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MODELING OF THE OPTIMAL LEVEL OF INTENSITY OF CROP PRODUCTION AT THE REGIONAL LEVEL

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Abstract

The paper studied the impact of the level of production intensity on productivity and profitability of crop production in agricultural enterprises of the regions of Ukraine. In order to answer the question of how to increase crop yields and financial returns of lands in the face of climate change, we built graphic-analytical models of dependence of the yield (productivity) of basic agricultural crops from the size of operating (production) expenses per 1 ha of harvested area in agricultural enterprises of the Ukrainian regions. The results of the analysis showed that the real increase in the yield of analyzed crops is directly related to an increase in the level of intensity, expressed by the value of expenses per 1 ha of harvested area. The paper employed the correlation and regression analysis for quantifying tightness and mathematical description of the relationship, in particular, the dependence of the yield of winter wheat grain, corn for grain, sunflower, soy, rape and potatoes from the size of production expenses per 1 ha harvested area. The predicted optimal level of intensity was determined, taking into account the action of the economic law of diminishing returns.

Key words: *financial support, intensification, sustainable intensification, intensity, optimization, costs*.

INTRODUCTION

The Ukrainian agricultural sector is characterized by an increase in the level of production intensity in recent years, but the achieved level remains lower than the average for the EU countries. Many studies often the argument is made that given the existence of the considerable yield gap (is the difference between the optimal yield and the actual yield of best practice), Ukrainian agricultural enterprises might be able to substantially increase total crop production [4; 7; 19; 20]. However, in this context, one of the main problems and barriers of agricultural enterprises was and remains the deficit of working capital for the full implementation of agricultural technologies and capital investments for updating and expanding fixed assets. This deficit is estimated by experts at 20–25 bln USD per year. This deficit did not allow Ukraine to significantly increase crop yields and reach the production level of 100 million tons of grain, impedes the development of capital-intensive directions of production, limits the development of the processing and food industries [1].

At the same time, no less important is the action of law of diminishing returns. In agriculture the law of descending return consists in that every next unit of costs results in an all less return as an additional volume of products and additional profit, operates clearly, then there is a necessity of such level of intensity of production, and, accordingly, and level of costs, that provides the achievement of maximal economic effect at the optimal indexes of costs [16]. This question is lately investigated by N. Kondratyuk [6], A. Kucher [7], N. Lialina [8], O. Lushnikova [9], D. Parmacli et al. [10], O. Oliynuk, V. Makohon, H. Badalov et al. [13; 14; 15; 16], D. Shuyan, M. Bozhko [19; 20], S. Vynohradenko [25].

The evolution and synthesis of the concept of sustainable development and the concept of intensification has led to the emergence and development of the concept of "sustainable intensification", which has been actively studied in recent years. In particular, the

following issues are in the focus of attention of scientists: conceptualising fields of action for sustainable intensification [26]; sustainable intensification of agricultural production [5; 11; 18] and its role in adapting to climate change [2]; agricultural innovations for sustainable crop production intensification [12; 21]; farming systems for sustainable intensification [22]; opportunities for sustainable intensification in European agriculture [17]. One of the components of sustainable intensification in the agrarian sector is the sustainable intensification of land use, which includes, in particular, land protection and soil fertility reproduction [3; 23] in the context of the sustainable development [24]. This paper studied the impact of the level of production intensity on productivity and profitability of plant growing.

MATERIALS AND METHODS

The data of the State Statistics Service of Ukraine on the main economic indicators of agricultural enterprises at the regional level were used as an information base in this article. The study used the following methods: economic-statistical and monographic (for study of the intensity of cultivation of the main types of crop products); grapho-analytical (for the visual representation of the identified dependencies); correlation and regression analysis (for quantifying tightness and mathematical description of the relationship); analysis, synthesis, abstract-and-logical (formulation of conclusions).

In order to answer the question of how to increase crop yields and financial returns of lands in the face of climate change, at the first step we constructed graphic-analytical models of dependence of the yield (productivity) of basic crops from the size of operating expenses per 1 ha of harvested area in agricultural enterprises of Ukrainian regions. At the second step, a correlation analysis was carried out and the developed regression equations were analyzed. The predicted optimal level of intensity was determined at the third step, taking into account the action of the economic law of diminishing returns.

