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MARKET, FERTILITY, AND PERFECTION OF AGRICULTURE: CONCEPTUAL SYNTHESIS IN A SINGLE FORMULA OF EFFICIENCY

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Abstract: *The aim of the study is to represent the author's methodology for assessing the excellence of agriculture, which would be implanted into a single efficiency formula, which involves conceptualization of the assessment of fertility reproduction processes. The authors started from the hypothesis that post-industrial agriculture will be more and more regulated according to the criteria of ecological, not market perfection. The industry will not focus on market efficiency, but the market will adapt to environmental requirements. At the same time, ecological perfection will be determined by the dynamics of soil fertility. The methodology (logic of cognition) was built on the specified hypothesis, according to which the efficiency of modern agriculture should be evaluated by the carbon balance in the production process. Methodologically, this means evaluating the dynamics and overall balance of organic matter (humus) in agriculture.*

Key words: *methodology, fertility, vegetable growing, soil-ecological balance, mineralization, humification.*

1. Introduction

Formulation of the problem. There is a certain set of axioms of civilization, including a post-industrial one: 1) the energy (bioenergy) basis of agriculture is farming and land use; 2) agriculture was, remains, and will always be a vital type of economic activity, which cannot be inefficient a priori under any market criteria; hence modern subsidies of the industry arise; 3) the economic system must ensure non-alternative sustainable functioning of agriculture, according to the biological criteria of the balance of assets that ensure this sustainability. Hence, the task of science is to ensure the sustainability and/or

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sustainable growth of the industry; the task of economics is such provision in market conditions.

At the same time, questions logically arise about what criteria can serve as indicators of changes, provided that they should relate to the assessment of farming and fertility. How should monetary and environmental indicators be reconciled? The answers to these questions will make it possible to build a general model of effective agriculture, which can be treated as the capacity for programmed production of products, market efficiency, as well as the non-alternative ability to perform these tasks in an immeasurable period, i.e. under conditions of sustainability. Such a model should have clear programs for evaluating positive and negative deviations from the given trend, which will form the basis of appropriate management.

The problems and issues mentioned above are objectively universal, which eliminates any differences including political, mental, civilizational, cultural, etc. ones. This problem will naturally become actualized for national economies throughout the post-industrialization progress.

Historical perspective of the problem. Purely ecological problems of land fertility gained economic importance thousands of years ago when all peoples' life was concentrated on the land as a source of feeding. That is why the study of fertility is retrospectively a traditional issue of civilization. Even the most ancient annals contained data about the years of famine and high yields, considering it as almost the main guarantee of survival. Bright examples of this are given in the research by F. Braudel (2009) and many other studies.

Nevertheless, since the second half of the 19th century, when a trend of decreasing crop yields and at the same time a humus content in the soil was recorded statistically for the first time in Western Europe (Malthusianism was largely based on these facts), the attention of agronomists and economists as well as the whole society has been more and more focused on the issues of how fertility is used, what consequences of using traditional technologies will be, and what regime of the industry is optimal.

The agricultural industry is known to have changed historically. A well-known periodization of civilization development can be transferred to agriculture, namely by dividing the latter into:

1) pre-industrial (conditionally until the middle of the 19th century);
2) industrial (until the 1980s);
3) post-industrial.

This emphasis is important for understanding the philosophy of agricultural modelling.

The pre-industrial industry was characterized by low (apparently insufficient) productivity for thousands of years under the absence of any dynamics in fertility and maximum dependence on weather conditions (R.V. Lohosha et al. (2023)).

The industrial stage was characterized by accelerated productivity growth due to the emergence of nitrogen fertilizers (mainly), etc. factors of industrial modernization, and the "green revolution" against the background of implementing scientific monitoring of fertility, as well as the activation of regulatory industry policy (G.M. Kaletnik et al. (2021), R.V. Lohosha et al. (2023), D.M. Tokarchuk et al. (2021), Y.V. Gontaruk, (2024), I.V. Honcharuk et al. (2023)).

Post-industrial agriculture is associated with productivity maximization under the comprehensive implementation of the “green revolution” to the state of overproduction, market-agreed regulatory limits on production, and emphasis on the role of carbon balance (fertility) in a socially acceptable industry model; the latter is being increasingly subsidized.

