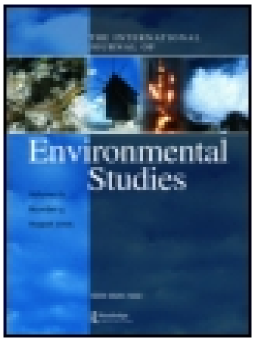

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ARTICLE

Assessment of agricultural lands as the basis of Ukraine's food supply

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ABSTRACT
A methodology is presented for calculating optimal values of the natural, ecological and economic elements of Ukraine's food system, these being the basis for agrarian enterprises. Criteria for the efficiency of the use of agricultural land according to the interaction of these elements are formulated, and the regional structure of the national food supply determined. Regions are clustered according to their level of food self-sufficiency, and agricultural enterprises are grouped according to the areas of land under agricultural crops in their farming system.

KEYWORDS
Agriculture; efficiency; enterprises; resources; soil; zoning

Introduction

Russia's invasion of Ukraine has brought devastation and denial of access to occupied territories; dreadful damage to those now recovered; and disruption across the whole country. Ukraine is fighting for its right to exist, domestic food security, and its hard-won position in the world market of agricultural commodities. And, as an agrarian country, it is trying to secure and rebuild the resource potential of its agricultural enterprises based on the laws of supply and demand, competition, and mitigation of the risks of agricultural land use.

Regardless of political and economic risks, the potential of agrarian enterprises depends on nature: resources, forces and events over which we have no control, but which determine the structure of agriculture and exert transformational effects, positive or negative. Recent years have seen profound changes in Ukrainian agriculture. Simultaneous changes in ownership and organisation mean facing up to economic realities but, also, to declining soil quality, loss of soil fertility and acceleration of erosion by activating resource- and energy-saving technologies; taking responsibility for conservation of natural resources and the risks involved in innovation. But, agriculture under conditions of martial law is another matter.

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Certainly, the assessment of the efficiency of agricultural land use should take account of environmental as well as economic factors – but there is dichotomy in the theory of organising the use of agricultural land: on the one hand as an object of labour or means of production and, on the other hand, as a natural resource. This makes it necessary to assess the state of the land in terms of the *resource potential* of the country's agriculture. A pantheon of scientists has engaged in developing technologies for the exploitation of land for agricultural crops, seeking to strengthen the material and technical base; increase the levels of concentration, specialisation and cooperation of production; and improve prices and financial mechanisms [1–8]. More specifically, analysis of the anatomy of agricultural lands and its impacts on the economic benefits of agricultural enterprises has been undertaken in Ukraine by Kravchuk *et al.* [9] and Kutsmus *et al.* [10], and elsewhere by Meyers *et al.* [11], Pasakarnis [12], and Randolph [13].

Our ideal farming system is one with the lowest costs of labour and materials, taking into account the resources required for conservation or restoration measures [14, 15]. With this in mind, our aim is to establish an index of the efficiency of agricultural land use that integrates the natural and ecological-economic elements of the resource potential of the food supply system [16]. This will be a star to steer by as we rescue, recover and rebuild our food system.

Materials and methods

We propose to supplement the existing indicators of the status of the food supply system with additional coefficients. The first is a *coefficient of completeness of the development of natural elements of the resource potential* – defined as the ratio of the area of agricultural land to the total land area (without taking into account the areas under water, swamps *etc.*). In addition, we propose a *coefficient of ploughing of agricultural land;* and a further *coefficient of ploughing of agricultural land within the territory of particular enterprises*. Ploughing accelerates biogenic processes but also accelerates erosion, physical soil degradation, and environmental pollution – all of which reduce the productivity of the land [17,18] – so, this last indicator [equation 1] characterises the intensity of land use and, at the same time, ecological tension in the countryside:

$$K_{pl} = \frac{S_{al}}{Sa} \times 100 \tag{1}$$

where, K_{pl} is ploughland in the territory of functioning of agricultural enterprises (%), S_{al} – area of arable land and perennial crops (thousand hectares), S_a – area of agricultural land (thousand ha).

