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ECOLOGICAL AND ECONOMIC ASPECTS OF ORGANIZATION OF CROP ROTATIONS IN MARKET TYPE AGRICULTURAL ENTERPRISES

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Abstract

The ecological and economic problems arising from the organization of crop rotations in agricultural enterprises, formed during the period of land relations reform in rural territories, are analyzed. Large agroholdings neglect the crop rotation factor in an effort to maximize the economic impact by growing highly profitable market-oriented crops in large areas. Their attempt to replace crop rotation by increasing the use of synthetic mineral fertilizers and pesticides can lead to environmental and socio-economic problems in the future. Farmers cannot organize crop rotations to the full extend due to the short land lease term. It is shown that the scientifically substantiated crop rotation can harmonize the economic interests of agricultural producers (high and sustainable crop yields, accompanied by the minimum use of material and energy resources) and the environmental safety (preserving the quality of the soil cover and the environment). In order to organize crop rotations in a changing market and climatic environment, it is suggested to use methodological approaches. These approaches are based on short-term rotation of crops, on dynamics of their placement depending on ecological and economic factors, on formation of homogeneous (by quality indicators) lands (fields), on choice of crops on the basis of evaluation of land prior to its cultivation, on compulsory environmental assessment of projected crop rotations using balance calculations.

Key words*: crop rotation, agricultural enterprises, land management, ecological and economic justification.*

INTRODUCTION

Crop rotation is a determining factor for economically efficient and environmentally safe use of agricultural land, ensuring sustainable agricultural land use, as opposed to the constant cultivation of the same plants on the same land plot for a long period, resulting in a decrease in their yield, in a depletion of the soil nutrients and moisture, and in the intensity of the spread of diseases and pests (Saiko et al., 2002). Therefore, scientifically substantiated crop rotation prevents the irrational use of land by continuously growing the most profitable crops on the same fields (in particular, sunflower or rapeseed); and without additional capital expenditures, it contributes to the reproduction of the soil fertility, provides the normative phytosanitary state of crops and ecological state of the environment, which certainly has a positive impact on the results of economic activity of market-based agricultural enterprises.

Transformation of land relations in the agrarian sector of the economy, change of boundaries and sizes of land business entities, formation of personal farms on the basis of former collective and state farms were accompanied, among other things, by the destruction of existing crop rotations. Because of this, the problem of forming cost-effective crop rotations for various organizational and economic forms of land use becomes especially relevant.

The other side of the problem is the issue of harmonization of the economic interests of land users (maximizing profits through the cultivation and sale of highly profitable crops) with the requirements of environmental safety (compliance with environmental regulations, preservation and reproduction of soil fertility, etc.). Moreover, the economic and environmental aspects of crop rotation are closely interlinked, since scientifically substantiated crop rotation can ensure high productivity of agro-ecosystems (Shevchenko et al., 2017) and significantly reduce the amount of material and energy resources used to control weeds, pests and plant diseases arising from monocultural cultivation.

The purpose of the case study is the analysis of ecological and economic aspects of organization of crop rotations in market-type agro-formations and substantiation of the possibility of introducing new methodological approaches to the formation of crop rotation arrays on the example of agricultural enterprises of the Kyiv region.

Literature review. The results of scientific studies, conducted in Ukraine and abroad, confirm the growing organizing role of crop rotation in solving the main tasks of modern farming systems: ensuring high productivity of agrocenoses in combination with the simultaneous protection of the environment from harmful anthropogenic influence. In particular, foreign scientists consider crop diversification with appropriate crop rotation and agro-biodiversity to be a mechanism to reduce market risks, to increase resource efficiency (Roest et al., 2018), to be an important factor in the sustainable provision of environmentally friendly food and in reducing the negative effects of climate change (Frison et al., 2011), to be a method of increasing the stability of agroecosystems (Erisman et al., 2016), to be the means of harmonizing (balancing) productivity, profitability and environmental friendliness of production (Davis et al., 2012) by reducing the use of chemical plant protection products and synthetic mineral fertilizers.

According to domestic scientists, the complete development of scientifically grounded crop rotations, developed for different soil and climatic zones of the country, in combination with other agrotechnical measures allows to increase the productivity of arable land by 40-50%, while ensuring the fertility of the surrounding environment (Kovalenko, 2007; Lebid et al., 1992).

