JEL: Q18, C52, O13

Andriy Skrypnyk[1], Nataliia Klymenko[1], Kateryna Tuzhyk[2], Liudmyla Galaieva[1], Kostiantyn Rohoza[1]

[1]National University of Life and Environmental Sciences of Ukraine
[2]HSWT International School for Applied Life Sciences, Weihenstephan-Triesdorf University of Applied Sciences
[1]Ukraine
[2]Germany

PREREQUISITES AND PROSPECTS FOR SUSTAINABLE DEVELOPMENT OF GRAIN PRODUCTION IN UKRAINE

Purpose. *The aim of the article is to identify the benefits of the chosen strategy of agribusiness (profit maximization, or yield maximization) based on the statistical observations of yields and production factors (fertilizers, plant protection products).*

Methodology / approach. *To analyze productivity growth in grain production under the influence of innovative technologies the data of long-term observations of winter wheat yield in Germany and the United States were selected. In this paper, to analyze the prerequisites and prospects for stabilizing of the crop production, mineral fertilizers and plant protection products were selected as production factors affecting the yield of wheat. Methods of time series analysis and nonlinear econometric analysis were used to assess the impact of these factors. Long-term trends of growth of wheat yields in Germany, the USA and Ukraine were analyzed using regression models. The general model of agrarian business profitability in grain production is based on non-linear correlations of individual factors of intensification and panel regression. In order to substantiate the conclusions of the calculation, the estimation of climatic risks is used. For this purpose, dispersion methods, nonlinear optimization methodology are used.*

Results. *Estimates of wheat yield fluctuations due to climate risks show that they will not significantly affect the problem of food security, so there is no need to impose restrictions on the export of wheat. On the choice of optimal strategy, based on analysis using econometric model of decreasing marginal utility of production resources, it is proved that the maximization of yields is achieved at lower costs than profit maximization.*

Originality / scientific novelty. *The main contribution of the article to the level of application is to analyze the impact of production factors on wheat yield, taking into account climatic risk and reducing the marginal utility of production factors. At the theoretical level of the study,* it represents a contribution to the discussion *of the vectors of the optimal path of wheat production in Ukraine. Analysis of data on wheat yield variability in Germany and the USA showed correlation of profitability and risk (indicators of expected yield and its variance). However, this means that an increase in wheat yields in Ukraine will also increase its variability and therefore requires the implementation of a long-term strategy that can ensure stable growth.*

Practical value / implications. *Based on the above calculations, it should be emphasized that the Ukrainian agrarian business (in particular, crop production) is developing its own way, not following the development path of Germany or the USA. However, some peculiarities of the development can be highlighted. After a rather long recession, the agricultural sector has embarked on a path of stable growth with an annual increase in wheat yields of around 1 hundred kg/ha. Furthermore, the extremely low proportion of forested land in Ukraine by European standards* *significantly increases the impact of weather and climate risks. Therefore, a further intensification of crop production while increasing the share of forested land at the expense of less productive land is probably the way to an ecologically balanced development of agriculture.*

Key words: *production factors, crop production, food security, function of profitability, dispersion, forecasting.*

Introduction and review of the literature. The instability characteristic of the Ukrainian economy, which is due to many reasons, has until recently also been a characteristic feature of the national agricultural sector as a whole. In recent years, against the background of the crisis in the Ukrainian economy, the agricultural sector looks no longer extremely risky. It is believed that the agricultural sector is subject to a large number of risks, of which the most influential on food security indicators are weather and climate. Therefore, in the former Union of Soviet Socialist Republics (USSR), in addition to significant geographical diversification of grain growing regions, there were situations when tens of millions of tons of wheat had to be imported. Therefore, in the 1980s, the USSR became one of the largest importers of grain in the world, importing an average of 36 million tons per year, most of which went to Russia Federation. In addition, the backlog of services that characterized the planned economy had considerable heterogeneity across sectors: it was the lowest in the processing sector and the highest in agriculture and light industry. Henceforth, there was a huge gap in the development of agricultural technologies between the developed countries and the former Soviet Union. In the first years of Ukraine's independence, the agricultural sector retained the main features of the socialist economy, with its extremely low efficiency and excessive use of physical labor. This, in our opinion, was due to the lack of information provision on the main directions of innovations in the agrarian business, lack of modern technical support and means to implement these innovations (Skrypnyk, 2019; Karpenko et al., 2020).

In the years of a planned economy, as well as in the first years of Ukraine's independence, agriculture developed under conditions of isolation from the information and technological development of agriculture of the main world centers.

If in the first years of independence, the main issue was to provide food to the population (solution of food security issues) and this issue was solved by quotas for agricultural exports, or introduction of customs duties, then gradually, growth of production volumes and reduction of variability of this indicator the need for these levers of state regulation disappeared. It should be emphasized that the first steps of the post-socialist agrarian sector were made using technical means and technologies which remained from the times of planned economy, i.e. only transition to market methods of management was sufficient to ensure profitability of the crop production sector. The success of the transition was facilitated by the fact that by the mid-1990s the Ukrainian government, due to the extremely difficult economic situation, lost the opportunity to support collective farms, which accelerated their collapse and the emergence of new enterprising agrarian entrepreneurs. Research shows that these processes facilitated the emergence of new efficient forms of farming in agricultural production. A consequence of these processes was a gradual accumulation of financial resources in the established types of agricultural business for the acquisition of the latest agricultural technologies. This process began around 2000, which, as we know, was the first year of growth of the Ukrainian economy. Since then, along with the growth of Ukrainian agrarian exports there was a growth of agrarian imports, which provided the implementation of innovations into the Ukrainian agricultural sector (Tscharntke et al., 2012; Zaburanna and Poprozman, 2015; Andrieu, 2017). The volume of imports of means of agricultural production in the crop sector has steadily increased from year to year, which contributed to the growth of yields. Over the last few years, Ukrainian grain yields have been steadily increasing and already exceed those of the USA. It should be stressed that this development path is intensive rather than extensive, as the area sown with the main types of grain does not tend to grow. Therefore, the question arises whether the path followed by a significant part of the Ukrainian agricultural business is economically viable. In addition to the average yield indicator, another important indicator is its variability, which can be measured as a deviation from trend or average values. Of course, excessive variability in yields was a major cause of food security risks, both in the years of the planned economy and in the early decades of transition to market relations.

