EVOLUTION SCENARIO FOR THE AVERAGE WHEAT YIELD IN THE WEST OF ROMANIA

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Abstract

Unbalanced fertilization and insufficient use of N, P and K fertilizers are direct factors that bring variability in the quality and quantity of the wheat yield at a national level. However, taking into consideration the (upward) trend in the use of these fertilizing elements in the past few years, the aim of the present study was to estimate the evolution of the average wheat yield for the west of the country, if the same growth rate of the fertilization level is maintained. The theoretical values of the average yields were obtained with a production function that indicates the correspondence between the yield and the quantities of N and of PK used. The expression of the production function is known (Q=f(N, PK)), due to previous studies on the behavior of Alex wheat in experimental conditions at BUASVMT; these conditions are considered to be representative for the West Plain, which is the reference area. In concordance with the particular data, which are specific from a physiological point of view, as well as in what the soil conditions, climate and technology are concerned, the results of the study bring useful information on the area under research, which can be used locally and regionally as well. In addition, the model can be expanded to cover the economic efficiency of the wheat crop through fertilization and to indicate some degradation processes in the fertility of soils.

Key words: average yield, fertilization, model, prediction, wheat

Wheat is one of the main agricultural crops in our country, Romania ranking among the largest wheat producers in Europe, together with Denmark and Spain (around 5 million tons each), after France, Germany, the U.K., Poland and Italy (Vigani M. *et al*, 2013; Eurostat Database).

The average area covered by wheat crops in Romania is approximately 2.135 million ha, and for an average yield of approx. 3479 kg ha^{-1} the total yield obtained was approx. 7.428 million tons (INS, 2014).

Improving the technologies for wheat cultivation and the quality of the biological material was the main ways to increase the average wheat yields worldwide (Vigani I. V. *et al,* 2013) and in our country. In most agricultural exploitations in our country, the fertilization level has not raised sufficiently compared with the current fertility of soils and the productivity of the cultivars used (Dumitru M., 2002; Hera C., 2010). A number of studies have created some models to show the behaviour of wheat crops in relation to nitrogen fertilization – this type of fertilization is frequently used due to the lower costs involved (Boldea M. and Sala F., 2013; Rujescu C.I. *et al,* 2014a). Other studies have assessed the influence of different doses of nitrogen applied with phosphorus and potassium considered together (Sala F. and Boldea M., 2011; Sala F. *et al,* 2015). In addition, models have been made to simulate the optimal areas to cultivate certain crops, with applicability to wheat, with a technology based on a fixed capital (Rujescu C.I. *et al,* 2014b, 2015).

The average wheat yield of Timiş County in the period 2013 - 2015 was somewhere between 3900-4800 kg ha^{-1}. More exactly, the average over the three years (2013, 2014, and 2015) was approximately 4385 kg ha^{-1} (INSSE). A simple observation of the mathematical expression of a production function regarding the Alex wheat cultivar in experimental conditions in the West Plain of Romania (Sala F. *et al,* 2016) highlights that the free term of the mathematical expression has a close value to the average yields recorded in this area. This fact obviously indicates low values of the average level of fertilizers applied on agricultural exploitations in Timiş County. As a matter of fact, it is known that things are not significantly different at national level in what the average yields are concerned (Dumitru M., 2002;

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Hera C., 2010), although the statistics show a slight increase in the local use of fertilizers, which indicates raised awareness about proper fertilization of agricultural lands (Vlad I.V., 2015; Eurostat 2016).

The aim of the present study was to deduce the average yield increases in Timiş County, if the evolution of the fertilization rate continues on the same upward tendency indicated at national level.

MATERIAL AND METHOD

The statistics regarding the use of N, P and K fertilizers in Romania, according to Eurostat estimations, for utilized agricultural areas (UAA), provide the data shown in Table 1. The values are given for guidance only, but what is of interest at this point is the upward trend noticed in the past few years regarding the utilization of the three elements.

