 – $N \cdot ha^{-1}$ leached to the depth of 90-120 cm in very light soil increases nitrates concentration in soil water by 2,65 mg NO_3- N mg$\cdot$ dm^3. The value of W_z

makes possible to assess the accessible amount of nitrogen leached to the soil 90-120 cm) – 4 kg NO_3- N mg·dm^3 for very light soil, 6 kg NO_3- N·mg dm^3 for light soil, 10 kg NO_3- N mg· dm^3 for medium soil and 15 kg NO_3- N mg· dm^3 for heavy ones. Of course, ground water with an exception of shallow wells is not the drinking water. Therefore, the simulated concentrations of the nitrates give only approximate values.

The differences between the autumn and the following spring in the quantity of nitrates can be treated as nitrogen losses to ground water. Of course, it is only a simplification, because part of the nitrates might be denitrified during the autumn – winter period, nevertheless, in the paper, the terms difference and losses would be used intermittently. In autumn, the losses in the medium class over winter period from medium and heavy soils are negligible and on light soils tolerable. Only very light, coarse - textured soils reveals a dangerous for nitrate leaching to the ground water. From the data presented it can be concluded, that the downward placement of nitrates below the depth 90 cm over the winter period depends on several factors among which soil texture and reserves of nitrates in autumn are the most important. The less influencing ones are intensity of crop production and the sum of rainfall from November to March. All the factors were aggregated at the administrative levels (NUTS – 2) of voivodship (Table 12) and included into cluster analysis. The results have been presented in the following subsection.

5. Discussion

The main achievement of this work was to establish the normative for N_{min} content on the base of a soil monitoring program carried on in Poland since 1997. The normative concerning spring period of soil sampling can be used for fertilizer recommendations, and that concerning autumn period of soil sampling for environment protection. The official fertilizer recommendation system covers the whole territory of the country and is focused on individual farms. As it has been already mentioned N_{min} soil test is, at present, an auxiliary tool superimposed on the standard nitrogen doses resulting from balance approach. Due to a very large number of farms in Poland, 1,5 millions altogether including about 0,3 millions of market oriented ones performing the N_{min} soil tests for each field in each farm is out of a question. Therefore, the results of monitoring program in its spring part, which are made available for general agricultural community are treated as reference points for similar farming conditions (Jadczyszyn, 2009).

The normative concerning autumn period of soil sampling as well as a difference in mineral nitrogen content between spring and autumn periods of soil sampling are used for delineating the areas threatened by surplus of nitrogen from agriculture. Such approach is presented on the NUTS-2 scale, i.e. for administrative units the highest order, called provinces or voivodships. The whole territory of the country is divided into 16 provinces, which are further divided into 314 counties (Figure 1). This division is based rather on historical and socio-economical and not on natural grounds. However, most of the statistical Kopiński, 2006; Kuś et al., 2006). For this reason, as well as for full transparency, the problem of nitrogen surplus from agriculture is presented for administrative level NUTS – 2. Discussing this problem not only the results of the soil monitoring program for mineral data concerning agriculture are available on NUTS-2 scale only and this level is considered in most of the publications dealing with regionalization of agricultural policy (Krasowicz & nitrogen but other relevant factors have been taken into consideration. These factors are listed in Table 14 and some of them will be discussed briefly.

Voivodship	Winter rainfall (1)	Soil texture (2)	Cropping system intensity (3)	N balance difference kg N·ha^{-1} (4)	Nitrates content in autumn kg N·ha^{-1} (5)	Nitrate loss kg N·ha^{-1} (6)
Dolnośląskie DLN	147	22,1	78,0	86,3	87	14
Kujawsko-pomorskie KUJ	178	71,2	65,6	85,3	67	14
Lubelskie LUB	171	71,9	66,3	75,5	61	-1
Lubuskie LUS	191	86,9	63,3	63,0	77	32
Łódzkie LOD	220	84,3	48,0	62,9	64	18
Małopolskie MAL	201	28,2	66,1	57,6	68	2
Mazowieckie MAZ	174	88,6	50,2	54,9	51	7
Opolskie OPL	207	42,5	79,8	50,5	73	11
Podkarpackie PDK	200	23,1	72,1	50,2	65	4
Podlaskie PDL	188	83,8	39,0	48,4	45	9
Pomorskie POM	208	66,3	61,9	48,1	50	11
Śląskie SLS	257	56,1	66,0	45,3	71	7
Świętokrzyskie SWT	207	64,5	67,6	42,1	67	-3
Warmińsko-mazurskie WAM	206	57,2	60,4	40,1	44	7
Wielkopolskie WLP	186	93,1	65,8	28,7	78	27
Zachodniopo-morskie ZAP	229	78,3	63,0	22,4	65	25
Polska	187	64,7	62,8	11	**63**	12

1) sum of rainfall in winter period (January 1st – March 31st)
2) % of coarse textured soil (very light and light)
3) % of samples from fields under intensive cropping system (see table 6)
4) difference between N input and N output annually (kg N·ha^{-1}).
5) amount of autumn nitrate N in soil profile 0-90 cm in kg ha $^{-1}$
6) differences between nitrate N content in autumn (1997-2005) and spring in kg ha $^{-1}$ (1996-2006)

Table 12. The losses of nitrate in winter period and influencing factors for voivodships in Poland

Winter rainfall. Analysis of data from monitoring program reveals that the nitrate losses in the period between spring and autumn soil sampling were related to the sum of rainfall in the period November to March. In the very dry years with winter rainfall below 100 mm the losses of nitrate were negligible. In the wet years with winter rainfall over 250 mm the losses of nitrates reached over 15 kg NO_3-N·ha^{-1}.