Within the perspective of national food supply, we expand the method of evaluating the efficiency of land use by elaborating the relationship between the natural and ecological and economic elements of the resource potential of its agricultural enterprises. Here, assessment of natural and ecological-economic elements of the resource potential is supplemented by a set of indicators of the ecological-economic efficiency of agricultural land use: i.e. the expected ecological-economic result of the use each plot of land for agricultural crops – including ecologically determined losses of income from the use of plots for agricultural crops, and expenses for ensuring the requirements of ecologically sustainable agriculture.

The value of the expected ecological and economic result from the use of any plot of land under the i-th agricultural crop (EE_i) may be defined as the economic result reduced by the losses caused by the destructive nature of the agricultural enterprise, and calculated according to equation (2) [17,18]:

$$EE_i = \sum_{j=1}^{J} E_{ji} \times P^{o/c}(E_{ji}) \times k_j^p \times k_j^a \times k_j^{im} \times k_j^{ae} \times k_j^n, \tag{2}$$

where, E_{ji} – the expected economic result from the use of the land plot under the i-th agricultural crop for the j-th scenario of the development of events; $P^{o/c}(E_{ji})$ – objective/subjective probability of realisation of the j-th scenario of the development of events; J – the number of scenarios of the development of events (in the simplest case, the pessimistic, optimistic and most likely scenarios are considered; if possible, the number of scenarios is determined by the requirements for the accuracy of calculations using the Monte Carlo method); k_j^p – is a correction coefficient to take into account the impact of radiation pollution on the quality of agricultural land under the j-th scenario of the development of events; k_j^a – a correction coefficient to account for atmospheric pollution on the quality of the land under the j-th scenario of the development of events; k_j^{im}– a correction coefficient to account for heavy metal pollution; k_j^{ae} – a correction coefficient to account for erosion; k_j^n – a correction coefficient to account for the impact of pesticide residues.

In order to evaluate the ecological and economic elements of the resource potential of agricultural enterprises, we determine the index of effective use of agricultural land with the establishment of its predicted standard, according to equation (3) [16]:

$$rn_i \times x_j \leq = \geq R_i, \tag{3}$$

where, rn_i is the cost rate of the i-th resource for the production of the j-th product unit; x_j – planned volume of the j-th product; R_i – the total volume of the i-th resource.

To forecast the natural and ecological and economic elements of the resource potential in the agricultural land use efficiency index, it is necessary to construct a relationship in which the resulting sign (Y) is associated with two or more factor characteristics $(X_1, X_2, \ldots, X_m)$. Making use of multifactor correlation-regression, economic and mathematical models may be used to establish the quantitative dependence of the obtained results on the existing influencing factors: in practice, two types of multiple regression equations:

linear (additive) [19]:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_m X_m + \varepsilon, \tag{4}$$

non-linear (multiplicative) [20]:

$$Y = \beta_0 \times \beta_1 X_1 \times \beta_2 X_2 \times \ldots \times \beta_m X_m, \tag{5}$$

where, Y is a dependent (resulting) feature; $X = X(X_1, X_2, \ldots, X_m)$ – independent (factorial) features; β – parameters to be determined; ε– random deviation; β_0 – is a free member that determines the value of Y, when all factor variables Y_m are equal to 0.

Not all maximum sub-indicator values are optimal: there are boosters, for which the highest value is optimal, and blockers, for which the lowest value is optimal. Thus, the values of boosting sub-indicators are defined as the ratio of the actual value to the optimal value; at the same time, if the actual value of the sub-indicator is higher or equal to the optimal value, it is equal to 1. Accordingly, blocking sub-indicators are determined by the ratio of the optimal value to the actual value, and if the value is lower than or equal to the optimal value, it acquires the value 1. Thus, the normalised values of sub-indicators are calculated according to the following equations [21,22]:

for boosters:

$$\hat{x}_i = 1,\ if\ x_i \geq y_i \tag{6}$$

$$\hat{x}_i = \frac{x_i}{y_i},\ if\ x_i \prec y_i \tag{7}$$

for blockers:

$$\hat{x}_i = 1,\ if\ x_i \leq y_i \tag{8}$$

$$\hat{x}_i = \frac{y_i}{x_i},\ if\ x_i \succ y_i \tag{9}$$

where, x_i is the actual value of the *i*-th sub-indicator; y_i – optimal (limit) value of the *i*-th sub-indicator (for boosters → max, blockers → min); *i*– the normalised value of the *i*-th sub-indicator.

