Changes in Efficiency of Fertilisers Use in Poland in the Years 1992-2009

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Abstract. This article aims to present the changes in efficiency of fertilisers' inputs in Poland in the period of 1992-2009. The tasks were threefold: 1) to evaluate total crop production in Poland in cereal units (c.u.); 2) to determine the amount of use of mineral fertilisers; and 3) to define the productivity of fertilisers. The data for the years 1992–2009 from the Central Statistical Office of Poland were used in the research. Production outputs in cereal units per 1 kg NPK in mineral fertilisers and changes in the efficiency of fertiliser use in time were determined from the data obtained. The study uses one- and multi-dimensional regression analysis. Also, the method of division of the aggregate determination coefficient in the multiple regression method was used in order to determine the relative impact of individual independent variables.
The research shows that the significant increase of fertiliser use in Poland has taken since 1992, but it was not significantly correlated to increasing the amount of total crop production. Consumption of mineral fertiliser in Polish agriculture has increased by 50% within the researched period, but at the same time the total amount of crop production has increased only by 4%. Crop production, counted in cereal units, from 1 kg of NPK-fertiliser has decreased by nearly 40%. The use of 1 kg of NPK-fertiliser has resulted in production of 0.35 c.u. in the first half of the 1990s and only 0.23 c.u. in the years 2006-2009. Productivity of inputs of N-fertiliser individually has also decreased, form 0.64 to 0.42 c.u. per 1 kg of N-fertiliser.
The higher inputs of fertilisers in Polish agriculture do not result in increased crop yields and production due to mistakes in production technology, for example, too small scope of pesticide use, and imbalanced nutrient supply. The other reasons can also be indicated, for example, very high share of soils with very high acidity in Poland (51%) and high acreage of light and very light soils with low capacity of sorption complex.
Key words: fertiliser, production efficiency, efficiency of fertilisers use, crop management.

Introduction

Nowadays, agricultural production requires high outlays from outside the agriculture. Without them, it would not be able to achieve high crops and it would be thus difficult to provide food to people in a certain country, and the world. One of the most important crop-supporting outlays includes mineral fertilisers. The use of mineral fertilisers is very high; although some highly developed countries have reduced the use of fertilisers.

In Poland, the use of mineral fertilisers at the end of the 1980s accounted for approximately 180 kg NPK per 1 hectare of arable land. After the economic transformation, the use of fertilisers in the Polish agriculture abruptly decreased, and in 1992, it accounted for only 62 kg NPK/ha. In the subsequent years, the use of fertilisers rose to approximately 100 kg NPK/ha in 2004, and after Poland's accession to the EU, to approximately 120 kg NPK/ha (Figure 1). In comparison with the "old" EU Member States with a similar character of agriculture, the figures are very much similar (Figure 2). It is notable that the use of fertilisers in the EU-15 countries has decreased. The foregoing resulted from the implementation of environmental programmes oriented at a reduction in the environmental impact of agriculture. In the period of 1997-2007, it has decreased by as much as 20-30% in some countries. At the same time, the use of fertilisers in Poland rose by more than 30%. It means that in the future, if the production technology improves, it will be possible to achieve a higher production without increasing the use of fertilisers also in Poland.

Different amounts of fertiliser use among different countries result not only from different production intensities of the basic agricultural plants, but also from the fact that in many countries there are significant areas that are extensively used for pasturage or semi-natural agricultural production.