RESULTS AND DISCUSSIONS

This section presents the results of assessing the impact of intensity of crop production on the yield of winter wheat grain (Fig. 1), corn grain (Fig. 2), sunflower (Fig. 3), soy (Fig. 4), rape (Fig. 5) and potatoes (Fig. 6) in agricultural enterprises of the regions of Ukraine. The constructed models mainly confirmed the hypothesis based on the assumption that the decisive role in the formation of the yield belongs to the sum of operating (production) expenses per hectare; this dependence is formed under the influence of the economic law of diminishing returns.

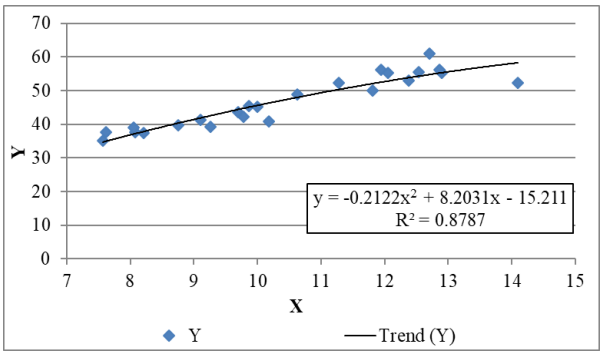

Fig. 1. Graph of the dependence of the yield of winter wheat grain (Y, centner/ha) from the size of production costs per 1 hectare harvested area (X, thousand UAH) in agricultural enterprises of the regions of Ukraine, 2016

Source: calculated and built by the authors based on data of the State Statistics Service of Ukraine.

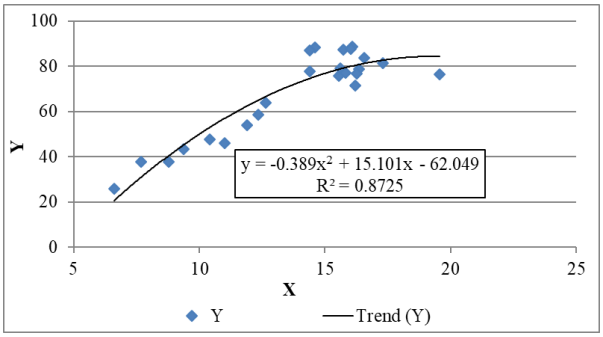

Fig. 2. Graph of the dependence of the yield of corn grain (Y, centner/ha) from the size of production costs per 1 hectare harvested area (X, thousand UAH) in agricultural enterprises of the regions of Ukraine, 2016

Source: calculated and built by the authors based on data of the State Statistics Service of Ukraine.

The graphical representation of the influence of the sum of costs per hectare on crop yields showed the polynomial nature of the

dependence, which is mathematically described by parabolas of the second order. The regression equations show that the increase in the amount of costs per 1 thousand UAH per hectare of harvested area of winter wheat contributed to the increase in yield by 8.20 c/ha, while the rate of increase in yield slowed by 0.21 c/ha, which led to a decrease in yield after achieving a certain amount of costs. The pairwise correlation coefficient is 0.937, which indicates a very close direct relationship between the sum of costs per hectare and the yield of winter wheat. The coefficient of determination shows that the variation in the yield of winter wheat by 87.9% depended on the variation in the amount of costs per hectare.

It was established that the increase in the amount of expenditures by 1,000 UAH per hectare of harvested corn area for grain contributed to the increase in yield by 15.10 c/ha, while the rate of increase in yield slowed down by 0.40 c/ha. The coefficient of pairwise correlation is 0.934, which, again, indicates a very close direct relationship between the amount of costs per hectare and the corn yield. The coefficient of determination shows that the 87.3% variation in maize yield depended on the variation in the amount of costs per hectare.

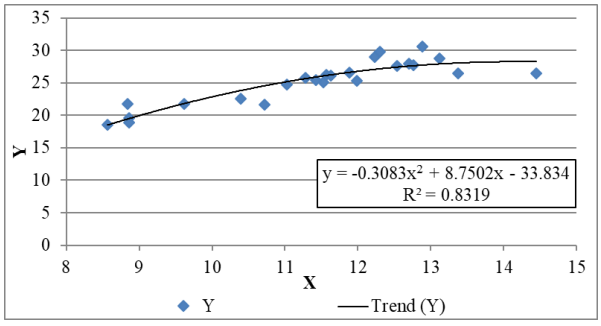

Fig. 3. Graph of the dependence of the yield of sunflower (Y, centner/ha) from the size of production costs per 1 hectare harvested area (X, thousand UAH) in agricultural enterprises of the regions of Ukraine, 2016
Source: calculated and built by the authors based on data of the State Statistics Service of Ukraine.

