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Soil productivity and its relation to the environment in the Czech Republic

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Abstract. Based on the evaluation of data from agricultural operations of 60 enterprises in the period 2012–2016 on 339 516 ha, frequent increases in nutrient dosages for production are mainly in marginal areas where higher production than is equivalent to optimal production on the soil is required. In the production of crops, it is most manifest in the production of feed crops, which are often used for the continuous flow of livestock production and biogas stations. Because of the above-standard utilization of fertilizers, yields rise above the level corresponding to the standard conditions for soil–climatic conditions, but also to decrease the efficiency of fertilizer utilization and thus to overload the optimal soil productivity. In contrast, the standard use of fertilizers is reflected in winter wheat, grain corn, triticale, potatoes and rye. Because of the lower strength of the humus horizon in marginal areas, it can be assumed that by increased fertilization, the agricultural enterprises solve the lower sorption capacity of the soil. The overall finding is also a warning to the occupation of quality land for non-agricultural purposes because their intensification cannot be transferred into marginal areas with no environmental impact.

1. Introduction

The economic effect of crop production determines the value of the agricultural land fund. This effect, however, is not only a result of soil quality as such but also depends on fertilization. Fertilizers P_2O_5, K_2O, as well as N are limiting crop yields at all sites [1]. In addition, fertilization increases efficiency and produces a better quality of product recovery in agricultural activities; it is one of the most critical techniques for crops [2]. Plant nutrition is one of the key factors in the intensification of production, which is limited by soil–climatic conditions and environmental constraints due to the protection of water resources and the prevention of soil degradation. Soil fertility is the integration of soil physical, chemical and biological properties, and therefore, there would be more merit to include the biological attributes to quantify soil fertility and predict crop yield in further research [3].

Nitrogen fertilization depends on many factors with varying yields. The options for expressing the value of land are for this purpose mainly based on the categorization of the agricultural land fund in the Czech Republic, which is based on the well-established valuated soil–ecological units (BPEJ). For the broader use of land value, other factors given local conditions can be used. For the selection of suitable indicators and compliance with the indicators described in the BPEJ code, the effect of nitrogen on crop yield as an integrating factor of production intensity is analysed. According to Zhang [4], the fertilization factor explains most of the crop yield variability (42%), while the soil organic carbon variance is primarily determined by the interaction of soil and climate factors (32%). Similar results were obtained by Voltr [5] when fertilization factors explain crop yield variability by 20% (for winter wheat). The effect of technology on soil preparation is also significant [6].

To determine soil fertility and the economic value of land, the basic standardization of soil and climatic conditions and economic evaluation of their relationship is used.

According to Neuberg *et al.* [7], the system of plant nutrition is based on the optimal utilization of the production and ecological conditions and the biological potential of the crops, taking into account to the maximum possible extent the economics of the manure measures and applies measures to avoid adverse environmental effects. In the recommended plant nutrition methodology, it was already stated in 1985 that it is necessary to optimize fertilization to the level of production and ecological conditions concerning the required quality of the harvest and the protection of the environment. Practical optimization of nitrogen fertilization includes not only doses but also forms, term and method of application of nitrogen fertilizers.

The need for nitrogen for plant nutrition changes throughout the year. For example, Zimolka *et al.* [8] reported about winter wheat that the proportion of nitrogen taken in the autumn is not more than 12% of total consumption and therefore applying high nitrogen doses before sowing is unnecessary and non-organic. Nitrogen pickup increases in the spring when plants have to regenerate biomass after winter. The growth of its pumping increases until the end of flowering. After flowering, plant nitrogen requirements are relatively low. At the end of the vegetation, up to 75% of nitrogen is accumulated in the grain. Converting to one tonne of grain and the corresponding amount of straw and wheat roots drains on average 25 kg nitrogen, Liu [9] concluded that a considerable amount of residual soil nitrate accumulated in the 0–200 cm soil profile was observed after crop harvest under 240 kg N ha^{-1} treatment, indicating a sizeable environmental risk of NO_3–N leaching loss, while the opposite was true of 120 kg N ha^{-1}. In addition, the current fertilizer management only NP fertilizers applied could lead to an imbalance in soil nutrients, and managers in this region should pay more attention to balanced fertilization.

The excess availability of reactive N has resulted in diverse environmental problems [10]. Excessive use of manure and fertilizers can increase the amount of nitrates in the soil and therefore increase the risk of N leaching and N_2O and NO volatilization. Depending on the amount of nitrate in the soil, the type of soil and the amount of rainfall and use of water and nitrate by plants, nitrate can leach into surface and groundwater, contributing to pollution of drinking water and eutrophication of surface waters. Denitrification depends on the amount of organic matter, soil water content, soil oxygen supply, soil temperature, soil nitrate levels and soil pH. N_2O is a potent greenhouse gas and contributes to climate change. Nitric oxide (NO) also contributes to smog. A part of N in fertilizers and manure applied to the soil, and in a lesser degree in decaying plants, is transformed into ammonia (NH_3) and emitted into the air.