The historical experience of agricultural development in the forest-steppe zone of the country convinces the existence of dependence of economic and industrial stability of a certain agricultural enterprise, in particular in market conditions, on the breadth of the range of highly profitable commodity products produced by the economy. In addition, weather and climatic conditions during the growing season have a significant impact on the productivity of agrocenoses, as they can be favorable either for all crop rotations or only for individual crops (Saiko et al., 2002).

Therefore, the diversity of crops in the structure of the cultivated land is the means of offsetting the negative impact of adverse abiotic factors, of increasing the resistance of agrocenosis to the harmful effects of biocenotic factors. This is especially true in the conditions of insufficient provision of chemical protection of crops in the vast majority of farms (Brazhenko et al., 2008).

MATERIALS AND METHODS

For the analysis of ecological and economic aspects of crop rotation organization in market-type agro-formations, we used the data of state statistical reporting, provisions of legislative and regulatory acts, as well as the materials of scientific works relevant to the chosen direction of research.

Land management planning and surveying activity were carried out at the territory of the State Enterprise “Research Entity Skvyrske” of the Institute of Agroecology and Nature Management of the National Academy of Agrarian Sciences of Ukraine, where the technological aspects of production are studied.

During the agrochemical examination of soils, we used methods, complying with the current national standard DSTU, GOST standard and methodical instructions. The humus content was determined according to DSTU 4289: 2004 by the Tiurin method (DSTU, 2004); the content of hydrolysable nitrogen – according to the DSTU 7863: 2015 by the Cornfield method (DSTU, 2015); the content of mobile compounds of phosphorus and potassium - according to DSTU 4115-2002 by the modified Chyrykov method (DSTU, 2002).

One of the main principles of short-term crop rotation should be the placement and rotation of crops in accordance with the laws of fruit rotation. This is important from the environmental (normative state of the environment) and the economic point of view (ensuring food security and expanding the range of quality crop products).

It is widely recognized that the only mechanism for practical implementation of scientific and methodological know hows in this field is the development of land regulation projects that provide ecological and economic justification for crop rotation and land management. However, today, according to official statistics, a significant number of land users are evading the development and introduction of crop rotation projects and are in constant search for the ways to circumvent the rules of the law (Poleiko, 2013). Some scientists attribute frequent violation of crop rotation principle in agricultural enterprises to the predominant orientation of commodity producers on the formation of static crop rotations (Kazmir et al., 2014), the methods of which are sufficiently covered in special literature (Kazmir, 2009).

The static crop rotation design algorithm provides justification for the size (area) of rotation, for the designation of the uniform-size fields (or with a normative deviation from the average field size), for drawing up a scheme of crop rotation, and for the designation of forest strips and field roads (Kazmir, 2009). However, the designed fields are not always characterized by homogeneous quality indicators.

The organization of dynamic crop rotation begins with the very formation of homogeneous fields, which are understood not as equal sizes of the crop rotation fields, but as the most homogeneous (in terms of quality) areas with fixed boundaries. For each such field, depending on its geographical features, a unique scheme of crop rotation is adopted, as well as protective forest strips, field roads, etc. are designed. The boundaries of such fields remain stable, regardless of changes in the types of crop rotation or changes in the economic situation. The stability of the fields contributes to the monitoring of lands and to the accounting for material and energy resources used, unlike fields of static crop rotation, where these measures are impossible in a long run.

Therefore, the number of fields and their area in dynamic crop rotations is determined not by the structure of the cultivated areas and the period of crop rotations, but above all by the soil and climatic conditions of a certain area. Because of this, organizing such crop rotations requires more detailed information on the qualitative status of each field. In addition, the effectiveness of forming a dynamic crop rotation system is related not only to the quality of the project design, but also to the annual operational work on these projects' introducetion. Given the wide variety of organizational and economic forms of land tenure and land use, the diversity of soil and climatic conditions of the regions of the country, there is an urgent need to improve methodological approaches to the organization of crop rotation areas in market type agroformations and to their ecological and economic development.

The set of crops in short rotations is influenced by the specialization of the business entity, which, in turn, depends on the geographical zone's soil and climate, as well as the market conditions. Given that, in order to maximize the productivity of crops, it is necessary to achieve the highest possible level of compliance in the soil-plant system: the soil-climatic conditions must meet the agrobiological requirements of the crops grown. The practical implementation of this is to assess the suitability of arable land for a particular farm to grow crops.

