Journal of Elementology ISSN 1644-2296

Lykhochvor V., Hnativ P., Petrichenko V., Ivaniuk V., Szulc W., Rutkowska B., Veha N., Olifir Y. 2022.
Threat of degradation of agricultural land in Ukraine through a negative balance of nutritional elements in growing of field cultures.
J. Elem., 27(3): 695-707. DOI: 10.5601/jelem.2022.27.2.2290

RECEIVED: 14 April 2022
ACCEPTED: 9 August 2022

ORIGINAL PAPER

THREAT OF DEGRADATION OF AGRICULTURAL LAND IN UKRAINE THROUGH A NEGATIVE BALANCE OF NUTRITIONAL ELEMENTS IN GROWING OF FIELD CULTURES

Vladimir Lykhochvor[1], Petro Hnativ[1], Vasil Petrichenko[2], Viktor Ivaniuk[1], Wiesław Szulc[3], Beata Rutkowska[3], Natalia Veha[1], Yuri Olifir[4]

[1] Department of Technology in Plant Breading, Agrochemistry and Soil Science
Lviv National Environmental University, Lviv, Ukraine
[2] Institute of Feed Research and Agriculture of Podillya
National Academy of Agricultural Sciences, Ukraine
[3] Agricultural Institute
Warsaw University of Life Sciences, Warsaw, Poland
[4] Institute of Agriculture of Carpathian Region
National Academy of Agricultural Sciences, Ukraine

Abstract

Fertilization in cultivation of grain and other crops in Ukrainian agriculture is insufficient, which may lead to the loss of fertility and irreversible soil depletion in the coming years. The article aims to identify the leading causes of land degradation and desertification in Ukraine, and to explore the problem of high deficits of nitrogen, phosphorus, and potassium caused by the alienation of nutrients from the soil and disproportionate ratios of fertilizers in intensive agricultural production. Since the beginning of the marketing year 2020/2021, Ukraine has exported approximately 27.6 million tons of cereals and legumes, i.e. 6.3 million tons less than in the same period of the previous marketing year. Specifically, 12.8 million tons of wheat, 3.89 million tons of barley, 10.52 million tons of corn, and 81.2 thousand wheat flour were exported. The calculations showed that – according to the content of nutrients in grain products – harvest from Ukrainian fields extracted more than 1.888 million tons N, 0.275 million tons P, and 0.386 million tons K. In 2019, 88.3% of N, 15.9% of P and 2.6% of K was exported from Ukraine with field crops. Corn absorbs the most essential nutrients among cereals. Winter wheat ranks the second. Reversing the negative balance of N, P, and K is possible by doubling mineral fertilization. Soil degradation and desertification are a disaster for Ukraine, and a significant threat to global food security. These processes can be stopped if the following measures are implemented: 1) additional application of organic fertilizers, 2) larger-scale cultivation of perennial legumes,

Beata Rutkowska, PhD, DSc, Prof., Agricultural Institute, Warsaw University of Life Sciences, Nowoursynowska 166, 02-787 Warsaw, Poland, e-mail: beata_rutkowska@sggw.edu.pl

3) growing green manure crops, 4) application of optimal doses of mineral fertilizers and microelements, 5) application of waste biomass as fertilizer, and 6) liming of soils.

Keywords: grain, nitrogen, phosphorus, potassium, balance of elements, soil degradation, desertification.

INTRODUCTION

The processes of desertification and soil degradation in Ukraine have begun and intensified under the unfavourable climate transformation conditions (Baliuk et al. 2012, Barbosa, Olsson, 2019, Petrichenko et al. 2020, Poliovyy et al. 2021). Degradation is a natural and/or anthropogenic process of the worsening of soil's biological properties and fertility. It reduces the economic value of agricultural land, and over time renders land unsuitable for growing crops. According to estimates of the research institution NAAS in Ukraine (Report… 2020, Baliuk et al. 2017), the surface area of degraded and infertile land with signs of desertification has already reached 10 million hectares. The annual increase in eroded land has already reached 80-90 thousand hectares.

Ukraine has significant land potential, accounting for 5.7% of Europe's territory. More than 70% of Ukraine's territory is occupied by agricultural land. Arable land covers 33.5 million hectares, approximately equal to the total area of countries such as Finland, Poland, or Italy. Ukraine has been an influential producer of grain throughout the history of mankind. Production of marketable grain of wheat, rye, barley, peas, buckwheat, and millet has reached its maximum now, and over the past 10-12 years it has also included sunflower, rapeseed soybean, corn, and other crops. On average, producers harvest 65 million tons of grains and legumes in Ukraine (Agriculture… 2021), from 15.3 million hectares in 2020, reached a record level of 74 million tons in 2019, and harvested 70 million tons in 2018.