Soil productivity can contribute to different levels of crop production in this process. It is essential to what extent the farmers' approaches to the soil affect the above process. For this reason, the relationship of farmers' level of fertilization with soil quality was evaluated.

2. Materials and methods

To compare the fertilization of individual crops according to the soil production capacity, a database of fertilizer recordings was used at the enterprise level, according to the Crop Research Institute. A total overview of the evaluated crops is given in Table 1. A total of 1366 crop yields and fertilizers were evaluated, with a total area of 339 516 ha, which was evaluated for a total of 60 holdings.

The basis for comparing the level of fertilization with the soil's production capacity is the assessment of the size of the valuated soil–ecological units (BPEJ). The average production capacity of the land, according to the economic evaluation of the BPEJ, ranged from 10 to 26 CZK/m^2 (approximately 0.5 to 1.3 USD/m^2).

2.1. Valuation of the land

The primary indicators for determining soil fertility, productivity and profitability are defined by the physical characteristics of the soil and the climate supplemented with technical data related to crop production. The analysed soil characteristics are those of topsoil and subsoil texture, pH, chemical composition, humus content, soil absorption complex and soil moisture during the vegetation period [10]. The analysed climatic data relate to the average values of precipitation and soil temperature for a specific month at any given location, as collected by the Czech Hydrometeorological Institute. The analysed technological data relate to fertilizers, plant protection and tillage as well as the penetrometric resistance of the soil.

In the Czech Republic, the soil fertility and soil productivity are evaluated based on a soil system broken down by the genesis, moisture conditions and soil texture. It is composed of a total of 78 groups, the so-called main soil units (HPJ) [11]. These main soil units (HPJ) are based on the climate further classified into a total of 557 main soil–climatic units (HPKJ) and concerning land configuration, soil thickness and skeleton altogether 2 199 valuated soil–ecological units (BPEJ) are defined in the Czech Republic. Their characteristics allow for the quantification of the underlying physical properties of soil and climate and the follow-up soil productivity modelling also about the basic soil fertility factors.

The categorization and evaluation of agricultural land in the Czech Republic is used in some Acts and related legislation. It is also used to calculate payments associated with production potential or to limit the value of inputs. The BPEJ system is based consistently on the natural conditions and characteristics of the given soil and site. The BPEJ system is thus associated with soil assessment capabilities within the categories given by the characteristics of each unit of the valuation system.

All BPEJ are in evidence of the cadastral system, see Figure 1, marked with a five-digit number:

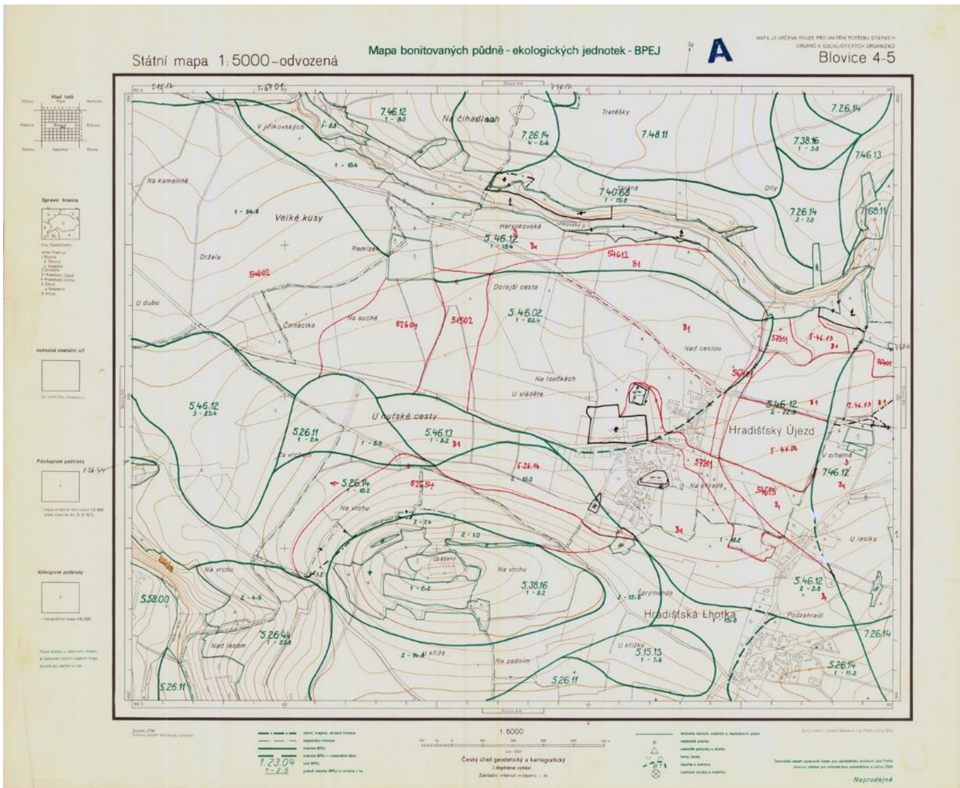

Figure 1. A sample of a BPEJ map on the terrain.

