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Forecasting the Consequences of the Cost of Mineral Fertilisers on the Development of the Corn Market in Ukraine Using AGMEMOD Models

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► **Abstract.** In the past decade, from 2012 to 2021, Ukraine has doubled its maize production. The increase in gross corn yields is associated with the use of modern cultivation technologies by farmers, which increase the resistance of plants to adverse environmental factors and adjust the mineral nutrition of plants with regard to weather conditions. One of the most important components of such technologies is the use of mineral fertilisers, the optimal amount of application of which depends not only on the level of grain yield, but also on the efficiency of production and grain quality. However, the rapid increase in world natural gas prices during 2021 has created new challenges and threats for the further development of the grain market in Ukraine. After all, world prices for mineral fertilisers have increased by 110% since 2021, according to the World Bank. Under these conditions, a radical increase in the cost of mineral fertilisers threatens to ensure the competitiveness of Ukrainian corn in the domestic and foreign markets, which would eventually lead to higher food prices and deterioration in the level of food security in the country. This may negatively affect the gross yields and export potential of the grain industry. The purpose of the study is to assess the current state of supply and demand in the corn market in Ukraine and predict the consequences of the impact of changes in the cost of mineral fertilisers on the main parameters of its development according to probable scenarios, using the AGMEMOD econometric partial equilibrium model for the period up to 2025, which creates prerequisites for improving the efficiency of making and implementing management decisions and contributes to achieving the goals of national agrarian policy. The following methods were applied: monographic, abstract and logical, comparative analysis and expert assessments, tabular, statistical and economic, factor analysis, economic and mathematical modelling. The result of the study is an assessment of the current state and identification of the main factors influencing supply and demand in the corn market. Using multiple linear regression, the influence of the main factors on the yield of corn for grain in agricultural enterprises of Ukraine for 2001-2020 is determined. The dynamics of the balance of supply and demand in the corn grain market in Ukraine is analysed. The consequences of changes in the cost of mineral fertilisers on the main parameters of the corn market development in Ukraine are predicted according to probable scenarios using the AGMEMOD econometric partial equilibrium model for the period up to 2025. Based on the calculations made, it is proved that the high yield of corn and the favourable current price environment for grain will ensure a sufficient level of profitability of this grain crop. Methods for improving the mechanism of reducing the cost or compensation of expenses for the purchase of mineral fertilisers for commodity producers are proposed. Methodological and practical aspects of forecasting the consequences of changes in the cost of mineral fertilisers on the main parameters of corn market development in Ukraine using the AGMEMOD econometric partial equilibrium model for the period up to 2025 have been further developed. The proposed methodological approaches and findings can be used by state and industry management bodies in the development of priority areas for improving the effectiveness of the grain industry in Ukraine

► **Keywords:** agricultural policy, grain market, energy crisis, econometric modelling

► Introduction

In recent years, Ukraine has significantly increased the volume of corn grain production, entering the group of some of the world's largest exporting countries, such as the United States, Argentina, and Brazil [1]. According to the Ukrainian Business and Trade Association [2], in 2020, the share of Ukraine in the world market of corn accounted for more

than 15%, and in terms of revenue received from its exports, it ranked 4th in the world, selling 27.9 million tonnes of grain worth USD 4.9 billion to foreign markets [3]. This was largely conditioned by the use of industrial technologies of agricultural production, which require, among other things, significant amounts of mineral fertilisers.

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However, the rapid increase in world natural gas prices during 2021 has created new challenges and threats for the further development of the grain market in Ukraine. Thus, according to the World Bank, global prices for mineral fertilisers, in the prime cost of which natural gas accounts for up to 80%, have increased by 80% in 2021, and by another 30% in the first quarter of 2022 [4]. All these problems are aggravated by two factors: a significant amount of mineral fertilisers (38% nitrogen, 50% phosphorus, and 80% potash [5]) are the object of purchase and sale on international markets, and a big part of this trade comes only from a few countries of the world, such as the Russian Federation, China, Canada, the USA, Belarus, Qatar, which have competitive advantages in the production of fertilisers through their own production of natural gas, coal, or other raw materials.

Economic sanctions imposed on Russia and Belarus for Russia's full-scale invasion of Ukraine, and export restrictions on fertilisers imposed by China and some other countries, pose a threat to further growth in world prices for mineral fertilisers. Such an increase in prices, combined with the availability of mineral fertilisers on the market, can stimulate both an increase in consumer prices for food and a potential decrease in corn yields for grain. An additional factor that can potentially influence the price increase may be a reduction in the gross yield of corn for grain due to the projected application of less than the technological need for mineral fertilisers. But the worst thing is that not only the gross yield will decrease, but also the quality of Ukrainian grain.

Under these conditions, the issue of forecasting the consequences of the increase in the cost of mineral fertilisers on the further development of the corn market in Ukraine, ensuring food security and its competitiveness in the world and domestic markets is becoming increasingly relevant.

Thus, in the context of rapid growth in prices for mineral fertilisers, there is an urgent need to introduce a balanced and systematic approach to the development and implementation of state agricultural policy aimed at balancing the interests of all participants in the corn market. Achievement of this goal will largely depend on the effectiveness of the mechanism for reducing the cost or compensating the cost of purchasing mineral fertilisers for grain producers in Ukraine in the face of global challenges.

The issues of developing the grain market, ensuring competitiveness, economic efficiency of its production and food and energy security, and forming the export potential of the grain industry occupy a major place in scientific research and are widely represented in the specialised literature. In particular, A. Skrypnyk, N. Klymenko, K. Tuzhyk, L. Galaieva and K. Rohoza [6], having analysed the prerequisites and prospects for stabilising grain production volumes, determined the impact of production resources, in particular, mineral fertilisers and plant protection products, on the efficiency of winter wheat production. Based on the developed econometric model of reducing the marginal utility of production resources, it is proved that maximisation

of yield is achieved at a lower cost than maximising profit.

Issues of ensuring the efficiency of grain production have become relevant in the last decade among the scientific community. Thus, S. Cheremisina and V. Rossokha [7] proved that the decrease in the level of profitability indicator is conditioned by a significant increase in the costs of labour, mineral fertilisers and plant protection products, fuel and lubricants, and an unjustified increase in other direct and general production costs. At the same time, a successful solution to the problem of increasing the economic efficiency of grain farming involves the implementation of a comprehensive system of actions to increase production and improve the quality of grain crops, while simultaneously reducing labour costs and material costs per unit of production.

The team of researchers consisting of D. Shiyani, N. Lialina, and K. Honcharova [8], studying the influence of the level of dependence of wheat yield on individual items of expenditure, proved that the relationship of the latter with the level of costs for mineral fertilisers and depreciation was the closest. This means that with an increase in the yield, the share of these items in the cost structure also increases. All this develops prerequisites for ensuring the effective development of grain farming.

Chinese researchers J. Wang and X. Hu [9] analysed the efficiency of corn grain production and identified factors influencing its increase in the main producing and exporting countries in the period from 2012 to 2019. The researchers concluded that with the growing cost of production resources in Argentina, the United States, Ukraine, and other countries has prompted producers to constantly improve corn production technologies to increase its efficiency.

Separately, it is necessary to highlight the study by S. Bereziuk and I. Zubar [10], who investigated modern economic and ecological aspects of fertiliser application in crop production. Based on the analysis, it is concluded that in recent years, the increase in grain yields in Ukraine was accompanied by an increase in the imbalance between the volume of NPK application (N – Nitrogen, P – Phosphorus, K – Potassium) and their removal by plants. The solution of the identified problems is proposed to be carried out through a system of measures, in particular, increasing the level of state support for the production of mineral fertilisers in Ukraine and scientifically based agricultural technology.

The ecological and economic efficiency of growing corn for grain was also studied by the author's team consisting of O. Stasiv, O. Kachmar, O. Vavrynovych, E. Arabska [11], who proved that the complex use of mineral ($N_{120}P_{100}K_{100}$) and organic fertilisers contribute to obtaining high productivity of corn grain with a yield of 6.10-6.87 t/ha of grain and ensure its high conditional level of profitability at the level of 72-104%.

The issue of increasing profits from corn exports to the world market has become relevant among Ukrainian researchers. In particular, D. Lialko [12],

comprehensively analysed the global corn market and substantiated the main areas of development of the domestic market, which would ensure the receipt of economic benefits by Ukrainian producers.

N. Tanklevska, V. Petrenko, A. Karnaushenko, K. Melnykova [13] conducted a comprehensive analysis and identified the main trends in the development of the world corn market, and based on the calculations made, substantiated the economic feasibility of deep processing of corn in Ukraine. I.V. Vashchenko substantiated the theoretical foundations of the establishment and operation of the corn market from the standpoint of the generation of supply and demand, world market conditions, and price fluctuations in the domestic and foreign markets [14].

A team of Romanian researchers E. Soare, I.A. Chiurciu, A.V. Bălan, L. David [15], after analysing the main indicators of the development of the world corn market, created forecasts of its development for the period up to 2025 and identified the main factors that would have the greatest impact in the future, in particular, these are natural and climatic conditions in the main producing and exporting countries.