It is established that the increase in the amount of costs by 1 thousand UAH per hectare of harvested area contributed to the increase in yield of sunflower by 8.75 c/ha, soybeans – by 2.80 c/ha, rapeseed – by 3.69 c/ha, while the rate the increase in sunflower yield slowed down by 0.31 c/ha, soybeans by 0.01 c/ha, and rapeseed by 0.10 c/ha. The coefficient of pairwise correlation is 0.912 for sunflower, 0.738 – for soybean, and 0.661 – for rapeseed, indicating a direct very close and noticeable relationship between the sum of costs per hectare and the yield of these crops. The coefficient of determination shows that the variation in yield of sunflower by 83.2%, soybean by 54.5%, rapeseed by 43.7% depended on the variation in the amount of costs per hectare.

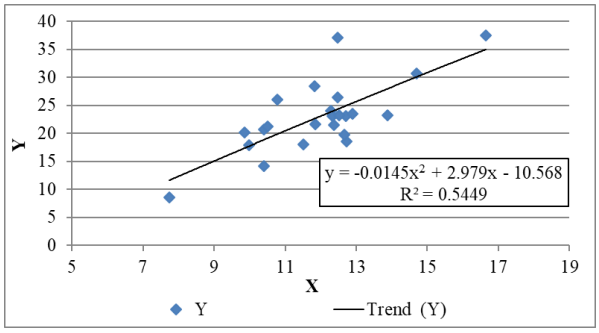

Fig. 4. Graph of the dependence of the yield of soy (Y, centner/ha) from the size of production costs per 1 hectare harvested area (X, thousand UAH) in agricultural enterprises of the regions of Ukraine, 2016
Source: calculated and built by the authors based on data of the State Statistics Service of Ukraine.

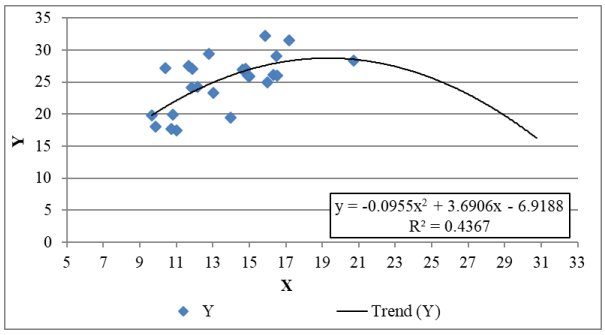

Fig. 5. Graph of the dependence of the yield of rape (Y, centner/ha) from the size of production costs per 1 hectare harvested area (X, thousand UAH) in agricultural enterprises of the regions of Ukraine, 2016
Source: calculated and built by the authors based on data of the State Statistics Service of Ukraine.

Thus, the constructed equations of the dependence of the yield of winter wheat, corn, sunflower, soybean and rapeseed on the sum of costs per hectare indicate a clear manifestation of the law of diminishing returns. The dependence of the yield of

potatoes from the size of production costs per 1 hectare harvested area most accurately describes the logarithmic function. The coefficient of pairwise correlation is 0.708, which indicates a noticeable direct relationship between the size of costs per hectare and the yield of potatoes. The coefficient of determination in our case shows that the 50.1% variation in yield of potatoes depended on the variation in the amount of costs per hectare.

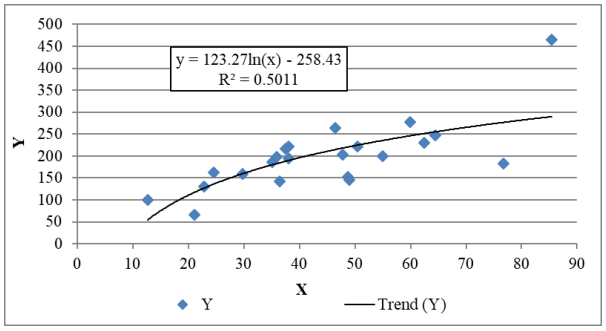

Fig. 6. Graph of the dependence of the yield of potatoes (Y, centner/ha) from the size of production costs per 1 hectare harvested area (X, thousand UAH) in agricultural enterprises of the regions of Ukraine, 2016
Source: calculated and built by the authors based on data of the State Statistics Service of Ukraine.

In turn, we note that the yield significantly influenced the amount of income and profit per hectare (Fig. 7-10), but the nature of the dependence and the degree of closeness of the relationship was different for specific crops.