2.2. Determination of gross annual rental effect (HRRE)

Gross annual rental effect enables the definition of profitability of land in soil–climatic conditions [12, 13]. The procedures for calculating HRRE are designed to be used when calculating the land price as the main means for determining the profitability of land for a particular farming regime given by the selection of crops and the focus of production. The final land valuation depends on the choice of production orientation and the size of the price support.

Mathematically, the relation of the gross annual rental effect to a particular location can be determined according to relationship 1.

$$HRRE_{ipoz} = HRRE_i * k_{poz}, \quad (1)$$

where: HRRE is the gross annual rent effect of i^{th} BPEJ, $HRRE_{ipoz}$ is the gross annual rental effect of i^{th} BPEJ on the given plot, k_{poz} the HRRE adjustment factor for a particular BPEJ plot

$$HRRE_{i,p} = (CPP_{i,p} - NPP_{i,p}) * K_{i,p}, \quad (2)$$

where: $CPP_{i,p}$ is the price of parametrized production of p^{th} crop on i^{th} BPEJ, $NPP_{i,p}$ the normative cost of parameterized production of p^{th} crop on i^{th} BPEJ, normative costs are described in more detail for all technical operations, $K_{i,p}$ is a dimensionless number resulting from the percentage representation of the p^{th} crop in a given valuation type structure on i^{th} BPEJ (%).

2.3. Calculation of the BPEJ price

Calculation of the official BPEJ price (3) is derived from the adjusted relationship for the calculation of the perpetual rent.

$$UCZPi = BCZP + \frac{(HRREi + P) * (1 - \frac{DP}{100})}{U/100}, \quad (3)$$

where: UCZP is the official price of agricultural land (CZK/ha), BCZP is the basic price of agricultural land (CZK/ha), HRRE gross annual rental effect on BPEJ (CZK/ha), P is the amount to derive BPEJ (CZK/ha), Corporate income tax in %. The calculated rate is 21%, valid for 2015, U is the interest rate for capitalization of HRRE in %.

The dependency of yield on nitrogen dose is derived by equation 4:

$$Y = K + K1 * Ypred + k_2 * difN + sign(difN) * abs(k_3 difN^2), \quad (4)$$

where: K, k_1, k_2 and k_3 are constants, difN is the difference between the actual and the predicted nitrogen dose conditions, Ypred is the predicted yield value for BPEJ under conditions without the effect of actual nitrogen doses [5].

The dependence of predicted yield and nitrogen dose is derived from the statistical survey (2002–2010). Figure 2 shows the rates of yield dependence in different soil–climatic conditions in the percentage of optimal nitrogen consumption relative to the optimal nitrogen dose under given conditions, which is marked above the curve of 0. The standardized dose of N in the next calculation is developed from the optimal point for all crops and valuated soil–ecological units.

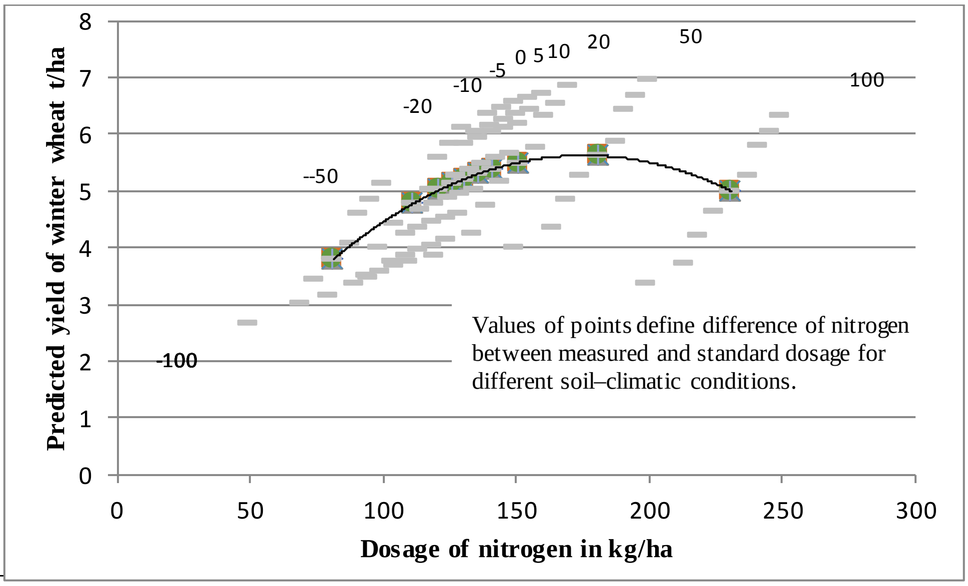

Figure 2. Rates of yield dependence in different soil–climatic conditions.

2.4. Fertilizing valuation

Fertilizing valuations for individual crops were evaluated by the balance of fertilizers with the OECD methodology [10], which are based on the so-called budgets, and the main emphasis is laid on nitrogen budget. The term 'nitrogen budget' is based on statistical dependencies for the major crops.

