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ASSESSMENT MODEL FOR THE IMBALANCE IN N AND PK FERTILIZATION FOR MAIZE: CASE STUDY FOR THE WESTERN PART OF ROMANIA

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ABSTRACT

The main aim of the study was to assess the profit increase in maize, starting from the yield response according to the nitrogen quantity applied on different PK backgrounds. Answers were searched for on the causes for the low interest in applying nitrogen fertilizers for maize in Romania. Maize yield response curves were determined according to quantities of N and PK, respectively, based on results of yield trials performed at the Didactic Station Timisoara of Banat`s University of Agricultural Sciences and Veterinary Medicine, during the period between 2013 and 2015. The production functions obtained facilitated the determination of adjusted yield values, based on the N quantities in the 0-200 kg range, active ingredient (a.i.) ha^{-1} for multiples of 50 for different PK levels, within the 0-150 kg range, a.i. ha^{-1}. Four distinct cases were analyzed, the average during 2013-2015 and each year independently. The slope (m), indicating the tangent the straight line creates with the abscissa axis, represented an indicator of the growth speed of the dynamic process represented by the yield in relation with the allotted N and PK doses. The slope related to the PK = 0 up to PK = 150 levels, displayed a growing trend ($m_{2013\text{-}2015}$ = 11.4-23.4; m_{2013} = 11.2-27.73; m_{2014} = 9.8-24.8; m_{2015} = 13.1-19.1), as the four sets of data analyzed strengthen the level of trust in a well-known principle of physiology and nutrition of plants - the synergic effect of nutrition factors. Such results confirm, as a potential cause for the low interest of some farmers for intensive N fertilization, the particular soil fund reduced in P and K, taking into account the lack of agricultural support policies with medium and long-term effects.

Keywords: fertilization, maize, optimization, slope, synergic effect.

INTRODUCTION

Nutrition deficiency of crops, as consequence of imbalanced and undersized fertilizations, is an actual issue for the vegetal production in several countries, and particularly, Romania (Dumitru, 2002; Hera, 2010; Rawashdeh and Sala, 2016). The insufficiency of nutritional elements, as compared to the biological requirements of crops, affects the physiological processes of plants and the production capacity, related to the yielding potential of cultivars and hybrids grown (Ding et al., 2005; Zhu et al., 2014; Jezec et al., 2015). Several studies, performed under various pedoclimatic conditions, highlighted the input of nutritional elements applied to the soil or by foliar means, over the vegetation indices, photosynthetic and the production for different agricultural crops, as maize benefits from special attention (Binder et al., 2000; Amanullah et al., 2014; Gul et al., 2015; Sala et al., 2015).

Of all nutritional elements, nitrogen is the element with the highest consumption in maize and the most visible impact on production, but balanced fertilization is much more efficient (Scharf et al., 2002; Law-Ogbomo and Law-Ogbomo, 2009; Ghaffari et al., 2011). The nitrogen fertilizer consumption, in agricultural crops, currently represents an indicator placing Romania in the lower half of such a table, according to the data supplied by European statistics (Eurostat, 2015). By relating the nitrogen consumption to the total used agricultural area (UAA), an increase was noticed, from the average level of approximately 17 kg ha^{-1}

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in 2006, to approximately 26 kg ha^{-1} in 2010, and 35 kg ha^{-1} in 2014. Compared to similar indicators, in Germany, the average of the latest years indicates values of approximately 100 kg ha^{-1}, in France, 75 kg ha^{-1}, in Poland, 60 kg ha^{-1}, and in Hungary, approximately 50 kg ha^{-1} (Eurostat, 2015). Certainly, the aforementioned values for Romania increase if relation is made only to maize, but they are still inferior to the values performed within the performing European systems, but also inferior to the economically optimal ones supplied in the literature, which usually vary between 150-250 kg ha^{-1}, or even higher, under certain pedoclimatic and technological conditions (Karasu, 2012; Boldea et al., 2015).

