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THE IMPACT OF AGRICULTURAL INPUTS ON CROP PRODUCTION EFFICIENCY ACROSS ROMANIAN DEVELOPMENT REGIONS: A MULTI-CROP ANALYSIS (2007-2023)

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Abstract

The paper aims to investigate the link between agricultural inputs and crop production in Romania's eight development regions over the period of 2007-2023 for the selected crops wheat, corn, barley and sunflower. The study uses data from the Romanian National Institute of Statistics to check how chemical fertilizers (nitrogen, phosphorus and potassium), mechanical equipment and other agricultural inputs influence crop production. Through correlation and regression analysis, strong and significant links between the use of chemical fertilizers and crop production with different levels of effectiveness in the regions and crops have been established. The result of the analysis revealed that phosphorus fertilizer had the highest correlation coefficient with wheat and barley production, while potassium had the highest correlation with sunflower production. It was also found that variation in the effectiveness of inputs was a crucial factor; the South-East and South-Muntenia regions were more effective in converting fertilizer inputs into output. The results show that wheat and barley are the most consistent in their response to fertilizer application (R^2 values are 0.21-0.29 and 0.24-0.25 respectively) while corn and sunflower have a relatively weaker response (R^2 values of 0.13-0.14 and 0.14-0.15, respectively). These results imply that fertilizer application should be done on a region and crop basis in order to enhance production in Romania

Key words: *agricultural inputs, crop production, regional development, fertilizer efficiency, Romanian agriculture*

INTRODUCTION

Agriculture represents the foundation of th eeconomical framework of Romania, by contributing to its national gross added value with aproximately 3.9% in 2023 [29], much more above the average score UE27 of 1.3% [31]. Taking into consideration that aproximately 45.7% of the Romanian population leaves in the countryside – in contrast with the EU27 avarage of 24% [32] – the importance of the field extends beyond the economical indicators including the social and teritorial development [17].
The regional agricultural development has been of main concern since Romania's entry in EU, especially regarding the process of turning into practice of the collective agricultural policy [1]. The regional variations concerning the agricultural productivity and the use of resources have become essential factors in understanding the agricultural development of Romania [4]. The differences regarding the use of farms inputs among regions especially fertilizers and pesticides [21, 22] led to variations of yields besides the influence of climate change. Each of the eight development regions in Romania presents distinctive agricultural features modeled by geographical, climatic factors and the Ministry of Agriculture and Rural Development [15] has established frames for aproaching regional agricultural challenges promoting at the same time a durable growth. Analyzing the data from the National Institute of Statistic from 2007-2023 the current research examines the connections between the agricultural inputs and the productivity in the regions in order to

offer recommendations based on evidence for optimizing the agricultural production at a regional level.

One of this important aspects of agriculture is the one referring to fertilization, which represents a fundametal pillar of modern agricultural production being essential to maintaining the fertility of the soil and maximizing the crops productivity [18]. In the last decades the fertility paradigma has been through a major transformation going through a significant transformation from the generalized application of chemical fertilizers to a sustainable, integrated approach based on data known as precise nutritional management [8, 12, 19].

The correct fertilizing ensures not only the macro and micro necessary nutrients in the physiological processes of plants, such as photosynthesis breathing or protein synthesis but also the balance between productivity and the impact of the environment. Recent studies emphasises that the traditional fertilizers NPK, although efficient, can lead to substantial losses leeching and gas emissions leading to the waters contamination and the lowering of soil quality if they are not properly managed [9].

A notable change in this field is the adoption of precision fertilization, which entails the local and synchronized appliance of nutrients according to the pants necessities, to the vegetation phase and the characteristics of the soil [16, 23, 25].

Moreover, the specific management of nutrients at plot level proved itself efficient in raising the production yield, the reducing of the greenhouse gasses emissions and the raising of farmers incomes [10, 24, 26].

This technological transformation reflects current trends in European agriculture, which is increasingly aligned with sustainability and efficiency goals [3]. By using modern technologies – sensors, satellite imagery and soil analysis – Romanian farmers are starting to adopt a data-driven farming model, where decisions are scientifically based. This step is essential to increase the competitiveness of the agricultural sector in the context of the European single market.

National and European agricultural policies also encourage the transition to sustainable practices through financial allocations and direct incentives, which contributes to the widespread adoption of modern methods of fertilization and soil management [2]. In this sense, the role of agriculture is no longer limited to food production, but extends to essential ecological and social functions [13, 20]. In combination with practices of conservative agriculture such as direct seeding and the keeping of the vegetal waste fertilization becomes not only an agricultural technique but an instrument to protect the environment and to fight climatic changes [14].