Table 1. Basic data of the evaluated crops.

Crop	Area (ha)				Yield (t/ha)						
	N	Sum	Minimum	Maximum	N	Mean	Minimum	Maximum	Std. Deviation	Geometric Mean	Variance
Potatoes	36	1330	0.38	188	36	25.97	22.40	30.48	2.50	25.85	6.27
Sugar beet	68	11252	12.00	458	68	63.88	57.75	69.73	2.84	63.82	8.05
Spring barley	170	34896	5.71	857	170	4.72	3.52	5.97	0.52	4.69	0.27
Winter barley	213	24415	3.00	289	213	5.45	4.21	6.34	0.50	5.42	0.25
Corn for silage	196	53100	19.00	1158	196	39.77	25.59	47.37	3.61	39.60	13.02
Corn for grain	113	28871	2.00	1988	113	7.65	6.26	8.82	0.55	7.63	0.31
Poppy	30	2918	4.00	274	30	0.88	0.69	1.03	0.08	0.88	0.01
Oat	55	2586	4.00	252	55	3.99	3.74	4.40	0.17	3.98	0.03
Winter wheat	208	118404	74.00	2674	208	6.11	4.52	7.37	0.54	6.08	0.29
Winter rape	189	54402	19.00	1058	189	3.27	2.74	3.73	0.19	3.27	0.04
Triticale	56	4819	8.00	259	56	5.28	4.46	5.72	0.39	5.26	0.15
Winter rye	32	2523	1.10	211	32	3.69	3.28	4.34	0.30	3.68	0.09
Total	1366	339516	152	9666	1366	171	139	195	12	170	29

The basis for the nitrogen account is built on the work of Leip *et al.* [14]. In this work, the nitrogen budget definition is used for the crop and the farm for a period of five years. A 'balance' is defined as: 'Ideally, the balance of a pool, a sub-pool, or a full Nitrogen Budget is closed, i.e., all nitrogen flows can be explained as input, output or stock changes. The balance equation is then Noutput +

Nstock_change – Ninput = 0. Such a closed N-balance is theoretically possible for each pool defined and for a full Nitrogen Budget. In practice, however, a closed balance is not a requirement of a Nitrogen Budget'.

Normative values for calculation of fertilizers' budget of crops and nutrient content of plants were used for conditions in the Czech Republic from plant nutrition methodology and fertilization and other papers [15, 16]. A global overview of the evaluated crops is given in Table 1.

Fertilizers' budget is given as follows:

Outputs:

Total nutrient consumption (main + by-product). Harvest nutrients are described with the average nutrient consumption of nitrogen, phosphorus, potassium, based on normative nutrient content on the base of kg of nutrients per tonne of crops and summarized according to the area of crops.

Inputs:

N, P_2O_5, K_2O for decomposition of straw, supply N, P_2O_5, K_2O by symbiotic fixation, a quick-release fertilizer with N, (inclusive with P_2O_5, K_2O), slow releasing fertilizers with N (inclusive with P_2O_5, K_2O), mineral fertilizers N, P_2O_5, K_2O

For each crop, the total nutrient supply according to the nutrient balance in the years 2012–2016 was evaluated by the nutrient dosages by the farm and the nutrients collected by the yield of the crop. The balance of nutrients collected by yield is based on the normative intake of fertilizers of VÚRV, calculated by Klír [15]. In the balance, nutrient outflows were also included in the by-product. The balance was determined using the following equations 5, 6:

$$Ny_{N,P,K} = \frac{X_{N,P,K}}{Y_p}; \tag{5}$$

$$Inp_{N,P.K} = d_{p\,N,P,K} * Y_p; \tag{6}$$

where $Ny_{N,P,K}$ is the nutrient dose per tonne of yield (kg/t), $X_{N,P,K}$ the nutrient dose kg/ha N, P_2O_5, K_2O, Inpp the nutrient intake by crops, dp the specific nutrient uptake by harvest, Yp the yield of p^{th} crop.

The total input and output balance are expressed by the nutrient input and crop intake for N, P_2O_5, and K_2O for each crop, enterprise and year of monitoring.

Comparison of the main final results for individual elements and applications of effective nitrogen fertilizers for selected crops is given in Table 2.

For evaluation of specific consumption of nitrogen according to the group of yield according to the division into 10 groups with percentiles was constructed as a graph (Figure 3). The graph illustrates, in the example of maize silage, that a low nitrogen yield per tonne of production is used on agricultural holdings at lower yield levels in percentiles than in other fertile areas. This link may be due to the greater need for silage maize in marginal areas due to the installation of biogas stations on farms that require increased doses of silage maize. The nitrogen dose may also be related to the P_2O_5 and K_2O dose and may also be dependent on the course of climatic conditions in the harvesting year. For this reason, a statistical evaluation of the data yields, N, P_2O_5 and K_2O doses by years using the linear models in the IBM-SPSS version 17 program was used in the following procedure. Because of the same database for different crops, the price of land that characterizes land profitability was used to compare nitrogen doses. These data also included dates for other crops to assess the rate of intensification of nitrogen fertilization. For the unification of the data, the economic value of the soil solvency—yield of the land according to relations 1–5—which are subject to the update of the input values of the income and costs, was used and the derived yields of the soil based on the average of years 2011–2015 were used in this model.