According to the results of the marketing year 2019/2020, the total volume of grain exports of all cereals gave Ukraine the second place in the world, after the United States (FAO Collections 2021, FAO… 2022, In Brief… 2021). Ukraine also ranked second in terms of barley supplies, fourth in terms of corn, and 5th in terms of wheat. The value of Ukrainian agricultural products imported to more than 190 countries reaches 19 billion USD.

Since the beginning of the marketing year 2020/2021, Ukraine has exported approximately 27.6 million tons of cereals and legumes, i.e. 6.3 million tons less than in the same period of the previous marketing year. Specifically, 12.8 million tons of wheat, 3.89 million tons of barley, 10.52 million tons of corn, and 81.2 thousand wheat flour were exported (Agriculture... 2021). At the same time, the UN predicts a reduction in world grain stocks to a minimum over the next five years (FAO Collects… 2021, Thinking... 2022).

However, the desire to obtain the maximum profit in the shortest possible time against the background of rapid climate change leads to ruthless, irrational exploitation of soil resources in Ukraine. Ukraine is therefore soon bound to face catastrophic consequences.

Ukraine occupies the first place in the global ranking of cultivated land. In terms of chernozem area, equal 28 million hectares in Ukraine, the country ranks fourth after Russia, the United States, and China. The area exceeds the total size of the UK or Romania. The soil resources of Ukraine are therefore not only the national wealth of an individual state. Ukraine's agricultural land is an invaluable asset that gives the Earth's population a chance to survive.

According to Volkov et al. (2020), the largest area of degraded land is located in Asia, followed by Africa, and other continents. Europe ranked fourth based on the calculation of soil degradation.

The substantiation of the main directions in solving the problems of land degradation and desertification in Ukraine, however, is still insufficient. There is a need to assess the looming threats, in the context of climate change, potentially affecting the natural areas of Ukraine due to excessive economic exploitation of soil resources.

Our research aims to determine the leading causes of land degradation and desertification in Ukraine, and to explore the problem of high deficits of nitrogen, phosphorus, and potassium caused by the alienation of nutrients from the soil, the disproportionate ratio of fertilizers in intensive agricultural production, and climate change.

MATERIAL AND METHODS

The research was conducted by the Department of Technology in Plant Breeding, Agrochemistry and Soil Science at the Lviv National Environmental University (LNEU), with the assistance of the Institute of Feed Research and Agriculture of Podillya at the National Academy of Agricultural Sciences (NAAS) in Ukraine, the Agricultural Institute Warsaw University of Life Sciences (SGGW, Poland), and the Institute of Agriculture of the Carpathian Region of (NAAS) in Ukraine. It was conducted in 2020-2021. We monitored, systematised, and conducted mathematical calculations, made a comparative analysis of state statistical reporting materials, and synthesised new scientific data on threats to the agricultural, and in the future also the social sector of Ukraine's economy.

Data from the State Statistics Service of Ukraine (Agriculture... 2021) used in the study are presented in Table 1. We used the mass balance approach (García-Ruiz et al. 2011, Amate 2012), including almost all input and output resources of nitrogen (N), phosphorus (P), and potassium (K) with

Table 1

Sown areas, yield, and total grain production of major crops in Ukraine, 2019 (Agriculture... 2021)

Crops	Area (million ha)	Yield of marketable grain (t ha^{-1})	Yield of secondary phytomass (t ha^{-1})	Gross grain harvest (million t)	Secondary phytomass (million t)	Grain exports (million t)	Share of exports from grown grain (%)
Winter wheat	6.70	4.17	4.17	27.94	27.94	17.00	60.8
Spring barley	2.60	3.48	3.48	9.05	9.05	5.00	55.2
Corn grains	4.80	7.30	14.60	35.04	70.08	27.00	77.1
Soy	1.60	2.32	2.32	3.71	3.71	2.50	67.4
Pea	0.24	2.35	2.35	0.56	0.56	0.50	89.3
Rapeseed	1.20	2.67	8.01	3.20	9.61	2.80	87.5
Total	17.14	–	–	79.51	120.96	54.80	68.9

the topsoil of agricultural lands for medium conditions (Howlett et al. 2011, Use of inorganic… 2020).