M. Palamarchuk's study [16] is devoted to the assessment of corn competitiveness and factors influencing its formation in Ukraine. In particular, the influence of the size of agricultural enterprises on the efficiency of corn production for grain in Ukraine is determined. The impact of world prices on the level of corn competitiveness in Ukraine is assessed and a system of measures to increase it is proposed. Among the main areas of increasing competitiveness, the researcher suggests the use of scientifically based cultivation technologies, including the optimal application of mineral fertilisers and the use of high-yielding corn hybrids of various ripeness groups.

Italian researchers F. Santeramo, E. Lamonaca, F. Contò, G. Nardone, A. Stasi [17] have stated that the determinants of price volatility are a significant step to preventing the potential negative consequences of uncertainty in the corn grain market. The authors proposed a new category of drivers of grain price volatility – endogenous and exogenous, and also substantiated the potential consequences that each of them can affect price dynamics.

A team of Ukrainian and foreign researchers consisting of A. Nykolyuk, P. Pyvovar, A. Chmil, M. Bogonos, P. Topolnycky, I. Cheban, and T. Fellmann [18] analysed the current situation and created forecasts for the development of the main agricultural markets of Ukraine for the period up to 2030 based on the AGMEMOD model. It is concluded that despite a slight increase in the gross wheat harvest, corn will become the dominant grain crop in Ukraine. The main driving force behind this trend is adaptation to climate change.

However, despite a significant number of papers on this issue, there are still a number of issues that require further study, substantiation, and improvement. In particular, it is the forecasting of the economic consequences of changes in the cost of mineral fertilisers on the main parameters of grain market development in Ukraine using the AGMEMOD econometric partial

equilibrium model. *The purpose of the study* is to analyse supply and demand in the corn market in Ukraine and develop forecasts of the impact of changes in the cost of mineral fertilisers on the main parameters of its development according to probable scenarios, using the AGMEMOD econometric partial equilibrium model for the period up to 2025, which creates prerequisites for increasing the competitiveness of Ukrainian grain and ensuring food security of the country.

► Materials and Methods

In the course of the study, the following methods were used: monographic – to detail the current level of efficiency of corn grain production; abstract and logical – to formulate conclusions; comparative analysis – to analyse the state and determine trends in yield, gross yields, and harvested area of corn for grain in the context of regions of Ukraine; tabular – to summarise and visually display analytical data and findings; statistical and economic – to collect and process analytical data on the main parameters of corn market development in Ukraine; factor analysis – to determine the influence of the main factors on the efficiency of corn grain production; econometric modelling – to assess the impact of changes in the cost of mineral fertilisers on the main parameters of corn market development in Ukraine.

The initial information during the study was the data from the Ministry of Economy of Ukraine, Ministry of Finance of Ukraine, Ministry of Agrarian Policy and Food of Ukraine, State Statistics Service of Ukraine, National Bank of Ukraine, the World Bank, the International Monetary Fund, the US Department of Agriculture, the Food and Agriculture Organization of the United Nations (FAO), the Organization for Economic Cooperation and Development (OECD), the Joint Research Centre (JRC) of the European Commission, foreign and Ukrainian research papers, as well as personal research and practical observations of the authors of this study.

To assess the impact of changes in the cost of mineral fertilisers on the main parameters of the corn market development in Ukraine, an econometric dynamic model of partial market equilibrium – AGMEMOD (Agricultural Member State Modelling) – was used. This model was developed to analyse the impact of the Common Agricultural Policy (CAP) on the development of agriculture in the European Union countries. The AGMEMOD model as an integrated system combines national partial equilibrium models for each EU country, possible candidate countries, and important neighbours. It includes about 50 types of agricultural products (for example, crop production includes such crops as wheat, corn, barley, rye, oats, rapeseed, soy, sunflower, sugar beet, legumes, potatoes, fruits, and vegetables) and more than 30 countries (including some non-EU countries, in particular – Ukraine, Turkey, Kazakhstan, the Russian Federation, North Macedonia) that which allows assessing the impact of agricultural policy decisions on agricultural production and predicting the development of agricultural markets in

the short, medium, and long term. The AGMEMOD partnership develops and maintains the model and is a consortium consisting of universities, research institutes, and government agencies in Europe and beyond. The main group of the AGMEMOD partnership is located in the Netherlands (Wageningen Economic Research) and Germany (Thünen Institute of Market Analysis).

Each common AGMEMOD model of the country consists of a system of submodels of the main types of agricultural products. The variables included in

each submodel represent consecutive positions in the balance sheet of each agricultural market. Supply is modelled on initial inventory, production, and imports, while demand is modelled on domestic consumption, exports, and final inventory. In each country, the corresponding domestic prices are also modelled for each product. A prerequisite for solving the model is to maintain equality between supply and demand in each market in each country. Figure 1 illustrates the general structure of the agricultural market model at the country level.

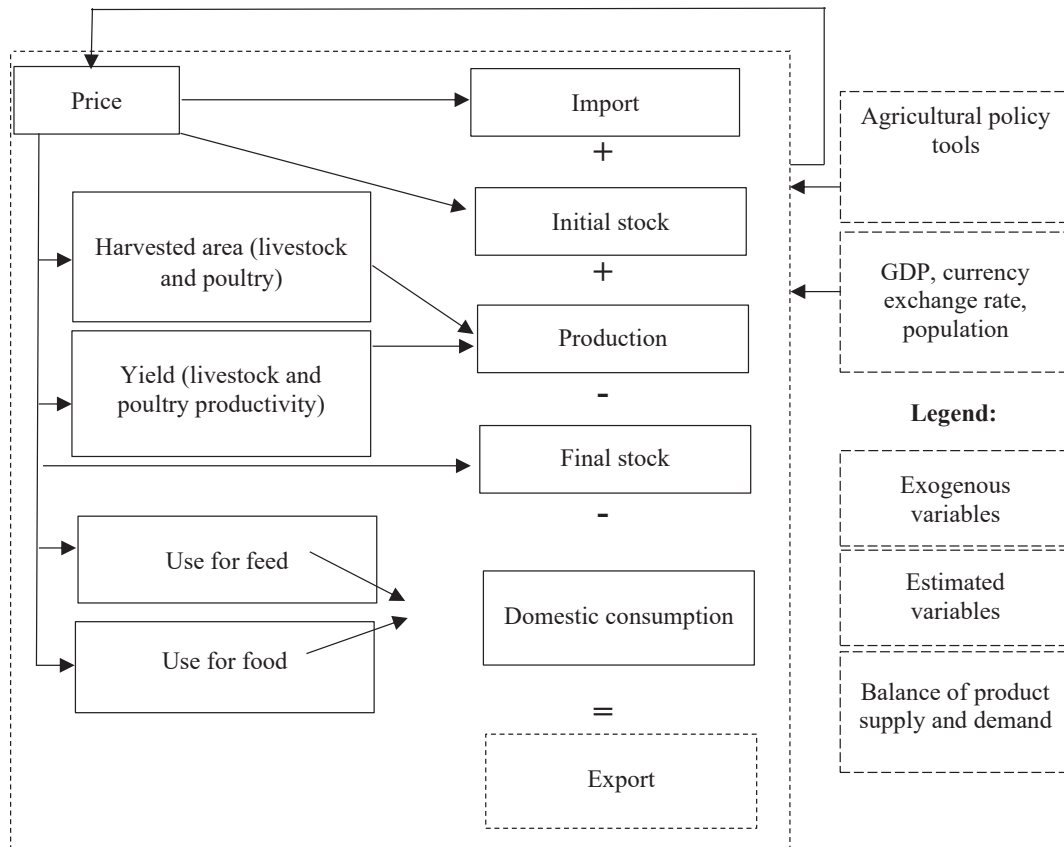


Figure 1. Country-level structure of the AGMEMOD model

Source: [19]

Agricultural markets in AGMEMOD are represented by supply and demand equations, stocks, international trade, and market prices. They represent the behavioural responses of economic agents to changes in prices and external variables, such as agricultural policy instruments, currency exchange rates, tariff quotas, etc. The parameters of equations are usually estimated as time series regressions with AGMEMOD databases [18].

The model uses a combination of exogenous and endogenous data to predict the development parameters of the agricultural market. The values of exogenous variables are estimated not by the model, but by other organisations. For example, using the forecasts of the United States Department of Agriculture (USDA) regarding world prices for major types of agricultural products.

Exogenous variables in AGMEMOD at the national level, such as GDP, GDP deflator, exchange rate, and population, are not calculated or predicted by the model. These data and their forecast estimates for the period up to 2030 were taken from data from the World Bank, the International Monetary Fund (IMF), and the United States Department of Agriculture (USDA). The inclusion of exogenous variables in the model allows for better visualisation of the processes and relationships in agricultural production. At the same time, each of the exogenous variables affects the variables that are estimated by the AGMEMOD model [20].

The model for grain crops develops forecasts of harvested area, yield per hectare, gross yield as a product of harvested area and yield, domestic consumption, import and export volumes, stocks, and

domestic market price [21]. Submodels of certain types of agricultural products are closely related to each other. For example, crop production models are linked to livestock production models using livestock production cost indices, which are functions of grain, oilseeds, and oil cake.

The regression equation for modelling the main parameters of the corn market in Ukraine in the AGMEMOD model was developed by Ukrainian and foreign researchers for “Agricultural markets in Ukraine: current situation and market outlook until 2030” [18].