From an economic point of view, an important criterion for the effectiveness of the projected crop rotation is crop yields and the level of profitability of crop production, which, in particular, amounted to 24.2% for cereals and legumes and 31,1% for sunflower in 2018. However, the ecological assessment of crop rotations requires considering the influence of the crop rotation on the basic parameters of soil fertility. Given the key role of humic substances in determining the level of soil fertility, it is advisable to carry out the balance calculations of these substances for environmental assessment of the projected crop rotation. In order calculate the average annual balance of humic substances in the soil without taking into account the losses from erosion, the method of G. Chesniak was used (Batsula et al., 1987):

$$B_{a.a.} = \frac{(\sum N_1 + \sum N_2)}{t_r} - \frac{\sum M}{t_r},$$

where:

$B_{a.a.}$ - average annual balance of humic substances during a single crop rotation, t/ha;

N_1 - quantity of the new humic substances due to plant residues, t/ha;

N_2 - quantity of the new humic substances due to organic fertilizers, t/ha;

M - mineralization of humic substances under crops, t/ha;

t_r - rotation duration (time), years.

RESULTS AND DISCUSSIONS

Analysis of the process of organization of crop rotations in market-type agro formations showed that large agro holdings are focused on maximizing profits by expanding the cultivation areas of highly profitable crops. At the same time, the negative impact of the constant cultivation of such crops is overcome by the significant use of synthetic mineral fertilizers and pesticides, which will undoubtedly lead to socio-environmental problems in the near future (environmental pollution, deterioration of health of rural population, etc.).
In their turn, farms, the vast majority of which use land plots of not more than 100 hectares, are unable to organize long-term crop rotations because of the short-term land lease. Therefore, for such farms, the optimal form of organization of their land use territory should be implemented through the introduction of highly specialized short-term crop rotations. Long-term crop rotations were justified in large collective farms, because they performed the function of providing maneuverability in the placement of crops (with respect to various soil and landscape factors), of providing more complete use of the bioclimatic potential of the territory, and contributed to the conservation and reproduction of fertility resources.
The result of the mapping and the land preparation work is the formation of a crop rotation area on the territory of the State Enterprise "Research Entity Skvyrske" of the Institute of Agroecology and Nature Management of the National Academy of Agrarian Sciences of Ukraine with a total area of 229.41 ha, where it is proposed to place a four-course arable crop rotation (average field size - 57.35 ha), which can be used as static or dynamic.

The territory of the studied entity is characterized by the soil and climatic conditions of the Skvyrske natural and agricultural district, which is located in the southwestern part of Kyiv region. The climate of the region is temperate continental, with an average temperature of –6.5°C in January and +19.6°C in July. In the summer, the air can warm up to +30°C and to cool down to –30°C in winter. Up to 550 mm of rainfall occur on average per year, and the rainfall is often stormy, which is a cause of increased erosion risk on sloping areas. The relief of the district is an undulating plain with a dense network of river valleys with numerous beams and ravines. Absolute heights of inter-river space vary within 230-250 m. The most common source rocks are water-glacial and glacial forest sediments. The northern part of the district is characterized by the dominance of the podzolic chernozem in the soil cover, and the low-humus chernozem is typical for the southern part. The valleys of beams and floodplains of rivers are covered with meadow and swamp soils. The upper root layer of chernozem soils has a humus content of 2.1-3.8%. Soils with high acidity occupy approximately a half of the arable areas of the district, which is why the average soil quality index of arable land is 55 points, perennial stands - 49, hayfields - 33, pastures - 30 points.
In the soil cover of the studied entity, the light and medium loamy chernozem is rather typical, and 94.6% of it is untouched by the water erosion, 3.9% is lightly eroded, and 1.5% is medium-eroded. Accordingly, a qualitative assessment of these soil erosion differences is 56, 54 and 42 points.
The results of the agrochemical examination of the soil cover of the crop rotation area are shown in Table 1.