Soil texture influenced strongly the content and losses of nitrate, and this factor was included in N_{min} normative. Particularly prone to nitrate losses are very light and light soils which share is very differentiated among the provinces. It is necessary to stress again upon the prevalence of light, sandy soils in Poland that contributes significantly to the nitrate outflow from the country.

Cropping system in Poland is partly linked to natural farming conditions, i.e. soil quality and climate. However, intensive, high demanding crops from economical reasons are often grown on light soils, and poor soil conditions are compensated by higher doses of mineral fertilizers.

Nitrogen balance is calculated in Poland according to OECD rules as a soil surface balance (OECD, 1999). N balance was positive in whole Poland. The mean N surplus was 57 kg N·ha^{-1}. The greatest surplus has been found in Kujawsko-Pomorskie and Wielkopolskie provinces. These regions are featured by a very intensive animal production and high consumption of mineral fertilizers. The smallest one has been found in Małopolskie and Podkarpackie voivodships characterized by the extensive agricultural production.

Factors listed in table 14, influencing the threat from nitrogen surplus have been included into the cluster analysis performed by Ward's method. The voivodhips were grouped in three clusters presented in table 15 and on the Figure 2.

Cluster	Voivodship	Factor 1 Winter rainfall 1)	Factor 3 Soil texture 2)	Factor 4 Cropping system intensity 3)	Factor 5 Autumn nitrate value 4)	Factor 6 Nitrogen surplus kg ha -1 5)	Factor 7 Nitrate loss 6)
I	KUJ, LUB, MAL, OPL, PDK, SWT	187	46,2	70,8	69,7	63,9	5,85
II	DLN, LUS, SLS, WLP, ZAP	215	78,6	64,5	72,7	39,9	22,7
III	LOD, MAZ PDL, POM, WAM,	199	76,8	51,9	50,8	50,9	10,0

Table 13. Clusters of voivodships (see Table 12)

The largest losses of nitrates were recorded in Dolnośląskie (DLN), Lubuskie (LUS), Śląskie (SLS), Wielkopolskie (WLP), Zachodniopomorskie (ZAP). Most of the area of these voivodships fall in the river Oder and/or 10 small rivers discharging directly to the Baltic Sea catchments. In the remaining voivodships grouped in clusters, I and III nitrates losses were much lower and did not exceed 10 kg $N0_3$ – N ha^{-1}. The reason for the low losses of nitrate nitrogen in voivodships in the cluster I is prevalence of good soils. In voivodships of cluster III, the low nitrate losses could be explained by low quantity of NO_3 – N in soil in autumn and the lowest share of intensive crops in crop rotation. Most of the areas of these voivodship are located in Vistula catchment. Thus, the potential losses of nitrates to the ground water are higher in North – Western part of Poland than in South – Eastern one.

