https://doi.org/10.15414/isd2018.s4.20

AGRONOMIC EFFICIENCY AND ECONOMIC EFFECTIVENESS OF MINERAL NITROGEN FERTILIZERS IN WINTER

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Abstract

The paper deals with the assessment of agronomic and economic efficiency of winter wheat fertilization with mineral nitrogen fertilizers. The nitrogen dose for basic and regenerative fertilization was determined on the basis of soil analysis. Due to the higher N_{min} content in the soil than 60 kg.ha^{-1}, basic pre-seeding nitrogen fertilization in individual experimental years was omitted. Nitrogen and phosphorus dosages for production and qualitative fertilization were determined on the basis of the plant analysis, i.e. based on the total nitrogen and phosphorus content of the above-ground plant mass and the dry weight of 100 plants. Regenerative fertilization was carried out in the phase DC 25, liquid fertilizers were used for production fertilization in the phase DC 30 and qualitative fertilization (DC 59). Each fertilization treatment was repeated four times with a plot area of 10 m^2. The efficiency of winter wheat fertilization was assessed on the basis of the calculated coefficient of economic effectiveness (K_{EE}), the profitability of fertilization and the profit (Z) per hectare due to applied nutrition. The purchase price for winter wheat and for fertilizers valid for the given experimental year was used for the calculation.

Keywords: *optimization of fertilization, grain yield, coefficient of economic effectiveness, profit, growth phases*

JEL classification: *Q 19*

1 Introduction

Nitrogen taken up by plant from soil significantly influences whole growth-productional process of winter wheat (Olšovská et al., 2014). Except carbon, nitrogen is the main element forming plant biomass and leaf area resulting to photosynthetic performance of crop and yield formation (Lawlor, 2002; Krček et al, 2008; Slamka et al., 2014). An amount of yield depends on total amount of nitrogen accepted by root system as well as on efficiency of its utilization for photosynthetic process and assimilates allocation into grains (Nátr and Lawlor, 2005; Hay and Porter, 2006). Under the surplus of nitrogen its total amount taken by plants increases, but efficiency of its utilization can decrease.

A relatively complicated pathway of nutrients from the surface of the leaf to its internal structures, together with a limited movement inside the plant and a relatively small dose of single-applied nutrients, limit the effective use of foliar fertilizers. Using only leaf fertilizers can not address long-term deficiencies in plant nutrition by macroelements. Therefore, foliar fertilizers are used in plant nutrition for supplementary or prophylactic fertilization (Hlušek and Lošák, 2006; Vaněk et al., 2006; Vaněk et al., 2013). Under no circumstances can they replace the plant's nutrition from the soil through the roots. It is possible for microelements as well as magnesium, but achieving optimal effect often requires repeated spraying.

The economic efficiency of nitrogen fertilizers is of particular interest from agricultural practice. The reason for this is the fact that the purchase and application of nitrogen fertilizers is associated with increased expenses. It is well known (especially for nitrogen) that the profitability of fertilization is not only influenced by the amount of harvest achieved, but also by its quality. At the same time, the effects of nitrogen fertilizers on the quality of production can significantly influence the resulting economic effect of their use. It is known that the highest crop quality is achieved at lower nitrogen doses and lower yields of the main product (negative correlation applies). In the search for economic efficiency, it is therefore important to decide whether it is preferable to fertilize for the maximum harvest or for the best quality.

Higher doses of nitrogen increase costs and the profitability of fertilization decreases. This is also confirmed by our results from field trials in Báhoň. When winter wheat was cultivated the highest profitability of fertilization was achieved at a dose of 80 $kg.ha^{-1}N$, with the application of 200 $kg.ha^{-1}$ the yield was significantly lower (Hanáčková, 1995; Hanáčková and Slamka, 2011; Hanáčková, 2012). Finding the economic efficiency of soil fertilization with nitrogen is basically a search for optimal dose of nitrogen fertilizers. The optimal nitrogen dose is a dose that delivers the highest crop yields, quality, and profitability. Economic cost and profit indicators must show that an increase in applied nitrogen dose brings such a yield increase that is profitable in terms of the costs incurred for its implementation (Bielek, 1998; Bielek, 2008).

The aim of the work was to assess the influence of various combinations of solid and liquid mineral fertilizers on wheat grain yield and the economic efficiency of fertilization in a three-year small-scale field experiment.