Modern fertilization is no longer regarded as a simple appliance of nutritive substances but as a complex process integrated part of the intelligent agriculture which contributes to the global food safety conserving the natural resources and to the agroecosystems towards the climatic stress. Thus, the integrated strategies of fertilizing based on the combination of organic and mineral fertilizers, the rotation of crops and the continuous analysis of the soil are fundamental for a durable agriculture in the long term [7].

Another important aspect is the economical one. Therefore, the technological modernization of fertility is not only an answer to the environmental changes but also a strategic economical process which offers opportunities for the development of new products and the raise of competitiveness in the global agricultural industry [11].

The importance of studying the efficiency of fertilizers in the Romanian agriculture is emphasised by the country’s position as a major producer of corn in the EU, having approximately 2.6 million cultivated hectares in 2015 (Tudor et al., 2017) [27]. Despite this and although Romania has the biggest cultivated area, the yields are significantly behind other EU countries, emphasizing the critical necessity to optimize the use of inputs.

Recent research has shown that the use of nitrogen fertilizers has a significant impact on the wheat production in Romania, the studies having shown that 78.76% from the variation of the production can be due to the levels of applying the nitrogen fertilizers [28].

The same study has shown that fertilizer consumption rates in Romania are significantly lower than in other countries in EU, having an average of only 38.65 kg N/ha, in contrast with higher rates in countries such as Poland (96.24 kg N/ha) and France (110,80 kg N/ha), emphasizing the potential to optimize the efficiency of using fertilizers.

In this context, the purpose of the paper is to investigate the link between agricultural inputs and crop production in the eight development regions of Romania, during the period 2007–2023, for wheat, corn, barley and sunflower crops.

MATERIALS AND METHODS

This research uses quantitive data from the National Institute of Statistics (NIS) of Romania for the years 2007, 2014, 2019, 2020, 2021, 2022 și 2023.

The set of data comprizes four major essential crops from the agricultural production in Romania: wheat, corn, barley and sunflower. For every crop we have collected data regarding the production volumes, the cultivated areas and the agricultural inputs from eight development regions of Romania, established by the law no. 315/2004 North-West, Center, North-East, South-East, South-Muntenia, Bucuresti-Ilfov, South-West Oltenia and West [4].

The study analyzes three different categories of agricultural inputs: chemical fertilizers (nitrogen, phosphorus and potassium), mechanical equipment (tractors, combines and seeders) and other factors of production including natural fertilizers and pesticides. We use the analysis of the correlations to examine the relation between these inputs and the vegetal production with levels of significance established at $p<0.01$ and $p<0.05$ because this statistic approach allows us to quantify the power and the direction of the relations between the agricultural inputs and the results of the productivity.

The statistic analysis was done using IBM SPSS Statistics Version 25.0, while the organizing of the data and preliminary calculations were done using Microsoft Excel 2019.

This methodological aproach is in agreement with the recent studies concerning the agricultural regional efficiency in Romania. As Chivu et al. (2020) [6] shows, the analysis of the agricultural productivity using the function Cobb-Douglas in classical form.

For the entries that present significant correlations we do regression analysis using the model:

$MP = \beta_0 + \beta_1 F + \varepsilon$

- MP represents the average productions
- β_0 is the constant term
- β_1 is the regression coeficient
- F represents the intake of fertilizers
- ε is the error term

The validity of the model is evaluated through the values R square, F statistics, Durbin-Watson statistics and the beta standardized coefficients.

This methodological frame is in agreement with current standards in the agricultural economical research [11] integrating at the same time the regional specificities of the Romanian agriculture.

The methodology followed the approach of systematic revision described by Dumitru et al. (2023) [9], where the data were collected through extensive searches in the databases, focusing on the publications revised by colleagues referring to the vegetable production and the impact of climatic changes. The systematic revision was combined with the bibliometric analysis to identify the main tendencies and models of research in the field.

RESULTS AND DISCUSSIONS

The regional distribution of the agricultural production

The analysis of the agricultural productions in the development regions of Romania shows distinctive models regarding the crops distribution and the varieties of the yield.

During the evaluated period of time (2007-2023), there have been significant differences between regions in volume as well as in the efficiency of the agricultural production.