The Ukrainian experience. It should be noted that the realities of the agricultural sector in the Soviet and post-Soviet Union were generally similar with a lag in time and intensity from Western counterparts. An extremely high level of agricultural development of the land fund (70%) and arable land (54%) has always been and remains a specific trait of Ukraine, which certainly actualizes these problems.

The fact that the agrarian science of the former USSR was formed based on the ideology of the so-called “socialist agriculture” (this term was intended to outline the uniqueness of the approach) from the 30’s of the 20th century is of great significance. Given the striking technical and technological lag behind the Western model, which has been chronic for centuries, “socialist agriculture” relied primarily on biological factors: crop rotation, the hypertrophied role of individual crops, organic fertilizers, etc., which is available to the technologically "poor" industry. The fertility factor and the idea of influencing productivity through fertility fit into the context of this ideology. All this determined the structure of the agricultural science of the USSR.

The above-mentioned ideology provided quite substantial grounds for a critical assessment of its effectiveness. At the same time, large-scale research on fertility issues in the Soviet and post-Soviet space made it possible to form a unique information base on universal natural processes. These data, in our opinion, are only becoming more relevant in today’s post-industrial era – when issues of sustainability of agriculture as an ecological system become more important than current market prices almost everywhere and above all in economically developed regions of the world. All this applies to the agrarian sphere of Ukraine both in the past and today. At the same time, the task of economic interpretation of this information is of high significance.

2. Literature Review

As mentioned above, exceptionally large-scale studies have been conducted in the organizational network of the Academy of Agrarian Sciences of Ukraine (under different names at different times) for 30-80 years or longer (some experiments even represented data on over 150-year observations of soil fertility) including the experiments studying the influence of various systems and agricultural factors on the soil fertility, as well as on fertility itself as a biological category. Thus, a fairly perfect methodical base was created at a high scientific level. Analysis of the above-mentioned issues has become the subject of separate studies. Now it should be emphasized that there are all reasons to rely on these data in today’s post-industrial reality since a certain set of biological principles remains universal beyond the boundaries of political models of societies.

Moreover, in the former USSR, several stages of agrochemical research (the last one that was the third in number took place in 1985) of all fields were carried out to monitor the dynamics of soil fertility. Such a grand survey confirmed the fundamental conclusion that in recent centuries, especially under the industrial model of the industry, agricultural production has been carried out against the background of a massive decrease in fertility. This happened everywhere, i.e. a global negative process of the civilizational level was taking place. A detailed description of such processes requires separate consideration.

Methodologically, the studies and their approbation carried out by the research teams under the leadership of S.A. Baliuk et al. (2016), A.M. Maliienko (2016), O.O. Batsula et al. (1987), V.V. Medvediev et al. (1992), M.I. Polupan et al. (1997), A.F. Saiko et al. (1993) and other researchers should be considered methodologically basic.

The extremely high cost of restoring soil fertility, and therefore social losses caused by ecologically unjustified agriculture, have been emphasized in the works of many scientists: S.A. Baliuk et al. (2015), B.S. Nosko, O.O. Batsula et al. (1987), Medvediev V.V. (2015), Butrym O.V. et al. (2015), O.H. Shvets, R.S. Truskavetskyi, L.V. Smishna-Starynska (2016), S.V. Zabaluiev (2016), M.A. Popirnyi (2016), M.O. Datsko (2016), Y.P. Tsvei et al. (2016), Yu.O. Tarariko et al. (2016), A.M. Maliienko (2016), Ye.V. Skrylnyk et al. (2015) and others.

Issues related to the study of soil fertility preservation are still of great interest in various countries and they have been researched by Barwicki et al. (2012), Šimanský et al. (2019), Novakovska et al. (2018), Jaafar et al. (2016), Montgomery et al. (2016), Oumenskou et al. (2018) and others.

Thus, Baliuk et al. (2017), Bulgakov et al. (2022), and Skrypchuk et al. (2020) studied the possibility of not just preserving humus content, but also increasing it, which has become a fundamentally new concept over the last 200 years of systematic observations.

In other studies (P. Boyko et al. (2018), R. Bogdanovich et al. (2014), E. Lebid et al. (2014), V. Volkogon et al. (2016), E. Litvinova (2020), P. Skrypchuk et al. (2020), A. Gorova et al. (2016) the analysis of the influence on fertility of a whole spectrum of factors from natural soil and landscape to individual substances, technologies, and technological techniques was carried out. What unites these works is the emphasis on the importance of the fertility factor and the need to find any techniques, methods, ways to have a programmed effect on the fertility.