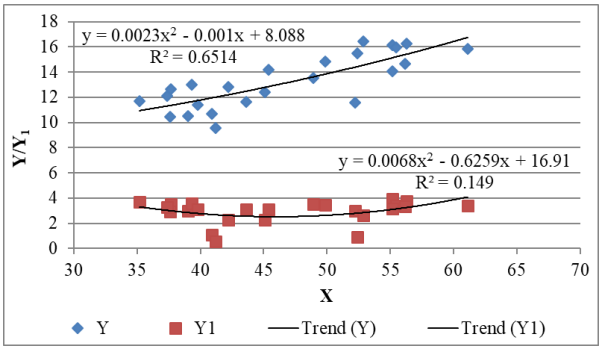

Fig. 7. Graph of the dependence of the income (Y, thousand UAH/ha) and profit (Y1, thousand UAH/ha) from the yield of winter wheat grain (X, centner/ha) in agricultural enterprises of the regions of Ukraine, 2016
Source: calculated and built by the authors based on data of the State Statistics Service of Ukraine.

It was found that the increase in yield by 1 c/ha contributed to the increase in income per hectare of soybeans by 1320 thousand UAH, rapeseed – by 0.895 thousand UAH, potatoes – by 0.335 thousand UAH, while the rate of increase in soybean income slowed by 0.011 thousand UAH/ha, rapeseed – by 0.004 thousand UAH/ha, potatoes – by 0.0002 thousand UAH/ha.

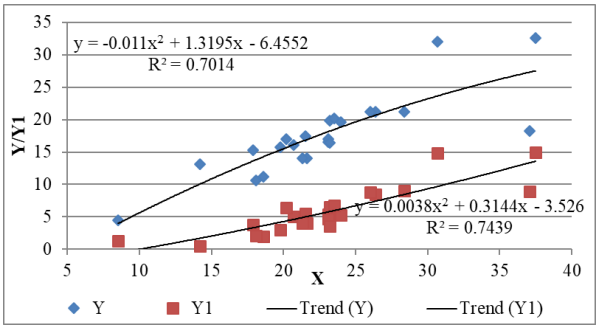

Fig. 8. Graph of the dependence of the income (Y, thousand UAH/ha) and profit (Y1, thousand UAH/ha) from the yield of soy (X, centner/ha) in agricultural enterprises of the regions of Ukraine, 2016
Source: calculated and built by the authors based on data of the State Statistics Service of Ukraine.

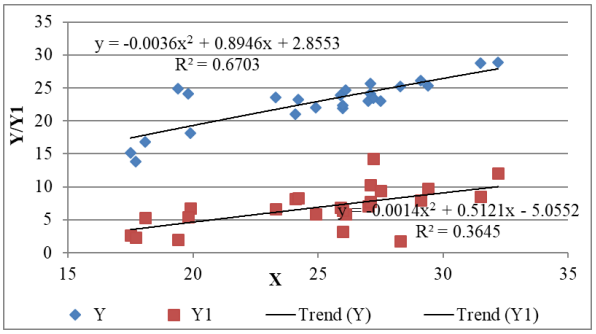

Fig. 9. Graph of the dependence of the income (Y, thousand UAH/ha) and profit (Y1, thousand UAH/ha) from the yield of rape (X, centner/ha) in agricultural enterprises of the regions of Ukraine, 2016
Source: calculated and built by the authors based on data of the State Statistics Service of Ukraine.

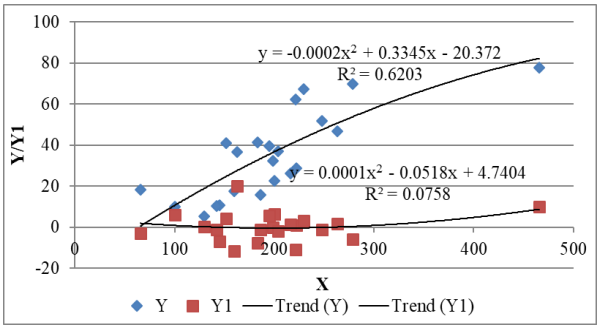

Fig. 10. Graph of the dependence of the income (Y, thousand UAH/ha) and profit (Y1, thousand UAH/ha) from the yield of potatoes (X, centner/ha) in agricultural enterprises of the regions of Ukraine, 2016
Source: calculated and built by the authors based on data of the State Statistics Service of Ukraine.