For this study, the model uses data from the State Statistics Service of Ukraine from 2000 to 2019 [22; 23]. To conduct the analysis, a panel database was created, based on which the linear regression equation was evaluated in the R software version 4.0.2. To estimate regression in R, the “pooling” model is used, this is when the same weight is given to relationships between years and between regions.

The estimated equations are entered in one of the main model files, which is responsible for the equations. In the model, the gross grain harvest is defined as the product of the average yield and the harvested area of corn. The distribution of agricultural land between different grain crops is based on the group substitution approach and is expressed in proportions. The substitute product for corn in the model is wheat.

Equations that reflect the specific weight of acreage of specific grain crops in these groups include

the gross income variable, which serves as an indicator of the level of profitability of their production and, thus, plays an important role in determining replacement coefficients.

Behavioural functions for grain acreage estimated from panel data are entered into the AGMEMOD model along with the multiplication factor. This coefficient represents the number of administrative regions and allows adjusting the average values per region obtained by regressions of panel data to the level of the entire country, as required by the model. Per capita consumption, feed use, losses, non-food processing, domestic market prices, export, import volumes, and changes in corn stocks were estimated based on time series data using the least squares method.

The coefficient of determination, which determines the proportion of variation in one of the variables that is explained by variation in other variables, was $R^2=0.0861$. This indicates that the regression equation only 8.61% of the variation of the effective feature is conditioned upon the variation of the independent (factor) feature. However, for such complex models with limited databases, the value of the coefficient of determination may be sufficient to assess its validity.

p – the value of the regression equation amounting to 0.00199. This means that in the regression model all variables were statistically significant because value is less than 0.05. All other results of regression estimation using the R packages are shown in Figure 2.

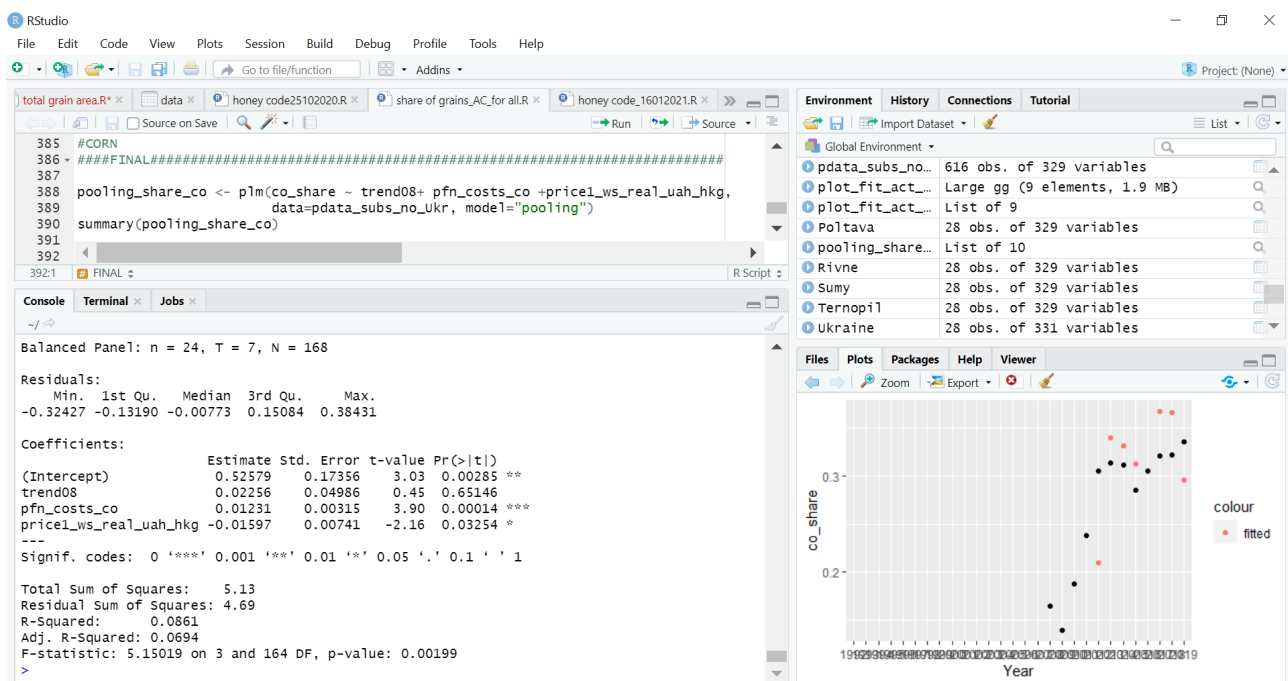


Figure 2. Results of regression estimation using R packages

Source: calculated by the author based on [18]

Equations for modelling and forecasting the main parameters of supply and demand in the corn market in Ukraine:

1. The area from which corn is harvested for grain, thsd. ha. (equation (1)):

$$COAHAUA=COASHUA*GRAHAUA \quad (1)$$

2. Corn yield, tonne per 1 hectare (equation (2)):

$$COYHAUA = 1.1475 + 1.0745 * TREND08 + 0.1421 * COEGUUA \quad (2)$$

3. Gross corn yield, thsd. t. (equation (3)):

$$COSPRUA = COYHAUA * COAHAUA \quad (3)$$

4. Corn import volume, thsd. t. (equation (4)):

$$COSMTUA = 21.86825 + 0.1017958 * COPFNU \quad (4)$$

5. Corn export volume, thsd. t. (equation (5)):

$$SOUXTUA = COSPRUA + COCCTUA (-1) + COSMTUA - COUDCUA - COCCTUA \quad (5)$$

6. Domestic consumption, thsd. t. (equation (6)):

$$COUDCUA = COUFOUA + COUFEUA + COUDLUA \quad (6)$$

7. Final residues, thsd. t. (equation (7)):

$$COCCTUA = -507 + 0.4560418 * COSSRUA + 116.0461 * (COPFNUA / COPMDUS * EXRDUA) \quad (7)$$

8. Feed usage, thsd. t. (equation (8)):

$$COUFEUA = 992.2123 - 33.98611 * COPFNUA / GDPDUA + 3.365268 * (PKSPRUA + POSPRUA) \quad (8)$$

9. Use for food purposes, thsd. t. (equation (9)):

$$COUFDUA = COUPCUA * POPUA \quad (9)$$

10. Use for sowing, thsd. t. (equation (10)):

$$COUFSUA = 0.01 * COAHAUA \quad (10)$$

11. Processing for non-food purposes, thsd. t. (equation (11)):

$$COUOTUA = COXFAUA + COUDPUA \quad (11)$$

12. Share of corn in the total grain area, % (equation (12)):

$$COASHUA = 0.52579 + 0.02256 * TREND08 + 0.01231 * COEGUUA - 0.01597 * WSPFNUA (-1) / GDPDUA (-1) \quad (12)$$

13. Profitability of corn production, thousand UAH (equation (13)):

$$COEGUUA = COPFNUA (-1) / GDPDUA (-1) - COCGUUA / GDPDUA \quad (13)$$

Designation:

COAHAUA – the area from which corn is harvested for grain;

COASHUA – share of corn in the total grain area;

GRAHAUA – total grain area;

COYHAUA – corn yield;

COEGUUA – corn profitability;

COCGUUA – corn production costs per 1 ha of acreage;

COSPRUA – gross corn yield;

COSMTUA – corn import volume;

SOUXTUA – corn export volume;

COPFNUA – price of 1 tonne of corn;

COUDCUA – volume of domestic consumption;

COCCTUA – final leftovers;

COUFEUA – use for feed;

COUDLUA – losses;

COUFDUA – use for food purposes;

COUFSUA – use for sowing;

COUOTUA – processing for non-food purposes;

WSPFNUA (-1) – price of wheat in the previous period, as a substitute product of corn;

GDPDUA – GDP deflator;

GDPDUA (-1) – GDP deflator of the previous period;

TREND08 – logarithmic trend;

COPMDUS – FOB corn import price, USD;

PKSPRUA – pork production volume;

POSPRUA – chicken production volume;

COXFAUA – other factory uses;

POPUA – population of Ukraine;

EXRDUA – the exchange rate of USD to UAH.

► Results and Discussion

Since 2016, there is an increase in acreage and gross corn yields in Ukraine. In particular, the average harvest of corn for grain in Ukraine in 2016-2020 amounted to 30,943.0 thsd. tonnes, which increased more than 5 times compared to 2001-2005. The increase in gross corn yields occurred both due to a 1.78-fold increase in yield and due to an increase in harvested areas by more than 2.8 times. On average, in 2016-2020, the harvested area of corn for grain in Ukraine was 4,735.2 thsd. ha. with an average yield of 65.5 c/ha (Table 1).

Table 1. Dynamics of gross yields, harvested areas, and yields of grain corn in Ukraine

Indicators	2001-2005	2006-2010	2011-2015	2016-2020	2016-2020 to 2001-2005
Gross yield, thsd. t.	6,145.9	9,546.6	25,314.6	30,943.0	503.5
Harvested areas, thsd. ha.	1,651.9	2,160.0	4,290.6	4,735.2	286.7
Yield, c/ha	36.8	43.7	59.0	65.5	178.0

Source: calculated based on: [22, p. 73-75]

At the same time, in 2021 in Ukraine, the gross yield and yield of corn for grain amounted to 42,109.9 thsd. t. and 76.8 c/ha, which, respectively, is 136.1% and 116.9% higher than the average values for 2016-2020 [22].