Simultaneously, from the point of view of national fertilization with P and K, respectively, there is no particular standout compared to other European states (Eurostat, 2016). A previous study (Sala et al., 2016) established potential causes of insufficient fertilization with P and K in wheat crops. Being aware of the interaction mechanism between the N,P,K elements amongst themselves or with other nutrients (Wu et al., 2005; Akinnifesi et al., 2007; Mete et al., 2015; Rietra, 2015), one of the main directions of the study herein was to highlight particularly the yield differences generated by different PK levels in maize fertilized with nitrogen – suspecting, as potential cause for such a low interest from farmers for intensive nitrogen fertilization, particularly the reduced P and K soil availability and the existing nutritional imbalance (Dumitru, 2002; Hera, 2010) related to the nutritional requirements and the production potential of currently grown hybrids. The purpose of the study herein was to assess the opportunity of allotting nitrogen and to therefore determine potential causes related to deficient fertilization in maize crops, under the current conditions in Romania.

MATERIAL AND METHODS

Experimental site, soil and climatic condition

Experiments were organized within the Didactic and Experimental Station of the Banat`s University of Agricultural Sciences and Veterinary Medicine Timisoara during the period between 2013 and 2015.

The soil within the experimental field was cambic black, representative for the range of trials. The soil is structurally characterized by a 27% sand content, 28.1% dust, 44.8% shale, while chemically, by neutral reaction (pH = 6.92), good nitrogen supply (N_{total} = 0.183%), weak phosphorus supply (P = 13.74 ppm) and good potassium supply (K = 169.53 ppm), according to the interpretation limits and signification (Davidescu et al., 1981, NRDISSAE, 2011; Rusu et al., 2005).

Biological material, treatments and experimental design

The biological material was represented by hybrid DKC 5143. The applied N quantities ranged between 0-200 kg ha^{-1} and PK between 0-150 kg ha^{-1}, considered altogether as a variable in the present study. The trial was designed in randomized blocks, in three repetitions.

Mathematical models

The response curve for the maize yield was determined based on the nitrogen quantities, as well as phosphorous and potassium quantities cumulated, using the production function presented in relation (1). Thus, the achievable values were envisaged for the allotment of nitrogen, located in the ascending segment of the production function, before reaching the technical maximum.

$$Q(N,PK) = a \cdot N^2 + b \cdot PK^2 + c \cdot PK + d \cdot N + e \cdot PK + f \quad (1)$$

Coefficients of the response functions were determined using the Wolfram Alpha application. Calculations were performed as four data sets, the average for the three years and separately, for each experimental year (2013, 2014 and 2015, respectively). After establishing the production function, values were adjusted, with yields being estimated for the possibility of allotting increased nitrogen quantities (N_0, N_{50}, N_{100}, N_{150}, N_{200}) for different fixed levels of PK (PK_0, PK_{50},

PK_{100}, PK_{150}). The estimation of the speed of production growth according to the factors of production (fertilizer in this case), was made using slope "m" ($m = \left(\frac{Q_{N=200} - Q_{N=0}}{200} \right) \Big|_{PK=0,\ldots,150}$).

Costs and rates

The study was performed considering the capitalization price for maize (BRM, 2016) and fertilizer purchase costs, respectively, as an average approximation of the market for 2015-2016.

RESULTS AND DISCUSSION

The differentiated fertilization with N and the PK complex, in the conditions of the trials, lead to a variation in the maize yield among experimental options, as well as in time, for the study duration. The results obtained are shown in Table 1, while the distribution of values by experimental years is shown in Figure 1.