To calculate the amount of alienation from fields of N, P, and K with products, we selected different indicators of the content of these elements (%) in grain and straw (Table 2) from scientific sources (Jackson et al. 1986, Howlett et al. 2011, Amate 2012). The ratio of marketable grain and secondary phytomass for winter wheat, spring barley, soybeans, and peas is 1 to 1, for grain corn 1 to 2, and for rapeseed 1 to 3 (Howlett et al. 2011).

We calculated amounts of extracted nutrients with consideration of their concentration in products in Ukraine according to the following formula:

Table 2

The average content of N, P, K in the dry matter of plant products (g kg^{-1})

Crops	Product	N	P	K
Winter wheat	grain	25.0	4.0	5.8
	straw	5.0	0.9	8.3
Spring barley	grain	20.0	3.7	4.6
	straw	05.0	0.9	8.3
Corn grains	grain	19.0	2.5	3.1
	straw	07.5	0.9	11.1
Soy	grain	58.0	4.6	10.5
	straw	12.0	1.6	4.2
Pea	grain	45.0	4.4	10.4
	straw	14.0	1.5	4.2
Rapeseed	grain	32.0	7.0	9.1
	straw	11.0	2.2	16.6

$$R_{NPK} = A_t\ C/100\ ton^{-1},$$

where:

$R_{summary/export\ NPK}$ – extraction volume of N, P, and K with harvest on summary/export, t;

A_t – amount of harvest on summary/export (t);

C – concentrations of N, P, and K in plants (g kg^{-1});

100 – coefficient (%) – Petrychenko et al. (2020).

We ran the calculations for the most common cereals and oilseed rape in Ukraine.

Volumes of mineral fertilizers in Ukraine were obtained from the State Statistics Service (Use of inorganic… 2020).

RESULTS AND DISCUSSION

According to our calculations (Table 3), grain corn absorbs the largest amount of N – 1191.4 thousand tons, P – 150.7 thousand tons, and K – 886.5 thousand tons, for the formation of grain yield and non-commercial biomass.

Table 3

Total assimilation of N, P and K in biomass of cereals and rapeseed and 2019 exports from Ukraine

Crops	Total accumulation in the biomass of cereals and rapeseed (thousand t)			The share of nutrients in exported grain (%)		
	N	P	K	N	P	K
Winter wheat	838.2	136.9	394.0	50.7	49.7	25.0
Spring barley	226.3	41.6	116.7	44.2	44.5	19.7
Corn grains	1191.4	150.7	886.5	43.1	44.8	9.4
Soy	259.7	23.0	54.6	55.8	50.0	48.2
Pea	33.0	3.3	8.2	68.2	66.7	63.4
Rapeseed	208.1	43.5	188.6	43.1	45.1	13.5
Total	2 756.6	399.1	1 648.6	47.0	46.9	15.9

Winter wheat ranked second in the assimilation of N, P, and K. The share of N exports in grain composition averaged 47.0%, P – 49.6%, K – 15.9% of the biotic assimilation of nutrients by biomass of cereals.

We investigated the amounts of nutrients removed with the harvest of cereals and oilseed rape from soils in the agricultural production in Ukraine (Table 4). The calculations show that together with total grain harvest, 1.888 thousand tons of N, 274.8 thousand tons of P, and 386.2 thousand tons of K were extracted from Ukrainian fields in 2019. Moreover,

Table 4

Total removal of N, P and K with the harvest of cereals and rapeseed from the soils of Ukraine in 2019 (thousand t)

Crops	Volume of extraction of batteries (thousand tons)					
	with gross grain harvest			with by-product biomass		
	N	P	K	N	P	K
Winter wheat	698.5	111.8	162.1	139.7	25.1	231.9
Spring barley	181.0	33.5	41.6	45.3	8.1	75.1
Corn grains	665.8	87.6	108.6	525.6	63.1	777.9
Soy	215.2	17.1	39.0	44.5	5.9	15.6
Pea	25.2	2.5	5.8	7.8	0.8	2.4
Rapeseed	102.4	22.4	29.1	105.7	21.1	159.5
Total	1 888.0	274.8	386.2	868.6	124.3	1 262.4