As evidenced by the data in Table 2, in the central region (Vinnytsia, Kirovohrad, Dnipropetrovsk, Poltava, and Cherkasy oblasts), the gross yield of corn grain in 2021, compared to 2018, increased from 15,640.6 thsd. t. to 16,334.3 thsd. t. or by 104.4% mainly due to the expansion of the harvested area by 106.8%, as the grain yield decreased by 1.1%. The share of the central region

in the gross grain yield of Ukraine for the period under study decreased from 43.7% to 38.8%.

But in 2021, compared to 2018, the share of the northern region (Kyiv, Zhytomyr, Sumy, and Chernihiv oblasts) in the gross yield of corn grain in Ukraine decreased from 32.0% to 31.4%, and the western region (Volyn, Zakarpattia, Lviv, Ivano-Frankivsk, Rivne, Ternopil, Khmelnytskyi, Chernivtsi oblasts), respectively, increased from 14.4% to 19.9%. At the same time, gross yields in the western region in the period from 2018 to 2021 increased by 162.5%.

Table 2. Gross yield, harvested area, and yield of corn for grain by regions of Ukraine, 2018-2021

Oblast	2018	2019	2020	2021	2020 to 2018, %
Gross yield, thsd. t.					
<i>Ukraine, incl.:</i>	35,801.1	35,880.1	30,290.3	42,109.9	117.6
North	11,453.6	11,689.8	11,355.8	13,232.6	115.5
Centre	15,640.6	15,336.9	9,410.9	16,334.3	104.4
West	5,159.6	5,197.1	6,472.5	8,383.9	162.5
South	1,709.8	1,681.7	1,274.2	2,284.3	133.6
East	1,837.5	1,974.6	1,776.9	1,874.8	102.0
Harvested area, thsd. ha.					
<i>Ukraine, incl.:</i>	4,564.2	4,986.9	5,392.1	5,481.8	120.1
North	1,233.6	1,442.3	1,631.7	1,647.5	133.6
Centre	2,024.9	2,187.6	2,263.1	2,162.6	106.8
West	589.3	625.4	762.1	918.2	155.8
South	336.0	335.4	333.8	354.7	105.6
East	380.4	396.2	401.4	398.8	104.8
Yield, c/ha					
<i>Ukraine, incl.:</i>	78.4	71.9	56.2	76.8	98.0
North	92.8	81.6	67.7	80.6	86.9
Centre	75.5	69.0	38.8	74.7	98.9
West	82.8	78.8	80.1	84.3	101.8
South	51.4	56.5	48.2	69.8	135.8
East	40.1	45.1	36.4	40.9	102.0

Source: calculated and compiled based on [22]

Note: (North – Kyiv, Zhytomyr, Sumy, and Chernihiv oblasts; Centre – Vinnytsia, Kirovohrad, Dnipropetrovsk, Poltava, and Cherkasy oblasts; West – Volyn, Zakarpattia, Lviv, Ivano-Frankivsk, Rivne, Ternopil, Khmelnytskyi, and Chernivtsi oblasts; South – Odesa, Mykolaiv, Kherson, and Zaporizhzhia oblasts; East – Kharkiv, Luhansk, and Donetsk oblasts)

The analysis shows that during the period under study, the most significant expansion of the harvested area of corn for grain occurred in the western and northern regions by 155.8% and 133.6%, respectively. The yield of corn in these regions for the period under study exceeds the average values in Ukraine. The analysis allows for the conclusion that during the period from 2018 to 2021, the corn belt expanded to the north and west of Ukraine. Such an extension is primarily associated with a lack of moisture, especially during the growing season of corn in the south-eastern regions of Ukraine.

Under these conditions, a significant task is to solve the problem of increasing the efficiency of using mineral fertilisers, which, along with ensuring an increase in the gross yield of corn grain, should help preserve soil fertility and have a high level of

payback. Difficulties often arise when solving these problems, primarily due to the rapid increase in prices for mineral fertilisers.

According to the State Statistics Service of Ukraine [22], in the structure of corn production for grain in Ukraine in 2018-2020, the share of agricultural enterprises was 73.8%, farming enterprises – 12.2%, and private households – 14.0% of the total volume. This distribution is conditioned by the fact that large and medium-sized agricultural enterprises are mainly focused on the export of corn, the production of which has a high marginality and, accordingly, requires significant costs per 1 hectare of crops. At the same time, in the structure of corn production costs of agricultural enterprises in Ukraine for 2018-2020, the key element of intensification were mineral fertilisers (Table 3).

Table 3. Costs of corn production for grain in agricultural enterprises of Ukraine per 1 ha of sown area

Items of expenditure	2018		2019		2020	
	UAH	%	UAH	%	UAH	%
Direct material costs, including:	9,365.2	50.3	9,476.5	51.5	7,816.3	48.2
seeds and planting material	2,546.5	13.7	2,505.4	13.6	2,114.4	13.0
mineral fertilisers	2,814.0	15.1	3,185.3	17.3	2,498.5	15.4
fuel and lubricants	1,731.2	9.3	1,638.9	8.9	1,214.5	7.5
other costs	2,273.4	12.2	2,146.9	11.7	1,988.9	12.3
Labour costs, (%)	810.6	4.4	877.3	4.8	899.4	5.5
Other direct expenses and general production expenses, incl.:	8,431.5	45.3	8,037.4	43.7	7,516.1	46.3
deductions for social measures	179.3	1.0	195.7	1.1	197.4	1.2
depreciation	1,088.3	5.8	1,288.9	7.0	1,426.3	8.8
payment for third-party organisations	2,583.0	13.9	2,276.0	12.4	1,836.6	11.3
other direct and general production costs	4,580.9	24.6	4,276.9	23.3	4,055.8	25.0
Total expenses	18,607.3	100.0	18,391.3	100.0	16,231.8	100.0

Source: calculated based on [24]

In particular, one of the most significant items in the structure of the cost of corn production for grain is the cost of mineral fertilisers, the share of which for 2018-2020 was in the range from 15.1% to 17.3%, or in absolute terms from UAH 2,814 in

2018 to UAH 2,498.5 in 2020 per 1 ha of crops. At the same time, the share of fertilised corn acreage for grain during the period under study tends to increase, in particular, from 94.7% in 2018 to 95.6% in 2020 (Table 4).

Table 4. Volumes of mineral fertilisers applied for corn for grain in agricultural enterprises of Ukraine

	2018	2019	2020	2020 to 2018, %
Share of fertilised area, %	94.7	95.0	95.6	101.0 p.p.*
Volume of mineral fertilisers applied, thsd. t. (in nutrients)	482.5	528	659.9	136.8
Cost of purchased mineral fertilisers, million UAH	4,074.6	4,762.7	4,429.3	108.7
Volume of mineral fertilisers applied per 1 hectare of sown area, kg	147	145	172	117.0

Note: * percentage point

Source: [25; 26]

The amount of mineral fertilisers applied when growing corn for grain in agricultural enterprises of Ukraine in 2020 increased from 482.5 thsd. t. in 2018 to 659 thsd. t. (in nutrients) in 2020, or by 136.8%. Per 1 ha of sown area, the volume of fertilisers applied also tends to grow from 147 kg in 2018 to 172 kg in 2020, or by 117%, over the period under study. According to the results of 2021, the volume of mineral fertilisers applied during corn cultivation increased to 683 thsd. t. (in nutrients), and per 1 ha – amounted to 171 kg, which is 1 kg less compared to 2020 [25].

In general, as evidenced by the data in Table 4, agricultural enterprises of Ukraine annually from 2018 to 2020 purchased mineral fertilisers for growing corn for grain in the amount of more than UAH 4 billion per year. Under these conditions, it is

important to determine from a scientific and practical standpoint how increasing the volume of mineral fertiliser application affects the yield of corn for grain in agricultural enterprises of Ukraine. Since the value of economic variables is usually determined not by one, but by several factors, multiple linear regression is used to measure their quantitative impact on performance.

The proposed model is based on the influence of the following factors on the yield of corn for grain (y), in particular, the share of the fertilised area with mineral fertilisers, the volume of application of mineral and organic fertilisers per 1 hectare of crops, and the level of profitability of production of this grain crop in agricultural enterprises of Ukraine for the period from 2001 to 2020 (Table 5).