It can be argued that scientific research on humus balance modelling has intensified during the last decade, as evidenced by some works (D. Heitkamp et al.; C. Brock et al. (2015), Schultz et al., P. Götze et al. (2016), A.P. Vlasyuk et al. (2018), L. Shostak et al. (2019).

In general, the vast majority of researchers recognize that the overall balance of humus with different crop rotations and fertilization systems, in different climatic and soil conditions, is formed with certain differences, however, such differences have allowed researchers (O. Batsula, V. Saiko et al.; V. Volodin, V. Levin, O. Medvedovskyi, P. Ivanenko, and Yu. Tarariko) to develop a general model of the balance.

3. Methodology

The authors started from the hypothesis that post-industrial agriculture will be more and more regulated according to the criteria of ecological, not market perfection. The industry will not focus on market efficiency, but the market will adapt to environmental requirements. At the same time, ecological perfection will be determined by the dynamics of soil fertility.

The methodology (logic of cognition) was built on the specified hypothesis, according to which the efficiency of modern agriculture should be evaluated by the carbon balance in the production process. Methodologically, this means evaluating the dynamics and overall balance of organic matter (humus) in agriculture. Perfection means achieving a zero-deficit or positive balance, which is hypothesized to mean industry stability and efficiency.

In the calculations and conclusions that are given below, the loss of fertility from soil erosion was not taken into account, the latter was considered as a scientifically and technologically researched issue for today. Another clarification is that the authors equated the terms "fertility", "organic/organic matter", and "humus", although, of course, there are methodological differences between them. After all, fertility dynamics are essentially global carbon dynamics, which have a direct economic expression.

4. Case Studies

As a basic branch of agriculture, farming is based on a global, universal, irreplaceable, and permanent process of using fertility for crop formation. Technologies of cultivation of some crops that have been developed and are functioning today based on artificially created soil mixtures (in greenhouses), which are not organic based, are only minor examples on the general scale of the industry. Thus, land is a direct economic resource of industry, which is limited and therefore needs to be restored. The processes of use and reproduction of soil fertility have the following economic interpretation, limitations, and content of the management task (1).

$$\begin{cases} E_f \rightarrow max \\ V_{reprod} \rightarrow max \\ F_{ec}\ V_{us} \rightarrow min \\ V_{us} \rightarrow E_{f\,max} \\ V_{reprod} \geq V_{us} \end{cases} \qquad (1)$$

where, F_{ec} – economic parameters of ecological farming;

E_f – efficiency of farming;

V_{us} – volumes of the use of soil fertility in the production process;

V_{reprod} – volumes of reproduction of soil fertility in the production process.

Limitations (1) are as follows:

1) maximization of economic efficiency;
2) the use of fertility should have an economic consistency with the efficiency and reproduction of fertility;
3) reproduction of fertility must be at least equal to the volume of used fertility;
4) the costs of restoring fertility should be minimized while maximizing the economic efficiency of the system as a whole.

The philosophical interpretation of the above implies a dialectical interdependence of the concepts of "natural" and "economic" fertility under the condition of finding an economically acceptable optimum between the criteria of agricultural productivity and the intensity of using fertility. This point of view presupposes, in particular, that the dynamics of fertility determine the productivity, stability, and economic efficiency of farming to a greater or lesser extent: a greater one – in the case when the technological level of the industry is insignificant, and a lesser one – when it comes to intensive, knowledge-intensive, high-tech industries forms of farming. At the same time, in the long term, a decrease in fertility will always lead to an increase in production costs and the cost of products, as well as some related environmental problems, e.g. pollution of agricultural landscapes, water sources, negative changes in the landscape microclimate and, ultimately, the climate as a whole.

In addition to the socio-ecological significance, the process of using and reproducing fertility in the process of farming in an economically developed society is logically perceived through the comparison of direct economic prices for agricultural products and their ecological interpretation (R.V. Lohosha et al. (2019). The side effects of fertility depletion, which relate to the pollution of air and water sources, products, etc. are also important. In turn, under market conditions, the issue of reproduction of the fertility of land resources naturally determines the impact on the market mechanisms of pricing. The mentioned aspect gained a new level of relevance under post-industrialism, namely, an economically efficient and ecologically inefficient market cannot be recognized as socially acceptable (R.V. Lohosha et al. (2024).