Determination of optimal (limit) values of sub-indicators is carried out according to their properties. In particular, a normative method is used to determine the reference value for certain sub-indicators. To calculate the value of the specified criteria (c_i), the sum of the normalised values of the set of sub-indicators included in them, adjusted according to their importance (equation 10), is determined [23]:

$$c_i = \sum_{i=1}^{n} \hat{x}_i \times g_i \tag{10}$$

where, $\hat{x}_i$ – is the normalised value of the *i*-th sub-indicator; g_i – weight factor of the *i*-th sub-indicator; *n*– the number of sub-indicators used during the calculation of criteria.

Finally, the *integral index of the efficiency of the use of agricultural land by natural and ecological and economic elements of the resource potential in the country's food supply system* (Ii_{lrp}) is defined as the arithmetic mean of the target vectors (v_i) and the calculated criteria, taking into account their weighting (equations 11-12) [23]:

$$v_i = \sum_{i=1}^{n} c_i \times g_i \tag{11}$$

$$Ii_{lrp} = \frac{\sum_{i=1}^{m} v_j}{m} \tag{12}$$

Table 1. Grades of agricultural land use efficiency.

Level of efficiency of the use of agricultural land	Value of integral index
Crisis	<0.35
Critical	0.36–0.60
Low	0.61–0.85
Satisfactory	>0.86

where, g_i is the weight coefficient of the i-th criterion; n – the number of indicators used during the calculation of criteria; m– is the number of target vectors used when calculating the integral index. Assessment based on the integral index includes a set of evaluation criteria and sub-indicators, and the algorithm of their normalisation according to optimal values allows objective evaluation and forecasting of the efficiency of agricultural land use, plot by plot. On this basis, we propose four grades of agricultural land use efficiency (Table 1).

Within this framework, the resource potential of agricultural enterprises can be developed according to an appropriate strategy for sustainable economic growth, taking account of any regulations for balanced agricultural land use and land protection.

Results and discussion

At its height, the Russian invasion brought not only occupation of some 20% of the country (now 13.5% of agricultural land) but countrywide disruption by missiles, mines and cluster bombs, theft and destruction of equipment and infrastructure, and defensive mobilisation of much of the workforce. Compared with 2018–2021, the costs of seeds, mineral fertilisers and fuel increased almost three-fold; stockfeed almost four-fold; and livestock have declined drastically. In order to stabilise demand and supply, the policy of price parities of food and agricultural products has almost doubled their costs [24–26].

Under martial law, monitoring of the efficiency of agricultural land use is considered in two respects. Firstly, in the absence of unambiguous market signals and replenishment of land resources, as a complementary tool to assess the expediency of growing particular agricultural commodities in particular ways in particular places. Secondly, as a guide to optimal ecological and economic land use at national and regional level.

The basis of the deployment of resources in agriculture is the worth of agricultural commodities. The extent to which potential production is realised depends on the deviation of the value of actual production from the potentially possible value. The potential value of agricultural products is calculated in terms of land, human and monetary (investment) resources and is calculated according to equation (13) [27]:

$$P_i = p_i \times V_i \tag{13}$$

where, P_i is the potential value of products grown on agricultural plots, which can be obtained from the available volumes of the i-th type of resource; P_i – the highest value of agricultural products per unit of the i-th type of resource among all regions of Ukraine; V_i– is the actual volume of the i-th type of resource in Ukraine.

The potential value of agricultural products may be increased by allocating labour and monetary investment to those regions that have both productive capacity and acceptable efficiency of agricultural land use. In 2018–2021, the greatest efficiency of the use of labour was in Kyiv region; and the greatest value of agricultural products per EUR of monetary investment was in Volynskyi (2018) and Chernivetskyi (2018–2021) regions. If all regions achieved the maximum productivity, it would be possible to increase the total volume and value of agricultural products by 68–83% by increasing the efficiency of agricultural land use; by 2.5 to 4-fold through increase in the efficiency of the use of labour; and 10 to 20-fold through increasing the efficiency of monetary investment [24–26].