Table 5. Source data for correlation and regression analysis of the influence of factors on the yield of corn for grain in agricultural enterprises of Ukraine

Year	Yield, c/ha	Share of the fertilised area with mineral fertilisers, %	Volume of fertiliser application per 1 hectare of sown area, kg		Level of profitability (unprofitability), %
			Mineral	Organic	
2001	26.9	32.0	27	887.6	38.0
2002	32.7	42.4	39	922.7	25.6
2003	32.3	42.3	34	778.2	50.3
2004	37.6	56.6	52	630.3	12.7
2005	45.9	59.0	65	660.8	-6.30
2006	38.1	71.7	68	729.5	10.9
2007	41.9	77.9	87	764.0	47.9
2008	49.5	84.4	99	932.0	10.6
2009	54.6	73.6	81	1,179.7	21.5
2010	47.0	81.0	92	749.0	29.9
2011	68.6	83.1	93	649.0	38.6
2012	51.5	86.5	96	612.3	19.8
2013	68.1	90.2	115	677.7	1.50
2014	66.6	89.8	113	683.3	26.2
2015	61.1	89.7	112	762.4	50.3
2016	72.4	93.6	130	725.6	45.7
2017	59.5	93.6	143	744.5	23.7
2018	87.0	94.7	147	834.0	67.6
2019	77.7	95.0	145	798.0	38.9
2020	60.9	95.6	172	785.0	42.2

Source: [22; 24; 26]

Using the source data of Table 4 and the MS Office Excel-2010 software suite, the following regression equation was obtained:

$y = 4.72831 + 0.41008x_1 + 0.14641x_2 + 0.00037x_3 + 0.11970x_4$
 where y – yield of corn for grain in agricultural enterprises of Ukraine, c/ha; x_1 – share of the fertilised area

with mineral fertilisers, %; x_2 – the volume of application of mineral fertilisers per 1 ha of sown area, kg; x_3 – the volume of application of organic fertilisers per 1 ha of sown area, kg; x_4 – level of profitability, %.

This equation shows that the greatest influences of all four factors on the performance indicator have:

1) the share of the fertilised area of crops – if the weight of the indicator increases by 1%, the yield of corn for grain will increase by 0.41 c/ha;

2) the volume of application of mineral fertilisers – if this factor increases by 1 kg per unit of sown area, the yield will increase by 0.14 c/ha;

3) the level of profitability – if the weight of the indicator of the level of profitability increases by 1%, the yield of corn for grain will increase by 0.12 c/ha.

The results of the regression equation showed that the volume of organic fertiliser application (x_3) does not significantly affect the increase in yield due to small amounts of application. In particular, if this factor is increased by 1 kg per unit of sown area, the yield will increase by only 0.00037 c/ha.

The multiple correlation coefficient is 0.87429, which indicates that there is a close correlation between the estimated level of the yield of corn for grain and the linear combination of the above parameters. Coefficient of determination $R^2=0.76438$, indicates that regression explains 76.4% of the variance in the

value of corn yield generation for grain in agricultural enterprises of Ukraine.

Thus, the analysis showed that the yield of corn for grain has a close and direct correlation with the volume of mineral fertilisers applied per 1 hectare of crops. Therefore, further increase in the effectiveness of grain production would also largely depend on the application of optimal volumes of mineral fertilisers in accordance with agrotechnological requirements and the region of their use.

If the gross yield of corn in Ukraine has increased significantly since 2016 (Table 1), then domestic consumption remains fairly stable. Therefore, changes in the gross yield of corn are not critical from the standpoint of ensuring domestic consumption, since if in 2010 its share was 52.8%, then in 2020 it decreased to 21.5%. On average, about 6.0 million tonnes of corn are used for feed purposes per year, while in relative terms – there is a tendency to decrease. In particular, if in 2010 the share of feed costs to production volumes was 44.8%, then in 2020 it decreased to 18.9% (Table 6).

Table 6. Dynamics of corn balance in Ukraine, thsd. t.

	2010	2018	2019	2020
Production	11,953	35,801	35,880	30,290
Inventory changes (at the end of the year)	997	6,580	-4,076	-4,821
Import	30	41	36	25
Total resources	12,980	29,262	39,992	35,136
Export	4,057	21,440	32,346	27,916
Feed costs	5,359	6,318	6,018	5,735
Sowing costs	155	151	199	197
Losses	469	641	642	500
Processing for non-food purposes	831	545	628	632
Consumption fund	117	167	159	156
<i>domestic consumption/production</i>	52.8%	19.6%	19.0%	21.5%
<i>feed/production costs</i>	44.8%	17.6%	16.8%	18.9%
<i>export/production</i>	33.9%	59.9%	90.2%	92.2%

Source: [23, p. 38]

The analysis shows that the domestic market is not able to meet the demand for existing volumes of corn grain production. Therefore, according to V. Rozhko, “... the growth of corn grain production in Ukraine is accompanied by an increase in its export opportunities, while domestic consumption remains

relatively stable” [27]. Over the past decade, Ukraine has significantly increased the volume of corn grain exports. In 2021, 24.7 million tonnes of Ukrainian grain were exported to foreign markets, which accounted for 48.6% of grain exports from Ukraine and is 6 times higher than the corresponding indicator in 2010 (Table 7).

Table 7. Dynamics of volumes, prices, and revenue from grain exports from Ukraine

Year	Total grain		Incl. corn		
	Export volumes, million tonnes	Export revenue, billion USD	Export volumes, million tonnes	Weighted average export price, USD	Export revenue, billion USD
2010	13.9	2.40	4.05	194	0.79
2011	14.1	3.60	7.80	254	1.98
2012	27.08	6.98	15.60	249	3.88

Table 7, Continued

Year	Total grain		Incl. corn		
	Export volumes, million tonnes	Export revenue, billion USD	Export volumes, million tonnes	Weighted average export price, USD	Export revenue, billion USD
2013	27.07	6.36	16.70	229	3.82
2014	32.5	6.48	17.50	191	3.34
2015	37.4	6.05	19.04	158	3.01
2016	40.2	6.08	17.29	153	2.65
2017	41.9	6.50	19.30	154	2.97
2018	42.9	7.24	21.40	164	3.50
2019	57.9	9.60	32.30	161	5.21
2020	52.2	9.55	27.92	175	4.88
2021	50.8	12.35	24.70	239	5.89

Source: [28; 29]

Despite the fact that in 2021 the physical volume of corn exports from Ukraine is slightly lower compared to 2019 and 2020, however, foreign exchange earnings from grain sales to foreign markets amounted to USD 5.89 billion. This is an absolute record for Ukraine in its entire history.

According to APK-Inform, in 2021, China occupies the largest share in the geographical structure of corn exports – 36.0% (8.5 million tonnes), the Netherlands – 11.0% (2.5 million tonnes), Egypt – 10% (2.4 million tonnes), and Spain – 8% (2.0 million tonnes) [27]. Difficulties in logistics and transportation caused by

the coronavirus epidemic, which created obstacles in the supply chains of grain, contributed to an increase in demand for it from the main traditional importers, in particular China. In addition, due to the poor corn harvest in major producing and exporting countries, the revision of US stocks, uncertainty and instability in the world related to COVID-19, exchange rate fluctuations, and the situation in the oil market contributed to increased price volatility in the global grain market. The current situation has led to a trend toward further growth in prices for corn grain, which began in May 2020 (Fig. 3).

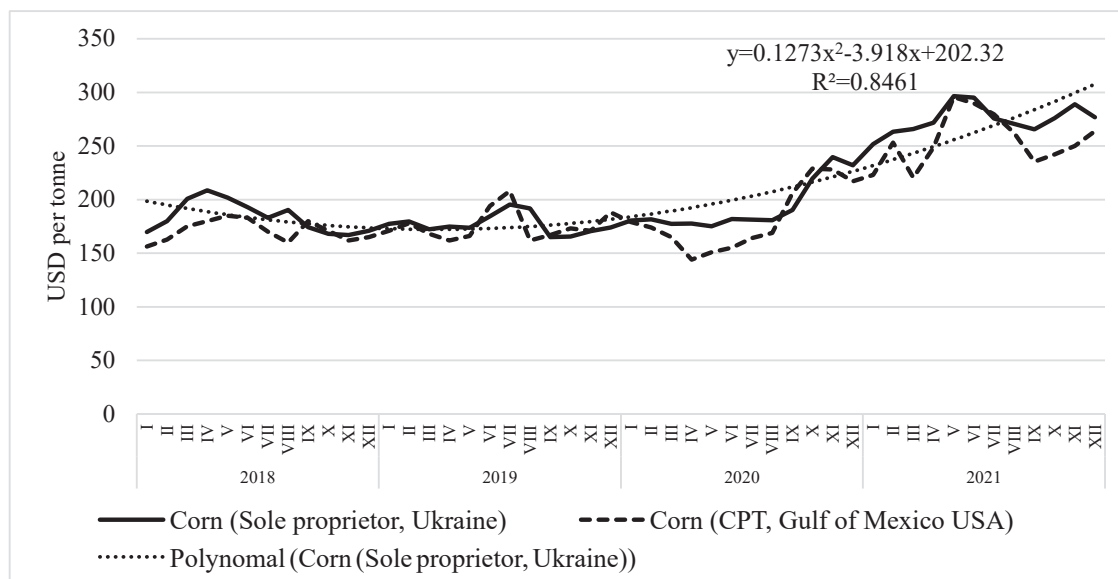


Figure 3. Dynamics of average monthly prices for corn grain, USD per tonne

Source: calculated and compiled based on [30]

The equation of the aligned dynamic series of average monthly prices for corn grain (Sole proprietor Ukraine) for 2018-2021 is a second-order polynomial trend, which is also called a quadratic trend: $y = 0.1273x^2 - 3.918x + 202.32$

The coefficient of determination is $R^2 = 0.8461$, which indicates a high reliability of the function, because it shows how close the trend is to the data

series (Fig. 3). As shown in Figure 3, "... export prices for corn grain (Sole proprietor Ukraine) are closely dependent on the dynamics of world prices and, to a lesser extent, on internal factors. Ukrainian export prices for grain are formed on the US market (on the Chicago Mercantile Exchange, CME), which is considered the world's largest producer and exporter of this product" [31, p. 20].

