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Geoinformational support for modeling the efficiency of crop cultivation in crop rotations

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***Abstract* – In the article was developed a tool in the ModelBuilder application, which evaluate the economic efficiency of the use of the selected plot of land and provide an opportunity to determine the most effective scientifically based crop rotation using the modeling method. The indicator of effective use is the profitability of growing products, when applying different sets of agricultural crops scientifically based crop rotation. The model was tested on a specific field of an agricultural enterprise with different crop rotation options, as well as when applying the same crop scheme for different fields.**

Keywords – yield; price of ball-bonitet; ModelBuilder; profitability

I. Introduction (Heading 1)

Fulfilling of the needs of the population in food products, branches of consumer industry in agricultural raw materials requires an increase in the production of agricultural products on the basis of rational and efficient use of land. The practice of management in market conditions confirms the indisputable truth that the effectiveness and efficiency of agricultural enterprises primarily depends on the effective use of land [5].

The issues of yield forecasting and optimization of plant cultivation are addressed in their works by G.I.Yarovy, O.V. Romanov, N.O. Didukh, T.A. Romanova. The task of crop programming is the theoretical justification and practical implementation of the possible level of use of solar energy, soil and climatic resources, genetic potential of zoned and promising varieties to obtain high crop yields with minimal material, monetary and energy costs [7].

Crop rotation modeling based on satellite data was the focus of the work of F´elix Quinton, Loic Landrieu Lastig. They take advantage of the increasing quantity of annotated satellite data to propose the first deep learning approach modeling simultaneously the inter- and intra-annual agricultural dynamics of parcel classification [4].

Crop rotation is a critical management strategy available to farmers to sustain soil fertility, combat pests, and improve crop yields. Because of the complex feedbacks occurring in the soil-plant-atmosphere continuum, legacy effects and their interactions with climate are generally not well understood, and their ultimate influence on yields and environmental quality is difficult to predict. Crop simulation models offer a way of parsing through this complexity [1].

Increasing the efficiency of land use is due to the use of modern technologies and means of management, planning and monitoring of agricultural activity. An example can be the work [6], where the concept of a tool for constructing a cartogram of ecological and economic suitability of lands in an automated mode using the ArcGIS software product is presented and implemented. The next stage, after identifying the most suitable areas for growing agricultural crops, is the design of scientifically grounded crop rotations on these areas, the main objective of which is to ensure the profitability of the agricultural enterprise while maintaining the ecological condition of the territory.

That is why the purpose of this work is to develop a tool in the ModelBuilder application [8] for mathematical modeling of crop yield and profitability assessment, which will allow for the formation of the most efficient and rational crop rotations. The purpose of this research is to develop a model of crop cultivation efficiency in crop rotation fields, which will allow automated configuration of the most efficient placement of crops.

II. Method and/or Theory

To achieve the objective of crop rotation planning, it is necessary to develop a tool within the ModelBuilder environment that would evaluate the economic efficiency of the selected land plot and provide the ability to determine the most effective, scientifically grounded crop rotation using a modeling approach.The tool should be based on a mathematical model for predicting yields, which will allow for fairly accurate calculation of yields depending on the location of crop rotation fields and soil properties.

Based on the analysis of literary sources, a mathematical model was selected, according to which the value of the predicted harvest based on the price of the ball-bonitet is determined depending on [2]:

$$H_{pr} = \frac{(B \cdot P + D_m \cdot P_m \cdot C_o) \cdot C_p \cdot C_{wat}}{100} , \quad (1)$$

where B – ball-bonitet of the soil; P – ball-bonitet price by crop yield kg/ball; Dm – dose of applied mineral fertilizers (full mineral nutrition), kg of active substance/ha; Pm – payback of mineral fertilizers by yield increase, c/c; Co – correction factor for the direct effect and after the effect of organic fertilizers; Cwat – correction factor for the technical level of water regulation; Cp – correction factor for production conditions.

For modeling, we consider the situation when we calculate the yield without applying organic fertilizers (at the same time Co=1,0), coefficients for production conditions and the technical level of water regulation are equal to 1.0. Based on this, the formula will have the following form:

$$H_{pr} = \frac{B \cdot P + D_m \cdot P_m}{100} \quad (2)$$

This formula will allow you to calculate the forecast yield of an agricultural crop, taking into account the dose of mineral fertilizers applied to soils with the corresponding credit scores. The prices of credit points for agricultural crops grown on the territory of Ukraine are obtained from the work of O.M. Kovalova [3]. The cost of growing agricultural crops per 1 ha and their prices were taken from specialized sites.

Thus, the following input data are required for the model to work:

- layer with boundaries of agro groups of soils, containing data about ball-bonitet of arable land on a specific agricultural group;
- a layer that contains data on the dose of fertilizers that is planned to be applied;
- layer with land boundaries and their name;
- a layer containing a list of crops that can be grown in the area, their ball-bonitet prices, selling prices, and cultivation costs excluding fertilizers
- a layer containing a list of crops that can be grown in the area, their ball-bonitet prices, selling prices, and cultivation costs excluding fertilizers.