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Table 1. The regional distribution of the agricultural production (the average on the selected years 2007-2023)

Region	Wheat (kg/ha)	Corn (kg/ha)	Barley (kg/ha)	Sunflower (kg/ha)
North-West	3,746	4,869	3,530	2,084
Centre	3,862	5,337	3,763	2,379
North-East	3,319	4,001	3,212	1,812
South-East	3,291	3,652	3,549	1,815
South-Muntenia	3,820	4,221	3,958	2,010
Bucharest-Ilfov	3,850	3,941	3,808	1,848
South-West Oltenia	3,556	3,882	3,653	2,021
West	4,502	4,981	4,278	2,405

Source: Processed data NIS [30]

Table 1 presents the distribution of the agricultural production in the eight development regions of Romania for the main evaluated crops (wheat, corn, barley and sunflower). The data indicates substantial regional variations regarding the volume of the production reflecting the differences regarding the cultivated areas, the agricultural practices and the use of resources.

South-Muntenia and South-East regions have constantly shown bigger volumes of production for all the crops that have been studied, especially for the wheat and corn crops.

This model is probably due to more factors, including favorable climatic conditions, larger agricultural areas and to the agricultural practices historically established in these regions.

On the other hand, Bucurest-Ilfov and Centre regions have recorded lower production volumes, mainly because of smaller agricultural areas and because of their more urban features.

Still, these regions have often shown a bigger efficiency in what the hectare yield is concerned, especially when it comes to crops such as wheat and corn.

The temporal analysis from 2007 until 2023 shows a general tendency of growth in the efficiency of production in all the regions, although there have been significant variations from one year to the other.

These variations reflect the impact of change in the meteorologic patterns of the rates concerning the adoption of technologies and of the evolution of agricultural practices in each of the regions.

The analysis of the wheat production

The analysis of the wheat production in connection with the agricultural inputs emphasized significant correlations with more key factors especially with chemical fertilizers.

Table 2 shows coefficients of correlation between different agricultural inputs and the wheat production.

Chemical fertilizers showed the strongest associations with the results of the wheat production.

Phosphorus fertilizers showed the biggest correlation ($r=0.541$, $p<0.01$), followed by nitrogen ($r=0.523$, $p<0.01$) and potassium ($r=0.456$, $p<0.01$).

However, the mechanical equipment and other intakes presented weaker correlations, insignificant to the levels of production.

The regression analysis of the three significant relations concerning the fertilizers have shown distinctive models.

Table 2. The analysis of the correlation: the production of wheat and the agricultural intakes

Input Variable	Pearson Correlation	Significance Level
Nitrogen fertilizer	0.523	**
Phosphorus fertilizer	0.541	**
Potassium fertilizer	0.456	**
Tractors	0.239	ns
Agricultural combines	0.150	ns
Mechanical seeders	0.115	ns
Natural fertilizers	0.052	ns
Fungicide	0.194	ns
Herbicide	-0.079	ns

Source: personal processing of NIS data [30].
Note: ** significant for $p<0.01$; ns= insignificant

The model of the fertilizer based on phosphorus gave a regression coefficient of 56.545 ($p<0.01$) with a standard error of

11.253, explaining 29.2% of the variation of the production (R^2= 0.292) and showing an adequate independence of the waste (Durbin-Watson=2.320). The analysis of the nitrogen fertilizers showed a regression coefficient of 43.210 (p<0.01) with a standard error of 10.792, explaining 20.8% of the variant (R^2= 0.208) and maintaining an adequate waste independence (Durbin-Watson = 2.384).

These findings point to the fact that, although all the three studied fertilizers significantly influence the wheat production, the phosphorus fertilizers prove to have the strongest effect, explaining approximately 29.2% of the production variation.

The positive coefficients for all the three studied fertilizers suggest that high usage rates are associated with higher production values, although the yield drops at higher usage rates.