A priori, it can be argued that any technological features of the industry always have a mutual influence on the market requirements of a given society, market mechanisms, including mechanisms and nature of pricing, as well as the state of the market in the end (R.V. Lohosha et al. (2020) (2).

$$S_m = f_{ecol} \, (S_f \ldots D_1/S_2 \ldots M_{pricing} \ldots R_{price}) \quad (2)$$

where, S_m – state of the market;

f_{ecol} – functional role of the environmental factor related to the use and reproduction of fertility;

S_f – social factors determined by environmental priorities;

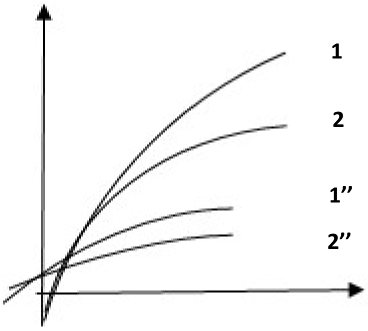
D_1/S_2 – features of the ratio of demand D_1 and supply S_2;

$M_{pricing}$ – available pricing mechanisms;

R_{price} – price rate.

That is why it is possible to evaluate the processes of use and reproduction of fertility, and hence the perfection of the industry, by the ratio of these processes, which finally comes down to calculating the balance between, on the one hand, use, and on the other, reproduction of fertility. This is possible given the comparability of the unit in both cases – it is organic matter (humus) in weight units (t, kg) per 1 ha of area.

Mass of plant residues of the main Yield and by-products



1 – by-products of stubble crops
2 – by-products of row crops
1'' – plant residues of stubble crops
2'' – plant residues of row crops

General quantitative parameters of the model

1. Historical level of mineralization in the industry: 1.0 – 1.2 t/ha.
2. Historical level of humification within [0.6...1.0 t/ha].
3. Parameters of mineralization of various crops [0.6...2.0 t/ha].
4. Historical maximum of manure application in the industry is up to 10-12 t/ha
5. The potential of siderate crops is 3-5% of the cropping areas
6. Potential for production of by-products is 1.5-3 t/ha of crop rotation.

Variable factor: 1) a set of crops with different humification parameters; 2) productivity; 3) utilization of by-products; 4) production and use of organic fertilizers; 5) application of farming practice of siderate crops.

Positive balance

Humification of organic matter of the soil due to:
1. Plant residues of the main yield
2. Organic fertilizers
3. By-products of the yield
4. Siderate cropppins

Limit of deficit-free balance of reproduction of soil fertility

Negative balance

Mineralization of organic matter of the soil

Variable factor: a set of crops with different mineralization parameters

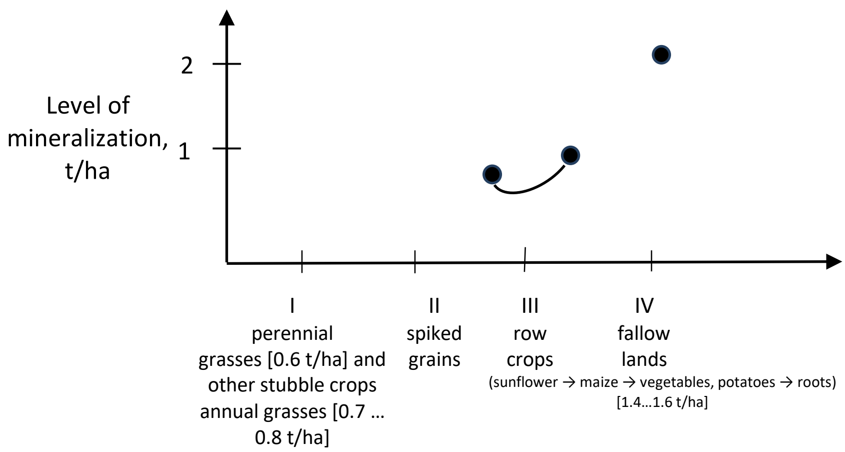


Fig. 1. *Analytical model for the description of the use and reproduction of soil fertility in agricultural production: Source:* author's generalization based on references

Therefore, during farming practices, a part of the organic matter will always decrease, and at the same time, the opposite processes of creating a new one will always take place as well. However, the ways it happens acquire diverse variations, finally forming farming (according to this criterion) as a system.