Structure of food supply in Ukraine

Notably, during 2018–2021, there was a general decrease in production of strategically important agricultural commodities (Table 2). An in-depth assessment of the level of food self-sufficiency of the most problematic agricultural products from the point of view of economic efficiency (meat and milk) indicates that, at the end of 2021 and for the second quarter of 2022, only the Vinnytskyi, Volynskyi and Cherkaskyi regions made effective use of their land for livestock forage (Figure 1). Moreover, in terms of self-sufficiency in milk, only 27% of the regions of Ukraine met more than minimum standards (Figure 2).

Table 2. Structure of food supply in Ukraine, %, calculated according to data [24,26].

Indicators	2018	2019	2020	2021
Agricultural products				
Cereals and legumes	45.5	45.9	47.6	48.4
Sunflower seed	7.2	8.5	9.8	9.7
Potatoes	16.9	15.9	15.7	15.6
Vegetables	6.9	7.0	6.8	6.5
Meat	1.7	1.8	1.7	1.6
Milk	7.9	8.1	7.5	7.1
Eggs	13.9	12.8	10.9	11.1
Foodstuffs				
Sausages from meat by-products	5.4	2.9	5.5	2.8
Unrefined sunflower oil	22.2	46.4	22.5	57.9
Milk and cream	31.0	5.9	28.7	5.6
Buttermilk, cheese, yogurt, kefir, sour cream	10.8	3.7	10.8	3.1
Wheat or wheat-rye flour	14.2	25.7	15.0	19.6
Bread and bakery products	16.4	15.4	17.5	11.0

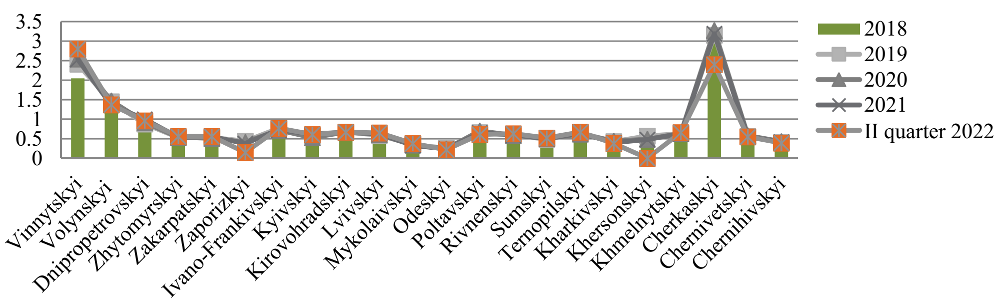

Figure 1. The level of meat self-sufficiency of the regions of Ukraine for 2018–2021 and the II quarter of 2022, calculated according to data [24–26].

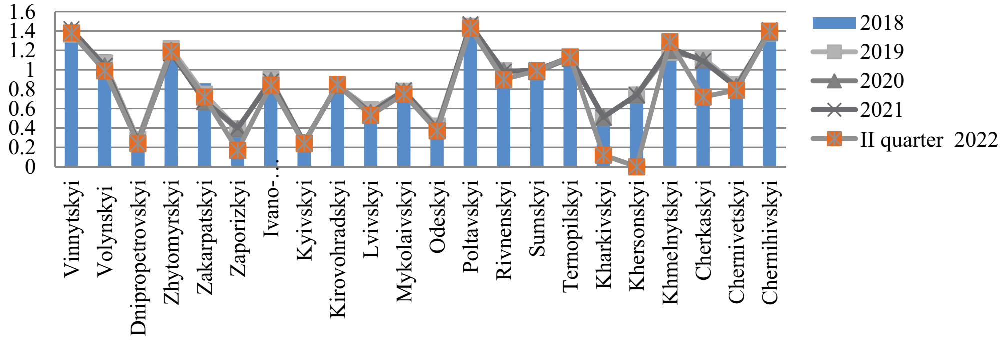

Figure 2. The level of food self-sufficiency of the regions of Ukraine with milk for 2018–2021 and the II quarter of 2022, calculated from data [24–26].

