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ECOLOGICAL AND ECONOMIC GROUNDING FOR CROP ROTATION IN WOODLANDS OF UKRAINE

The article gives ecological and economic grounding for 3 crop rotation models for different specialization types of farms in the woodlands of Ukraine, the compliance with which would ensure profitable agricultural production and expanded soil fertility reproduction.
Keywords: *crop rotation; soil fertility reproduction; woodlands.*

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ЕКОЛОГО-ЕКОНОМІЧНЕ ОБҐРУНТУВАННЯ СІВОЗМІН ДЛЯ ПОЛІССЯ УКРАЇНИ

У статті наведено еколого-економічне обґрунтування 3 моделей сівозмін для господарств різних типів спеціалізації Полісся України, дотримання яких забезпечить прибуткове виробництво сільськогосподарської продукції і розширене відтворення родючості ґрунтів.
Ключові слова: *сівозміна; відтворення родючості ґрунтів; Полісся.*
Табл. 3. Літ. 14.

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ЭКОЛОГО-ЭКОНОМИЧЕСКОЕ ОБОСНОВАНИЕ СЕВООБОРОТА ДЛЯ ПОЛЕСЬЯ УКРАИНЫ

В статье представлено эколого-экономическое обоснование 3 моделей севооборота для хозяйств разных типов специализации Полесья Украины, соблюдение которых обеспечит прибыльное производство сельскохозяйственной продукции и расширенное воспроизводство плодородия почвы.
Ключевые слова: *севооборот; воспроизводство плодородия почв; Полесье.*

Problem setting. Implementation of agrarian reforms in Ukraine and transition to market type of land use led to numerous violations of the existing crop rotations (Kaminskyi and Saiko, 2013). It became typical to disregard crop rotations and to grow crops making gross violation of the laws of their rotation or even growing monocrops, largely due to market conjuncture, especially when "profitable" crops are needed in any circumstances (Boiko et al., 2000).

Such dangerous process is now getting spontaneous and eventually can lead to total chaos in Ukrainian agriculture (Boiko et al., 2000). Failure to comply with science-based farming system based on the use of crop rotation is considered as one of the main factors of poor ecological condition of agroecosystems in Ukraine (Order of Ministry of Agrarian Policy, 20.08.2003, No. 280).

Scientists of the Institute for Economics and Forecasting of the National Academy of Sciences of Ukraine propose to adopt the National code for sustainable agricultural economy as the collection of basic rules for good agricultural practices (including compliance with crop rotation) and fixing the requirements for compliance with the established environmental parameters in legislation. Only compliance with these conditions may provide farmers with the guarantee to obtain state support (Borodina et al., 2012).

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Recent research and publications analysis. The strategic direction of increasing and stabilizing productivity in agriculture under current conditions is a comprehensive approach to the development of science-based crop rotations combined with rational fertilization and soil preservation (Boiko et al., 2005; Boiko et al., 2013; Zubets et al., 2010). Crop rotations should become the basis for adaptive-landscape agriculture systems formation. Fertilization and cultivation systems, protection from pests and diseases most effectively manifest in the developed crop rotation, the amount of weeds decreases more than 5 times. Developed crop rotation is the key factor in crop production (Kaminskyi and Saiko, 2013: 22–23).

Foreign experience shows that 100% of cultivated lands in the EU and 85% of those in the US are used in compliance with crop rotation (Saiko, 2011: 8). Unfortunately, the use of land in Ukraine is conducted with complete disregard for crop rotation and the law of nutrients return to the soil. At this, energy loss associated with the mineralization of organic matter and removal of nutrition elements is 5 times higher than its renewal by means of organic and mineral fertilizers application (Saiko, 2011: 5).

Compliance with science-based crop rotation is able to provide non-deficit balance of essential nutrients of the soil. Among many principles of crop rotation formation the prevention of growing biologically close crops is the most important one. Repeated growing of crops, monocrops and technical crops in the agriculture of Ukraine is the major cause for catastrophic loss of soil fertility, pollution of soil with pests and pathogens ultimately leading to decrease in yields and product quality (Lebid et al., 1992; Saiko et al., 2002).