In the agroecological literature, the following terms can be synonymous: the use of fertility is associated with the so-called "mineralization" of soil organic matter and reproduction with "humification" of it. The perfection of agriculture according to the ecological criterion depends on which of these mentioned processes prevails: ecologically justified type of production is the one where the volumes of annually humified (i.e., newly created) organic matter are greater than or at least equal (i.e., "deficit-free regime") to the volume of the one, which during the same time is mineralized (decomposed) (R.V. Lohosha et al. (2018). A graphic representation of the analytical model describing the use and reproduction of fertility is shown in figure 1.

Hence, the loss of fertility depends directly on the crops produced, while the recovery depends on the crop yield, supply of organic matter in the form of organic fertilizers, by-products, plant and post-harvest residues, as well as the intensity of their conversion to the state of soil organic matter. It is most expedient to calculate the balance for the calendar year, which in the conditions of Ukraine coincides with the growing season of the vast majority of agricultural crops of the open ground. Certain features of the specified calculation relate to greenhouse vegetable growing, however, in view of the small areas of the use of such technologies when analysing the industry as a whole and its significant sectors it is advisable to follow the general algorithm defined in Figures 1.

The calculations made by O. Moroz (1997) can show differences between crops regarding the formation of the annual balance of soil fertility (Table 1).

Table 1

Ecological specifications of crop cultivation for achieving annually deficit-free soil fertility balance (without application of organic fertilizers)

Crops	**Mineralization of organic matter, t/ha**	**Required yield (by main products), t/ ha**
Winter cereals	0.7	4.2
Barley	0.7	5.4
Peas	0.8	6.7
Maize (grain)	1.56	11.8
Maize (silage)	1.47	89.0
Sugar beets	2.0	430.0
Fodder beets	2.0	559.0
Sunflower	1.4	11.2
Potato	1.6	155.0
Vegetables	1.6	401.0
Annual grasses, green mass	0.7	20.0
Perennial grasses, green mass	0.6	7.2

Source: data interpretation for O. Moroz (1997)

According to the data (Table 1), the differences between crops are generally a very important factor, and the interpretation of the given data allows us to draw some fundamental conclusions. Firstly, it can be argued that the achieved productivity indicators cannot compensate for the loss of fertility in most cases (most often crops with increased mineralization are characterized by higher prices on the market). As for different crops, it ranges from 5% (for row crops, root crops) to 80% (cereal stubble). A deficit-free balance can be achieved only regarding perennial grasses at the expense of biological productivity.

All this is also relevant, for example, for vegetable growing (comprehensive studies on these issues were carried out directly by the authors of the article and in detail by R.V. Logosha (2017). Based on the achieved level of vegetable yield in Ukraine (about 20.0 t/ha) in recent years as well as economically developed countries (about 40.0 t/ha) and in the world (15.0-25.0 t/ha), according to Table 1, it is possible to compensate from 8 to 17% of the lost fertility per calendar year for vegetables due to the biology of the crops themselves.

Secondly, the indicated ratios (Table 1) show that for most crops of intensive farming, compensation of fertility losses can be achieved only at the expense of organic fertilizers (manure, and other sources of organic matter). However, it is necessary to emphasize a well-known fact that the production of manure has very large limitations, which is reasoned by the fact that livestock farming must operate for this purpose. The latter does not make economic sense only for the production of organic fertilizers under any conditions. In turn, in some technologies, the production and application of manure make up to 50% or more costs, which sharply limits the optimism regarding this factor of influence.

The generalized formula for calculating the dynamics of soil fertility, which is based methodologically on the above-mentioned studies (A.F. Saiko et al. (1993), S.A. Baliuk et al. (2016), V.V. Medvediev (2015), M.I. Polupan et al. (1997), Batsula et al. (1987), O.V. Moroz (1997) assumes that by-products, root, and post-harvest residues, as well as organic fertilizers, are the main controlled parameters of humus replenishment.