Even so, production was greater than consumption volumes for all agricultural and food products (Figures 3–4).

The regions were clustered hierarchically and by k-means according to the coefficients of food self-sufficiency in agricultural products, the consumption of food products, as well as their average annual growth rate for the production of vegetables, fruits and berries, meat and milk, bread and bread products). Six clusters emerged (Table 3).

The fifth cluster is characterised by the highest level of food self-sufficiency, where there is an increase in meat production and the least decline in milk production. In the second cluster, almost all indicators are somewhat higher than the national average. A stable level of self-sufficiency in egg production is observed only in the first and third clusters. The sixth cluster corresponds to the lowest level in terms of all classification features thanks to the threat or actuality of occupation (Figure 5).

Compared with 2018, agricultural enterprises comprising 3-5thousand ha per farm reduced the area under cultivation by 4.6% in the second quarter of 2022 [24–30]. Over the same period, there was a decrease in the number of agricultural enterprises and, accordingly, the area of agricultural land in their use, with the exception of enterprises smaller than 1000 ha. During 2018–2021, market conditions brought about the decline of livestock and saturation of crop rotations with cereals with a simultaneous decrease in the share of fodder crops (Figure 6).

Timely soil conservation measures and rational land use can arrest land degradation, or even regenerate soil quality, and increase crop yields. But, soil conservation activities have been cut back, resulting in ever more soil erosion and significant losses to agricultural producers and the country as a whole (Table 4).

A component-by-component study with further systematisation of the above research arrives at the integral index of the efficiency of the use of agricultural land by natural and ecological and economic elements of the resource potential in the country's food supply system (Figure 7).

Table 5 ranks all regions of Ukraine according to the integral index of the efficiency of agricultural land use as of the second quarter of 2022. According to the integral index and aggregate indices of the criteria of ecological and economic vectors of the efficiency of the use of agricultural land, the regional differences demonstrate the imbalance of these two components in the resource potential of the food supply system (Figure 8). Thus,

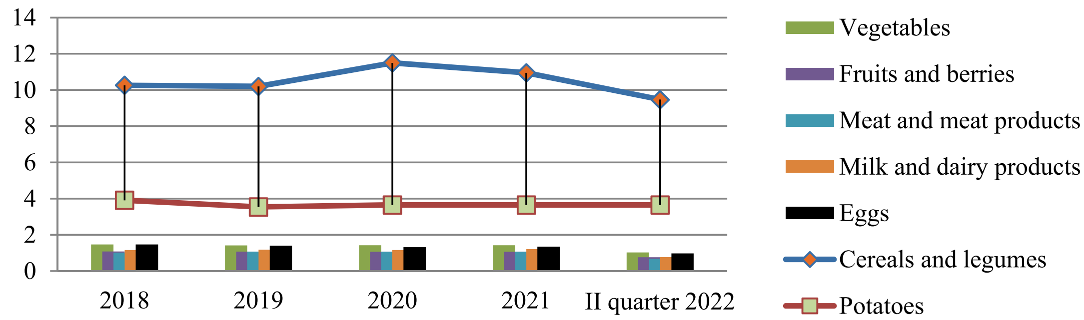

Figure 3. Ratio of production and consumption of agricultural products in Ukraine for 2018–2021 and the second quarter of 2022, data from [24–26,28,29].

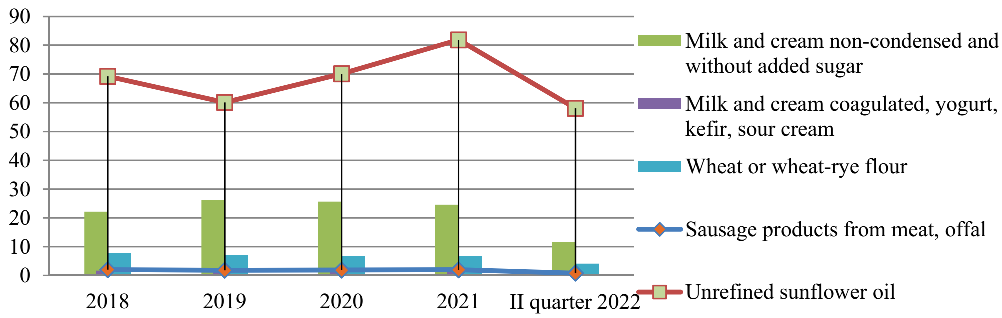

Figure 4. Ratio of production and consumption of food products in Ukraine for 2018–2021 and the II quarter of 2022, data from [24–26,28,29].