Crop rotation is also necessary for solving the following issues: regulation of water balance, soil organic matter and mineral nutrition elements in soil; maintaining its satisfactory structural condition and other physical properties; regulation of phyto-sanitary state of agrocenoses and reducing the amount of weed in crops; prevention of erosion and deflation processes (Boiko et al., 2013).

Science-based crop rotation provides, on the one hand, proper selection of precursors, on the other hand, optimal saturation of crop rotation with single-species crops, which takes into account the allowable frequency of their cultivation. In case of crop rotation with recommended precursors and compliance with crop return periods it is possible to make crop rotation schemes of any type and kind. Under such conditions crop rotation maximally performs its primary biological function – phytosanitary; crop protection chemicals are not used on agricultural crops once again. Infestation of plants with diseases and pests is reduced 2–4 times compared with monocrops (Boiko et al., 2000: 31).

Implementation of science-based crop rotation and the use of side plant products can adjust the supply of organic matter to soils. To stabilize the humus state it is necessary to optimize the ratio between cultivated, complete sowing crops, including legumes, to increase the area under perennial grass. It is also important to introduce intermediate (topping and stubble) crops (Boiko et al., 2013).

Under the current energy crisis, when energy prices are constantly rising, to reduce energy-intensive expenses and the cost of crop production, it is advisable not only to improve agricultural technologies, but also to carry out adjustments in the direction of saturation of plant production with "cheap energy" crops. Growing legumes, intermediate crops both as green feed and green manure, the use of side products etc. will not only maintain an appropriate level of fertility, but will also help improve the performance of these plants and significantly reduce economic and energy costs (Boiko et al., 2013).

It should be noted that the benefits of crop rotation as compared to other technological methods and crop protection chemicals include wide and effective complex activities, safety for workers and the environment, as well as availability and cheapness (Boiko et al., 2000).

To sum it up it should be noted that the basic principles of crop rotation, capable to provide rational fertilization and preservation of soil fertility, are worked out sufficiently. However, approaches to crop rotations design, which ensure soil fertility reproduction together with profitable agricultural production for Ukrainian woodlands, need to be improved.

Research objectives. Ecological and economic grounding and crop rotation development for different specialization types of farms of the woodlands of Ukraine, which ensure profitable agricultural production and expanded soil fertility reproduction.

Key research findings. The current level of farming and production needs under market conditions require such placement of crops in crop rotations that would satisfy the market needs, provide crop productivity increase, promote soil fertility stabilization, and would not cause harm to the environment (Boiko et al., 2013).

Taking into account soil and climate zones of woodlands and the peculiarities of growing crops there we propose the models for typical crop rotations for them. Particular attention is paid to ensuring optimal science-based terms of crop return and the best selection of precursors (Order of Ministry of Agrarian Policy, 18.07.2008, No. 440/71). Important, in our view, is the inclusion of microbial fertilizers to the fertilization system. Their use increases the coefficients of fertilizer active ingredient use by plants and productivity growth of agrocenoses (Volkohon, 2006).

The first of the proposed crop rotation models is focused on the development of livestock:

1. Clover for 2 growths *– fertilization – optimal is the use of $P_{60}K_{60}$, but taking into account the manure afteraction plants absorb 5 kg/ha of phosphorus and 16 kg/ha of potassium; hence mineral fertilizers are applied at the rate of $P_{55}K_{44}$; also Ryzobofit is applied (products are disposed).*

2. Winter rye *– fertilization – optimal is the use of N60P60K60, but taking into account the manure afteraction plants absorb 7 kg of nitrogen, 3 kg of phosphorus and 11 kg of potassium; hence mineral fertilizers are applied at the rate of $N_{53}P_{57}K_{49}$; also Diazobakteryn is applied (straw is disposed) + postharvest sowing of oil radish (extra costs – Albobakteryn).*

3. Potatoes *– fertilization – 40 t/ha of manure + $N_{60}P_{60}K_{60}$ + Biogran* (residues remain, to which we do not add mineral nitrogen as it is sufficient in the soil).