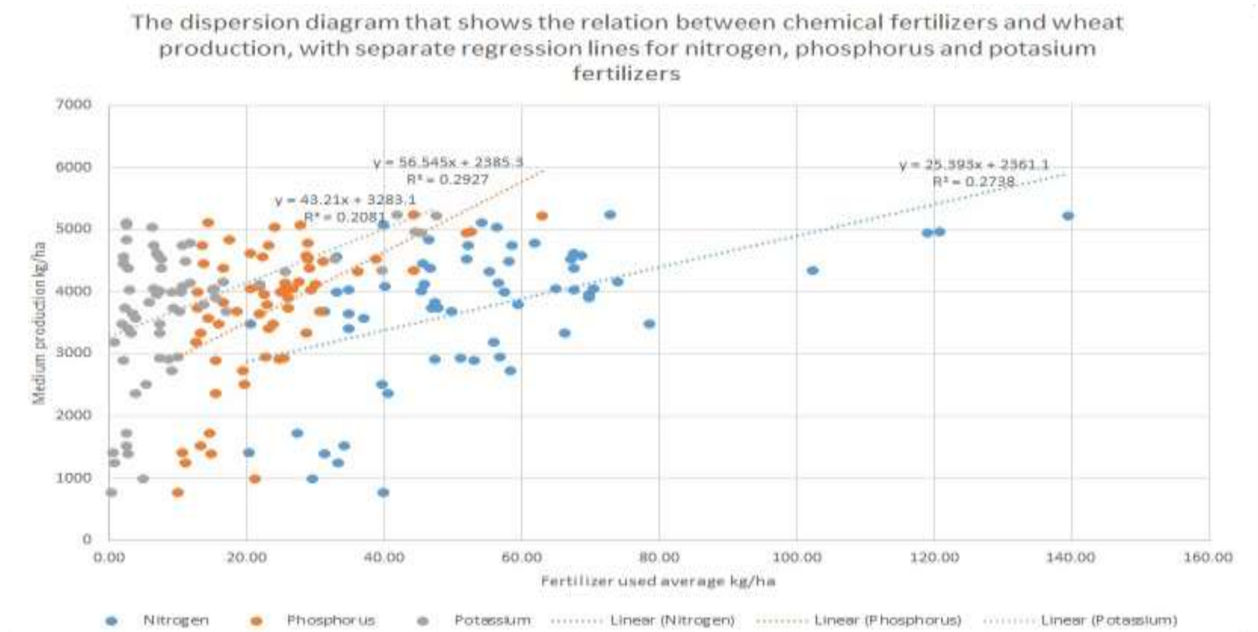

Fig. 1. The dispersion diagram that shows the relation between chemical fertilizers and wheat production, with separate regression lines for nitrogen, phosphorus and potasium fertilizers
Source: personal processing of NSI data [30].

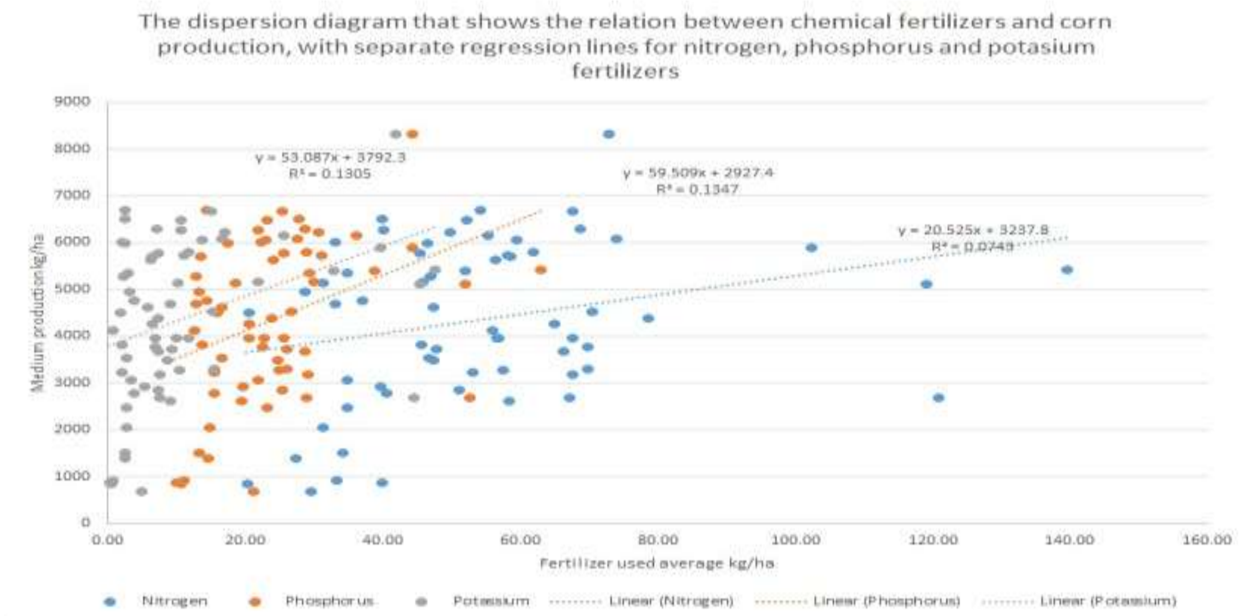

Fig. 2. The dispersion diagram that shows the relation between chemical fertilizers and corn production, with separate regression lines for nitrogen, phosphorus and potasium fertilizers
Source: personal processing of NSI data [30].