Table 1

The average fertilizer use at national level, per hectare, per UAA

No.	Year	Average fertilizer use (active substance, kg ha^{-1})	
		N	PK
1	2006	16.43	3.13
2	2007	22.09	4.15
3	2008	19.98	2.59
4	2009	23.52	3.06
5	2010	25.77	4.50
6	2011	25.64	4.56
7	2012	26.45	4.50
8	2013	33.26	6.56
9	2014	33.88	6.72

Source: Eurostat (July 2016)

The assessment of the status of the average wheat yield in Timiş County started from the expression of the production function communicated by Sala *et al.* (2016), which was based on the experimental data on Alex wheat cultivar, relation (1).

$$\begin{aligned} Q(N,PK) = &- 0.0643\ N^2 - 0.0237PK^{\ 2} + \\ &+ 0.02362\ N\,PK + 26.333\ N + \\ &+ 5.361PK + 3300.533 \end{aligned} \quad (1)$$

The fertilization rate that leads to a certain average yield marked Q_m is determined by using the equations (2).

$$\begin{cases} Q(N,PK) = Q_m \\ \dfrac{N}{PK} = \dfrac{n}{1} \end{cases} \quad (2)$$

where n:1 is the relation between the fertilization elements.

By solving only the first equation from the system we are not led to a concrete solution, but instead to the isoquant that corresponds to the average yield (Intrilligator, 2002). In order to choose, out of all the combinations of the N and PK values, only the ones that lead to the given production, we have to consider also the fertilization ratio represented by the second equation. The calculations and graphical representations of experimental data were made with the Wolfram Alpha program (www.wolframalpha.com).

RESULTS AND DISCUSSIONS

The average fertilization rate that led to the average yield in Timiș County in the period 2013 – 2015, namely 4385 kg ha^{-1} (INSSE), was estimated by using equation (2):

$$Q(N,PK) = 4385$$

Equation (2) became (2'):

$$\begin{aligned} &- 0.0643\ N^2 - 0.0237\ PK^2 + 0.02362\ N \cdot PK + \\ &+ 26.333\ N + 5.361\ PK + 3300.533\ \ = 4385 \end{aligned} \quad (2')$$

From the point of view of geometry, the previous equation is an ellipse and every point on the ellipse will represent a combination of the values of N and PK that lead to the average yield Q =4385 kg ha^{-1} (*figure 1*).

In other words, the solutions to the equation are situated on isoquant Q (N, PK) = 4385, and in order to determine a certain solution, we admit the hypothesis that the N to PK ratio was

5:1 in 2015.

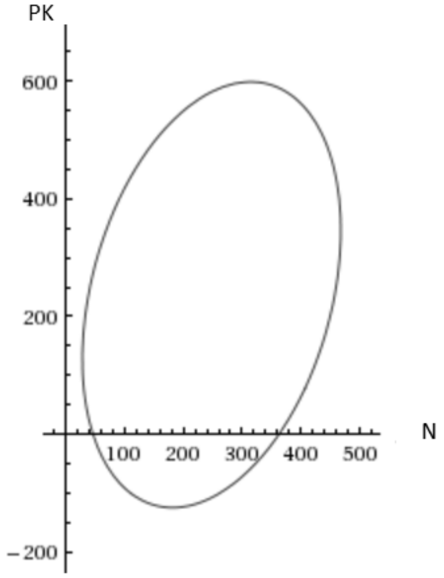

Figure 1 **Graphical representation of isoquant Q (N,PK)=4385**

Thus, we consider $PK = \frac{N}{5}$ and from equation (1) was obtained equation (3), with the graphical solution in *figure 2*.

$$-0.0643\ N^2 - 0.0237\left(\frac{N}{5}\right)^2 + 0.02362\ N \cdot \left(\frac{N}{5}\right) + 26.333\ N + 5.361\left(\frac{N}{5}\right) + 3300.533 = 4385 \quad (3)$$

Therefore this had led us to equation (4):

$$-0.060524\ N^2 + 27.4052 + 3300.53 = 4385 \quad (4)$$

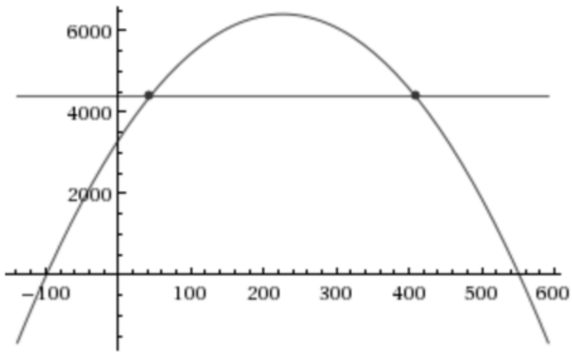

Figure 2 **Graphical solution to equation (3)**

The solution to the quadratic equation is N=43.8 kg ha^{-1}; based on proportionality, it follows that PK=8.7 kg ha^{-1}. So we obtained the average values of N and PK quantities respectively that lead to the average yield of 4385 kg ha^{-1}.