4. Barley *– fertilization – optimal is the use of $N_{60}P_{60}K_{60}$, but taking into account the manure afteraction plants absorb 21 kg of nitrogen, 9 kg of phosphorus and 32 kg of potassium; hence mineral fertilizers are applied at the rate of $N_{39}P_{51}K_{28}$ + Mikrogumin (straw is disposed).*

5. ***Grain lupine*** *– fertilization – optimal is the use of $N_{45}P_{45}K_{45}$, but taking into account the manure afteraction plants absorb 11 kg of nitrogen, 5 kg of phosphorus and 16 kg of potassium; hence mineral fertilizers are applied at the rate of $N_{34}P_{40}K_{29}$ + Ryzogumin (2.55 t/ha of straw remains, which requires 2 kg/t of nitrogen – 15 kg/ha of ammonium nitrate) + postharvest sowing of oil radish (extra costs – Albobakteryn).*

6. ***Corn for silage*** *– fertilization – optimal is the use of 40 t/ha of manure + N60P60K60, but taking into account the manure afteraction plants absorb 7 kg of nitrogen, 3 kg of phosphorus and 11 kg of potassium; hence mineral fertilizers are applied at the rate of $N_{53}P_{57}K_{49}$ + Biogran.*

7. ***Oats with clover undersowing*** *– fertilization – optimal is the use of $N_{60}P_{60}K_{60}$, but taking into account the manure afteraction plants absorb 21 kg of nitrogen, 9 kg of phosphorus and 32 kg of potassium; hence mineral fertilizers are applied at the rate of $N_{39}P_{51}K_{28}$ + Mikrogumin + Ryzobofit (straw is disposed).*

Given that the proposed crop rotation is focused on the development of livestock, almost all straw is used for animals' needs. Positive humus balance (+0.43 t/ha) comes from growing clover and application of manure under weeded crops. Without these factors humus balance is negative (-3.34 t/ha).

The analysis of economic effectiveness of the proposed models of crop rotation is performed by profit and profitability indicators. In order to determine production effectiveness, the performance indicators are calculated in two price options, prices for products and resources in 2013 and prices as of 01.02.2015. Calculations of technological and expenditure parts of flow process charts were made on the methodical basis of (Sabluk et al., 2008, vol. 1–2), taking into account the specific characteristics of the investigated crop rotation models and application of microbial preparations.

Calculations of economic effectiveness of growing crops in the rotation is presented in Table 1.

Table 1. **Economic effectiveness of growing crops in the rotation, focused on the development of livestock,** *author's*

Crops	Prices of 2013		Prices of 2015	
	Profit, UAH/ha	Profitability, %	Profit, UAH/ha	Profitability, %
Clover (hay)	671.00	16.00	1212.00	15.10
Winter rye	970.00	21.40	1774.00	20.70
Potato	80272.00	324.60	61118.00	175.20
Lupine	2009.00	47.40	5975.00	76.80
Barley	1782.00	42.20	4057.00	49.30
Corn for silage	790.00	16.00	1235.00	13.60
Oat	1324.00	37.80	2019.00	30.00
By crop rotation	x	175.50	x	91.70
Costs for soil fertility improvement measures in the appropriate fields of crop rotation, UAH	704.00		10481.00	
By rotation considering the costs of measures	x	138.50	x	70.30

As we can see, growing of all crops in the proposed crop rotation model, focused on the development of livestock, is profitable. For most crops in the rotation there is generally slight decrease in the profitability of production due to the economic situation as of 01.02.2015 in comparison with 2013. This can be explained by the underrun in growth rate for agricultural prices as compared to the rise in prices for materials and equipment.

Thus, production cost for clover hay per 1 ha of cultivated area increased by nearly 92% during this period, and the price of hay – by 81.2%. Although the profit thus increased by 82.9 "inflation" interest, the profitability level remained virtually unchanged – it decreased by 0.9%.