Table 1. Maize yields based on nitrogen quantities and cumulated phosphorous and potassium quantities ($kg \cdot ha^{-1}$)

N and PK doses (kg a.i. ha^{-1})		Maize yields during the study period (kg ha^{-1})			
N	PK	2013	2014	2015	Average
0	0	3370	3207	2315	2964.0
100	0	4505	4210	3560	4091.6
200	0	5835	5620	4780	5411.6
50	50	4565	4325	3710	4200.0
100	50	5310	5180	4485	4991.6
200	50	6690	6580	5530	6266.6
100	100	5560	5345	4520	5141.6
150	100	6855	6610	5265	6243.3
200	100	8190	7940	6115	7415.0
150	150	5920	5805	5170	5631.6
200	150	7415	7180	6235	6943.3

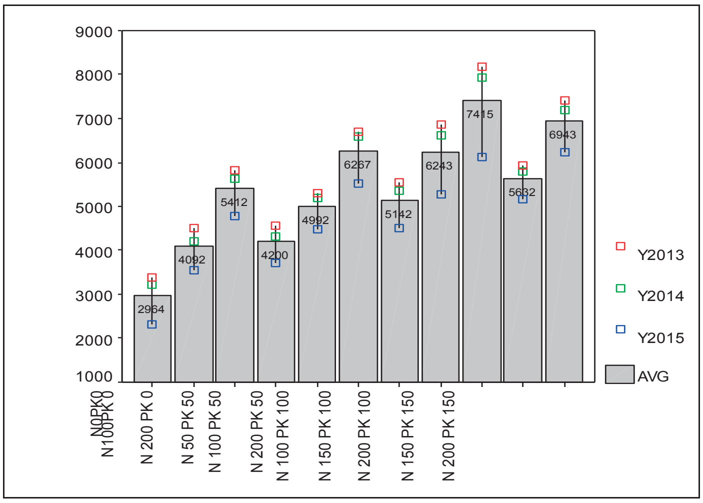

Figure 1. Maize yield ($kg \cdot ha^{-1}$) based on nitrogen quantities and cumulated phosphorous and potassium quantities ($kg \cdot ha^{-1}$)

The average of the 2013-2015 values led to the production function presented as the one in relation (2).

$$Q(N, PK) = 0.00\ N^2 - 0.15\ PK^2 + 0.08\ N \cdot PK + 11.41\ N + 16.54\ PK + 2962.66 \quad (2)$$

The value of the N^2 coefficient was found to be quite close to zero (coefficients were expressed by rounding to two decimals). This fact indicated an almost linear increase in yield based on the applied nitrogen doses, for values lower than the technical maximum. In the event that the experimental values had surpassed the nitrogen technical maximum, the N^2 coefficient would have shown a negative value, indicating a descending production trend for that particular range. Thus, the subject of this study was not to physiologically analyze the development of maize plants and crop under the effect of nitrogen, but the focus was solely on the economic segment for allotment of nitrogen, within the 0-200 kg ha^{-1} value range.

Starting from the expression of the production function Q(N,PK), Table 2 shows the adjusted yield values, according to the allotted nitrogen quantity (between 0 and 200 kg/ha, for multiples of 50), at different PK fertilization levels. The graphical distribution shown in Figure 2, indicates the (adjusted) evolution trend of yield as a reaction to the variable nitrogen doses applied.

Table 2. Maize yield based on nitrogen quantities and cumulated phosphorous and potassium quantities at different levels (adjusted values, for the 2013-2015 period)

N	PK_0	PK_{50}	PK_{100}	PK_{150}
0	2962.6	3414.6	3116.6	2068.6
50	3533.1	4185.1	4087.1	3239.1
100	4103.6	4955.6	5057.6	4409.6
150	4674.1	5726.1	6028.1	5580.1
200	5244.6	6496.6	6998.6	6750.6
m	11.4	15.4	19.4	23.4