In Figure 4, based on the dynamics of the average monthly global spot price of corn (USA, Gulf of Mexico) and prices in Ukraine based on FOB from January 2019 to December 2021, their volatility is calculated as a percentage of changes compared to prices from month to month.

The analysis showed that fluctuations in the average monthly price changes in USD. The US dollar

peaked in 2019 compared to the previous month from -22.1% to +16.9%, in 2020 – from -12.7% to +21.9%, in 2021 – from -12.9% to +18.8%. On the FOB basis for Ukraine, price fluctuations ranged from -14.0% to +6.2% in 2019 compared to the previous month, from -2.3% to +15.4% in 2020, and from -6.5% to +8.5% in 2021.

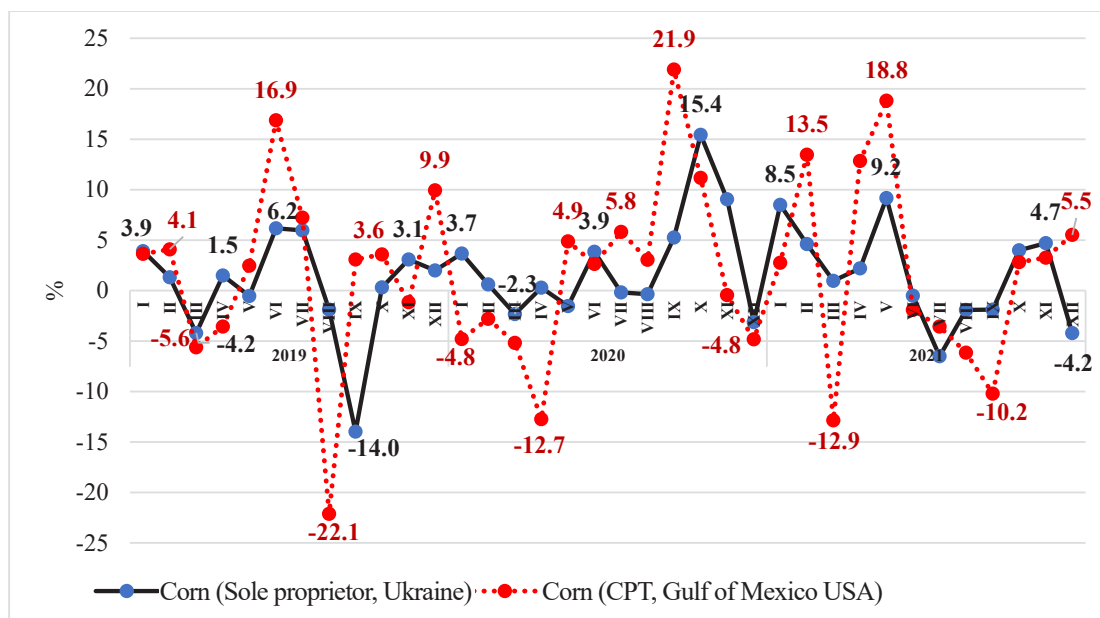


Figure 4. Corn grain price volatility in Ukraine on Sole proprietor and global market terms (CPT, Gulf of Mexico, USA) for 2019-2021

Source: calculated based on [30]

Usually, price volatility increased during the sowing campaign is quite high during the growing season, and any information about the weather and gross yield forecast affects forward corn prices. As a rule, volatility begins to decline in September, when the expected

harvest becomes clear [31]. However, in September 2020, unlike in previous years, price volatility significantly increased in the corn grain market. Corn price volatility in Ukraine is estimated using the standard deviation of average monthly prices during 2019-2021 (Table 8).

Table 8. Standard deviation of monthly average Sole proprietor price of corn in Ukraine

	2019	2020	2021
Average annual FOB price of corn grain (Ukraine), USD per tonne	177.1	193.1	274.8
Standard deviation interval of the average monthly corn price on Sole proprietor terms (Ukraine):			
- USD per tonne	9.5	23.2	13.3
- %	5.4	12.0	4.9

Source: calculated based on [30]

Calculations showed that in average annual terms, the monthly volatility of corn grain Sole proprietor prices in Ukraine was the highest in 2020 and amounted to 12% (or USD 23.2 per tonne). At the same time, the average annual price in 2021, compared to 2019, increased by almost USD 100 per tonne, or 1.6 times.

As evidenced by foreign and domestic experience, price volatility is a common phenomenon for

commodity markets. At the same time, significant price fluctuations pose a threat to economic entities. A sharp increase in prices for agri-food products can potentially both negatively affect the provision of food security for the population, and limit the indicators of economic efficiency of production in those industries that use agricultural raw materials as input resources [32, p. 1]. According to the Food and Agriculture Organization of the United Nations (FAO),

global food prices reached a ten-year high in September 2021. In particular, the FAO Food Price Index it showed that they grew by 32.8% over the year. At the same time, at the end of 2021, the average value of the FAO grain price index was 131.2 points, which is 28.0 points (27.2%) higher than in 2020 and is the highest annual average since 2012. And the average prices for corn in 2021, compared to 2020, increased by 44.1%, which is primarily conditioned by an increase in demand and limited supply from the main grain exporters [33].

The increase in corn prices in Ukraine provoked an increase in mixed feed prices by 40-45% in 2020 compared to 2019. According to the Association “Union of poultry breeders of Ukraine”, “Pig breeders of Ukraine” and “Union of feed producers of Ukraine”, starting from October 2020, the production of certain types of livestock products in Ukraine has become

unprofitable. In particular, the level of profitability (unprofitability) of poultry meat was minus 12%, eggs – minus 17%, and pork – minus 3%. Such a situation may negatively affect the further development of the livestock industry in Ukraine, in particular, reduction of livestock and poultry with all the negative social consequences [34].

Moreover, the rapid increase in world prices for natural gas in 2021 provoked an increase in prices for mineral fertilisers, because it is natural gas that accounts for up to 80% of the cost of fertiliser production. According to the World Bank, prices for mineral fertilisers increased by an average of 80% during 2021. In the first quarter of 2022, prices increased by almost 30% [4]. As the data in Figure 5 show, carbamide prices in March 2022 exceeded the maximum values of 2008, while prices for phosphates and potassium chloride are heading towards the level of 2008.

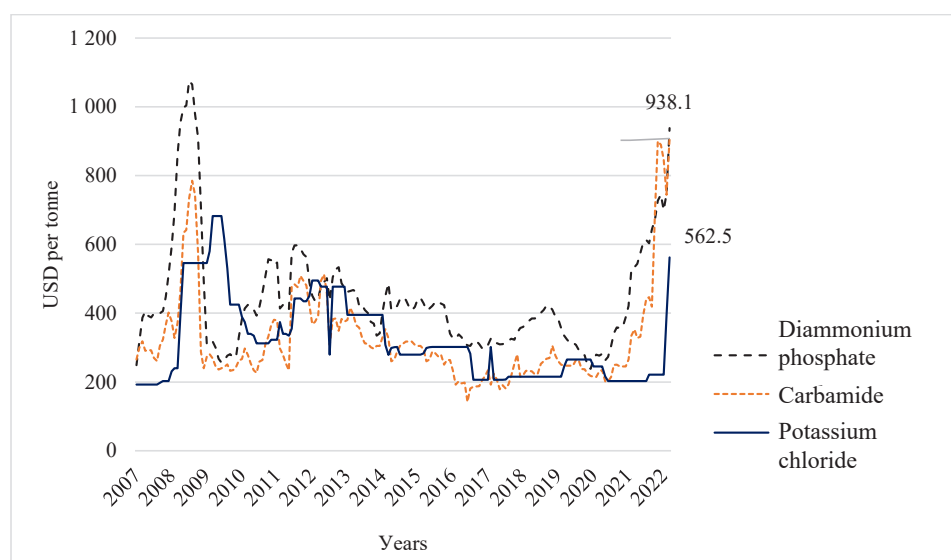


Figure 5. Dynamics of world prices for mineral fertilisers, USD per tonne

Source: compiled based on [4, p. 43]

Further growth in world prices for mineral fertilisers in 2022 is conditioned by the introduction of economic sanctions against Russia and Belarus for Russia’s full-scale invasion of Ukraine, and due to export restrictions on the export of fertilisers imposed by China [4].

According to the newspaper “Uryadovy Kuryer”, in Ukraine ammonium nitrate (nitrogen fertilisers), the most popular Ukrainian fertiliser, in February-March 2021 cost UAH 9 thousand per tonne with delivery, then in February 2022 – more than twice as expensive: UAH 18-19 thousand per tonne. Carbamide (concentrated nitrogen fertilisers) with delivery as of February 2022 was sold at UAH 27.7 thousand per tonne, or almost three times more expensive than at the beginning of the year. Prices for imported products are higher by another 2-3 thousand UAH per tonne [35].

In turn, the increase in prices for mineral fertilisers will affect the cost of corn production for grain. According to the calculations of the Institute of Agrarian Economics, the production cost of agricultural

products may increase by 10-12% due to the rise in the price of fertilisers. Small and medium-sized, family-owned farms with small land areas – up to 400-500 hectares and insignificant working capital for the purchase of fertilisers – will be the first to suffer. Therefore, farmers will be forced to reduce the use of fertilisers, since the additional effect of their use does not compensate for the purchase costs [34].