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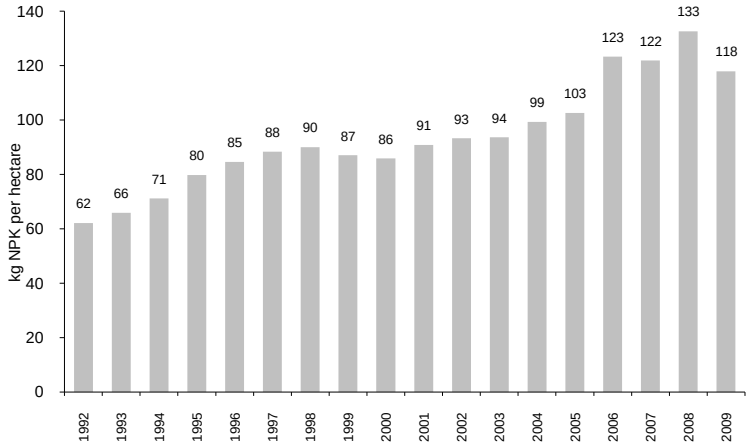
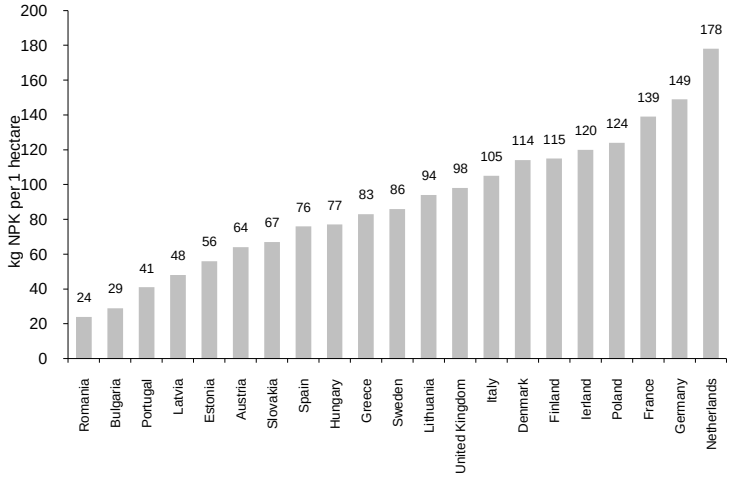


Source: data of the Central Statistical Office of Poland

Fig.1. **Mineral fertiliser use per 1 hectare in Poland in the period of 1992-2009**



Source: author's calculations based on the data from Eurostat for 2007 (fertiliser use/agr land use)

Fig. 2. **Mineral fertiliser use per 1 hectare in selected countries of the European Union**

The increase in the fertiliser use enables to increase not only the production output. It results also from the fact that the new varieties are often adjusted to higher intensity and yield poor crops if fertiliser use is low (White E., Wilson F., 2006). Wheat varieties grown in the 1950s yielded 45 kg grain per one kilogram of nitrogen used in the production, with fertiliser use of 75 kg N/ha, and varieties grown in the 1980s yielded as much as 70/kg grain per kg N (CGIAR, 1997). It also depends on the place of production, so varieties should be tested at specific locations in order to find the ones that are best adjusted to production at a particular place (CGIAR, 2010).

The use of artificial fertilisers involves high-energy consumption. Fertilisers constitute as much as 32% of energy used in the wheat production (Jankowiak J., Miedziejko E. 2009), and the increase in the use of fertilisers by plants is the most important factor increasing the energy efficiency of crop production (Rathke G.W., et al. 2007). Therefore, the higher the production efficiency of fertilisers, the cheaper is the agricultural production. High opportunities in that respect result from the application of precise agricultural methods (Meyer-Aurych A., et. al. 2010, Schumann A., 2010) and division of one fertiliser portion into several parts (Chen D., et al. 2008) as well as adjustment of outlays to the crops planned (Andreas T., et al., 2010), since otherwise it results in high losses of nutrient components (Cui Z. et. al., 2010). Also, the balance of nutrient components (Jate M., 2010), and soil quality and acidity (Shafran S., et. al., 2010) are very important for the use of nutrient components from fertilisers.

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It is common knowledge that using mineral fertilisers contribute to higher yields, in particular in comparison with results of agriculture where no fertilisers are used. The average natural soil productivity in Poland is estimated at 15 dt cereal per 1 ha. The percentage of the nutrient components derived from fertilisers used by plants has decreased together with an increase in the use of fertilisers. The use of fertilisers may be higher and still effective since many new varieties better use higher portions of fertilisers (White E., Wilson F., 2006) and there is progress in the production technology. On the example of highly developed EU countries, it may be concluded that it is possible to reduce the average use of mineral fertilisers in agriculture without considerably reducing crops. In Poland, mineral fertiliser use is still the most important factor deciding on the crop yield (Wicki L., Dudek H., 2009).

The aforementioned factors show that a higher use of mineral fertilisers does not always contribute to a higher crop yield. It depends, largely, on the technologies used and whether the use of fertilisers is adjusted to the expected crops.

This article aims to present changes in efficiency of fertilisers' inputs in Poland in the period 1992-2009. The tasks were threefold: 1) to evaluate total crop production in Poland in cereal units (c.u.); 2) to determine the amount of use of mineral fertilisers; and 3) to define the productivity of fertilisers.