Noteworthy is the economic effectiveness of winter rye grain production. This crop is characterized by low profitability level. During the study period practically the same percentage of expenses (88.8%) and sales price (87.8%) increase is observed. As a result, the amount of profit per 1 ha of crops increased by 82.9%, but it almost did not affect the dynamics of profitability, which fell by 0.7%.

As for potato production, an increase in costs by 41.1% is observed, but, in contrast to all other investigated crops, the increase in production costs is accompanied by the decrease in sales prices (by 8.6%), which reduced profit per 1 ha of cultivated area by 23.9% and profitability level – by 149.4%. The indicated price decline can be explained primarily by price hike for potato in 2013 (e.g., 3.18 times higher as compared to 2012).

Regarding the production of grain lupine a significant increase in profitability (29.5%) should be noted due to growth of sales price (by 120.0%) as compared with the increase of costs per 1 ha (by 83.3%). This price hike can be explained by the increased demand for high-protein and high-energy crops, as evidenced by the following examples of soybeans and grain corn.

Some increase in production profitability is observed for barley. Thus, the amount of costs per 1 ha of cultivated area increased by 90.5%, and the price thus increased by 104.7%. As a result, the amount of profit per 1 ha of crops increased by 127.7%, and the level of profitability – by 7.1%.

The growth of calculated price level for corn for silage (by 80.0%) slightly underruns the growth of costs (83.7%), which led to a much smaller increase of profit per 1 ha of cultivated area (by 56.3%) and corresponding reduction in production profitability (2.4%).

This also concerns grain oats production. Thus, costs per 1 ha of crops increased by 92.0%. At this, sales price increased by only 81.2%. As a result, the amount of profit per 1 ha of cultivated area increased by only 52.5%, and production profitability decreased by 7.8%.

In general for crop rotation, taking into account soil fertility improvement measures per 1 ha, the expenses increased by 58.8% and the profit decreased by 19.5%. As a result, the profitability level declined by 68.3%. This significant drop in profitability is caused by the decrease in potato return in combination with high relative share of this crop in the structure of costs and revenues in the rotation.

Another crop rotation model is focused on the development of plant growing (respectively, at compliance with it, such component of reproduction of humus in the soil as manure is absent):

*1. **Seed clover** – fertilization – Ryzobofit.*

*2. **Winter rye** – fertilization – $N_{60}P_{60}K_{60}$ + Diazobakteryn/application* of 9.77 t/ha of straw without compensation for nitrogen (as the following crop is legume) + postharvest sowing of oil radish *(extra costs – Albobakteryn).*

*3. **Grain lupine** – fertilization – $N_{45}P_{45}K_{45}$ + Ryzogumin* (2.55 t/ha of straw remains, that requires 2 kg/t of nitrogen) – *15 kg/ha of ammonium nitrate* + postharvest sowing of oil radish *(extra costs – Albobakteryn).*

*4. **Corn for grain** – fertilization – $N_{80}P_{80}K_{80}$ + Biogran* – plant remains are bedded into soil, compensation for nitrogen – by the following calculation: at grain yield at the level of 6 t/ha dry residues remain in the amount of 10,56 t/ha, so the need for ammonium nitrate is 306 kg/ha.

*5. **Oats with clover undersowing** – $N_{30}P_{60}K_{60}$ + Mikrogumin + Ryzobofit,* straw is later sold.

Positive humus balance (5.02 t/ha) is subject to the use of green manure, straw and clover sowing. Thus, green manure contributes to the preservation of humus at the rate of 0.58 t/ha, rye, corn and lupine straw humifies and additionally provides the synthesis of 8.09 t/ha of humus. Given mineralization processes soil humus fund is replenished by the abovementioned 5.02 t/ha.

Economic performance of crop rotation is presented in Table 2.