Observing the values in *table 1* on the dynamics of fertilization at national level in years 2006-2014, we can determine the average annual growth for p_N and p_{PK}. So we have:

$$p_N = \frac{33.88 - 16.43}{8} = 2.18\,\text{kg N/ha/year}$$

$$p_{PK} = \frac{6.72 - 3.13}{8} = 0.44\,\text{kg PK/ha/year.}$$

In this way were obtained the estimated values for N_{TM} and PK_{TM} respectively, representing the average fertilization rates in Timiș County, considering that kept growth dynamics at the nationwide in recent years, in concordance with the average growth determined previously. The data are presented in *table 2*.

Table 2

Estimated values of the average fertilization rate in Timiș County

No.	Year	Estimated average fertilizer consumption (kg ha^{-1})	
		N_{TM}	PK_{TM}
1	2015	43.8	8.7
2	2016	45.9	9.1
3	2017	48.1	9.5
4	2018	50.3	10.0
5	2019	52.5	10.4
6	2020	54.7	10.9
7	2021	56.8	11.3
8	2022	59.0	11.7
9	2023	61.2	12.2
10	2024	63.4	12.6
11	2025	65.6	13.1

* Source: our own calculations

Going back to expression (1) of the production function, the estimation of the average wheat yield in Timiș County until the year 2025 was made by replacing in (1) the estimated values N_{TM} and PK_{TM}.

$$Q*_{estimated} = Q(N_{TM}, PK_{TM}).$$

After solving function (1) with the estimated values N_{TM} and PK_{TM} for the period under study, we obtained the average wheat yields that are presented in table 3, with the graphical distribution in figure 3.

$$Q*_{2016} = Q(45.9;\, 9.1) = 4432\ \text{kg ha}^{-1}$$
$$Q*_{2017} = Q(48.1;\, 9.5) = 4479\ \text{kg ha}^{-1}$$
$$...$$
$$Q*_{2025} = Q(65.6;13.1) = 4837\ \text{kg ha}^{-1}$$

The data obtained are presented in *table 3*.

Table 3
Estimated values of the average wheat yields in Timiș County

No.	Year	Estimated Q* (kg ha^{-1})
1	2015	4384.4
2	2016	4432.3
3	2017	4479.6
4	2018	4526.4
5	2019	4572.6
6	2020	4618.2
7	2021	4663.3
8	2022	4707.7
9	2023	4751.6
10	2024	4794.9
11	2025	4837.7

* Source: our own calculations

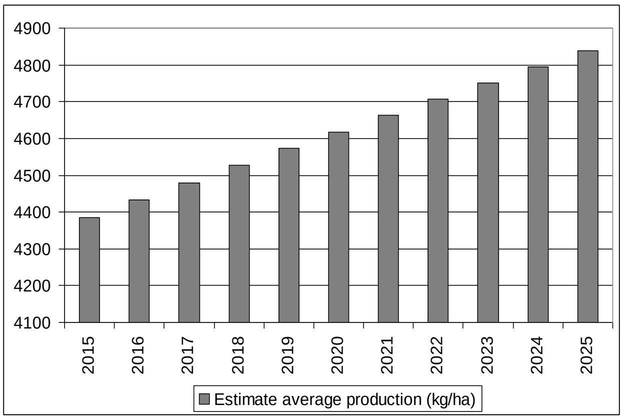

Figure 3 **Estimated values of the average wheat yields in Timiș County in relation to the growth rate of the consumption of N and PK fertilizers.**

The model thus obtained can be expanded to estimate the average wheat yield in any other county or interest area, for local or regional planning of cultivated areas, for technologies or for macroeconomic studies. Moreover, the approach can be adapted to various other agricultural crops.

Similar studies have been made for the prediction of wheat yields (and for other cereal crops, as well) in relation to fertilization rates (especially with nitrogen), to herbicide application rates, to climate changes and rainfall regime (Lobell D.B. and Burke M.B., 2010; Raun W.R. *et al,* 2011; Dumont B. *et al,* 2014), to edaphic factors, technological and economic factors (del Carmen Vera-Diaz M. *et al,* 2008) and to the vulnerability level of some crops and agricultural systems (Luers A.L. *et al,* 2003).