In this case, it should be emphasized that humus content is methodically determined by rather simple laboratory methods. However, asserting the importance of the method of constructing an estimated fertility balance as an alternative to the laboratory method, the realities of analysis should be taken into account, namely: 1) there is a problem of soil variegation, where there is always a certain difference in the indicators of the content of organic matter (and others) in any place compared to a neighbouring plot, and this requires mandatory generalization and averaging of the indicator, again by calculation; 2) it should be understood that the determination of the humus content requires the extraction of a soil sample, therefore it is simply impossible to determine the dynamics of the indicator in the same soil sample over time.

The choice of appropriate indicators of mineralization and humification became a fundamental issue since scientific literature emphasizes a sufficiently high variability of their values under different natural and climatic, technological and weather conditions. When choosing normative coefficients and indicators, the most recognized works of scientists based on the materials of long-term research on the fertility of land resources within the scope of the activities of the research institutions of the former All-Union Academy of Agricultural Sciences named after Lenin, the National Academy of Agrarian Sciences, other research institutions, as well as those focused on soil and climatic condition of Ukraine. Table 2 shows the results of research conducted by the scientists of the All-Union Academy of Agricultural Sciences of the former USSR.

Table 2

Average losses of humus and its reproduction due to plant residues when growing various crops

Crop	Humus losses, t/ha	Plant residues		Replenishment of humus due to plant residues, t/ha
		t/ha	K, from the main products	
Winter grain crops	0.7	4.0-5.0	1.2	0.5-0.6
Spring spiked grains	0.6	3.0-5.0	0.9	0.4-0.5
Peas and other grain crops	0.8	2,0-3.0	0.8	0.4-0.6
Maize	1.0	2.5-3.0	0.8/0.2*	0.3-0.4
Sugar beets	1.5	0.5-0.8	0.04	0.04-0.06
Sunflower	1.0	4.0-5.0	2.0	0.4-0.5
Potatoes, vegetables	1.2	1.5-2.0	0.06	0.1-0.2
Annual grasses perennial	0.8 0.2	2.5-3.5 5.0-8.0	0.8/0.2* 1.5/0.2*	0.5-0.7 1.2-20
Fallow land	1.5	-	-	-

Note: K – conversion factor 1 t/ha

* – when harvesting for grain and hay, and also (in the denominator) for green mass

Source: data interpretation

In these studies, the data provided by O.O. Batsula et al. (1987), V.V. Medvediev (2015), and O.V. Moroz (1997) were used as normative data. The equation by V. Levin and Yu.O. Tarariko et al. (2016) was used to determine the mass of plant residues by the yield. Calculations were made based on methodical material published in the scientific literature (A.F. Saiko et al.(1993), S.A. Baliuk et al. (2016), V.V. Medvediev (2015), M.I. Polupan et al. (1997), Batsula et al. (1987), O.V. Moroz (1997).

The next controversial point is the formulas or recommended values of the volumes of by-products, as well as plant residues and roots, which form the appropriate sources of organic matter entering the soil.

Thus, some research, such as O.O. Batsula et al. (1987), V. Levin can be recommended in this case (Recommendations for the formation of bioenergy agroecosystems (2010). The research by Y.P. Tsvei et al. (2016) has some inconsistencies, namely clearly overestimated values of the proposed formulas when calculating the volumes of the indicated sources of organic matter, therefore Levin's equation, which generally correlated with other works V.V. Medvediev et al. (1992), M.I. Polupan et al. (1997), O.V. Moroz (1997) was used (Table 3).

Table 3

Field crop yields and regression equations for determining plant residues by the yield level of the main products

Crop	Yield, centers per ha				Equation for regression of mass determination		
	Main products	By-products	Surface residues	Roots	By-products	Surface residues	Roots
Vegetables	50-200 250-400	6.5-24 30-48	2.5-5 5.1-6	8-16 17-22	x=0.12y+0.5 x=0.12y+0.0	x=0.02y+1.5 x=0.006y+3.6	x=0.06y+5.0 x=0.04y+6.0

Source: Y.P. Tsvei et al. (2016)

As for other coefficients, there were chosen normative values generally agreed in works (Recommendations for the formation of bioenergy agroecosystems (2010), O.O. Batsula et al. (1987)) regarding calculations of humification and volumes of plant residues with corrections for the content of dry matter, e.g. a coefficient of 0.86 for the main agricultural products and the corresponding coefficient for other types of products including green mass of siderates, root crops, etc. In turn, when calculating manure humification, approximate recommended ratios were followed, according to which 1 ton of dry matter (under 77% moisture content of litter manure) produces 60 kg of humus (Table 4).