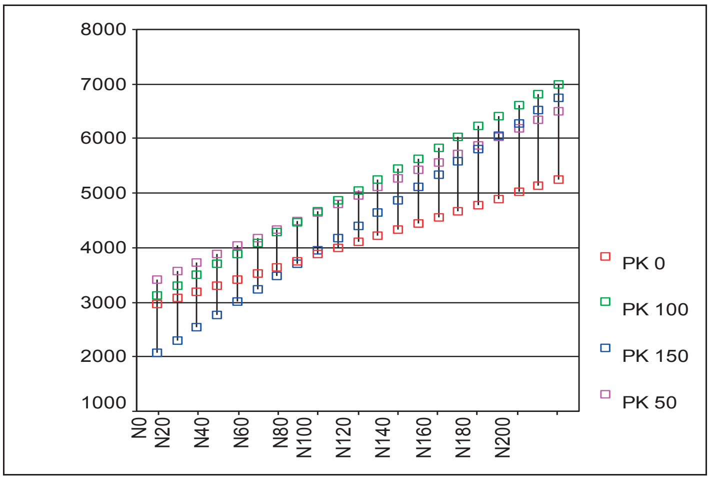

Figure 2. Graphical distribution of the maize yield (kg·ha^{-1}) based on the cumulated N and PK quantities (kg a.i. ha^{-1}) at different levels (adjusted average values, for the 2013-2015 period)

The slope (m), which in theoretical mathematics indicate the tangent of the angle of the straight line with the abscissa axis, it becomes a potential indicator of the growth speed of a dynamic process. Thus, if at the fertilization level PK = 0, the value of m is $m = \frac{5244.66 - 2962.66}{200} = 11.41$, at the level of PK = 150, it becomes m = 23.41. An increase in the growing speed of yield is noticeable, occurring as a response to the applied nitrogen doses, when the PK fertilization level is high.

Additionally, Figure 3 indicates the response to the applied PK doses, at different nitrogen levels (N = 0, N = 50, ..., N = 250). The Figure 3 shows that, for the range between PK = 0 and PK = 200, there is a maximum of the function and a descending portion characteristic to the segment where the PK doses exceed the technical maximum.

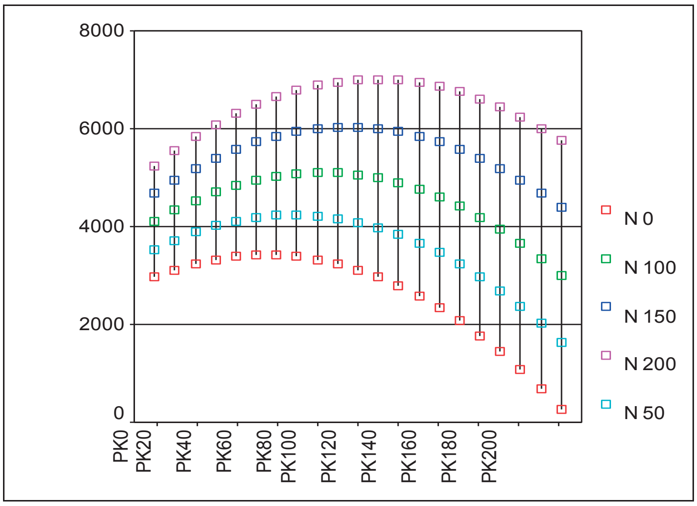

Figure 3. Graphical distribution of the maize yield (kg·ha^{-1}) based on the cumulated N and PK quantities (kg a.i. ha^{-1}) at different levels (adjusted average values, for the 2013-2015 period)

Similarly, the expression of the production function at the level of 2013 was determined by means of (3).

$$Q(N,PK) = 0.00\ N^2 - 0.18\ PK^2 + 0.11\ N \cdot PK + 11.23\ N + 16.77\ PK + 3352.15 \quad (3)$$

The adjusted values are presented in Table 3, and the graphical representations in Figure 4. The focus is, in the case as well, on slope values, with a tendency of growth simultaneous to the PK fertilization level.