Imaging methods based on the analysis of satellite images, whether aerial or terrestrial, are very useful for the real-time assessment of crop dynamics and the nutrition state of plants, and for recommending fertilization corrections in order to reach the estimated yields (Shou L. *et al,* 2007; Herbei M. and Sala F., 2015) or for predicting the production of biomass (Serrano L. *et al,* 2000; Herbei M. and Sala F., 2016).

Based on the average growth rate of the quantities of fertilizers used (N, PK) and on a mathematical model obtained in experimental conditions, the present study predicted the average wheat yields in the conditions characteristic for Timiș County, West Plain, Romania. The model can be expanded to cover other regions and agricultural areas, thus facilitating the decision-making process on the optimization of the wheat yield by improving the fertilization system, the crop technologies as a whole, or by the dynamics of the cultivated areas.

The present study designed an evolution scenario for the wheat yield in the West of Romania based only on the growth rate of the fertilization levels and on the average ratio of N:PK. The impact of fertilizers on the wheat yield also depends largely on the degree of assurance and on other technological and climatic factors (e.g. rainfall).

In the context of the crop technologies specific for the reference years (the period when the data were collected), which, together with the soil and climate conditions in the area under study, presumably appeared in the values of the output, our model predicted on real bases the evolution of the wheat yield only in relation to one factor, i.e. fertilization, whose dynamics was deduced through calculations.

At the same time, various other studies obtained more complex models for predicting wheat yields, taking into consideration a larger number of parameters specific for certain areas. Thus, Wagner N.C. *et al*, (2007) used 5 variables (wheat crop, density of wild oat species, nitrogen rate, herbicide rate and rainfall during the growth season) in order to develop a complex model for predicting the wheat yield. Similar studies that used traditional or unconventional methods and techniques were made by Kastens T.L. *et al* (2001), Lukina E.V. *et al* (2001), and Mullen R.W. *et al* (2003).

Mann M. and Warner J. (2015) have made an extensive study on wheat crop productivity, taking into consideration the climate conditions, the quality classes of the cultivated lands, the fertilization rate, social and economic conditions, etc. The study resulted in a GAP methodology for estimating the wheat yields under the given conditions.

CONCLUSIONS

Although fertilization has seen an upward trend in recent years, the annual growth rhythm is slow, as the fertilization level is still too low. The production increase is also low, at approximately 45 kg/year. In these conditions, the average wheat yield in the year 2025 would be approximately 4840 kg ha^{-1}, which are still very small values when compared with the values in other European countries.

Therefore it is necessary to adopt policies that stimulate fertilization on agricultural exploitations, because the speed at which the fertilization rate increases must become higher than it has been in recent years.

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REFERENCES

Boldea M., Sala F., 2013 – *Optimizing the Area fertilized with nitrogen-based chemical fertilizers for wheat crops.* Applied Mathematics, 3(3): 93-97.

Borlan Z., Hera, Cr., 1982 – *Tabele si nomograme agrochimice,*Editura Ceres, Bucuresti.

Dumitru M., 2002 – *Factors that influenced fertilizers consumption in postrevolutionary Romania.* Fertilizarea echilibrată a principalelor culturi în România. p. 23-46.

Dumont B., Basso B., Meza Morales W., Bodson B., Destain J.-P., Destain M.-F., 2014 – *Nitrogen fertilisation recommendations: could they be improved using stochastically generated climates in conjunction with crop models ?* Proceedings of the 12th ICPA, 1-7.

Del *Carmen Vera-Diaz M., Kaufmann R.K., Nepstad D.C., Schlesinger P., 2008* – An interdisciplinary model of soybean yield in the Amazon Basin: The climatic, edaphic, and economic determinants. *Ecological Economics, 65(2): 420-431.*

Hera C., 2010 – *CIEC – 77 years sdedicated to enhancing soil fertility for the benefit of sustainable performing agriculture.* Proceedings of the 15th World Fertilizer Congress of the International Scientific Centre for Fertilizer (CIEC) 29 Aug-2 Sept. Romania, 17-29.

Herbei M., Sala F., 2015 – *Use Landsat image to evaluate vegetation stage in sunflower crops,* AgroLife Scientific Journal, 4(1): 79-86.

Herbei M., Sala F., 2016 – *Biomass prediction model in maize based on satellite images.* AIP Conference Proceedings, 1738: 350009-1-350009-4.

INS (2014) – *Crop production for the main crops in 2013.* National institute of statistics, No. 75, March 31, 2014. pp.5.

Intriligator M.D., 2002 – *Mathematical optimization and economic theory.* 1st Edition, Society for industrial and applied mathematics (SIAM), Philadelphia.