Thus, from a scientific and practical standpoint, it is important to determine the economic consequences of the impact of changes in the cost of mineral fertilisers on the effectiveness of corn production and export from Ukraine. Such calculations can only be estimated since there is not enough information for analytical calculations. In particular, some agricultural producers were able to buy mineral fertilisers earlier, some are buying now, and the other part is saving for spring in the hope of reducing market prices or compensating expenses from the state budget.

To assess the impact of changes in the cost of mineral fertilisers on the efficiency of corn production

and export, in particular – yield, gross yield, harvested areas, and the main parameters of corn supply and demand formation in Ukraine, an econometric dynamic model of partial market equilibrium was used – AGMEMOD.

As is known from economic theory, the markets of agricultural products and factors of production are closely related and influence each other. For example, an increase in the volume of gross grain harvesting leads to an increase in demand for mineral fertilisers. Such an increase stimulates an increase in domestic prices for these fertilisers, which in turn affects market prices for cereals [36-38].

To assess the impact of factors of production on the development of the corn market, the AGMEMOD model includes the costs of its production, in particular: rent for property and land, labour remuneration, fuel and lubricants, seeds, mineral fertilisers in the calculation per 1 hectare of harvested area for the period from 2000 to 2019:

$$\text{COCGUUA} = \text{RP} + \text{R} + \text{S} + \text{SPM} + \text{FL} + \text{MF} * \text{K}_n \quad (14)$$

where COCGUUA – corn production costs per 1 ha of acreage; RP – rent for property per 1 ha, UAH; R – rent for 1 ha of agricultural land, UAH; S – labour costs per 1 ha, UAH; SPM – expenses for seeds and planting material per 1 ha, UAH; FL – fuel and lubricants costs per 1 ha, UAH; MF – costs of mineral fertilisers per 1 ha, UAH; K_n – coefficient of change in mineral fertiliser costs.

The authors of this study suggest that the influence of the cost of mineral fertilisers on the effectiveness and export of corn is carried out through changes in their costs per 1 ha of crops. To assess the

impact of changes in the cost of mineral fertilisers on the performance of corn production and export, 4 scenarios were modelled.

Baseline scenario – it is expected that the cost of mineral fertilisers per 1 ha would be determined in 2019 prices. Scenarios “+50%”, “+75%”, and “+100%” – provide that the cost of mineral fertilisers per 1 ha would grow by 50%, 75%, and 100%, respectively, compared to the baseline scenario. To introduce scenarios into the model, the coefficient of change in the cost of mineral fertilisers (K_n) (equation 14). For scenarios “+50%”, “+75%”, and “+100%” K_n it would be 1.5, 1.75, and 2.0, respectively.

As evidenced by the data in Table 9, the simulation results confirm that domestic consumption will remain stable at 8,304 million tonnes in all possible scenarios. This is primarily conditioned by problems in the development of the livestock industry in Ukraine. After all, the share of feed costs in domestic corn consumption in Ukraine over the past 10 years, according to the State Statistics Service of Ukraine [25], was about 77%. According to the simulation results, an increase in the cost of mineral fertilisers compared to the baseline scenario would lead to a decrease in gross yields and corn exports from Ukraine. In particular, the gross yield of corn grain in Ukraine, according to the likely scenarios of increasing the cost of mineral fertilisers, compared to the baseline scenario of 2020 by 50%, 75%, and 100%, will decrease by 3,037 thsd. tonnes, 4,474 thsd. tonnes, and 5,875 thsd. tonnes, respectively. At the same time, export volumes under the above-mentioned scenarios will decrease by 2,898 thsd. tonnes, 4,269 thsd. tonnes, or 5,606 thsd. tonnes, respectively.

Table 9. Modelling of scenarios of the impact of changes in the cost of mineral fertilisers on production efficiency and the main parameters of the corn balance in Ukraine using the model AGMEMOD

	Baseline scenario 2020	Scenarios for changes in the cost of mineral fertilisers to the baseline scenario of 2020		
		“+50%”	“+75%”	“+100%”
Average yield, t/ha	5.54	5.30	5.18	5.06
Harvested area, thsd. ha.	5,954	5,653	5,508	5,362
Share of corn in the total area of grain crops, %	39.9	39.4	38.4	37.4
Gross yield, thsd. t.	32,997	29,960	28,523	27,122
Import, thsd. t.	58.4	58.4	58.4	58.4
Change in inventory at the end of the year, thsd. t.	-35.0	-35.1	-35.1	-35.1
Total resources	33,090	30,053	28,617	27,215
Export, thsd. t.	22,839	19,941	18,570	17,233
Feed costs, thsd. t.	7,600	7,600	7,600	7,600
Sowing costs, thsd. t.	59.5	56.5	55.1	53.6
Losses, thsd. t.	1,473	1,338	1,274	1,211
Processing for non-food purposes, thsd. t.	354	354	354	354

Table 9, Continued

	Baseline scenario 2020	Scenarios for changes in the cost of mineral fertilisers to the baseline scenario of 2020		
		“+50%”	“+75%”	“+100%”
Consumption fund, thsd. t.	349	349	349	349
Other uses, thsd. t.	414	414	414	414
Total resources	33,090	30,053	28,617	27,215
Domestic consumption	8,304	8,304	8,304	8,304
domestic consumption/ production	25.2	27.7	29.1	30.6
feed/production costs	23.0	25.4	26.6	28.0
export/production	69.2	66.6	65.1	63.5

Source: calculated by the author based on [22; 25]

Thus, the results of the modelling allowed quantifying the impact of changes in the cost of mineral fertilisers under probable scenarios on the performance indicators of corn production and export from Ukraine. Table 10 shows the obtained relative values of the impact of changes in the cost of mineral fertilisers on the average yield, harvesting areas, gross yields, and corn exports relative to the baseline scenario. For example, if the cost of mineral

fertilisers increases by 100% compared to the baseline scenario of 2020, this would lead to a decrease in the gross yield of corn for grain by 17.8% and its exports from Ukraine by 24.5%. Under these conditions, if not for the high gross yields of corn and favourable prices for it, it would be possible to predict a gradual rejection of its cultivation in favour of other more profitable crops, in particular soybeans.

Table 10. Impact of changes in the cost of mineral fertilisers on the performance of corn production and export from Ukraine in comparison with the baseline scenario, %

Indicators	Scenarios for changes in the cost of mineral fertilisers to prices in 2020		
	“+50%”	“+75%”	“+100%”
Average yield, %	-4.3	-6.5	-8.7
Harvested area, %	-5.1	-7.5	-9.9
Gross yield, %	-9.2	-13.6	-17.8
Export	-12.7	-18.7	-24.5

Source: calculated by the author

To ensure profitability at the level of previous years, producers will also have to review technological operations, deliberately reducing productivity per hectare in favour of ensuring economic efficiency. Calculations show that from an economic standpoint, it is better for producers to save on expensive mineral fertilisers and get a yield of 4 tonnes of corn per hectare, providing themselves with USD 200. By doubling the yield to 8 tonnes per hectare in compliance

with intensive agricultural technologies, it is possible to get a financial result of USD 250 per hectare.

Using the AGMEMOD model, a forecast of the medium-term consequences of the increase in the cost of mineral fertilisers (scenario “+100%” of the cost of mineral fertilisers in comparison with the actual data of 2020) for the development of the corn market in Ukraine for the period 2025 was developed (Table 11).

Table 11. Forecasting the consequences of changes in the cost of mineral fertilisers on the main parameters of corn market development in Ukraine using the AGMEMOD model (scenario “+100%” to the cost of mineral fertilisers compared to 2020)

	Actual data for 2020	Forecast data for the period up to:			
		2022	2023	2024	2025
Average yield, t/ha	5.62	5.06	5.00	5.00	5.06
Harvested area, thsd. ha.	5,392	5,362	5,442	5,453	5,481

Table 11, Continued

	Actual data for 2020	Forecast data for the period up to:			
		2022	2023	2024	2025
Import, thsd. t.	25.0	58.4	59.5	61.2	62.2
Export, thsd. t.	27,9e16	17,233	17,235	17,216	17,554
Feed costs, thsd. t.	5,735	7,600	7,670	7,737	7,827
Sowing costs, thsd. t.	197	53.6	54.4	54.5	54.8
Losses, thsd. t.	500	1,211	1,216	1,218	1,238
Processing for non-food purposes, thsd. t.	632	354	354	354	354
Consumption fund, thsd. t.	156	349	347	345	344
Domestic consumption/production, %	21.5	30.6	30.7	30.9	30.8
Feed/ production costs, %	18.9	28.0	28.2	28.4	28.2
Export/production, %	92.2	63.5	63.3	63.1	63.3

Source: calculated by the author using the AGMEMOD model based on [22; 25]

The forecast results show that under the scenario of “+100%” to the cost of mineral fertilisers, the main parameters of the corn grain balance in Ukraine, in comparison with the actual data of 2020, will reach the following indicators in 2025:

- the average yield will decrease to 5 t/ha;
- the area from which corn is collected for grain will increase by 1.65%;
- gross tax will decrease by an average of more than 3 million tonnes, or 10.5 %;
- the volume of exports will decrease by more than 10.4 million tonnes, or 37.1%. This is conditioned by a potential decrease in the level of competitiveness of Ukrainian corn on the world market in comparison with the largest competitors, in particular, from the United States;
- grain costs for livestock feed will increase by more than 2 million tonnes, or by 36.5%, which is primarily conditioned by the increase in livestock in animal husbandry;
- grain losses will increase by more than 2.5 times, which is primarily due to a decrease in the use of mineral fertilisers and a violation of agricultural technologies for growing corn;
- the ratio of domestic consumption to production will increase from 21.5% to 30.8%;
- the feed-to-production cost ratio will increase from 18.9% to 28.8%;
- the export-to-production ratio will decrease from 92.2% to 63.3%.