2 Data and methodology

The small plot field experiment with winter wheat, variety PETRANA, was established at the plant breeding station in Sládkovičovo - Nový Dvor between 2002/2003 and 2004/2005 in order to verify the agronomic efficiency and economic efficiency of applied nitrogen fertilizers. The experimental site is characterized by a long-term normal rainfall of 500 mm per year and an average annual temperature of 10.5 ° C. The pre-crop of wheat was peas. The trials were based on a block method on medium heavy loam degraded blackearth. The agrochemical properties of the soil prior to the start of the experiment are shown in Table 1.

Table 1 **Agrochemical analysis of soil before starting the experiment**

Year	Content of available nutrients ($mg.kg^{-1}$)					pH_{KCl}	Humus (%)
	N_{min}	P	K	Mg	S		
2003	14,1	59	385	361	42	7,15	3,66
2004	13,5	55	365	352	39	6,96	3,55
2005	14,4	60	395	377	45	6,92	3,48

Source: Own processing, 2003-2005.

Nitrogen, phosphorus and sulfur doses and a summary of the fertilizers used in each of the fertilization variants are shown in Table 2 and Table 3.

The dose of nitrogen for basic and regenerative fertilization was determined on the basis of soil analysis (Michalík et al., 1986). Due to the higher N_{min} content in the soil than 60 $kg.ha^{-1}$, basic pre-seeding nitrogen fertilization in individual years was omitted. Nitrogen and phosphorus dosages for production and qualitative fertilization were determined on the basis of the plant analyses, i.e. based on the total nitrogen and phosphorus content in the above-ground plant mass and the weight of dry matter in 100 plants (Michalík and Ložek, 1986).

Table 2 **Doses of nutrients (average of years 2003 - 2005)**

Treat.	Fertilizers	Doses of nutrients (kg.ha-1)						
		regener.	productional			qualitative		
		N	N	P	S	N	P	S
0	No fertilization	-	-	-	-	-	-	-
1	LAD	43,7	-	-	-	-	-	-
2	LAD + DAM	43,7	30	-	-	-	-	-
3	LAD + DAM	43,7	30	-	-	15	-	-
4	LAD + DAM + FOSTIM	43,7	30	10	-	-	-	-
5	LAD + DAM + FOSTIM	43,7	30	10	-	15	5	-
6	LAD + dusadam	43,7	30	-	4,6	-	-	-
7	LAD + dusadam	43,7	30	-	4,6	15	-	2,3
8	LAD + DAM + DUFOS	43,7	30	10	12,5	-	-	-
9	LAD + DAM + DUFOS	43,7	30	10	12,5	15	5	6,25

Source: Own processing, 2003-2005.

Table 3 **Applied fertilizers in respective fertilization treatments**

Variant	Applied fertilizers			
	Basic fertilization	Regeneration fertilization	Productional fertilization	Qualitative fertilization
0	-	-	-	-
1	-	LAD	-	-
2	-	LAD	DAM	-
3	-	LAD	DAM	DAM
4	-	LAD	DAM + FOSTIM	-
5	-	LAD	DAM + FOSTIM	DAM + FOSTIM
6	-	LAD	DUSADAM	-
7	-	LAD	DUSADAM	DUSADAM
8	-	LAD	DAM + DUFOS	-
9	-	LAD	DAM + DUFOS	DAM + DUFOS

Source: Own processing, 2003-2005.

Regeneration fertilization with fertilizer LAD 27 (27% N) was carried out in the phase of DC 25 and for production fertilization in the phase of DC 30 and qualitative fertilization after earing before flowering (DC 59) the following fertilizers were used: DAM 390 (30% N), FOSTIM 8-24-0 (8% N, 10.56% P), DUSADAM 26-0-0-4 (26% N, 4% S) and DUFOS 9-11-6 (9% N,4.84% P, 6% S). Each treatment was repeated four times with a plot area of 10 m^2. After harvesting with a small harvester, grain yield of wheat was determined by weighing. Grain yields for individual fertilization variants are listed in Table 4.

The efficiency of winter wheat fertilization was assessed on the basis of the calculated coefficient of economic effectiveness (K_{EE}), profitability of fertilization and profit (Z) per hectare (Fecenko and Ložek, 2000) (Table 5). In the calculation the purchase prices of winter wheat and fertilizers valid for the given experimental year were used (Ložek et al., 2007).

3 Results and discussion

From the point of view of weather conditions in the three-year experimental period 2002/2003 to 2004/2005, it can be briefly stated that two years were favorable and one unfavorable. This fact positively influenced the 3 - year average grain yields of wheat in this experimental period on different fertilization variants and thus also average of all fertilization variants when the grain yield of them achieved 6.72 $t.ha^{-1}$ (Table 4). The statistical evaluation of winter wheat grain harvest over the three experimental years is shown in Table 4.