Table 3. Regions of Ukraine by the level of food self-sufficiency in agricultural products and food consumption.

Cluster	Number of regions	% of total	Regions
1	8	36.4	Volynskyi, Dnipropetrovskyi, Zakarpatskyi, Lvivskyi, Poltavskyi, Rivnenskyi, Ternopilskyi, Chernihivskyi
2	4	18.2	Vinnytskyi, Kirovohradskyi, Mykolaivskyi, Odeskyi
3	1	4.5	Kyivskyi
4	4	18.2	Ivano-Frankivskyi, Sumskyi, Cherkaskyi, Chernivetskyi
5	2	9.1	Zhytomyrskyi, Khmelnytskyi
6	3	13.6	Zaporizkyi, Kharkivskyi, Khersonskyi

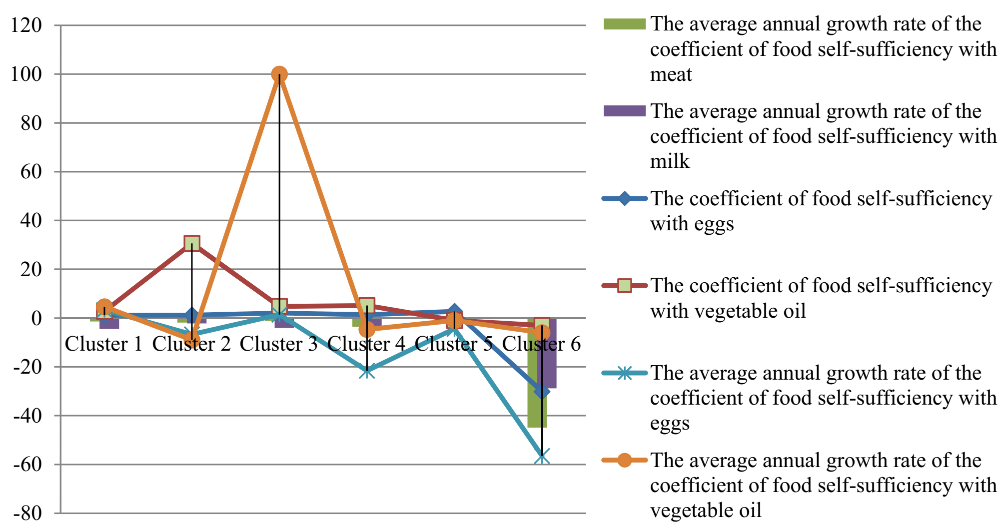

Figure 5. Regional self-sufficiency in agricultural products and food consumption for the second quarter of 2022.

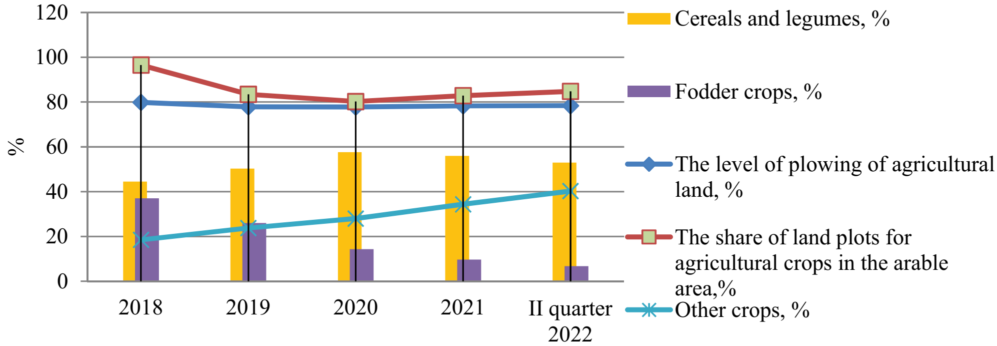

Figure 6. Structure of agricultural land use in Ukraine, 2018–2021 and the second quarter of 2022, data from [24–30].