Data and methods

The analyses use the statistical data of the Polish Central Statistical Office concerning the amounts of mineral fertilisers used in Poland in the period of 1992–2009, and the crop yield of the basic agricultural plants. The agricultural production output was established in cereal units (c.u.) determined by Woermann (1944). The production of cereals, industrial plants, fodder plants, production on permanent grasslands, and production of vegetables and fruits were taken into account.

Production outputs in cereal units per 1 kg NPK in mineral fertilisers and changes in the efficiency of fertiliser use in time were determined from the data obtained. The study uses one- and multi-dimensional regression analysis. The OLS method was used to estimate coefficients of the regression equation. The study lacks the description of the method used, since it is a well-known and described method (Seber G., Lee A. 2003, Allison P. 1991). In addition, the method of division of the aggregate determination coefficient in the multiple regression method was used in order to determine the relative impact of individual independent variables (amount of N, P, and K used). The strength of the individual impact of individual independent variables used in the models was determined according to the characteristics $d_{yxj} = b_j \times \frac{S_{yxi}}{S^2_y}$, the sum of which for all j is equal to the determination index specified for the model. Characteristics d_{yxj} shows the division of impact of single explanatory variables on the determination index (Ostasiewicz W., 1999). In order to determine the average annual change dynamics, the following equation was used: $(\ln(Y_n/Y_0))/n$, where 0 refers to 1992, and n = 17 to 2009. The analyses do not use methods as TFP or Cobb-Douglas function, since not all production factors in agriculture (land, labour, and capital) were taken into account jointly, but one of the outlays only.

Results

In the period of 2006–2009, the use of mineral fertilisers in Poland accounted for 1995 thousand tons of pure NPK component, out of which 54% was constituted by nitric fertilisers. The figure was much higher than that observed earlier. In the period directly following the political transformation (1992-1994), an average of nearly 1200 thousand pure NPK component were used, 64% of which was constituted by nitrogen. Thus, the use of fertilisers grew by nearly 800 thousand tons NPK, i.e. by 65%. The use of fertilisers in the period analysed is presented in Figure 3. In the whole period analysed, the average annual pace of changes in the use of fertilisers accounted for 3.0%. Subsequent years observed different dynamics of the use of fertilisers. It abruptly increased after Poland's accession to the EU, which was due to the direct payments obtained by Polish farmers.

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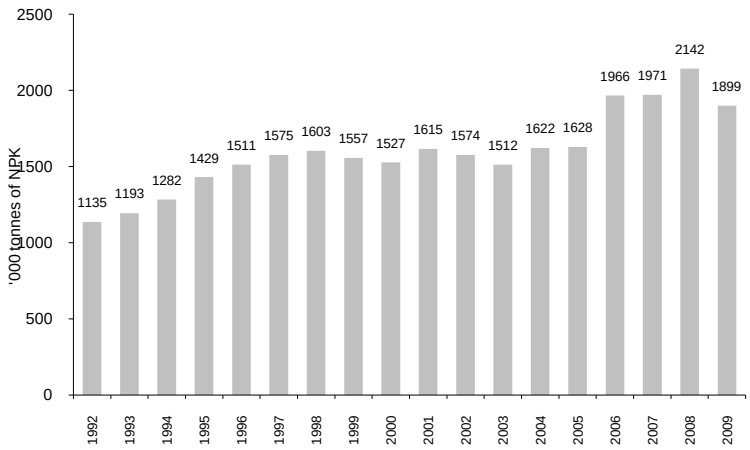
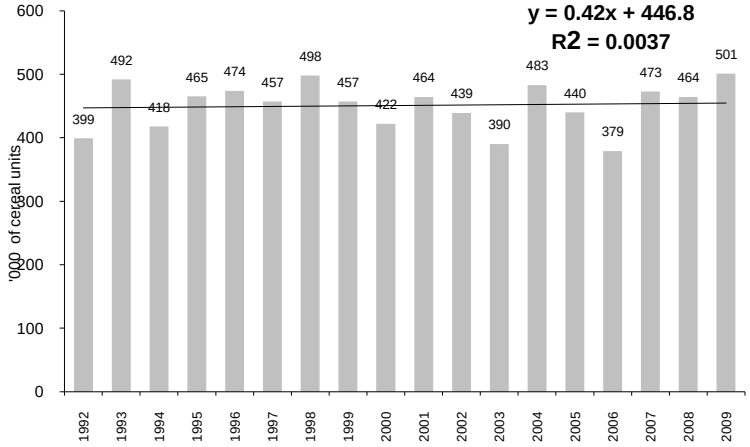


Source: data from the Central Statistical Office of Poland

Fig. 3. **Mineral fertiliser use in Polish agriculture in 1992-2009**

In the period analysed, the agricultural production output in Poland changed rather due to variable weather conditions in subsequent years than changes in the use of fertilisers. The total production output in cereal units and the production trend is presented in Figure 4. The effect of higher use of fertilisers in the form of higher production output is not observed. The average annual increase in the production output accounted for 1.3% in the period of 1992-2009. The production growth dynamics were thus more than twice as low as those observed for the use of fertilisers were.