Table 4

Technical indices for the calculation of mineralization and humification in vegetable growing

Indicators	Manure	By-products, surface residues, and roots	All vegetable crops
Mineralization index, t/ha annually	X	x	1.2
Humification index	0.23	0.13	x
Dry matter content, %	0.23	0.86	x
For the final calculation of organic matter: per 1 t	60.0	112.0	x

Source: A.F. Saiko et al. (1993), Recommendations for the formation of bioenergy agroecosystems (2010), O.O. Batsula et al. (1987)

Therefore, such a differentiation has not been followed in our research. Analysis of the structure of Ukraine’s cropping areas under vegetables shows that almost all main crops are row crops with an intensive impact on the soil through the main and inter-row cultivation (Table 5). A high agrotechnical background of fertilization and protection is recommended for all these crops. The share of crops that differ by the specified parameters and for which the soil mineralization index could be defined as significantly lower was only from 11% (1990) to 3% (2016) (in Table 5 – column “others”), so these differences in mathematical calculations can be neglected.

Table 5

Structure of cropping areas under vegetable crops in Ukraine

Crops (open ground)	**Years**			
	1990	**1995**	**2000**	**2022**
Cucumbers	55.2	59.4	61.4	45.1
Tomatoes	100.9	104.6	105.9	51.5
Cabbage	85.1	74.8	86.6	60.1
Red beat	31.4	36.9	41.5	34.8
Carrot	27.7	33.7	41.0	38.2
Onion	57,1	67.7	64.5	44.2
Garlic	10,3	20.1	23.4	20.5
Sweet and bitter capsicum	6.3	12.7	15.0	10.3
Zucchini	11.0	26.9	30.6	26.8
Eggplants	6.0	5.5	6.7	2.2
Pumpkins	4.7	20.9	25.1	25.1
Others	49.3	22.5	14.3	16.1
Total	*445.0*	*485.7*	*516.0*	*3749*

Source: statistical data https://www.ukrstat.gov.ua/

The mathematical apparatus for direct calculations of humus balance is suggested to contain the following set of formulas. Thus, the general balance formula (3) is a mathematical representation of the ratio of the humification index (H_{umif}) – synthesis – to mineralization (M_{ineral}) – to decomposition or loss of humus. A final value that equals or exceeds 1.0 indicates gaining a deficit-free or positive balance, while less than 1.0 is negative; in turn, the size of the deficit is determined by the figures of such a deficit.

$$D_{eb.mat.soil} = H_{umif} / M_{ineral} \quad (3)$$

where, H_{umif} – volumes of annually synthesized organic matter in the soil, t/ha;

M_{ineral} – volumes of annual losses of soil organic matter, t/ha

Sources of mineralization and humification require substantive and mathematical um of the following four sources:

H_{umif1} – pinterpretation. Thus, the formula for calculating total humification (4) provides for the slant residues of crops ("yield factor"),

H_{umif2} – a synthesized organic matter at the expense of organic fertilizers, primarily manure, as well as peat, faeces, etc. (factor of "organic fertilizers");

H_{umif3} is a synthesized organic substance at the expense of crops' by-products ("by-product factor");

H_{umif4} – at the expense of siderate crops (special crops, the plant mass of which is ploughed as fertilizer – the factor of "green fertilizers").

$$H_{umif} = H_{umif1} + H_{umif2} + H_{umif3} + H_{umif4} \quad (4)$$

where, H_{umif1} – annual humification of plant residues (yield factor), t/ha;

H_{umif2} – humification of applied organic fertilizers (manure, etc.), t/ha;

H_{umif3} – humification of by-products, t/ha;

H_{umif4} – humification of siderate crops ("green fertilizers"), t/ha

In turn, the formula for determining sources of humification can be presented as follows (3–5):

$$H_{umif1} = A_1 I_{humif1} + A_2 I_{humif2} + A_n I_{humifn} \quad (5)$$

where, $A_{1,2,..n}$ – area under a particular crop, ha;

I_{humifn} – index of annually synthesized organic matter of the soil at the expense of a given crop or component of the agricultural land, t/ha

$$H_{umif2} = V_1 c_1 + V_2 c_2 + \ldots\ldots + V_n c_n \quad (6)$$

where, V_n – volumes of applied organic fertilizers, t;

c_n – humification index for this type of organic fertilizers, relative units (r.u.)

$$H_{umif3} = V_1 c_1 + V_2 c_2 + V_n c_n \quad (7)$$

where, V_n – volume of by-products used as fertilizer, t/ha;

c_n – humification index for this type of by-product, r.u.

$$H_{umif4} = c_1 A_1 I_{humif1} + c_2 A_2 I_{humif2} + \ldots.. + c_n A_n I_{humifn} \quad (8)$$

where, A_n – area under siderate crops, ha;

I_{humifn} – index of synthesized organic matter of the soil as a result of growing this type of siderates.