Table 4 **Grain yield of winter wheat (var. Petrana), average of 3 years**

Variant	Yield ($t.ha^{-1}$)				Relatively %	
	years				0 = 100 %	2,4,6,8 = 100 %
	2003	2004	2005	average		
0	5,18	6,75	6,60	6,177	100,0	-
1	5,40	7,16	6,91	6,490	105,1	-
2	5,55	7,41	7,09	6,683	108,2	100,0
3	5,58	7,52	7,16	6,753	109,3	101,0
4	5,60	7,58	7,20	6,793	110,0	100,0
5	5,65	7,67	7,27	6,863	111,1	101,0
6	5,58	7,46	7,14	6,727	108,9	100,0
7	5,60	7,57	7,20	6,790	109,9	100,9
8	5,71	7,70	7,31	6,907	111,8	100,0

Variant	Yield ($t.ha^{-1}$)				Relatively %	
	years				0 = 100 %	2,4,6,8 = 100 %
	2003	2004	2005	average		
9	5,73	7,83	7,38	6,980	113,0	101,1
Average	5,558	7,465	7,126	6,716	-	-
LSD $_{0,05}$ = 0,21$^+$ 0,17$^+$ 0,22$^+$ LSD years $_{0.05}$ = 0,05 $^+$ LSD treatments $_{0,05}$ = 0,13$^+$ $_{0,01}$ =0,24$^+$ 0,0,20^{++} 0,26^{++} $_{0,01}$ = 0,06^{++} $_{0,01}$ = 0,16^{++}						

Source: Own processing, 2003-2005.

LSD = least significant difference

The economic evaluation of the effect of applied nutrition on regenerative, production and qualitative fertilization of winter wheat is shown in Table 5.

These results show that on all fertilized variants (1 to 9), a statistically high increase in grain yield was achieved over non-fertilized control, with yield increments ranging from 0.313 $t.ha^{-1}$ to 0.803 $t.ha^{-1}$, i.e. from 5.1% to 13%.

The lowest grain yield increase was achieved at the regeneration fertilizer with LAD-27 fertilizer at a rate of 43.7 kg $N.ha^{-1}$ (var. 1), with an increase in grain yield of 0.313 $t.ha^{-1}$, i. e. by 5.1%. The profit per hectare was 11.69 €, fertilizer profitability was 34.4% and the coefficient of economic effectiveness (K_{EE}) was 1.34, that is 1 € spent on fertilizer purchase and its use brought a financial effect of 1.34 €.

The combination of nitrogen regeneration and production fertilization (var.2) 43.7 kg $N.ha^{-1}$ for regeneration and 30 kg of $N.ha^{-1}$ for production fertilization (in the form of DAM 390) increased the grain yield compared to the unfertilized control by 0.506 $t.ha^{-1}$, i.e. by 8.2%. The profit per hectare was 15.97 € and profitability represented 27.6%. The effect of production fertilization showed an increase in grain yield by 0.193 $t.ha^{-1}$ compared to regeneration fertilization which generated an increase in profit of 4.28 € $.ha^{-1}$.

Table 5 **Economic evaluation of winter grain yield increment as a consequence of fertilization (average of 3 years)**

Variant	Increment of yield		Costs for fertilizers and their application (€$.ha^{-1}$)	K_{EE}	Profit (€$.ha^{-1}$)	Rentability of fertilization (%)
	$t.ha^{-1}$	€$.ha^{-1}$				
0	-	-	-	-	-	-
1	0,313	45,71	34,02	1,34	11,69	34,4
2	0,506	73,89	57,92	1,28	15,97	27,6

Variant	Increment of yield		Costs for fertilizers and their application ($€.ha^{-1}$)	K_{EE}	Profit ($€.ha^{-1}$)	Rentability of fertilization (%)
	$t.ha^{-1}$	$€.ha^{-1}$				
3	0,576	84,11	73,19	1,15	10,92	14,9
4	0,616	89,96	76,28	1,18	13,68	17,9
5	0,686	100,18	100,74	0,99	- 0,56	- 0,6
6	0,550	80,33	59,82	1,34	20,51	34,3
7	0,613	89,52	76,01	1,18	13,51	17,8
8	0,730	106,62	90,02	1,18	16,60	18,4
9	0,803	117,27	121,36	0,97	- 4,09	- 3,4

Source: Own processing, 2003-2005.