Table 2. **Economic efficiency of growing crops in crop rotation in the absence of livestock,** *author's*

Crops	Prices of 2013		Prices of 2015	
	Profit, UAH/ha	Profitability, %	Profit, UAH/ha	Profitability, %
Clover (seed)	691.00	42.00	1211.00	40.60
Winter rye	765.00	16.10	1224.00	13.40
Lupine	1701.00	37.40	5148.00	59.80
Corn for silage	555.00	9.20	3837.00	29.60
Oats (per 1 ha)[1)]	1656.20[1)]	42.60[1)]	2491.00	33.10
By crop rotation	x	25.70	x	33.80
Costs for soil fertility improvement measures in the appropriate fields of crop rotation, UAH	2362.00		5202.00	
By rotation considering the costs of measures	x	12.90	x	18.80

[1)] as for oats the sales of straw are as well provided, the cost parameters are defined per 1 ha of crops.

Economic calculations show the profitability of growing crops in rotation, when livestock is absent. As for the production of clover seed a slight decline in profitability (1.4%) is observed with an increase in expenses by 81.3% per 1 ha of crops, growth of sales prices by 79.5% and profit by 75.1%.

Production costs of winter rye grains per 1 ha of the cultivated area increased over the period by 92.2%, sales prices increase was 87.8%. As a result, the amount of profit per 1 ha of crops increased by only 60.0%, and profitability declined by 2.7%.

As for lupine in this crop rotation production profitability is also observed (by 22.5%) due to an advance growth of sales price (by 120%) as compared with the growth of costs per 1 ha of crops (by 89.1%). At this, the amount of profit per 1 ha of cultivated area increased by 202.7%.

This applies to the production of corn grain – profitability increased by 20.4% due to higher sales price growth (by 154.5%) as compared to the increase of costs per 1 ha of cultivated area (by 114.4%). At this, the amount of profit per 1 ha of cultivated area increased by 591.7%.

As a result of significantly advance growth of oat grains production costs per 1 ha of cultivated area (by 94.1%) as compared to the increase of sales price (by 81.2%), the amount of profit per 1 ha of cultivated area increased by 50.4% and profitability decreased by 9.6%.

In general, costs per 1 ha increased almost twice (99.8%), and profit amount – almost 3 times (by 189.7%). Production profitability increased by 5.8%. Increased profitability indicators are primarily subject to significant growth of profitability of corn and lupine grain and their high share in the creation of economic indicators of crop rotation.

We also modelled the third variant of crop rotation, designed for the development of crops and livestock (the latter – up to 40%):

***1. Soya** – fertilization – $N_{30}P_{45}K_{45}$ + Ryzogumin (straw remains for fertilization and is compensated by mineral nitrogen at the rate of 2 kg/t, i.e. 6 kg/ha – taken from corn fertilization).*

***2. Corn for grain** – fertilization – 40 t/ha of manure + $N_{60}P_{60}K_{60}$ + Biogran (side products remain in the field, so it is necessary to balance the nitrogen – 105.6 kg/ha, at this, 25 kg come from manure and 80.6 kg/ha are provided by the application of fertilizers).*

***3. Spring wheat** with clover undersowing – fertilization – optimal is the use of N60P60K60, but taking into account the manure afteraction – 30% (in the second year 21 kg of nitrogen, 9 kg of phosphorus and 27 kg of potassium are used) use mineral fertilizers at the rate of $N_{39}P_{51}K_{28}$; Polimiksobakteryn is also applied* (straw remains for fertilization, nitrogen is not applied with regard to the following legume in rotation).

***4. Clover** for 2 growths – fertilization – optimal is the use of $P_{60}K_{60}$, but taking into account the manure afteraction (15%) plants absorb 4.5 kg/ha of phosphorus and 13.5 kg/ha of potassium; mineral fertilizers are applied at the rate of $P_{55}K_{44}$; also Ryzobofit is applied (products are disposed).*

***5. Winter rape** – optimal in traditional growing conditions is $N_{90}P_{90}K_{90}$. But considering the precursor and the manure afteraction we can reduce the dose of nitrogen fertilizer to 60 kg/ha, phosphorus – to 87 kg/ha and potassium – to 81 kg/ha; Albobakteryn is also applied (side products remain in the field, so it is necessary to be balanced by nitrogen – nitrogen is applied in the amount of 60 kg/ha);* Green manure – blue lupine.