Similarly to the case of calculating the amount of humification based on the yield of a representative crop (2.3), the amount of mineralization of soil organic matter is suggested to be calculated according to mineralization characteristics of each crop with subsequent generalization of the index by crop rotation or the territory of the enterprise's economic activity (9). As pointed out, in our research we adhered to the normative indicator of mineralization for vegetables of 1.2 t/ha.

$$M_{iner} = H_{umif1} = A_1 I_{miner1} + A_2 I_{miner2} + A_n I_{minern} \quad (9)$$

where, A_n – area under a particular crop, ha;

I_{minern} – index of annual mineralization of organic matter for this crop, t/ha

Considering the peculiarities of vegetable growing, it is advisable to use the formulas of the above mathematical apparatus at the level of a separate farm or a separate crop rotation.

In turn, the factor of "organic fertilizers" for Ukraine as a whole may play a role only from the point of view of the use of manure; other types of organic matter, including siderate crops are used in very small amounts and mathematically can be ignored in calculations.

It should be emphasized that the role of mineral fertilizers has a direct mathematical interpretation in the specified formulas. The role of this is indirect, as the increase in productivity logarithmically determines the increase according to the formulas that are given (Recommendations for the formation of bioenergy agroecosystems (2010)) and used by us to calculate the balance, in particular the volume of plant residues, and as a result an increase in H_{umif1} index. Traditionally, the source of "plant residues" includes surface residues and roots, the volumes (mass) of which were calculated according to the recommended regression equations.

The specified effect of the increase in the mass of organic matter under the influence of an increase in productivity against a high background of fertilizers applies to the same extent to such a source of humification as "by-products" (the $Humif_3$ index in formulas (4, 7).

As a final generalized indicator that would provide a correct idea of the current state and the optimal option for the use and reproduction of fertility, the "coefficient of soil-ecological balance" (KSEB) is proposed, which reflects the balance between the use (mineralization) and reproduction (humification) of soil organic matter in comparable units – t/ha, and is expressed either in percentage units or in percentages of humified matter concerning mineralized matter.

The monetary expression of fertility indicators is proposed to be carried out by the value of manure, which is biologically equivalent. For example, according to our data, nowadays, the average annual balance of most vegetable farms in Ukraine is low deficit amounting to about 100 kg/ha (maximum values can be higher). This is equivalent to applying up to 2 t/ha of manure. At market prices of 2023, the cost of one kilogram of mineralized humus can be estimated at about $ 0.1. It should be emphasized that such a cost may seem insignificant only at first glance since these are widespread and large-scale processes, and total annual losses reach enormous volumes.

5. Conclusions

a. Conceptually, agriculture has no prospects in the short-coming future under environmental restrictions of alternatives. Moreover, such restrictions will play a higher role in economically developed countries, while for others it is only a function of time.
b. The main (perhaps the only) large-scale criterion for the industry greening, based on which the development strategies can be built, is the dynamics of fertility that can be logically, expediently, and technically identified based on the balance between the spent and newly created organic matter of the soil.
c. Fertility is both a natural and a socio-economic phenomenon that is complex, multifactorial, diverse, relative, and dynamic by its content.
d. The scientific and informational base developed and accumulated in society ensures a programmed control of fertility, which is recorded for the first time in the history of mankind and provides grounds for ecological optimism, at least in this context.

e. It is possible to influence fertility due to productivity, the specifics of using by-products, changes in crop rotations and technologies, fertilizers, and other factors of the industry that affect a carbon cycle. At some point, society will have to choose in favour of less economic features of business activity (for example, in the case of choosing between the use of by-products for biofuel production or their use as a source of organic matter), but neither the volumes nor the economic content of the changes look dramatic.

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