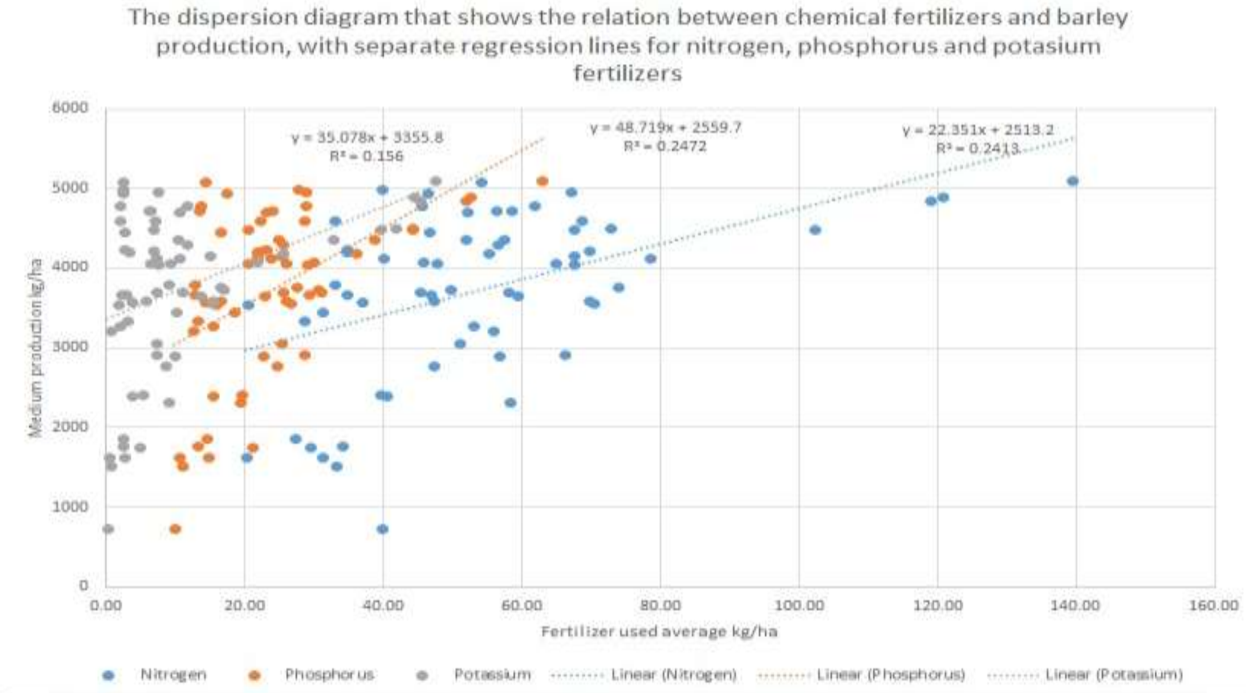

Fig. 3. The dispersion diagram that shows the relation between chemical fertilizers and barley production, with separate regression lines for nitrogen, phosphorus and potasium fertilizers
Source: personal processing of NSI data [30].