Table 2. Applications of effective nitrogen fertilizers for selected crops.

Soil quality (CZ crowns/m^2)	Winter barley				Maize silage				Winter wheat			
	Balance N per ton of output	Balance P_2O_5 per ton of output	Balance K_2O per ton of output	Dosage kg of N per ton of output	Balance N per ton of output	Balance P_2O_5 per ton of output	Balance K_2O per ton of output	Dosage kg of N per ton of output	Balance N per ton of output	Balance P_2O_5 per ton of output	Balance K_2O per ton of output	Dosage kg of N per ton of output
10	13.31	3.19	9.92	22.24	4.86	1.05	0.48	6.17	1.48	-5.86	-10.21	24.54
11	26.45	3.83	13.72	34.82	4.27	1.24	0.76	5.55	1.19	-6.58	-9.63	23.88
12	10.74	-7.52	-12.08	30.68	10.76	6.01	6.88	9.22	5.85	-9.19	-13.80	30.11
14	5.33	-5.99	-9.21	24.48	5.69	1.95	1.22	6.74	5.72	-3.43	-6.06	27.66
15	13.64	-4.20	-2.45	29.13	3.29	1.28	0.42	5.14	7.78	-5.76	-4.79	28.98
16	6.64	-8.14	-8.16	24.54	3.07	1.64	-2.05	5.59	9.45	-5.13	-1.44	29.35
17	7.80	-2.62	-0.51	23.14	4.64	0.83	-0.33	6.53	3.09	-4.51	-4.71	24.67
18	4.63	-7.09	-9.48	24.36	2.09	0.60	-1.47	4.43	3.17	-5.68	-6.76	25.28
19	5.93	-3.87	-4.24	23.31	2.20	-0.03	-2.57	4.97	5.86	-4.22	-3.26	26.85
20	-1.30	-4.74	-9.12	16.84	0.30	-0.09	-2.69	3.31	10.53	-0.29	-2.70	31.38
21					0.00	-0.63	-3.74	3.50	-1.01	-4.63	-6.03	20.44
22	28.73	-7.80	-6.00	45.73	1.25	-0.18	-2.36	4.34	7.05	-0.78	-2.87	29.61
23					3.20	0.33	-2.12	6.11	19.45	-6.43	-5.15	40.96
24					1.69	-1.09	-4.60	5.39	37.99	-8.72	-10.72	61.16
26					-1.01	-0.87	-3.11	2.69	-4.54	-4.50	2.42	16.63
Average	8.11	-3.81	-3.70	24.46	2.81	0.66	-1.21	5.10	7.42	-3.80	-4.38	28.91

The graph illustrates, in the example of maize silage, that a low nitrogen yield per tonne of production is used on agricultural holdings at lower yield levels in percentiles than in other fertile areas. This link may be due to the greater need for silage maize in marginal areas due to the installation of biogas stations on farms that require increased doses of silage maize. The nitrogen dose may also be related to the P_2O_5 and K_2O dose and may also be dependent on the course of climatic conditions in the harvesting year. For this reason, a statistical evaluation of the data yields, N, P_2O_5 and K_2O doses by years using the linear models in the IBM-SPSS version 17 program was used in the following procedure. These data also included dates for other crops to assess the rate of intensification of nitrogen fertilization. For the unification of the data, the economic value of the soil solvency—yield of the land according to relations 1–5—are subject to the update of the input values of the income and costs, was used and the derived yields of the soil based on the average of years 2011–2015 were used in this model.

Nitrogen dose Ns as an independent variable in linear models related to the intensity of production based on the relationship 7:

$$Ns = \frac{Ntot}{Ytot}, \tag{7}$$

where Ntot: total nitrogen per hectare, Ytot: total crop yield per hectare.