Table 1. Basic fertility parameters of the soil cover of the entity

№ of field	Humus, %			N			P_2O_5			K_2O		
				mg/100 g of soil								
	1*	2*	Difference	1*	2*	Difference	1*	2*	Difference	1*	2*	Difference
I	2.90	3.14	+0.24	14.42	11.76	-2.66	15.71	11.23	-4.48	8.41	9.20	+0.79
II	2.92	3.14	+0.22	14.40	11.64	-2.76	15.87	11.35	-4.52	8.35	9.33	+0.98
III	2.94	3.16	+0.22	14.56	11.76	-2.80	15.65	11.47	-4.18	8.13	9.37	+1.24
IV	2.90	3.18	+0.28	14.42	11.39	-3.03	15.71	11.11	-4.60	8.47	9.25	+0.78
Average	2.91	3.15	+0.24	14.45	11.64	-2.81	15.73	11.29	-4.44	8.34	9.29	+0.95

*1 - data from the X round of the soil examination (2011-2015)
*2 - data from the XI round of the soil examination (2016-2020)
Source: developed by authors.

As shown in Table 1, the soil cover of the entity according to the results of the X round of agrochemical examination is characterized by an average content of humus, and of the XI round - increased, which is explained by an increase in the flow of organics to the soil and increase in its humification. A similar trend was observed for potassium metabolism, which increased by an average of 11.4%. At the same time, the content of mobile forms of nitrogen and phosphorus during the indicated period decreased by 19.4 and 28.2%, respectively, which is due to a significant decrease in the supply of these nutrients to the soil with synthetic mineral fertilizers.

These soil and climatic conditions are generally favorable for the cultivation of the majority of crops, in particular, winter wheat, barley, corn, sugar beet, sunflower, etc., which is confirmed by the data in Table 2. The data in Table 2 indicates the presence of high adaptive cultivation potential of the forest-steppe zones of the Kyiv region; the deep chernozem is suitable for such crops as basic cereals and industrial crops (I class of suitability), the meadow-chernozem soils for winter wheat, barley (I class of suitability), maize, sugar beet and sunflower (suitability class II).

Table 2. The suitability of the soil cover of the Kyiv forest-steppe zone for growing crops

Soil types	Net area		Class of suitability of arable land for crop cultivation:								
	in thousand hectares	%	winter wheat	winter rye	barley	maize	potato	sugar beets	sunflower	soy*	rapeseed*
Deep chernozem, 54 (light loamy soils, medium loamy soils)	621.3	33.1	I	I	I	I	-	I	I	I	I
Meadow and meadow-chernozem soils, 121 (light loamy soils), 124 (hard loamy soils)	125.0	6.6	I	II	I	II	-	II	II	III	III
Shallow chernozem, 52 (sandy loam soil), 53 (medium loamy soils)	89.7	4.8	II	I	II	II	-	II	II	II	II

*authors' own calculations
Source: Dobriak et al., 2009.

In order to improve the quality of the soil cover, it is necessary to plant perennial legumes (clover or alfalfa) which, due to the deep root system, can transfer calcium from the lower layers of soil and from the source rock, and accumulate it in the root layer. In addition, increasing the area under perennial legumes is an important measure to preserve and restore soil fertility, especially soil with an increased erosion risk on slopes of 3 to 5°.

The high agricultural potential of the above-mentioned crops in the Kyiv region is confirmed by the State Statistics Committee of Ukraine. Its 2018 data shows that wheat yield averaged 46.7 q/ha on the area of 190.1 thousand hectares (16.0% of the total cultivated area of the region), maize corn - 97.2 q/ha on an area of 290.9 thousand hectares (24.4%), soybeans - 25.8 q/ha on an area of 135.1 thousand hectares (11.3%), sunflower - 29.7 q/ha on an area of 191.7 thousand hectares (16.1%); sugar beet - 606,0 q/ha on the area of 23.1 thousand hectares (1.9% of the total cultivated area of the region) (State Statistics Service of Ukraine, 2019).

Given that, the following set of crops is suggested for the projected crop rotation field: field I - half a field - perennial grasses, another half - legumes; II - winter cereals; III - half a field - sugar beets, another half - maize corn; IY - half a field - spring cereals, another half - oilseeds. In this crop rotation, the direct use of arable land is one. In this crop rotation, the index of the direct use of arable land equals to one. At the same time, cereals and legumes occupy 62.5% of the crop rotation area, including winter crops - 25% and industrial crops - 25% (12.5% of them are the sugar beets and 12.5% - oilseeds). The main products of almost all of the listed crops can be sold outside the enterprise as commodities.