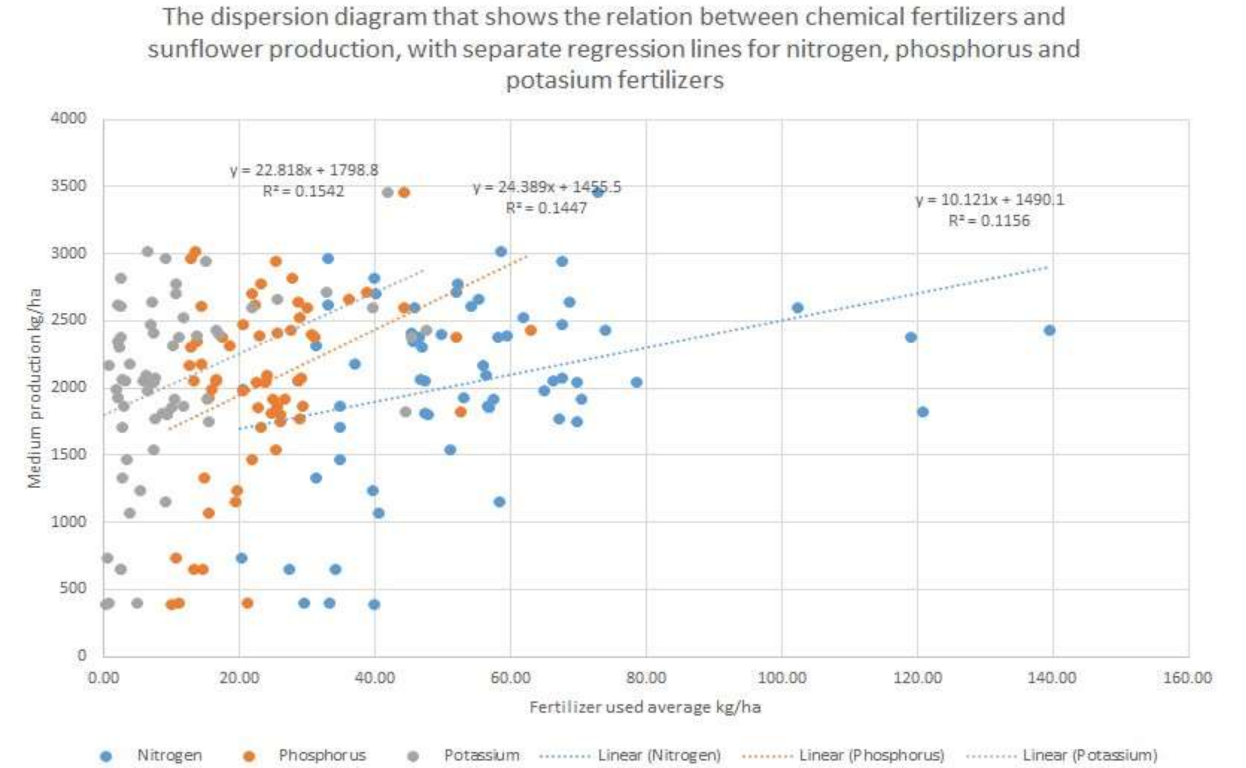

Fig. 4. The dispersion diagram that shows the relation between chemical fertilizers and sunflower production, with separate regression lines for nitrogen, phosphorus and potasium fertilizers
Source: personal processing of NSI data [30].

The analysis of corn production

The analysis of corn production emphasized different models regarding the intake efficiency in contrast with the wheat production.

Table 3. The analysis of the correlation: Wheat production and agricultural inputs

Input Variable	Pearson Correlation	Significance Level
Phosphorus fertilizer	0.367	**
Potassium fertilizer	0.361	**
Tractors	0.322	*
Nitrogen fertilizer	0.273	*
Natural fertilizers	0.260	*
Agricultural combines	0.258	*
Mechanical seeders	0.217	ns
Fungicide	0.166	ns
Herbicide	0.076	ns

Source: personal processing of NSI data [30].
Note: ** significant for p<0.01; * significant for p < 0.05; ns= insignificant.

The analysis of the correlations identified significant relations with both chemical fertilizers, as well as with mechanical equipment, as shown in Table 3.

Unlike the wheat production corn has presented moderate correlations with the mechanical equipment, especially tractors ($r = 0.322$, $p < 0.05$). Of all the chemical fertilizers, phosphorus and potassium have shown the strongest correlations ($r = 0.367$ and $r = 0.361$, $p < 0.01$).

The regression analysis for the most significant inputs emphasized complementary models between different types of fertilizers. The phosphorus fertilizer model had a regression coefficient of 59.509 ($p<0.003$) with a standard error of 1,597.274, explaining 13.5% of the production variation ($R^2=0.135$) and proving an acceptable independence of the Durbin-Watson=1.902. For the potassium fertilizer, the analysis revealed a regression coefficient of 53.087 ($p<0.004$) with a standard error of 1,691.138, being responsible for 13% of the variation ($R^2= 0.130$), proving an adequate independence of the residual value (Durbin-Watson = 1,936).

The regression models explain between 13% and 13.5% of the variation of the corn production, although the influence of the fertilizers applied is significant we can conclude that factors like soil quality and meteorological conditions play a more important role in determining the corn production yield in comparison with the wheat production.

The analysis of barley production

The analysis of the barley production emphasized strong correlations with the chemical fertilizers, having different models in comparison to wheat and corn. Table 4 shows the results of the correlation analysis for different agricultural inputs. Barley showed to have the strongest response to phosphorus fertilizers ($r=0.497$, $p<0.01$) and to nitrogen fertilizers ($r=0.491$, $p<0.01$), with correlation coefficients that were larger than the ones for the corn production.

The influence of the potassium fertilizer, although significant ($r=0.395$, $p<0.01$) was lower in comparison to the other two studied fertilizers.

Table 4. The analysis of the correlation: Barley production and agricultural inputs

Input Variable	Pearson Correlation	Significance Level
Phosphorus fertilizer	0.497	**
Nitrogen fertilizer	0.491	**
Potassium fertilizer	0.395	**
Agricultural combines	0.061	ns
Mechanical cultivators	0.042	ns
Natural fertilizers	0.001	ns
Fungicide	0.139	ns
Herbicide	-0.188	ns

Source personal processing of NSI data [30].
Note: ** significant for p<0.01; * significant for p < 0.05; ns= insignificant.