K_{EE} = coefficient of economic effectiveness

The combination of nitrogen regeneration, production and qualitative fertilization at doses of 43.7 kg $N.ha^{-1}$ + 30 kg $N.ha^{-1}$ + 15 kg $N.ha^{-1}$, respectively (var.3) increased the grain yield of wheat compared to the non-fertilized control by 0.576 $t.ha^{-1}$, i.e. by 9.3%, with a profit of only 10.92 € ha^{-1}at 14.9% profitability of fertilization and K_{EE} = 1.15.

The addition of 10 kg of $P.ha^{-1}$ within production fertilization of wheat to nitrogen nutrition (var. 4) did not produce a statistically significant increase in grain yield compared to var. 2 (the increment was only 0.11 $t.ha^{-1}$). The profit per hectare at variant 4 has fallen from 15.97 € at variant 2 with only nitrogen nutrition to 13.68 €, so adding phosphorus to production fertilization was economically ineffective. An analogous situation occurred when phosphorus was also applied in qualitative fertilization at a dose of 5 kg $P.ha^{-1}$ together with nitrogen nutrition (var. 5). The highest profitability of fertilization (34.3%) and profit (20.51 € $.ha^{-1}$) was obtained in variant 6, i.e., when N + S were applied together within production fertilization in the form of DUSADAM fertilizer. The yield increase was 0.550 $t.ha^{-1}$, K_{EE} = 1.34.

A statistically significant yielding effect was obtained when phosphorus with sulphur were applied to nitrogen nutrition for production fertilization (var. 8) at doses of 10 kg of $P.ha^{-1}$ and 12.5 kg of $S.ha^{-1}$ and also by co-application of phosphorus (5 kg $P.ha^{-1}$) and sulfur (6.25 kg $S.ha^{-1}$) to nitrogen nutrition also for qualitative fertilization (var.9). In the case of production fertilization with phosphorus and sulfur added to nitrogen nutrition (var. 8), the grain yield compared to the nitrogen nutrition (var.2) increased by 0,224 $t.ha^{-1}$, but the profit per hectare increased only by 0.63 € from 15,97 € to 16,60 €.

For variant 9 where phosphorus was added to the nitrogen nutrition, and sulfur to both production and qualitative fertilization the crop yield increased compared to the applied nitrogen nutrition at variant 3 by 0.227 $t.ha^{-1}$, but the economic efficiency of this fertilization was negative, because it produced loss per hectare of 15.01 € ha^{-1} (compared to variant 3) and even with the nitrogen nutrition this variant (9) was economically ineffective (loss was -4.09 €.ha^{-1}), although it produced the highest grain yield increment of 0.803 $t.ha^{-1}$ from all experimental variants compared with unfertilized control. This situation confirms the current reality that input prices (fertilizers, fuels) are growing much faster than the prices of output production, which stagnate or even decrease in some commodities.

4 Conclusion

On the basis of the three-year results obtained, the following conclusions can be drawn:

1. Grain yields of winter wheat and the qualitative parameters were affected by fertilization and weather conditions.
2. The highest increase in grain yield of winter wheat of 0.803 $t.ha^{-1}$ was achieved by joint application of N, P and S in production and quality fertilization (variant 9: DAM + DUFOS), but the cost of fertilizers and their application were higher than the yield increment, resulting in a loss of 4.09 € .ha^{-1}. The inefficiency of fertilization was also confirmed by the K_{EE} value (K_{EE} = 0.97).
3. Despite the increase in grain yield by 0.686 $t.ha^{-1}$ and achieved favorable qualitative parameters, i.e. content of crude protein =12,8% (class A) wet gluten = 30.0% (E), bulk density = 806 gl^{-1} (E), fertilization was unprofitable (-0.6%) for foliar application of fertilizers DAM + FOSTIM at production and qualitative fertilization (var. 5). The loss was - 0.56 €.ha^{-1}, K_{EE} = 0.99.
4. The highest profitability of fertilization (34.3%) and profit (20.51 € .ha^{-1}) was achieved in variant 6, i.e. when N + S were co-applied within production fertilization in the form of DUSADAM fertilizer. The grain yield increase was 0.550 $t.ha^{-1}$, K_{EE} = 1.34. At the same time, the quality parameters monitored corresponded to class A (content of crude protein = 12.7%, wet gluten = 29.2%) and to class E (bulk density = 805 $g.l^{-1}$).

Acknowledgments

This work was co-funded by European Community under project no 26220220180: *Building Research Centre „AgroBioTech"*.

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