Based on the initial data described above, a model of the efficiency of growing agricultural crops was developed depending on profitability.

The result of the developed model for automated assessment of the efficiency of growing certain crops in a particular field is the following table (Fig. 1). As you can see from the figure, this table is not convenient to use, so there was a need to develop a template that would format the final result of the model in the form of a report for convenience and clarity.

The next step is to customize and edit the report's appearance. To automate the generation of the final table, which is obtained from the model in the form of a customized report, we will use the file with the template of the report.

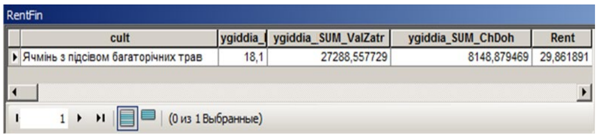

Figure 1. The result of the developed model

III. Results

For an example of the application of the model, let's use the set of crops most widespread for the studied area: perennial grasses for green fodder, winter wheat, sugar beet, corn for grain, peas, barley with sub sowing of perennial grasses. It will form the 8th complete crop rotation, which will be implemented on the territory of the agricultural enterprise, which is located within the Zdolbuniv territorial community of the Rivne region.

To demonstrate the work of the model, we will apply it to two 8-field crop rotations, where the set of cultivated crops for the same field will differ, and we will also present the corresponding reports. At the first stage, we choose the dose of mineral fertilizers.

Further, by means of GIS analysis, we establish agricultural production groups of soils for the selected field and their area and credit score. The next step is the automatic calculation of the cost of mineral fertilizers that will be used for the selected field. At the next stage, we select agricultural crops that are planned to be grown on the selected field for the 8-year crop rotation. Next, for each of the selected crops, formula (2) automatically calculates the forecast yield, taking into account the applied mineral fertilizers.

Gross costs for each of the crops are calculated according to the formula (3):

$$G_i = \sum H_i * P_i * L_a , \quad (3)$$

where Hi – yield of the i-th agricultural crop, c/ha; Pi – price for the i-th product, hryvnias/c; La – land area, ha.

The net income from growing each crop is calculated automatically by formula (4):

$$N_i = G_i - C_p , \quad (4)$$

where Ni – net income from the plot, hryvnias; Gi – gross income of the plot, hryvnias; Cp – costs for the production of products, hryvnias.

The next step is to calculate the total values of gross costs and net income for the cultivation of agricultural crops on all agro groups of soils that are on the selected plot of land, and for yield, the average value for the field is calculated.

Next, from the obtained values of gross costs and net income, we calculate the profitability of growing this agricultural crop on the selected field according to formula (5).

$$P_p = \frac{N_i}{C_p} \times 100\% \ , \qquad (5)$$

where Pp – profitability of production, %.

For the convenience of presenting the results, a report is generated that contains data on the effectiveness of the modeled crop rotation. Analyzing the reports, we can see that the profitability of the first set is 17.6%, and the second set is 33.2%, i.e., the profitability is lower when growing the first set of crops (Fig. 2). Therefore, the second set is more cost-effective to grow on the selected field. Similarly, the user of this model can experimentally select the optimal site for growing a particular set of crops in a crop rotation.

Agricultural crops for for growing in the 8-year	**Sugar beet**
Average yield of agricultural crop, c/ha	118.8
Total gross costs for growing agricultural crop, hryvnias	44686
Net income from the growing agricultural crop, hryvnias	-16230
Profitability of the growing agricultural crop, %	-36.3

As a whole for the selected field:

Area of the field, ha	**34**
Dose of applied mineral fertilizers kg/ha	**100**
The cost of applied fertilizers	**40832**
Total gross costs for growing agricultural crops of the selected crop rotation, hryvnias	**246425**
Net income from the growing agricultural crops of the selected crop rotation, hryvnias	**43323**
Profitability of the growing agricultural crops, of the selected crop rotation %	**17.6**

Agricultural crops for for growing in the 8-year	**corn for grain**
Average yield of agricultural crop, c/ha	28.8
Total gross costs for growing agricultural crop, hryvnias	32393
Net income from the growing agricultural crop, hryvnias	18255
Profitability of the growing agricultural crop, %	56.4

As a whole for the selected field:

Area of the field, ha	**34**
Dose of applied mineral fertilizers kg/ha	**100**
The cost of applied fertilizers	**40832**
Total gross costs for growing agricultural crops of the selected crop rotation, hryvnias	**234132**
Net income from the growing agricultural crops of the selected crop rotation, hryvnias	**77809**
Profitability of the growing agricultural crops, of the selected crop rotation %	**33.2**

Figure 2. Report fragment for the first and second sets of crops

CONCLUSIONS

Therefore, in this work, a tool was developed that allows mathematically modelling the yield of crops and choosing the most effective crop rotations. The indicator of effective use is the profitability of crop production when applying different sets of agricultural crops within a scientifically grounded crop rotation.

The model was tested on a specific field of an agricultural enterprise with different crop rotation options, as well as when applying the same crop scheme for different fields. The developed model will allow you to automatically calculate the profitability of growing crops in crop rotation fields and, accordingly, configure the most efficient placement of crops.

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