From regression analysis of the significant relations between fertilizers produced distinctive models, one for each type of fertilizer. The phosphorus model had a regression coefficient of 48.719 ($p<0.001$) and explained almost a quarter (24.7%) of the variation of the production ($R^2 = 0.247$) with an adequate independence of the rezidual value (Durbin-Watson = 2.161) and a standard error of 900.273. This statistical relations are visually represented in image 3, that shows the

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graphical representation of the barley yield response to different fertilizers in different regions of Romania.

The regression models for barley explain approximately 24-25% of the variation of the production, having a stronger predictive relation in comparison with corn. The mechanical inputs showed a small correlation with the barley production, this find suggesting that managing fertilizers can be more useful for optimizing the yield of the barley crops than mechanical inputs.

The analysis of the sunflower production

The analysis of the production of sunflower created different models, with significant variations regarding inputs efficiency in comparison to other studied crops.

Table 5 shows the correlation coefficients between the agriculture inputs and the sunflower crop production

Input Variable	Pearson Correlation	Significance Level
Potassium fertilizer	0.393	**
Phosphorus fertilizer	0.380	**
Nitrogen fertilizer	0.340	**
Agricultural combines	0.241	ns
Mechanical seeders	0.221	ns
Natural fertilizers	0.205	ns
Fungicide	-0.171	ns
Herbicide	0.041	ns

Source personal processing of NSI data [30].
Note: ** significant for $p<0.01$; ns= insignificant.

In comparison with other crops in the present study, the sunflower crops proved to have the strongest response to the potassium fertilizers ($r=0.393$, $p<0.01$), followed by phosphorus ($r=0.380$, $p<0.01$) and nitrogen ($r=0.340$, $p<0.01$). The findings are in accordance with the known high potassium need of the sunflower plant for oil production.

The potassium fertilizer model had a regression coefficient of 22.818 ($p<0.01$) and accounted for 15.4% of the variation of the production ($R^2 = 0.154$), with an adequate independence of the residual value (Durbin-Watson = 1.870) and a standard error of 6.842.

For the phosphorus fertilizer the model has shown a regression coefficient of 24.389 ($p<0.01$) and explained 14.5% of the variance ($R^2 = 0.145$), showing an acceptable independence of the residue (Durbin-Watson = 1.764) and a standard error of 7.592.

The regression models explain approximately 14-15% of the variation of the sunflower production, which suggests that while the chemical fertilizers play a significant part, other factors, such as the soil condition and the climate, can have a substantial impact on the production yield. The mechanical entries have presented weaker correlations in contrast with other crops, which suggests the fact that the management of the fertilizers could be more important for the optimization of the sunflower production than the mechanical intervention.

Comparative analysis

The analysis of the inputs-outputs relations for all the four crops show distinctive models regarding the efficiency of the fertilizers and the regional success.

The chemical fertilizers have constantly shown significant correlations with the production of all crops, although with different degrees of impact (Table 6).

Table 6. The comparative analysis of the impact of fertilizers on crops

Fertilizer	Wheat	Corn	Barley	Sunflower
P	0.541**	0.367**	0.497**	0.380**
N	0.523**	0.273*	0.491**	0.340**
K	0.456**	0.361**	0.395**	0.393**
R^2 range	0.21-0.29	0.13-0.14	0.24-0.25	0.14-0.15

Source: personal processing of NSI data [30].
Note: ** significant for $p<0.01$; ns= insignificant.

The phosphorus fertilizers have shown the strongest correlation with wheat ($r=0.541$) and barley ($r=0.497$), while the production of sunflower has shown the biggest correlation with the potassium fertilizer ($r=0.393$). Corn has shown more moderate correlations among all the types of fertilizers, phosphorus showing the strongest relation ($r=0.367$).

New successful regional models have appeared for all the studied crops, revealing distinctive tendencies regarding both the inputs efficiency and the regional performance. In what the variance of the inputs efficiency is concerned, the wheat and the barley have shown the strongest response to the inputs of fertilizers, with R^2 values of 0.29 and respectively 0.25, while the corn and the sunflower have presented more moderate responses, suggesting a higher influence of other environmental factors. Particularly, the mechanical inputs have presented a significant correlation only with the corn production. As for the regional models of performance, the efficiency of the chemical fertilizers varied significantly according to the region, the strongest responses being noticed in the South-east region and South-Muntenia. The impact of the mechanical inputs has presented less regional variations in contrast with the chemical fertilizers, while the efficiency of the natural fertilizers remained low in all the regions and crops.