Table 4. Implementation of measures to protect agricultural land in Ukraine, 2018–2021, data from [24–30].

Indicators	2018	2019	2020	2021
Reclaimed agricultural land, thousand ha	3.0	2.0	0.8	0.3
including: plots of land for agricultural crops	3.0	2.0	0.8	0.3
of which; arable land	1.5	1.5	1.2	0.3
Construction of anti-erosion structures				
Dikes, ditches, km	135.2	9.3	3.6	4.1
Sediment-capture ponds, ha	177	24	7	6.6
Water discharge structures, pcs	51	18	2	12
Shore defences, km	1	4.7	3.9	4.3
Reclamation of highly degraded and contaminated arable land, thousand ha	12.8	15.0	6.3	1.1

Zhytomyrskyi region (0.76), Zakarpatskyi region (0.8), Ivano-Frankivsk region(0.76) and Kyivskyi region (0.77) show the highest level of agricultural land use efficiency; most regions of Ukraine have a low level of the integrated index (in the range from 0.51 to 0.70); Zaporozhye region (0.41) and Kharkivskyi region (0.39) have a crisis/critical state of land use for the cultivation of agricultural crops; and the Khersonskyi region, occupied by Russian forces since February 2022, is in absolute crisis (0.0).

Conclusions

A comprehensive assessment of agricultural lands, encompassing the interaction of natural, ecological and economic elements of the resource potential, highlights the current severe pressures on land resources in Ukraine.

Land degradation and reduced yields follow from the unsystematic allocation and exploitation of land for row crops and other demanding uses that offer little protection from the elements.

More effective, less destructive use of agricultural lands might be achieved by territorial zoning, for instance by agro-ecological zones suitable for specific cropping patterns, combined with specific guidance – strictly regulated use necessitated by current problems. Along these lines, it is advisable to specify the level of potential fertility and the