***6. Buckwheat** – fertilization – $N_{45}P_{45}K_{45}$ + Diazobakteryn (straw is disposed for livestock needs).*

***7. Winter wheat** – fertilization – $N_{60}P_{60}K_{60}$ + Polimiksobakteryn (straw is disposed for livestock needs).* Green manure – oil radish.

Positive humus balance (1.21 t/ha) is subject to growing clover, despite the fact that part of it is used for livestock needs, and application of manure under grain corn. Humus balance is negative without clover (-0.88 t/ha).

The key indicators of economic effectiveness of crop production in such crop rotation variant are presented in Table 3.

Table 3. **Economic effectiveness of growing crops in the rotation focused on the development of crop growing (livestock – up to 40%),** *author's*

Crops	Prices of 2013		Prices of 2015	
	Profit, UAH/ha	Profitability, %	Profit, UAH/ha	Profitability, %
Soya	4480.00	81.10	10422.00	125.10
Grain corn	1290.00	24.30	5817.00	53.00
Spring wheat	535.00	16.60	1079.00	15.00
Clover (hay)	673.00	16.00	745.00	9.20
Winter rape	5974.00	138.40	2589.00	25.10
Buckwheat	4078.00	115.80	7460.00	98.90
Winter wheat	1195.00	24.90	2915.00	28.30
By crop rotation	x	59.0	x	49.5
Costs for soil fertility improvement measures in the appropriate fields of crop rotation, UAH	6072.00		11942.00	
By rotation considering the costs of measures	x	32.9	x	25.6

Growing all crops under such crop rotation variant is profitable both at prices of 2013 and price situation of 2015.

In the investigated crop rotation the soya grain production demonstrates high growth of yield indicators mainly, as it was already noted, due to the increase in demand. Thus, the increase in costs per 1 ha of crops amounted to 50.9%, and in sales prices – 87.5%. The amount of profit per 1 ha of the cultivated area increased by 132.7%, and production profitability increased by 44.0%.

Similar phenomenon is observed for corn grain in this crop rotation – the profitability level increased by 28.7% and the profit per 1 ha of cultivated area – by 351.1%. This happened under the influence of less high cost increase per 1 ha of cultivated area (by 106.8%) as compared with the increase in prices (by 154.5%).

Price increase for wheat grain (by 120.0%) is somewhat behind the increase in production costs per 1 ha of cultivated area of its spring variety (by 123%), as a result the increasing profit per 1 ha of cultivated area was slower (by 101.8%) and the production profitability level decreased by 1.6%.

Clover hay production profitability markedly reduced (by 6.8%) due to advanced growth of expenses per 1 ha of crops (by 91.7%) as compared with price increase by 81.2%. For this reason, profit per 1 ha of crops increased at slower rate (by 10.7%).

Of all the crops of a given crop rotation production profitability of winter rape decreased most – by 113.3%. The reason for this was a slight increase in sales prices (by 25.4%) on the background of bigger cost increases per 1 ha of cultivated area (by 138.9%). The amount of profit per 1 ha of crops also decreased – by 56.7%.

Similar trends, although to lesser extent, also apply to buckwheat. The cost of cultivation of this crop per 1 ha of cultivated area increased by 114.1%. At this, sales price increased by 97.4%. As a result, profit per 1 ha of crops increased by only 82.9%, and production profitability decreased by 16.9%.

As for winter wheat, unlike spring one, the costs per 1 ha of cultivated area increased to lesser extent – by 114.0%, allowing to increase the amount of profit per 1 ha of crops by 144.0% and increase profitability by 3.5%.

In general by crop rotation per 1 ha (including soil fertility improvement measures) expenses increased to a greater extent (by 101.9%) than profit (by 57.1%), resulting in general profitability reduction by 7.3%.

Conclusions and development prospects. This study shows that establishment of sustainable agriculture must be performed solely in compliance with zonal crop rotations according to biological, ecological and economic criteria. The three proposed crop rotation models for the main directions of farm specialization provide profitable economic management regardless the prices at the market and soil fertility reproduction.

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