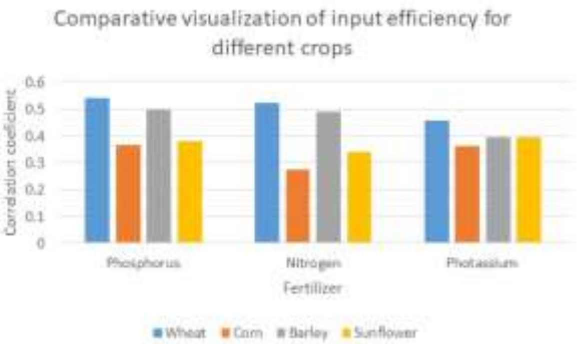

Fig. 5. The comparative visualization of the inputs efficiency amongst crops
Source personal processing of NSI data [30].

The regional distribution of the agricultural production reflects the patterns noticed by Bălan (2014) [3] in his territorial analysis. Despite the territorial distribution, which is relatively balanced, between regions (ranging from12.25% to 15.46% of the national territory) with the exception of București-Ilfov region, the agricultural production varies significantly. This variation is obvious especially in South-Muntenia region and South-East, where a combination of favorable soil conditions adequate climate and extended agricultural areas contribute to higher volumes of production of the main crops.

South-Muntenia and Sount-East regions have constantly shown higher volumes of productions [16].

The persistent regional disparities in the Romanian agricultural field by comparison to the EU model reflects significant structural challenges. As Ciutacu et al. (2015) [5] shows in their comprehensive analysis, while Romania was owning 7.7% of the utilized agricultural area of the EU, it hired 25% of the agricultural working force of the EU in 2010. Their research shows that Romanian farmers received a much smaller support only 158.3 EUR/ha, in comparison to the EU average of 274 EUR/ha, and the total support represented just 33.6% of the sectors gross added value, in contrast to 47.8% the EU average. These structural disadvantages contribute to the explanation of the variation in the regional agricultural productivity and emphasizes the necessity of more balanced support mechanisms.

This comparative analysis suggests that, although chemical fertilizers are essential for all the crops, their optimal use has to be adjusted to specific crops and to regional conditions. The variation of the R^2 values amongst crops indicate different levels of predictability of the results of the production founded on the levels of the inputs, the wheat and the barley showing the most consistent answer to applying fertilizers.

CONCLUSIONS

The analysis of the agricultural inputs and their relation to the vegetal production in the developing regions of Romania has underlined some significant models which have important applications for the management of the agriculture and policy making.

Chemical fertilizers have constantly shown significant correlations with the production f all the studied crops, although with different degrees of impact. Phosphorus fertilizers have shown strong relations with the wheat production (r=0.541) and barley (r=0.497), while potassium fertilizers have shown the strongest correlation with the production of sunflower (r=0.393). These relations suggest that the specific strategies to apply the fertilizers could significantly improve the results of the production. The regional variation in what the efficiency of the inputs is concerned have appeared as an important factor in the agricultural productivity. The South-East and South-Muntenia regions have generally shown a stronger efficiency for converting the fertilizers input into vegetal productions, especially for the wheat and corn production. This regional variation suggests the necessity of agricultural management strategies adjusted to the local level rather than an unique approach.

The analysis has shown that different crops show different levels of response to the agricultural inputs. The wheat and the barley showed the most consistent and strongest responses to the fertilizers use (R^2 values of 0.21 -0.29 and respectively 0.24-0.25), while the corn and the sunflower have shown more moderate answers (R^2 values of 0.13-0.14 and respectively 0.14-0.15). This variation suggests that the strategies to manage the specific inputs of the crops could optimize the use of resources and improve the efficiency of the production.

These findings have more important implications for the agricultural policy and practice in Romania. The development of guidelines regarding the use of specific fertilizers to each region could improve the efficiency of inputs in different areas. The investment in testing and monitorization of the soil could contribute to the optimization of the usage rate of the fertilizers according to the local conditions. The implementation of the management strategies specific to each crop could improve the results of the production by adjusting the approaches the to the unique needs of each crop. In addition, the continuing the researches regarding other factors that affect the crops yield could offer additional information to optimize agriculture, leading to more comprehensive and efficient agricultural practices.

The results of the study offer support for making decisions based on evidence in the Romanian agriculture, particularly in what the allocation of resources and the strategies of input management is concerned. Still, monitoring and continuously analyzing the input-output relations will be essential to adjusting to the changing agricultural conditions and to the maintaining of a long term improvement of the productivity.

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