Source: author's calculations

Fig. 4. **Total crop production in Poland in '000 of cereal units (100 thousand of c.u. is equivalent to 10 million tonnes of cereals)**

The greatest percentage of the production structure was constituted by cereals, fodder plants, and industrial plants (Figure 5). In subsequent years, the percentage of cereals and industrial plants in the production structure was growing; while the percentage of fodder plants decreased. In the period of 2006-2009, the percentage of cereals in the crop production accounted for 58.5%, and it was by 8.8 percentage points higher than the average in the period of 1992-1994. In the same period, the percentage of industrial plants increased by 4.7 percentage points, and that of potatoes was by as much as 10.6 percentage points lower.

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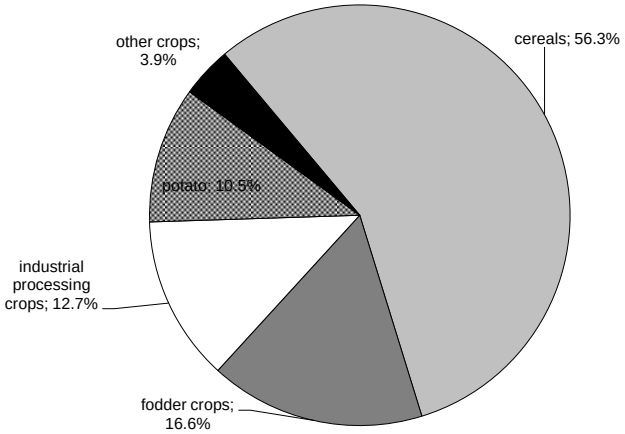
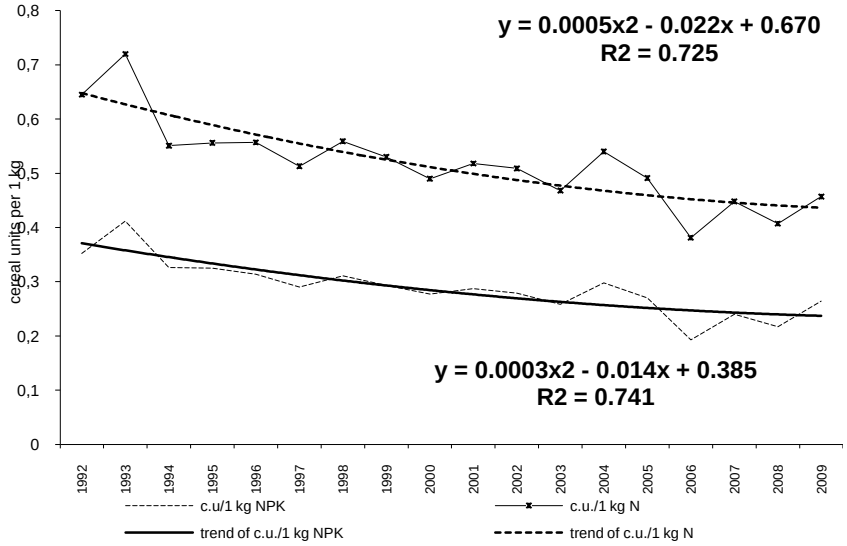


Source: author's calculations

Fig. 5. **Structure of crop production in Poland (calculated on base of production in cereal units, average for the period of 1992-2009)**

Crop production output in cereal units per 1 kg NPK used in fertilisers has decreased. Analogically, the periods 1992-1994 and 2006-2009 were compared to each other. In the former period, the productivity of 1 kg NPK accounted for 0.363 c.u. gross; while in the latter period - only for 0.228 c.u. The foregoing means that between the analysed periods the production output obtained from 1 kg NPK has decreased by 37% in comparison with the reference level. The reduction in the efficiency is not justified by the crop yield and the production output. With the increase in the average crop yield, it could be expected that the use of nutrient components from fertilisers would decrease. Figure 6 presents the efficiency of total NPK outlays in mineral fertilisers and also separately for N outlays in the period analysed. Both, production in c.u. on 1 kg NPK as well as on 1 kg N decreased. The efficiency of NPK outlays decreased by an average of 0.73% per annum, and that of N outlays by an average of 0.88% per annum. The decrease in the efficiency of fertiliser use was not stopped in the period analysed, and no stabilisation is observed. The non-lineal regression models estimated for the observed changes enabled to adjust slightly better the trend line measured by the determination coefficient for the regression model. However, the minimum of those functions was not achieved.