The pairwise correlation coefficient is 0.837 for soybeans, 0.819 for rapeseed, and 0.788 for potatoes, indicating a direct close relationship between crop yields and income per hectare. The coefficient of determination shows that the variation in income per hectare of soybean by 70.1%, rapeseed by 67.0%, potatoes by 60.2% depended on the variation in yield of these crops. The profit per hectare in this case depended less on crop yields, which is associated with other factors shaping its size.

Using the developed regression models, we determined the optimums of the function of the dependence of crop productivity from the size of operating expenses in investigated agricultural enterprises of Ukrainian regions and developed the forecast of optimal costs per 1 hectare for 2022 (Table 1).

Table 1. Actual and predicted value of the optimum of the function of dependence of crop productivity from the size of production costs in agricultural enterprises of the regions of Ukraine

Crops	Optimum of functions, 2016 year		Actual values in agricultural enterprises of Kharkiv region, 2016 year		Forecasted value of optimal costs for 2022 year, thsd. UAH/ha*
	Operating (production) costs, thsd. UAH/ha	Yield, c/ha	Operating (production) costs, thsd. UAH/ha	Yield, c/ha	
Winter wheat	19.3	64.1	9.9	45.4	34.3
Corn grain	19.4	84.5	12.4	58.8	34.5
Sunflower	14.2	28.3	12.2	29.0	25.2
Rape	19.3	28.7	9.6	19.8	34.3

*Calculated taking into account the aggregate expenditure index (177.7%) for crop production in 2017-2021. For 2021, the cost index is taken for 9 months (January-September).

Source: calculated and built by the authors based on data of the State Statistics Service of Ukraine.

According to forecast, the optimal (under average farming conditions at the meso level) operating expenses for 2022 will account for winter wheat 34.3 thsd. UAH/ha, corn grain – 34.5, sunflower – 25.2, rape – 34.3 thsd. UAH/ha. These costs will ensure the achievement of yields of these crops, respectively, at the level of: 64.1 c/ha, 84.5, 28.3 and 28.7 c/ha. The results can be used at the regional level of management to make decisions to improve the financial support to optimum level. At the micro level, there is a need for additional research.

Comparing the results of our research with the existing works [14; 15; 16; 19; 20], it should be noted that, in general, they do not contradict each other and complement and develop them, in particular, in terms of managing the sustainable intensification of crop production at the regional level, taking into account certain predicted optimal levels of intensity. Thus, it was established that:

(i) agricultural enterprises of Ukraine have significant reserves for increasing crop yields to the optimal level, which mainly corresponds to the average indicators of the EU countries;

(ii) real growth in crop yields is directly related to an increase in the level of intensity, expressed by the value of costs per 1 hectare of harvested area;

(iii) since production costs have not reached the maximum level, it is proposed to increase them to optimal values with simultaneous optimization of their structure, which will significantly increase economic efficiency and competitiveness;

(iv) a significant problem of increasing the level of intensity is the action of the law of diminishing returns, which entails a decrease in the payback of additional costs and ultimately limits the amount of profit per hectare. In the EU countries, high levels of production intensity are partially offset by budgetary subsidies;

(v) in Ukraine, overcoming the law of diminishing returns should be linked to the introduction of innovative technologies that optimize (minimize) the costs of enterprises while increasing crop yields.

CONCLUSIONS

Using the constructed graphic-analytical models, we can conclude that the productivity of crop production in agricultural enterprises in the regions of Ukraine was formed under the conditions of the economic law of diminishing return. Yet it is worth noticing that the effect of this economic law was not found in potato production, which is probably due to the relatively low level of expenses per

hectare. It was found that real growth in crop yields is directly related to an increase in the level of intensity, expressed by the amount of expenses per 1 hectare of harvested area.

It is proposed to increase production costs to optimal values with simultaneous optimization of their structure, which will significantly increase economic efficiency and competitiveness. According to forecast, the optimal (under average farming conditions at the meso level) operating expenses for 2022 will account for winter wheat 34.3 thsd. UAH/ha, corn grain – 34.5, sunflower – 25.2, rape – 34.3 thsd. UAH/ha. Overcoming the law of diminishing returns in Ukrainian crop production should be linked to the introduction of innovative technologies that optimize (minimize) the costs of enterprises while increasing crop yields.

The obtained results can be used at the regional level of management to make decisions to improve the financial support to optimum level. At the micro level, there is a need for additional research, which will be a promising area of our study in the future.

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