Table 3. Maize yield (kg ha^{-1}) based on the N quantities, and the cumulated PK quantities (kg a.i. ha^{-1}), respectively, at different levels (adjusted values in 2013)

N	PK_0	PK_{50}	PK_{100}	PK_{150}
0	3352.1	3740.6	3229.1	1817.6
50	3913.6	4577.1	4340.6	3204.1
100	4475.1	5413.6	5452.1	4590.6
150	5036.6	6250.1	6563.6	5977.1
200	5598.1	7086.6	7675.1	7363.6
m	11.2	16.7	22.23	27.73

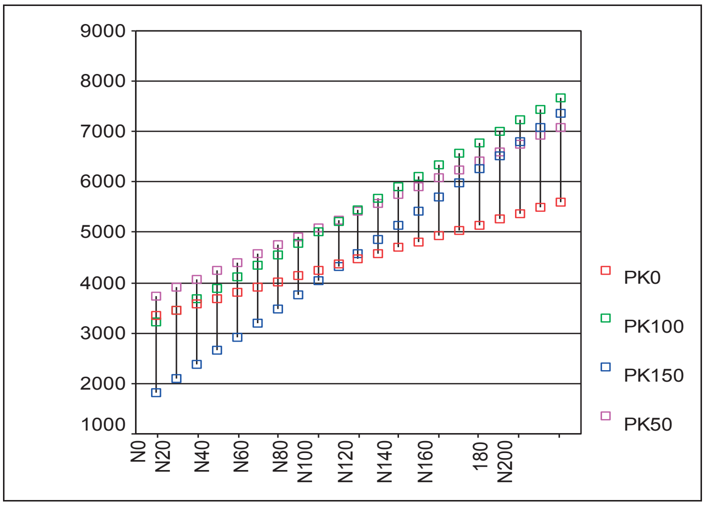

Figure 4. Graphical distribution of the maize yields (kg ha^{-1}) based on the N quantities, and the cumulated PK quantities (kg a.i. ha^{-1}), respectively, at different levels - adjusted values for 2013

The expression, based on the 2014 data, is shaped by relation (4).

$$Q(N, PK) = 0.00\ N^2 - 0.18\ PK^2 + 0.10\ N{\cdot}PK + 9.84\ N + 18.433\ PK + 3162.53 \qquad (4)$$

The data, obtained similarly to that previously calculated for year 2013, by adjustment, and the slope values, respectively, are shown in Table 4, while graphical distribution trends are presented in Figure 5.

Table 4. Maize yields (kg ha^{-1}) based on the N quantities, and the cumulated PK quantities (kg a.i. ha^{-1}), respectively, at different levels (adjusted values in 2014)

N	PK_0	PK_{50}	PK_{100}	PK_{150}
0	3162.5	3634.0	3205.5	1877.0
50	3654.5	4376.0	4197.5	3119.0
100	4146.5	5118.0	5189.5	4361.0
150	4638.5	5860.0	6181.5	5603.0
200	5130.5	6602.0	7173.5	6845.0
m	9.8	14.84	19.8	24.8

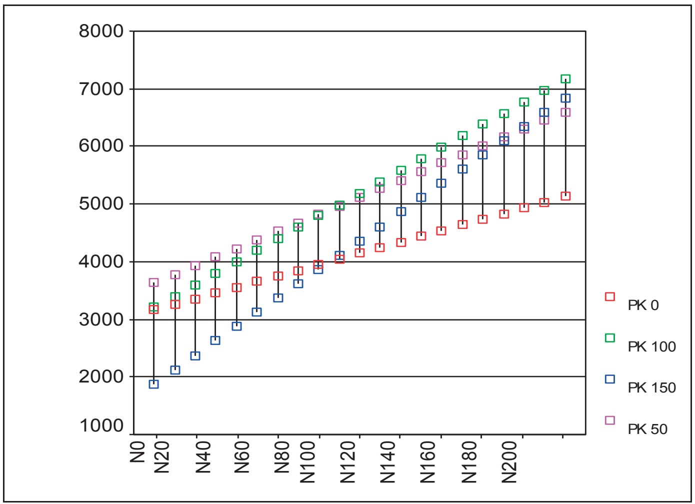

Figure 5. Graphical distribution of the maize yields (kg ha^{-1}) based on the N quantities, and the cumulated PK quantities, respectively, at different levels (kg a.i. ha^{-1}) - adjusted values for 2014