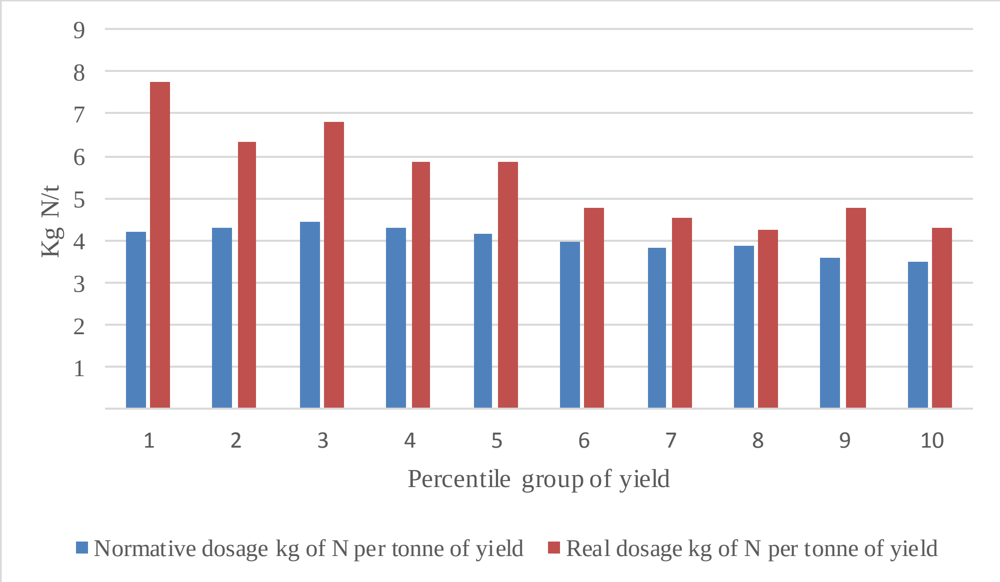

Figure 3. Specific consumptions of nitrogen per tonne of the yield of maize silage.

3. Results

3.1. Results of linear models

Linear models depend on the data of agricultural farms according to the area of each crop. For this reason, linear models were calculated using weighted values of acreage (Table 3).

Table 3. Model Summary[a].

Crop	R[a]	R Square	Adjusted R Square	Std. Error of the Estimate
Grain corn	0.166	0.028	0.027	7.20116
Oat	0.554	0.306	0.305	6.27548
Poppy	0.779	0.607	0.606	34.82108
Potatoes	0.866	0.750	0.750	0.92781
Winter rape	0.324	0.105	0.105	17.81356
Silage maize	0.321	0.103	0.103	2.78136
Spring barley	0.552	0.305	0.305	5.86287
Winter triticale	0.122	0.015	0.014	7.77036
Winter barley	0.526	0.276	0.276	7.49721
Winter rye	0.451	0.203	0.202	8.12836
Winter wheat	0.441	0.194	0.194	9.56603

[a]Predictors: (Constant), year, soil productivity level, K_2O dose, P_2O_5 dose

Coefficients show a relatively low value, which is mainly justified by the individual conditions of agricultural holdings, but relatively few explanatory variables are presented in the models, and the models are significant at the 1% level (Table 4). The number of variables robustly achieved by the coefficient of determination is mostly unchanged, see adjusted R square.

Table 4. ANOVA[a,b] statistics of models.

	Model	Sum of Squares	df	Mean Square	F	Sig.
Grain corn	Regression	41998.648	4	10499.662	202.475	0.000[a]
	Residual	1484917.900	28635	51.857		
	Total	1526916.548	28639			
Oat	Regression	43428.496	4	10857.124	275.690	0.000[a]
	Residual	98303.743	2496	39.382		
	Total	141732.239	2500			
Poppy	Regression	4481668.492	4	1120417.123	924.049	0.000[a]
	Residual	2900779.479	2392	1212.508		
	Total	7382447.971	2396			
Potatoes	Regression	3421.433	4	855.358	993.631	0.000[a]
	Residual	1137.558	1321	.861		
	Total	4558.991	1325			
Winter rape	Regression	1983095.740	4	495773.935	1562.365	0.000[a]
	Residual	16939847.916	53384	317.323		
	Total	18922943.656	53388			
Silage maize	Regression	44803.710	4	11200.928	1447.901	0.000[a]
	Residual	390181.414	50437	7.736		
	Total	434985.124	50441			
Spring barley	Regression	509577.678	4	127394.419	3706.207	0.000[a]
	Residual	1162422.366	33818	34.373		
	Total	1672000.044	33822			
Winter triticale	Regression	4424.427	4	1106.107	18.320	0.000[a]
	Residual	290644.313	4814	60.378		
	Total	295068.740	4818			
Winter barley	Regression	513626.347	4	128406.587	2284.485	0.000[a]
	Residual	1346066.179	23948	56.208		
	Total	1859692.526	23952			
Winter rye	Regression	41649.213	4	10412.303	157.594	0.000[a]
	Residual	163373.333	2473	66.070		
	Total	205022.546	2477			
Winter wheat	Regression	2491436.518	4	622859.130	6806.544	0.000[a]
	Residual	10328676.636	112871	91.509		
	Total	12820113.155	112875			

[a.] Predictors: (Constant), year, soil productivity level, K_2O dose, P_2O_5 dose
[b.] Dependent Variable: Dose of nitrogen per tonne of yield (kg/t).

Independent variables for all models for dependent variables are soil productivity level, dose of P_2O_5 and K_2O and year.

The results show that soil productivity as an independent variable is significant at 1% level for all used crops. The level in Table 5 in one part of crops is increasing—blue colour for grain corn, potatoes, winter rape, triticale, rye, winter wheat, but with red colour for decreasing Ns for soil productivity level is marked oat, poppy, silage maize, spring barley, sugar beet, spring and winter barley.

Table 5. Linear models.