Kastens *T.L., Schmidt J.P., Dhuyvetter K.C., 2001* – Yield models implied by traditional fertilizer recommendations and a framework for including nontraditional information. *Soil Science Society of America Journal, 67(1): 351-364.*

Lobell D.B., Burke M.B., 2010 – *On the use of statistical models to predict crop yield responses to climate change.* Agricultural and Forest Meteorology, 150(11): 1443-1452.

Luers *A.L., Lobell D.B., Sklar L.S., Addams C.L., Matson P.A., 2003* – A method for quantifying vulnerability, applied to the agricultural system of the Yaqui Valley, Mexico. *Global Environmental Change, 13(4): 255-267.*

Lukina *E.V., Freeman K.W., Wynn K.J., Thomason W.E., Mullen R.W., Stone M.L., Solie J.B., Klatt A.R., Johnson G.V., Elliot R.L., Raun W.R., 2001* – Nitrogen fertilization optimization algorithm based on in-season estimates of yield and plant nitrogen uptake. *Journal of Plant Nutrition, 24(6): 885-898.*

Mann M., Warner J., 2015 – *Ethiopian Wheat Yield and Yield Gap Estimation: A Small Area Integrated Data Approach. Research for Ethiopia's Agriculture Policy,* IFPRI, Addis Ababa, 1-44.

Mullen *R.W., Freeman K.W., Raun W.R., Johnson G.W., Stone M.L., Solie J.B., 2003* – Identifying an in-season response index and the potential to increase wheat yield with nitrogen. *Agronomy Journal, 95(2): 347-351.*

Raun W.R., Solie J.B., Stone M.L., 2011 – *Independence of yield potential and crop nitrogen response.* Precision Agriculture, 12(4): 508-518.

Rujescu C. I., Ciolac R., Martin S. C., Butur M., 2014a – *Minimization plan of nitrogen fertilizers allocation, dictated by the agricultural market,* SGEM 2014 Conference Proceedings, 3: 277-284

Rujescu C. I., Ciolac R., Martin S. C., Butur M., 2014b – *The use of a two-factor model for the fertilization of agricultural crops in order to determine the optimal production area,* LSMA XVI(1):9-12.

Rujescu C. I., Mateia A. N., Martin S., Ciolac R., 2015 – *Determination of the optimum productions surface (monofactorial model) having an initial* *fixed capital,* Quaestus Multidisciplinary Research Journal, 149.

Sala F., Rujescu C., Constantinescu C., 2016 – *Causes and solutions for the remediation of the poor allocation of p and k to wheat crops in Romania*. AgroLife Scientific Journal, 5(1): 184-193.

Sala F., Boldea M., Rawashdeh H., Nemet I., 201 – *Mathematical model for determining the optimal doses of mineral fertilizers for wheat crops.* Pakistan Journal of Agricultural Sciences 52: 609-617.

Sala F., Boldea M. 2011 – *On the Optimization of the Doses of Chemical Fertilizers for Crops.* AIP Conference Proceedings, 1389: 1297-1300.

Serrano L., Fiella I., Peñuelas J., 2000 – *Remote Sensing of Biomass and Yield of Winter Wheat under Different Nitrogen Supplies.* Crop Science, 40: 723-731.

Shou L., Jia L., Cui Z., Chen X., Zhang F., 2007 – *Using high-resolution satellite imaging to evaluate nitrogen status of winter wheat.* Journal of Plant Nutrition 30(10): 1669-1680.

Vlad I. V. (coord.), 2015 – *Strategia de dezvoltare a României în următorii 20 de ani.* Vol. I, în P.5 Hera C., Otiman P.I., coordonatori, 2015, *Securitate şi siguranţă alimentară*, pp. 225-231, Editura Academiei Române.

Vigani M., Dillen K., Cerezo E.R., 2013 – *Proceedings of a workshop on "Wheat productivity in the EU: determinants and challenges for food security and for climate change".* European Comission, EUR 25934 EN: 1-36.

Wagner N.C., Maxwell B.D., Taper M.L., Rew L.J., 2007 – *Developing an empirical yield-prediction model based on wheat and wild oat (Avena fatua) density, nitrogen and herbicide rate, and growing-season precipitation.* Weed Science, 55: 652-664.

http://statistici.insse.ro (07.2015)

ec.europa.eu/eurostat (07.2015)

http://www.wolframalpha.com/