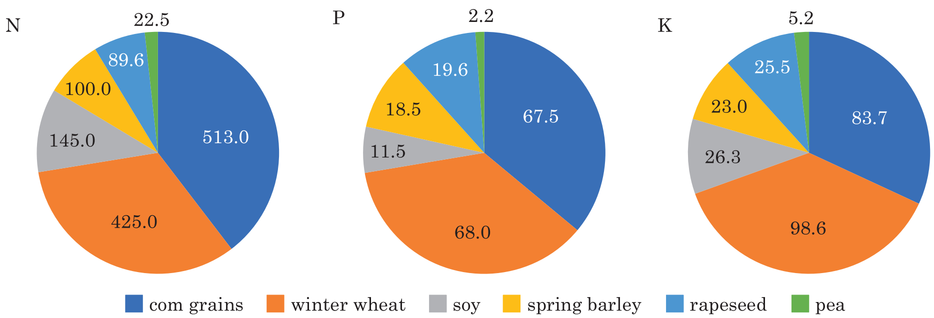

Fig. 1. Withdrawal of the main elements of mineral nutrition with the export of cereals and rapeseed outside Ukraine in 2019, thousand tons

1295.1 thousand tons of N, 187.3 thousand tons of P, and 262.2 thousand tons of K were transported outside Ukraine as part of export grain that year.

Grain corn contained the most significant amount of N – 513 thousand tons (Figure 1), exported with grain sold by Ukraine in 2019, compared to other crops. Winter wheat had the highest P and K exported with grain abroad. Moreover, 144.0 thousand tons of N and 26.3 thousand tons of K are exported with soybeans.

The calculations showed that grain corn does not require much N to form one ton of grain (Table 5). The crop, however, takes the most of the element from the soil (182.5 kg ha^{-1} N), although the most significant amount of N (151.1 kg ha^{-1}) is exported with pea grain.

Rapeseed requires most critically P for grain formation, and causes the most extensive P extraction with exports per unit area. Grain corn is the leader in terms of the need, assimilation, and export of K with products per unit area.

Table 5

Total export of N, P and K in the grain harvest from 1 hectare of arable land and their export outside Ukraine in 2019

Crops	N			P			K		
	(kg t^{-1}) grain	uptake from grain (kg ha^{-1})	export (kg ha^{-1})	(kg t^{-1}) grain	uptake from grain (kg ha^{-1})	export (kg ha^{-1})	(kg t^{-1}) grain	uptake from grain (kg ha^{-1})	export (kg ha^{-1})
Winter wheat	32.0	133.4	81.1	4.4	18.3	11.2	16.6	69.2	42.1
Spring barley	25.0	87.0	48.0	4.4	15.3	8.5	12.5	43.3	23.9
Corn grains	25.0	182.5	140.7	4.4	32.1	24.8	16.6	121.2	93.4
Soy	65.0	150.8	101.6	5.3	12.2	8.3	16.6	38.5	26.0
Pea	72.0	169.2	151.1	6.2	14.5	12.9	16.6	39.0	34.8
Rapeseed	60.0	160.2	140.2	11.9	31.7	27.8	12.5	33.2	29.1

The higher yield and the higher fertilizer dose, the higher the removal of nutrients from the soil. The amount of nutrients in the plant available form is therefore insufficient for growing crops without fertilizers, even in fertile soils (Hanáčková et al. 2008). The ground also loses its self-healing functions without fertilizers (Baveye, Wander 2019). Therefore, there is an evident need to replenish nutrient losses by applying mineral fertilizers (Khromiak et al. 2019, Baveye et al. 2020). On the other hand, much of nutrients remains in the soil in the post-harvest residues of cultivated crops (Torma et al. 2018). These nutrients must be taken into account when fertilizing the soil.

As shown in Figure 2, the use of fertilizers in Ukraine increased in 2015-2019. Agricultural producers supplied 76 kg N, and 17 kg P and K per unit per hectare of agricultural land in 2019. The total amount of N, P, and K is much higher in Europe, and ranges from 200 to 300 kg ha^{-1}. However, farmers did not consider the necessary fertilizer doses or nutrient ratios when fertilizing crops. Nitrogen fertilizers were preferred. In the case of fertilization with high doses of nitrogen and phosphorus, there is a risk of contamination of both ground and surface water resources (Torma et al. 2019)

Table 6 shows the amounts of N, P, and K in the area of all agricultural land in 2019. From these quantities, we subtracted the part of N, P, and K that is exported to the grain content. 88.3% of N was exported with grain. The difference between imported and exported P is negative. The excess of P lost with exports is 26.0 thousand tons, or 15.9%. The quantity of K lost with exports is slightly smaller, reaching 6.7 thousand tons, or 2.6%.