Crop	Variables	Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.

Grain corn	(Constant)	169.809	78.625		2.160	0.031
	Soil productivity level	0.236	0.020	0.071	12.039	0.000
	P_2O_5 dose	-0.019	0.002	-0.114	-11.220	0.000
	K_2O dose	-0.004	0.001	-0.033	-3.241	0.001
	year	-0.075	0.039	-0.011	-1.915	0.055
Oat	(Constant)	1 607.632	213.700		7.523	0.000
	Soil productivity level	-0.379	0.042	-0.159	-9.037	0.000
	P_2O_5 dose	0.199	0.009	0.820	22.897	0.000
	K_2O dose	-0.055	0.005	-0.395	-10.837	0.000
	year	-0.787	0.106	-0.128	-7.420	0.000
Poppy	(Constant)	-10 123.107	1 182.255		-8.563	0.000
	Soil productivity level	-8.920	0.522	-0.263	-17.080	0.000
	P_2O_5 dose	0.813	0.020	0.631	41.110	0.000
	K_2O dose	-0.049	0.015	-0.045	-3.321	0.001
	year	5.151	0.588	0.117	8.753	0.000
Potatoes	(Constant)	-568.974	55.408		-10.269	0.000
	Soil productivity level	0.032	0.011	0.045	2.952	0.003
	P_2O_5 dose	0.006	0.001	0.155	4.953	0.000
	K_2O dose	0.013	0.001	0.670	23.725	0.000
	year	0.283	0.028	0.170	10.290	0.000
Winter rape	(Constant)	9 352.982	132.702		70.481	0.000
	Soil productivity level	0.509	0.025	0.086	20.136	0.000
	P_2O_5 dose	0.075	0.003	0.140	21.420	0.000
	K_2O dose	0.014	0.002	0.046	6.890	0.000
	year	-4.623	0.066	-0.290	-70.134	0.000
silage maize	(Constant)	-470.886	21.107		-22.309	0.000
	Soil productivity level	-0.158	0.004	-0.188	-39.756	0.000
	P_2O_5 dose	0.014	0.000	0.221	29.787	0.000
	K_2O dose	-0.002	0.000	-0.041	-5.269	0.000
	year	0.237	0.010	0.096	22.644	0.000
Spring barley	(Constant)	1 572.429	53.328		29.486	0.000
	Soil productivity level	-0.874	0.010	-0.409	-88.836	0.000
	P_2O_5 dose	0.090	0.001	0.385	60.436	0.000
	K_2O dose	-0.011	0.001	-0.065	-10.036	0.000
	year	-0.766	0.026	-0.135	-28.931	0.000
Winter triticale	(Constant)	-649.771	215.164		-3.020	0.003
	Soil productivity level	0.018	0.046	0.006	0.394	0.693
	P_2O_5 dose	-0.088	0.012	-0.509	-7.213	0.000
	K_2O dose	0.040	0.006	0.468	6.602	0.000
	year	0.334	0.107	0.049	3.130	0.002
Winter barley	(Constant)	6 121.631	80.294		76.241	0.000
	Soil productivity level	-0.758	0.017	-0.272	-44.454	0.000
	P_2O_5dose	-0.022	0.003	-0.084	-7.636	0.000
	K_2O dose	0.027	0.002	0.180	15.551	0.000
	year	-3.023	0.040	-0.422	-75.787	0.000
Winter rye	(Constant)	-553.262	310.317		-1.783	0.075
	Soil productivity level	0.396	0.059	0.129	6.695	0.000
	P_2O_5 dose	0.232	0.016	0.419	14.876	0.000
	K_2O dose	-0.011	0.010	-0.031	-1.119	0.263
	year	0.281	0.154	0.033	1.823	0.068
Winter wheat	(Constant)	8 196.931	49.764		164.717	0.000
	Soil productivity level	0.100	0.010	0.028	10.393	0.000
	P_2O_5 dose	0.027	0.002	0.065	17.223	0.000
	K_2O dose	-0.004	0.001	-0.010	-2.702	0.007
	year	-4.059	0.025	-0.443	-164.208	0.000

The results show that agricultural holdings behave selectively for crop fertilization. Some crops, in marginal areas, are over-fertilized with nitrogen and are marked in red, these crops being typically fed in the production areas in a standard manner. These are mostly fed crops, but they are grown from more fertile areas with a profitability of CZK 15/m^2 and more and spring barley. For other crops labelled blue, these are mainly market crops, but these crops do not normally have an increase in N consumption above the normative limit. The role of P_2O_5 and K_2O in models is somewhat individual. It can be inferred from these results that increased doses of fertilizers for crop production in marginal areas are mainly based on the need to ensure higher production of livestock feed and to ensure the operation of biogas stations, which are used in the peripheral parts of Czech Republic for supply in Germany and Austria.

3.2. Summary of nitrogen use according to the profitability of land

The results are particularly interesting from profitability where sufficient funds in marginal territories due to subsidy titles allow the use of inefficient nitrogen doses for crop production.