At the level of the year 2015, the production function has the shape offered by relation (5), and the adjusted values and graphical distribution are presented in Table 5 and Figure 6, respectively.

$$Q(N, PK) = 0.00\ N^2 - 0.09\ PK^2 + 0.04\ N{\cdot}PK + 13.15\ N + 14.41\ PK + 2373.28 \qquad (5)$$

Table 5. Maize yields (kg ha^{-1}) based on the N quantities, and the cumulated PK quantities, respectively, at different levels (kg a.i. ha^{-1}), adjusted values, in 2015

N	PK_0	PK_{50}	PK_{100}	PK_{150}
0	2373.2	2868.7	2914.2	2509.7
50	3030.7	3626.2	3771.7	3467.2
100	3688.2	4383.7	4629.2	4424.7
150	4345.7	5141.2	5486.7	5382.2
200	5003.2	5898.7	6344.2	6339.7
m	13.1	15.1	17.1	19.1

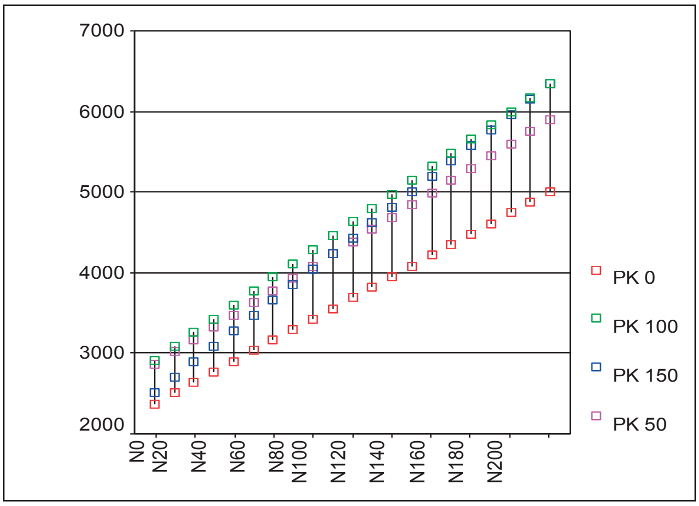

Figure 6. Graphical distribution of the maize yield (kg ha^{-1}) based on the N quantities, and the cumulated PK quantities, respectively, at different levels (kg a.i. ha^{-1}), adjusted values for 2015

It is notable that, in this case, as well, the slope of straight lines related to the PK=0 up to PK=150 levels, displayed a growing trend, as the four sets of data analyzed confirm a well-known principle of physiology and nutrition of plants - the synergic effect of nutrition factors, according to which an increase in the PK fertilization level (up to an optimal value) also leads to the increase in the capitalization degree of nitrogen reflected in the higher yield levels.

Was calculated average yield increase for 1 kg of nitrogen applied, for each of the analyzed PK levels. This was also taken into account because the indicator - the increase in the yield/kg N, is far more suggestive, directly and quantitatively indicating the effects of the adopted fertilization policies. The technical calculations concerning the yield response to the applied fertilizer doses allowed the determination of the average yield increase for each unit (1 kg) of nitrogen at different PK fertilization levels (Table 6 and Figure 7).