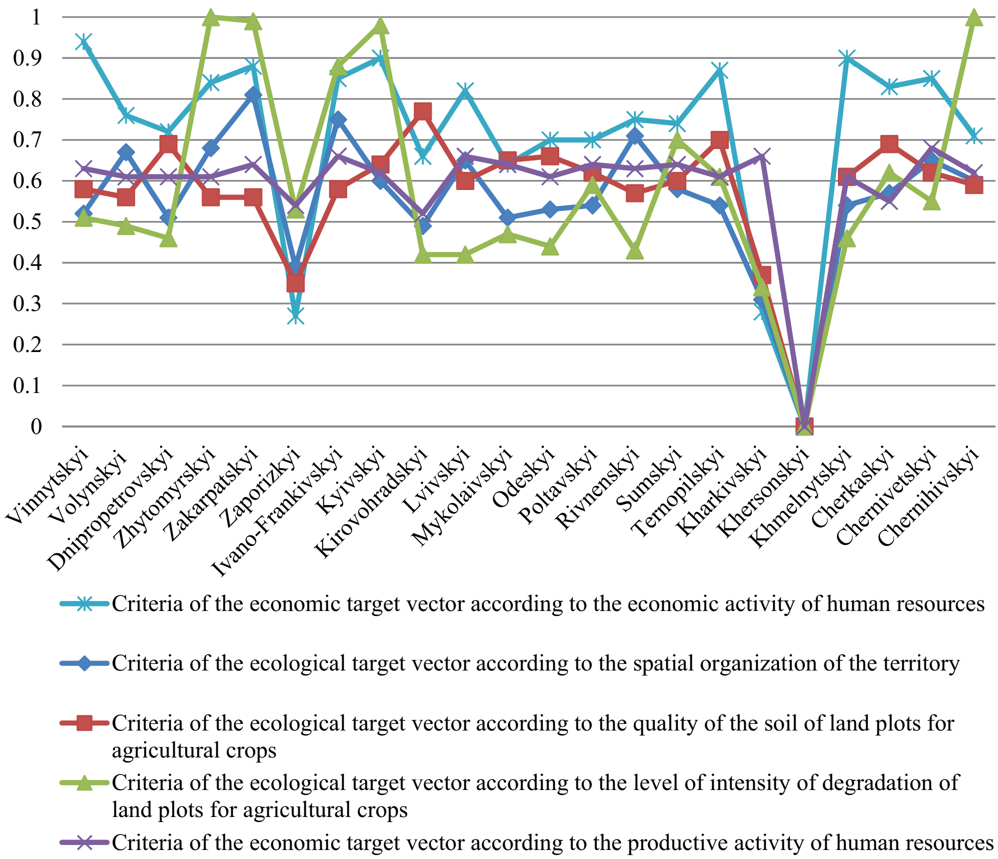

Figure 7. Criteria for the efficiency of the use of agricultural land in the food supply system of the regions of Ukraine for the second quarter of 2022.

Table 5. Ranking of regions of Ukraine by the level of efficiency of agricultural land use for the second quarter of 2022.

Integral index criteria	Regions
Crisis (< 0.30)	Khersonskyi (0.0)
Critical (0.31–0.50)	Zaporizkyi (0.41), Kharkivskyi (0.39)
Low (0.51–0.70)	Vinnytskyi (0.69), Volynskyi (0.64), Dnipropetrovskyi (0.61), Kirovohradskyi, (0.58), Lvivskyi (0.66), Mykolaivskyi (0.59), Odeskyi (0.6), Poltavskyi (0.63), Rivnenskyi (0.64), Sumskyi (0.67), Ternopilskyi (0.69), Khmelnytskyi (0.67), Cherkaskyi (0.68), Chernivetskyi (0.7), Chernihivskyi (0.71)
Satisfactory (> 0.70)	Zhytomyrskyi (0.76), Zakarpatskyi (0.8), Ivano-Frankivskyi (0.76), Kyivskyi (0.77)

manifestation of negative environmental factors in the composition of agricultural lands, viz., *especially valuable* (the most suitable plots of land for sectoral agricultural crops with the cultivation of more demanding plants on them); *productive* (land of sectoral agricultural value – for arable crops, perennial and forage crops – but which has moderate constraints due to erosion risk, lower soil quality, waterlogging, *etc.*); *unproductive and degraded* land characterised by negative natural properties, erosive processes, low fertility, on which conventional agricultural use will be uneconomic.

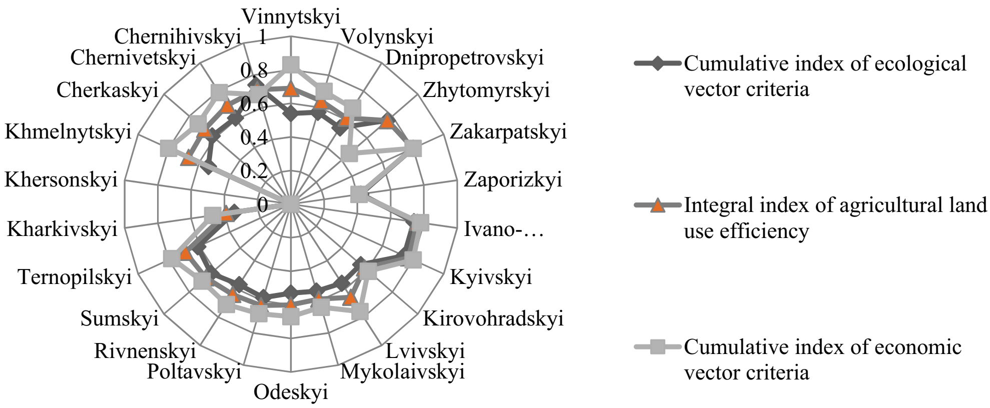

Figure 8. Integral index of the effectiveness of the use of agricultural land and the interaction of natural and ecological and economic elements of the resource potential in the food supply system of the regions of Ukraine for the second quarter of 2022.

In connection with current events, further thought might be given to regulating land use by a zoning procedure under martial law. This might mitigate the problems in the existing food system, in particular insufficient attention to soil, water, biodiversity, and environmental services. Of course, experience shows that this would throw up other problems.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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