Thus, according to the results of forecasting for the period up to 2025, an increase in the cost of mineral fertilisers by 100% compared to 2020 will have a significant impact on the development of the grain market in Ukraine.

In 2021, due to the rapid increase in prices for mineral fertilisers, a task was set for the national governments of many countries to ensure food security. After all, providing their farmers with mineral fertilisers and keeping food prices low are new global challenges for many countries. Therefore, the prospect for further study within the framework of Ukrainian state agricultural policy should be to substantiate an effective mechanism to protect

Ukrainian farmers from sharp fluctuations in the price of mineral fertilisers.

► Conclusions

As a result of the study, the following conclusions were made:

1. In Ukraine, over the past 10 years, the gross corn yield has increased 2-fold – from 20.9 million tonnes in 2012 to a record 42.1 in 2021. Such a significant increase in gross yield is conditioned by both an increase in the yield of corn for grain, respectively, from 47.9 c/ha to 76.8 c/ha due to the use of modern industrial technologies by farmers, and an increase in the harvested area by 125.4%. If the gross yield has tended to increase in recent years, then the volume of domestic consumption of corn has systematically decreased in favour of exports. Based on the results of 2021, Ukraine exported 24.7 million tonnes of corn worth USD 5.89 billion.

2. In recent years, the increase in corn production and exports from Ukraine has been accompanied by trends towards an increase in world grain prices. This was facilitated by the COVID-19 pandemic, which significantly increased the demand for grain from the main importers to increase their reserves.

3. Modern developed agriculture is impossible without the use of sufficient mineral fertilisers. Currently, almost half as many mineral fertilisers are applied in Ukraine as in the United States and EU countries, which leads to soil degradation. Therefore, a radical increase in the cost and shortage of mineral fertilisers can lead to a decrease in their application compared to previous years, increase the dependence of the crop on weather conditions, contribute to the deterioration of grain quality, and also worsen the soil fertility.

4. The quantitative influence of production factors on the yield of corn for grain in agricultural enterprises of Ukraine is determined using the developed econometric model for the period from 2001 to 2020. The results of multiple linear regression showed that the yield of corn for grain has a close and direct correlation with the volume of mineral fertilisers applied per 1 ha of sown area, the share

of the fertilised area of crops and the level of profitability of its production in agricultural enterprises of Ukraine. The statistical value of the result obtained is confirmed by a high coefficient of determination which is $R^2=0.764$.

5. Based on the findings of the study, the influence of changes in the cost of mineral fertilisers on the main parameters of demand (domestic consumption, export) and supply (yield level, harvested area, gross yields) in the corn market is quantitatively substantiated according to probable scenarios using the AGMEMOD econometric partial equilibrium model. Calculations showed that under the “+100%” scenario (an increase in the cost of mineral fertilisers compared to 2020), the gross yield of corn in Ukraine would decrease by 17.8%, and the export of this grain – by 24.5%, or USD 1,513.6 million.

6. The forecast results for the period up to 2025 showed that under the “+100%” scenario (an increase in the cost of mineral fertilisers compared to 2020), it would lead to a significant reduction in the supply of corn and the export potential of the grain industry. In particular, the gross corn harvest will be reduced by more than 3 million tonnes by reducing its average yield to 5.0 tonnes per 1 ha. At the same time, the volume of exports of this grain crop would decrease by more than 10.4 million tonnes, or by 37.1%, which is conditioned not only by a reduction in production volumes, but also by a potential decrease in the competitiveness of Ukrainian corn on the world market due to an increase in its production cost. As a result, this would lead to a shortfall in Ukraine's foreign exchange earnings of about USD 2.5-3.0 billion per year at the current level of the world price of corn grain.

7. It is proved that the high yield of corn and the favourable current price environment for grain will ensure a sufficient level of profitability of this grain crop. However, a radical increase in the cost of mineral fertilisers threatens to ensure the competitiveness of Ukrainian corn in the domestic and

foreign markets, which would eventually lead to higher food prices and a deterioration of the country's food security and a decrease in the export potential of the grain industry.

8. To ensure profitability at the level of previous years, agricultural producers will be forced to deliberately review technological operations, reducing productivity per hectare in favour of ensuring economic efficiency.

9. In order to optimise costs, agricultural producers need to diversify their mineral nutrition systems. In particular, invest in fertilisers in advance, without which the production of agricultural products is impossible. And the second factor is that it is necessary to buy those forms of fertilisers that reduce the cost of technology, for example, anhydrous ammonia.

10. Improvement of the efficiency of corn grain production in Ukraine can be achieved through the introduction of scientifically based doses of mineral fertilisers, transformation of the cost policy for the purchase of effective fertilisers, and substantiation and implementation of effective measures to stimulate and support grain production adapted to market conditions.

11. Government agencies need to develop an effective mechanism for reducing the cost or compensating the cost of purchasing mineral fertilisers for agricultural producers. In particular, at the expense of forward purchases of mineral fertilisers through PJSC “Agrarian Fund”, which would provide them with fertilisers for the sowing campaign.

12. In the context of export-oriented grain production, which brings the main revenues of the industry, a decrease in gross yield may lead to a decrease in foreign exchange earnings in the country. In addition, it is necessary to maintain a sufficient level of soil enrichment to further ensure both high performance indicators of corn grain production, and to preserve the ecological parameters of soil fertility.

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Прогнозування наслідків впливу вартості мінеральних добрив на розвиток ринку кукурудзи в Україні з використанням моделі AGMEMOD

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► **Анотація.** За останнє десятиріччя з 2012 по 2021 рр. Україна подвоїла обсяги виробництва кукурудзи. Збільшення валових зборів кукурудзи пов'язують із застосуванням аграріями сучасних технологій вирощування, що підвищують стійкість рослин до несприятливих факторів середовища, коригують мінеральне живлення рослин з урахуванням погодних умов. Однією із найважливіших складових таких технологій є застосування мінеральних добрив, від оптимального обсягу внесення яких залежить не лише рівень урожайності зернових культур, але й ефективність виробництва та якість зерна. Проте стрімке зростання світових цін на природний газ протягом 2021 р. сформувало нові виклики та загрози для подальшого розвитку ринку зерна в Україні. Адже світові ціни на мінеральні добрива зросли з 2021 р., за даними Світового банку, на 110 %. За цих умов радикальне зростання вартості мінеральних добрив створює загрозу забезпечення конкурентоспроможності української кукурудзи на внутрішньому та зовнішньому ринках, що в підсумку призведе до підвищення цін на продовольство та погіршення рівня продовольчої безпеки країни. Це може негативно вплинути на валові збори та експортний потенціал зернової галузі. Метою дослідження є оцінка сучасного стану попиту і пропозиції на ринку кукурудзи в Україні та прогнозування наслідків впливу зміни вартості мінеральних добрив на основні параметри його розвитку за ймовірними сценаріями, з використанням економетричної моделі часткової рівноваги AGMEMOD на період до 2025 року, що створює передумови для підвищення ефективності прийняття і реалізації управлінських рішень і сприяє досягненню цілей державної аграрної політики. У процесі дослідження використовувалися наступні методи: монографічний, абстрактно-логічний, порівняльного аналізу та експертних оцінок, табличний, статистико-економічний, факторного аналізу, економіко-математичного моделювання. Результатом роботи є оцінка сучасного стану та визначення основних чинників, що впливають на формування попиту і пропозиції на ринку кукурудзи. За допомогою множинної лінійної регресії визначено вплив основних факторів на врожайність кукурудзи на зерно в сільськогосподарських підприємствах України за 2001–2020 рр. Проаналізовано динаміку балансу попиту і пропозиції на ринку зерна кукурудзи в Україні. Здійснено прогнозування наслідків впливу зміни вартості мінеральних добрив на основні параметри розвитку ринку кукурудзи в Україні за ймовірними сценаріями з використанням економетричної моделі часткової рівноваги AGMEMOD на період до 2025 року. На підставі проведених розрахунків доведено, що висока врожайність кукурудзи та сприятлива нинішня цінова кон'юнктура на зерно забезпечать достатній рівень прибутковості цієї зернової культури. Запропоновано напрями удосконалення механізму здешевлення або компенсації витрат на купівлю мінеральних добрив для товаровиробників. Набули подальшого розвитку методико-практичні аспекти прогнозування наслідків впливу зміни вартості мінеральних добрив на основні параметри розвитку ринку кукурудзи в Україні з використанням економетричної моделі часткової рівноваги AGMEMOD на період до 2025 року. Запропоновані методичні підходи та результати дослідження можуть бути використані органами державного і галузевого управління при розробці пріоритетних напрямів щодо підвищення результативності вітчизняної зернової галузі

► **Ключові слова:** аграрна політика, ринок зерна, енергетична криза, економетричне моделювання