In this order, crop rotations are all placed after the best precursors: winter wheat - after perennial grasses and legumes, sugar beets and maize corn - after winter cereals, spring corns - after sugar beets, oilseeds - after maize corn. The crop set of this crop rotation allows one to maintain the optimum periodicity of the return of a particular crop to its previous location. In particular, in order to return oilseeds (such as sunflowers) and sugar beets to their previous place of cultivation not after 4 years, but after 8 years, it is necessary to exchange perennial leguminose grasses and leguminous crops after every rotation in the first field (from which the rotation starts). In addition, it is possible to expand or reduce the acreage of a particular crop in such crop rotation (but without disruption of the accepted order of crop placement) in accordance with the market situation, weather peculiarities of the year, organizational and economic reasons. If necessary, such crop rotation has the opportunity to change the set of cultures. For example, the composition of the spring crops can be wheat, barley, buckwheat, millet, and among the oilseeds - sunflower, rapeseed, soybeans.

For the ecological assessment of the projected crop rotation, we used indicators of the annual average balance of humic substances in the soil, the initial data for which is given in Table 3.

Given the indicators of new humic substances (ΣN_1) and mineralization of humic substances (ΣM) shown in Table 3, the humus balance in this rotation without organic fertilizers ($\Sigma N_2 = 0$) is:

$$B_{a.a.} = \frac{(3{,}38 + 0)}{4} - \frac{3{,}25}{4} = 0{,}03\ t/ha$$

Therefore, a crop set of this crop rotation can provide a non-deficit balance of humic substances in the soil even without the use of organic fertilizers.

The additional application of 10 tons of organic fertilizers per 1 ha of cultivated area will provide an annual increase in humus of 0.02%, and 20 t/ha respectively 0.03%.

Table 3. Humus balance in a projected four-year crop rotation

№ of field	Culture	Crop yield, q/ha	Coefficient of plant residues	Coefficient of humification	New humic substances (N_1), t/ha	Mineralization of humic substances (M), t/ha
1	½ clover	222	0.20	0.25	1.11	0.30
	½ pea	24	0.80	0.23	0.44	0.80
2	winter wheat	47	1.10	0.25	1.29	0.70
3	½ sugar beets	606	0.04	0.10	0.24	1.50
	½ maize corn	97	0.80	0.20	1.55	1.10
4	½ buckwheat	16	1.10	0.22	0.39	0.60
	½ soy	26	0.80	0.23	0.48	0.80
Σ					3.38	3.25

Source: developed by authors.

CONCLUSIONS

The basis for an effective organization of modern crop rotations is a harmonious combination of environmental and economic aspects. The environmental aspect lies within the possibility of reducing the level of use of synthetic mineral fertilizers and pesticides on the soil cover due to scientifically based crop rotation, resulting in a normative state of the environment. The economic aspect involves adapting a set of cultivated crops to the changing conditions of the market environment, because the ultimate goal of any producer is to maximize profits by growing highly profitable crops.

In its turn, the highly productive crop rotation contributes to ensuring the food security of the country, increases revenues to local budgets, and helps to maintain the health of rural population through the safe environment, as well as to maintain the health of the urban population through the high-quality agricultural products. The only mechanism for solving this problem is the development and implementation of land management projects for ecological and economic justification of land regulation and crop rotation. The use of crop rotations with short rotation period is promising in market conditions for small land-use areas. The main methodological approach to the organization of these areas is the formation of homogeneous (by the soil cover) lands and a set of crops based on the assessment of the suitability of arable land for their cultivation.

The introduction of the short-term crop rotations will allow farmers to address issues related to the reduction of crop rotation development time, to provide a high level of specialization in cultivation of market-oriented crops, to reduce the set of tools and machines for crop production and costs for their maintenance and operation, to simplify the management system of the crop care processes, to use the land efficiently under short-term lease conditions through the correct combination of static and dynamic crop rotations. The latter one will allow to get out of strict frameworks (restrictions) of static crop rotations and to provide economically feasible (taking into account the changing market conditions of the crop production) and environmentally safe (preserving the quality of land through the selection of the best agro-technical variants of growing separate crops and prompting introduction of new technological developments in the practice of agricultural production) use of crop rotation arrays.

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