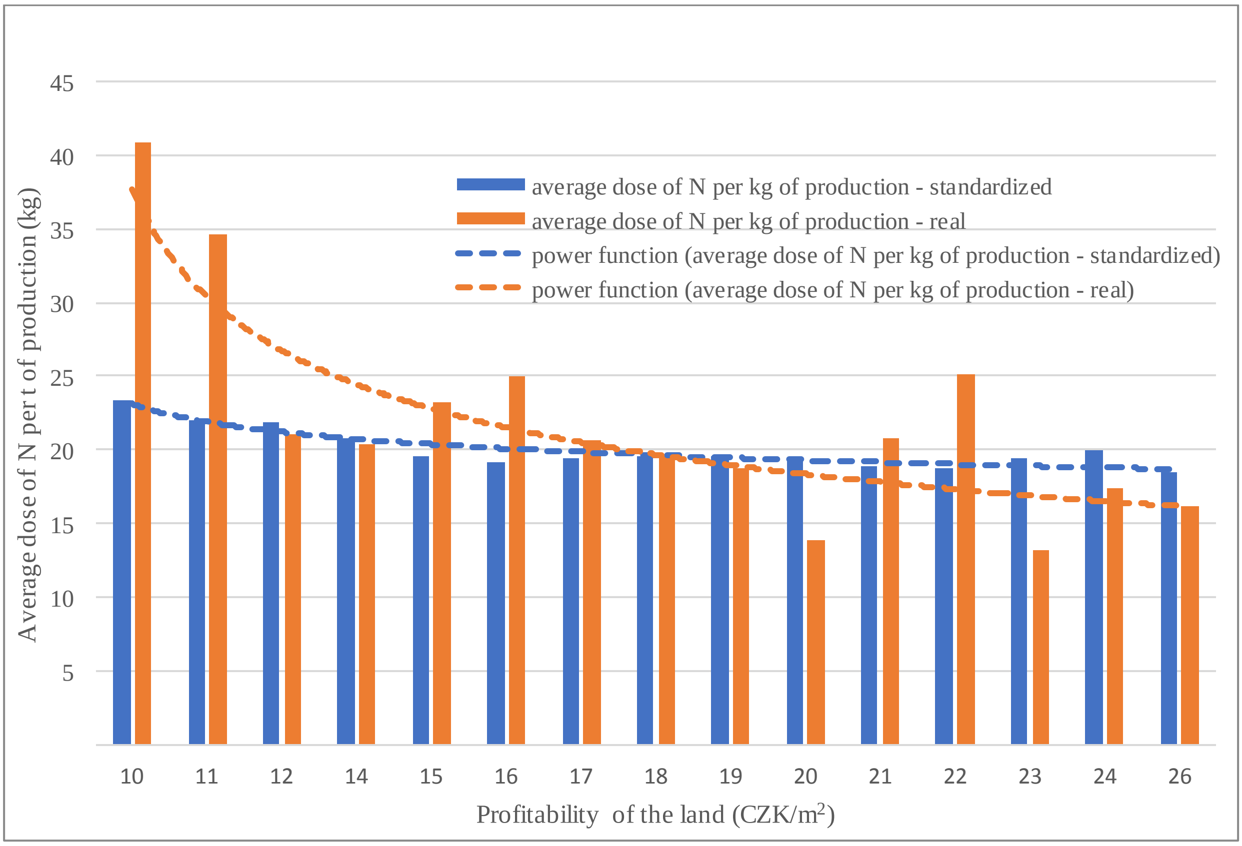

Figure 4. The weighted average of a dose of N per tonne of production for all selected crops.

The result of the findings mainly affects the deteriorating ecological parameters of the soil in marginal areas that have not yet been subject to fertilizer management restrictions under the Nitrate Directive. The increased nutrient load has an impact on their crop resorption (Figure 4) and leads to the leaching of fertilizers into the water.

The overall average consumption per tonne of production, depending on the yield of the soil, shows that the trends described are the predominant average of the total of enterprises and crops, and in marginal areas, there is a higher nutrient supply than plants need for their growth.

4. Conclusion

Data on nutrient intake for crops from 60 agricultural holdings were obtained in 2012–2016. Data evaluation shows that in marginal areas there is increased fertilization with nitrogen fertilizers, especially for feed crops. Linear regression models for the main crops were developed, taking into account both the nitrogen fertilizer dose per tonne of production and the P_2O_5 and K_2O doses and the crop year of the crop that confirmed this trend. These conclusions are partly related to climate change, where farms may expect higher temperatures at higher elevations to support plant growth. Because of the lower strength of the humus horizon in the marginal areas, it can be assumed that by increased fertilization the agricultural enterprises solve the lower sorption capacity of the soil. This is also related to the need to provide feed for livestock production, along with the supply of biogas stations that often occur in marginal areas. At the same time, there is a demand for silage maize for foreign biogas stations.

The overall finding is also a warning to the occupation of quality land for non-agricultural purposes because their intensification cannot be transferred into marginal areas with no environmental impact.

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