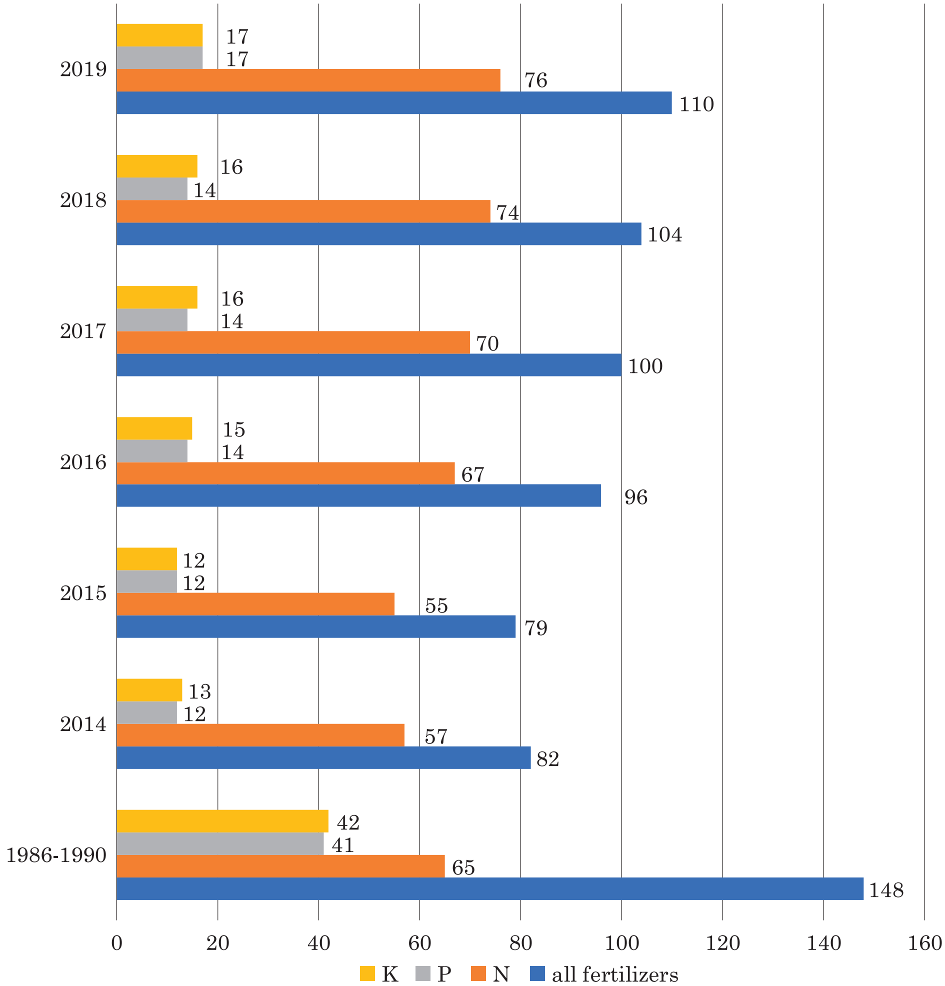

Fig. 2. Dynamics of mineral fertilizers application (kg ha^{-1}) on the area of all agricultural lands in Ukraine (Use of inorganic fertilizers…, 2020)

Table 6

Balance of mineral nutrients of agricultural crops, which was in the agriculture of Ukraine in 2019 (thousand t)

Balance	Mineral nutrients		
	N	P	K
Imported on the area of all agricultural lands (thousand t)	1 467.5	161.6	255.5
Extracted from the soil and exported with the export of grain (thousand t)	1 295.1	187.3	262.2
Difference +/– (thousand t)	172.4	–26.0	–6.7
Proportion of exported nutrients (%)	88.3	115.9	102.6

There is a debate whether it is safe to grow and export grain products due to the depletion of Ukraine's soil resources. Is this a problem of Ukraine or a global one?