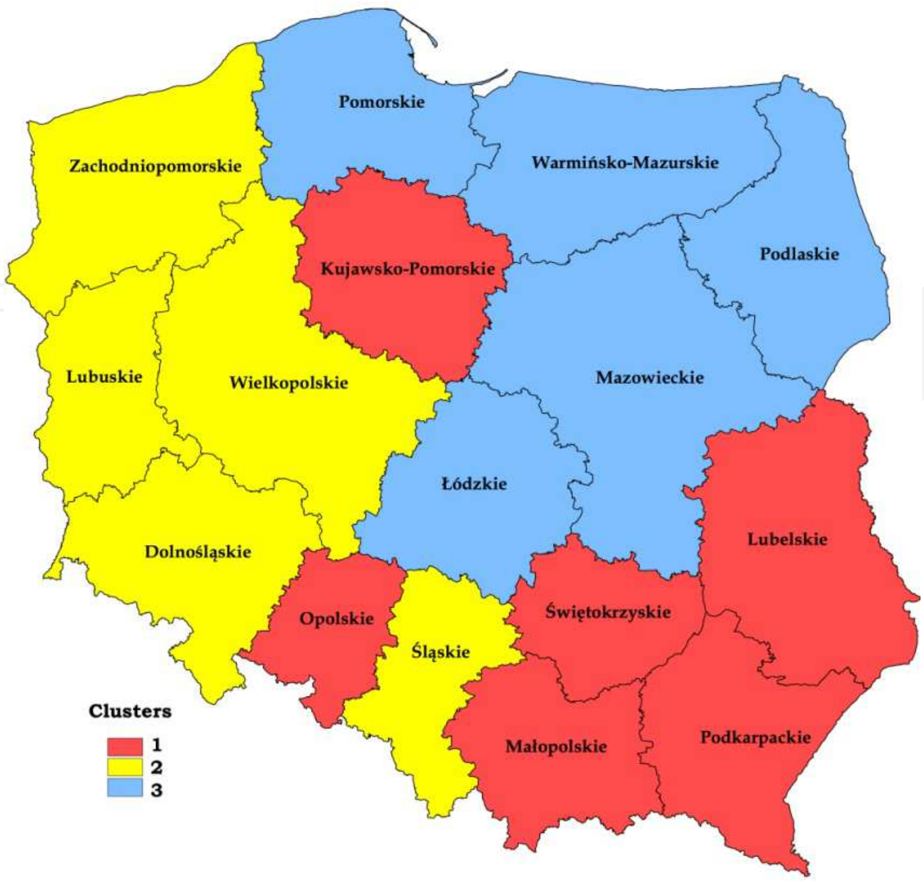

Fig. 2. Regional distribution of NO_3 – N losses over winter in Poland (kg N· ha^{-1}) (see Table 12)

The most effective way for delineating the area threatened by excess of nitrate in drinking water originating from agriculture would be the monitoring program of ground water quality. Such program has been indeed launched in 1997 together with the program of soil monitoring for mineral nitrogen (Igras, 2004). However, the monitoring sites for both programs were fixed separately. Besides, the number of sites of the ground water program was much lower than for N_{min} program. Since 2007, both programs have been merged, and until now the preliminary results are available (Jadczyszyn et al., 2010). Therefore the only representative data concerning nitrate concentration in ground water are showed in the present paper. Nevertheless, these data are simulated and need validation by comparison with the "true" concentration of nitrate in the ground water from the same sampling point. For these simulated data, the cluster analyses has been performed in order to group the voivodship according to the expected concentration of nitrate in the ground water. The percent of sampling points where this concentration exceeds the limit set by Nitrate Directive (Table 14) was also taken into consideration.
The simulated concentrations of nitrates in soil water widely differ among the voivodships. On the base of Table 14 it has been concluded that in five voivodships grouped in clusters III and IV the median of nitrate concentration is very high and only about 40% of soil samples is in accordance with the Nitrate Directive. The soils of remain 11 voivodships are in the range of the safe limit below 11,3 mg NO_3 – N·dm^{-3} but still in quite numbers of samples concentration of nitrate exceed this limit. The problem of delineating areas in Poland threatened by excess on nitrate in ground water needs further investigations, particularly in smaller than NUTS-2 territorial scales.

Cluster	Voivodship in the cluster	Median value mg NO_3-$N \cdot dm^{-3}$ water	% samples <11,3 mg NO_3 – N dm^{-3}	Localization of voivodship in the cathment*
I	LUB, OPL, SWT	0,2	60	LUB, SWT – **V** OPL - **O**
II	DLN, MAL, MAZ, PDK, PDL, POM, SLS, WAM	8,0	55	MAL, PDK, MAZ, PDL, WAM – **V** POM – **V/R** SLS – **V/O** DLN - **O**
III	KUJ, LOD, ZAP	25,2	40	KUJ, LOD - **V/O** ZAP - **O/R**
IV	LUS, WLP	46,8	35	LUS, WLP - **O**

*V – Vistula, O – Oder, R - 10 rivers directly charged to the Baltic Sea

Table 14. Clusters of voivodships according to simulated concentration of nitrates in ground water

6. Conclusions

- In the paper the normative of mineral nitrogen content in arable soils in Poland are presented. These normative correspond to the percentile distribution of the values of NO_3-N and NH_4-N content in the country-wide monitoring programme.
- The five-classes normative (pentiles) are calculated for each of four soil textural classes separately. The method of recalculation the content of nitrate in bulk soil into its concentration in soil water (assuming soil saturation to full water capacity) is proposed.
- The method for simulating nitrate concentrations below the rooting zone was proposed.
- The regions of Poland with high risk of ground water pollution by downward placement of nitrate were designated.

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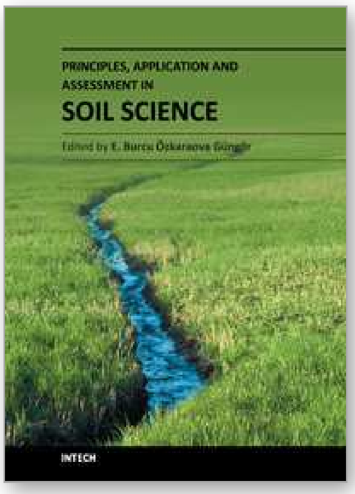

Principles, Application and Assessment in Soil Science
Edited by Dr. Burcu E. Ozkaraova Gungor

ISBN 978-953-307-740-6
Hard cover, 394 pages
Publisher InTech
Published online 22, December, 2011
Published in print edition December, 2011