Table 6. Average maize yield increase for 1 kg of nitrogen, at different levels of cumulated phosphorous and potassium

PK fertilization levels	Average yield increase (kg ha^{-1}/1 kg N)			
	2013	2014	2015	Average 2013-2015
PK_0	11	9	13	11
PK_{50}	16	14	15	15
PK_{100}	22	19	17	19
PK_{150}	27	24	19	23

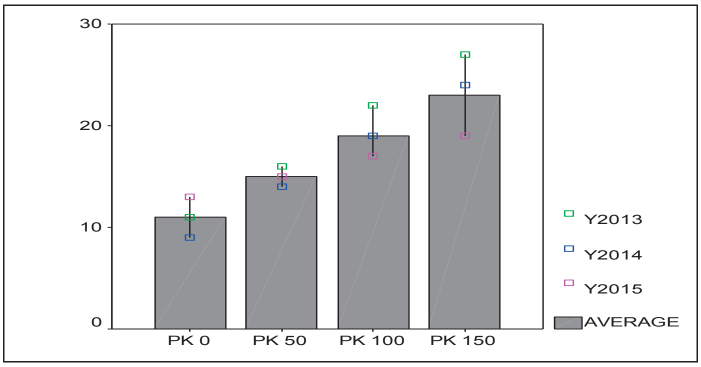

Figure 7. Graphical representation of average maize yield increase for 1 kg of nitrogen, at different cumulated PK levels

It is notable that the yield increase given by N is superior at high PK fertilization level, as the synergic effect of these fertilizers is well known. However, knowing the current Romanian trend for deficient application of P and K (Dumitru, 2002; Hera, 2010), one may conclude that the yield increase shows low values of 10-15 kg of maize / ha / 1kg N, for the majority of maize crops in Romania. According to the Romanian Commodities Exchange, the price of maize was rated at Lei 536 /ton, for the Banat area (approximately 0.119 €/kg). An increase of 10-15 kg of maize/ha/1kg N covers on the edge, without a high economic efficiency, fertilization expenses. In Table 7 and Figure 8, respectively, an overview is shown on the adjusted values of the average yield increase expressed in kg of maize/ha/1kg N, and the value profit value expression (€/ha/1 kg N), respectively, for a value of 1 €/kg of nitrogen. It is worth mentioning that technical fertilization expenses were not taken into account on this instance, which, in 2016, were at the approximate value of 15 €/ha per application (NIS). Table 7 also shows the major influence that the purchase price of the nitrogen fertilizer may bear. With known fluctuations on the current fertilizer market, even reduced variations in the purchase price of fertilizers may have disastrous economic consequences at the first PK fertilization levels, where the profit increase would not even achieve positive values. Figure 9 indicates the out-phasing of the profit increase for a 50% increase in the nitrogen price.

Table 7. Average increase in maize yield ($kg \cdot ha^{-1}$) for 1 kg active ingredient (a.i.) of N, and profit increase, at different cumulated PK levels (adjusted values)

PK level	Average yield increase (kg of maize/ha/1 kg N)	Profit increase (€/ha/1 kg N)
0	11.0	0.309
10	11.8	0.4042
20	12.6	0.4994
30	13.4	0.5946
40	14.2	0.6898
50	15.0	0.785
60	15.8	0.8802
70	16.6	0.9754
80	17.4	1.0706
90	18.2	1.1658
100	19.0	1.261
110	19.8	1.3562
120	20.6	1.4514
130	21.4	1.5466
140	22.2	1.6418
150	23.0	1.737

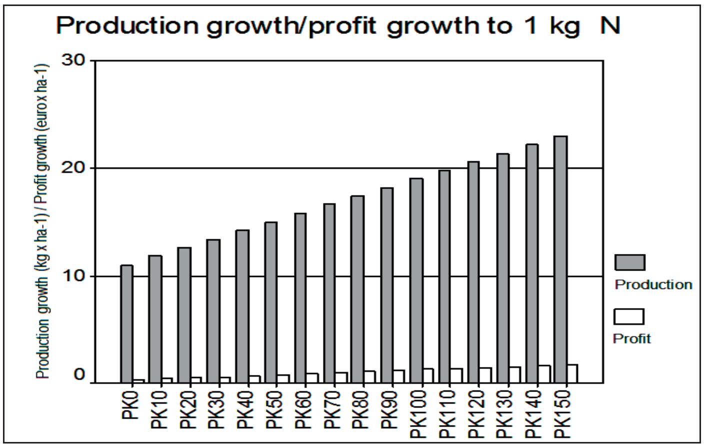

Figure 8. Average increase in maize yield ($kg \cdot ha^{-1}$) and profit ($€ \cdot ha^{-1}$) for 1 kg of N, at different cumulated PK (adjusted values)