According to the National Research Centre "Institute of Soil Science and Agrochemistry of NAAS in Ukraine", the most common type of degradation is dehumification (Baliuk et al. 2012, Petrichenko et al. 2020). Dehumification is the gradual loss of humus and nutrients (Lal 2016, Soil organic… 2021). One of the reasons for developing degradation processes in soils is the application of insufficient doses of organic and mineral fertilizers, lime, and dolomite flour. At the same time, highly productive heat-loving cereals spread to the north of Ukraine (Polovyy et al. 2021), where they need intensive fertilization. This results in a poor balance of nutrients in the soils (Baliuk et al. 2017, Poliovyy et al. 2021). A gradual decrease in the content of nutrients in the soil results from significant excess of their removal along with formed crop over a return to the soil with fertilizers. Grain producers remove much more macro-and micronutrients from the ground than they return. To prevent soil depletion, it is necessary to compensate for all the removal of nutrients with the crop and other flows of losses. Noteworthy, in Ukraine nutrients from plant products are mainly exported abroad. After all, most of the grain grown is exported: 80% corn, 72% wheat, 58% soybeans, and 52% barley. Harvesting and removal of N, P, K, Ca, Mg, S, microelements, and loss of organic carbon from the soil occurs against the background of negative trends in climate change in the natural areas of Ukraine.

The Intergovernmental Panel on Soil Experts (ITPS) has defined soil health as "the ability of soil to support the productivity, biodiversity, and ecological services of terrestrial ecosystems" (Towards... 2020, Lehmann et al. 2020). In agricultural systems, soil degradation can be prevented and soil health can be maintained, strengthened, or restored through the implementation of sustainable soil management methods (Zornoza et al. 2015, Weil, Brady (late) 2017, Vogel et al. 2018, World Soil… 2021).

The ways and means of increasing crop yields, preserving soil fertility, and protecting soils from degradation and desertification have been discussed in many scientific papers (Vozhehova, Hranovska 2019, Petrychenko, Lykhochvor 2020, Poliovyy et al. 2021). Intensification of grain production in Ukraine involves using modern, scientifically sound farming systems. They are based on the introduction of crop rotations with short rotation, and application of the latest tillage systems, fertilizers, and crop protection from pests (Poliovyy et al. 2021).

At the same time, the intensification measures increase the risks caused by narrowing the range of crops grown by monoculture, which they usually have high nutrient requirements for soil (Baliuk et al. 2017, Petrichenko et al. 2020). In this situation, against the background of modern climate dynamics in the natural areas of Ukraine, rational methods of sustainable grain production need to be searched for. This requires a scientific justification for the efficient use of soil resources that will not induce degradation and desertification of the agricultural land of Ukraine. It is also necessary to take into account the cultivation of crops in optimal conditions. Soil parameters (soil type, soil texture, soil deep, contents of gravel) are an important factor in the production of high yields (Vilček et al. 2020)

The systematic application of minimum doses of fertilizers that automatically causes spontaneous reproduction of soil fertility has been researched and theoretically justified. Khristenko (2020) proposed a model of the economic level of nutrient balance for sustainable soil fertility. The model considers probable changes in climatic conditions, fertilizer prices, crop rotations, and modernisation of agrotechnology.

According to our calculations, a possible solution to the negative balance of N, P, and K is increasing funds for the purchase and application of mineral fertilizers. For example, it is not recommendable to apply $N_{76}P_{17}K_{17}$ (Fig. 2) in the future, but it is needed to add $N_{74}P_{24}K_{18}$ and apply at least $N_{150}P_{41}K_{35}$. This can be done if the following is implemented: 1) additional application of organic fertilizers, 2) larger-scale cultivation of perennial legumes, 3) growing of green manure crops, 4) application of optimal doses of mineral fertilizers and microelements, 5) application of non-commercial phytomass as fertilizer, and 6) liming of soils.

CONCLUSIONS

Soil depletion and desertification in Ukraine is a problem in Ukraine and in many other parts of the world, posing a threat to human food security. Today, Ukraine is one of the leading exporters of food, grain, and other agricultural products.

Producers of agricultural products in Ukraine should be encouraged to apply all types of fertilizers containing at least $N_{150}R_{41}K_{35}$ to the fields. To do this, they ought to abandon the goal of earning the maximum profit on fertile soils by saving on the cost of fertilizers and soil reclamation.

The Government of Ukraine must impose, and agricultural producers should implement the principles of sustainable land use to provide conditions for the reproduction of agricultural land fertility. Such a state policy and rational management in the agricultural sector will stop the degradation of fertile and sometimes unique Ukrainian soils. Moreover, it will prevent the desertification of Ukraine in the face of unpredictable climate change. Ukraine will continue to be a leading producer and exporter of grain globally under this approach.

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