Source: author's calculations

Fig. 6. **Changes of productivity of NPK and N inputs in Polish agriculture in the period of 1992-2009 (in c.u. per 1 kg of NPK and N respectively)**

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In addition, the relation between the production output and the use of fertilisers was analysed based on the regression analysis. The results are presented in Table 1. For the model with one independent variable, the regression coefficient for NPK outlays is equal to 0.022, which means that in the period analysed, a very poor though positive relation between total mineral fertiliser use and the production output was observed (ca. 2.2 kg of cereals per one additional kg of NPK used). The relation is insignificant from the statistical point of view, and the regression coefficient value shows a zero relation between the figures analysed.

In the other model, three basic components N, P, K were adopted as independent variables. The model obtained is significant from the statistical point of view with p-value of 0.083. Individual independent variables have differently affected the production output. Nitrogen and potassium outlays enabled to increase the production output, and phosphorus outlays were negatively correlated to the production. With the significance value of 0.05, only the impact of nitrogen fertilisers was significant from the statistical point of view. The determination index of 42% was obtained for the estimated multiple regression model. The index was decomposed into parts that may be assigned to individual independent variables and determine the extent to which a given variable individually affects the dependent variable. The following values of partial determination were obtained: for N outlays – 48.6%, for P outlays – 9.0%, and for K outlays – 0.4%. The foregoing shows that in the period analysed the crop production output in Poland was affected, mainly, by the use of nitric fertilisers, and also potassium fertilisers. Nitrogen contributes the most to the crop yield; while phosphorous fertilisers contribute to the crop yield depending on the saturation of soil with phosphor, and the fertiliser used is available for plants even several years after the use. Even lack of phosphorous fertilisers in a particular year does not usually result in a considerable decrease in the crop yield.

Table 1

Results of regression analysis for dependence of crop production on fertiliser input

Variable	Regression coefficient	Model R^2	P-value for regression coefficient	F statistics	P-value for model
Simple linear regression model					
Intercept	416180	2.4%	0.0000	0.402	0.5352
NPK	0.022		0.5352		
Multiple linear regression model					
Intercept	289032	42.0%	0.0006	3.422	0.0829
N	0.516		0.0077		
P	-1.051		0.1818		
K	0.109		0.8365		

Inputs are in tones of nutrient component and production is in thousands of c.u.. It means that if inputs of N fertiliser increase by 1 tonne, the production increases by 0.516 thousand c.u. (approximately 51.6 kg of cereals per one kg of N).
Source: author's calculations

Conclusions

The study has analysed the changes in the efficiency of use of mineral fertilisers in Poland in the period of 1992-2009. It was concluded that there was a considerable increase in the use of fertilisers, which was particularly vivid in the period following Poland's accession to the EU. However, the increase in the use of fertilisers did not translate into an increase in the crop production output. In the period analysed, the fertiliser use increased by more than 50%; while the crop production output did not change more than 4%. The production obtained from 1 kg of NPK component decreased by nearly 40%. With 1 kg NPK, it was obtained from 0.35 c.u. in the first half of the 1990s to only 0.23 c.u. in the period of 2006-2009. The productivity of N outlays in the same period have also decreased from 0.64 to 0.42 c.u./kg N.

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The considerable increase in the fertiliser use resulted from an improvement in the economic situation of agricultural farms in connection with direct payments obtained from 2004. It may be supposed that higher use of fertilisers did not contribute to the crop yield due to mistakes made in the production technology, e.g. poor protection of plants against pathogens, and due to limitations arising from deficiency of other components. The factor limiting the increase in the efficiency of fertiliser use may also involve high soil acidity in Poland, and cultivation of light soils with small sorption complex. The percentage of acid and very acid soils in Poland is more than 51% (Kopiński J., Krasowicz S., 2010:11). The increase in the efficiency of the use of fertilisers will require farmers to adjust the outlays to the conditions of a specific farm and the expected production output as well as to improve the production technology to affect, first, factors that most limit the yield.

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