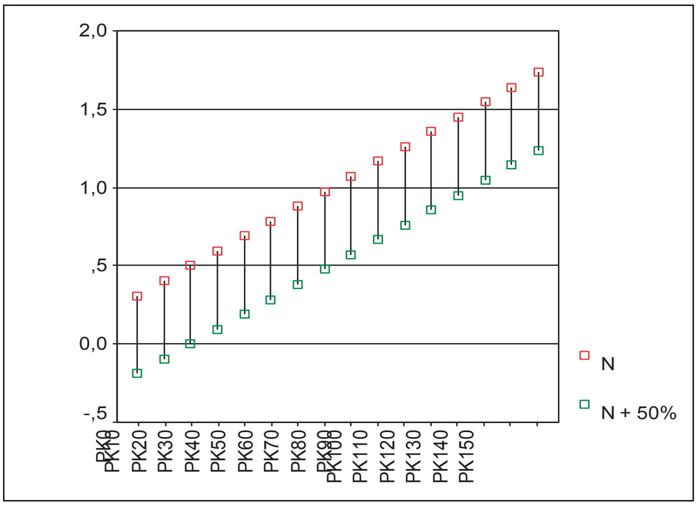

Figure 9. Graphical distribution of the profit increase under a 50% increase in the price of nitrogen

At the level of medium and large agricultural farms, adequate fertilization has become a firmly applied fundamental principle; however, this aspect does not apply to small farms. Statistics regarding average values of fertilization at the country level suggest that the national low average values are mainly due to users of small or subsistence farms, who do not adopt best fertilization practices and whose contribution to the food security is low (Graeub et al., 2015). Even if lately, Romania acknowledged a trend in agglomeration of agricultural surfaces, the degree of disintegration of agricultural surfaces persists. The large number of small agricultural farms shall probably be maintained in the following years, as well, and it is necessary thus to direct the means of approach related to the correction of the deficient means fertilization is performed in, towards such segment of agricultural entrepreneurs. Such issues were also identified within other higher-scale studies, in relation to the future of small farms regarding their sustainability and perspective (Hazell et al., 2008). Several high-value crops need considerable cash investment in grain, fertilizers and pesticides. Smaller farms are, however, less capable to obtain agricultural credits, as opposed to large farms, or to obtain inputs at comparable prices (Dorward et al., 2004, 2006).

Moreover, the instability trend of fertilizer prices, practiced in Romania, becomes quite significant at the level of the current period, perhaps due to the massive fertilizer imports our country required during the latest period, as the internal fertilizer production has been insufficient (NIS). As such, if large farms, by means of an efficient stock management system, can prevent the effects of such fluctuations, smaller farms are quite vulnerable to changes in the fertilizer expense structure, as small farmers have a first tendency to reduce the fertilizer costs (Plastina, 2016).

CONCLUSIONS

Due to a low level of fertilization with P and K (0-10 kg ha^{-1}), respectively, the average yield increase for 1 kg of nitrogen, applied to the surface unit (ha), is also low, approximately 10-12 kg ha^{-1}. Considering the current nitrogen purchase price and capitalization of maize, application of nitrogen is not very attractive. Beginning with the current fertility status and the known P and K deficit in the soils in Romania, the data of this study could be an important source of scientific information and arguments concerning the improvement in national fertilization policies. It is also noticeable that an increase in the PK soil enrichment effort would also indirectly assume an increase in the efficiency for use of nitrogen, thus immediately indicating a growing interest of several farmers concerning supplementation of nitrogen allotment to maize. This can also be accomplished by means of a long-term policy for supporting farmers' efforts in this particular regard.

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