In addition, the issue of climate change is crucial to agricultural development, which can lead to significant losses in agricultural production (Kadiyevskyy and Klymenko, 2014; Skrypnyk, 2021; Babenko et al., 2021). On the other hand, the yield indicator is related to the level of ploughed land, which exceeds all admissible values in Ukraine (Kaminskyi, 2018). This shows that the state is at a stage of social development when economic performance is much more important than the state of the environment. Globally, however, there is a general trend towards an increasing degree of afforestation as a significant factor affecting atmospheric carbon concentrations. Of course, the choice of farming model is a decision for each entrepreneur, but the environment and the ecological and economic use of land is a matter of social utility (FAO, 2018). To date, most researchers (Angelsen and Kaimowitz, 2001; Börjeson, 2007; Pretty and Bharucha, 2014) are proponents of intensive farming theory based on the assumption of getting more production with fewer inputs, which is most commonly interpreted as increased yields per hectare. Most agricultural systems are based on the use of different cultivation methods with crop rotations, have adopted the use of genetically modified varieties of wheat, rice and maize with the use of mineral fertilizers, crop protection products, farm machinery and irrigation systems (Pretty and Bharucha, 2014). In the mid-twentieth century, proponents of intensive farming point to the “miracle” of the “green revolution” in Latin America and Asia, when the first use of high-yielding seed varieties, fertilizers, pesticides led to a doubling of yields of rice, wheat and maize (Pingali, 2012). At the time, the positive impact of agricultural intensification on overcoming hunger became impressive, the reduction in population experiencing malnutrition was measured in billions of people, and economic growth in agriculture became unequivocal (Haddad et al., 2016).

Today, the model of agricultural intensification is the dominant one in the world. FAO data show that in recent years, in developing countries, farmers have invested approximately 153 billion USD annually in agricultural development, almost the same as in developed countries, 156 billion USD. Analysis of pesticide use is the mainstay of agricultural intensification, as confirmed by a number of researchers (Silva et al., 2019). Since 1960, the average world yields of rice, wheat and maize have more than doubled as the use of pesticides has increased by 15–20 times and the use of mineral fertilizers, land irrigation systems have increased by 7 and 2 times respectively (Oerke, 2005). Worldwide about 3 million tons of pesticides are used annually, corresponding to a market value of USD 40 billion (Pimentel, 2009). In the European Union (EU) there are almost 500 active substances approved for use as pesticides with annual sales of 374 thousand tones. The results of numerous studies (Ahrends et al., 2018; Bustos, 2016) highlight the need to consider the importance of long-term soil fertilizer management to explore the interaction between genetic potential and management. Research (McArthur et al., 2017) demonstrates the role of agronomic inputs in improving grain yields in developing countries. Increasing by 1 kg in nitrogen fertilizer application has been shown to consistently increase yields by 8 kg. For example, in the USA, intensive farming has been consistently criticized in terms of global ecology and social justice and has been a defining feature of a wide range of movements and paradigms: food sovereignty (Jarosz, 2014; McMichael, 2011; Chrzan, 2004), local food movements (Hinrichs, 2003), agroecological farming (Altieri and Toledo, 2011; Altieri et al., 2011; Scherr and McNeely, 2008; Tscharntke et al., 2012). But the population is growing, which leads to an increasing issue of food consumption. Therefore, the world will need to grow more food without increasing the area under agriculture (Foley et al., 2011; Haddad et al., 2010).

According to the authors (Ickowitz et al., 2019) this fact remains the main justification for the inevitable use of agricultural intensification. In the USA, it has been concluded that increased seeding rates increase weed and plant competition, limited fertilizer limits the availability of nutrients to germinating weeds (Strydhorst et al., 2008). Farmers there have therefore switched to crop rotations, no-tillage, which allow for optimum grain yields, enrich the soil with minerals and optimize costs and increase profits. For example, it has been determined (Aramburu et al., 2015; Behnke et al., 2018; Millar et al., 2010) that when maize and soybeans are rotated, they increase yields and the need for mineral fertilizers is reduced, reducing costs and CO_2 emissions.

Regarding Ukraine, increasing in grain yields due to higher production costs are discussed (Mesel-Veseliak, 2018; Oliinyk, 2019), but the issue of cost structure, profitability and environmental impact remains open for further discussion (Voronenko et al., 2020; Kaminskyi et al., 2021). Based on the carried out analysis, the researchers tried to form directions for the development of the agriculture sector modeling (Muller et al., 2016).

The purpose of the article. The agricultural sector has focused on yield increasing of the grain to provide the food security in the country. Therefore, the purpose of the presented work is to identify the benefits of the chosen strategy of agribusiness (profit maximization, or yield maximization) based on the statistical observations of yields and production factors (fertilizers, plant protection products), taking into account climate risk.

Methodology. The paper analyzed the dynamics of grain production, especially winter wheat, as an economically priority market crop for Ukraine in comparison with the USA and Germany. In order to analyze long-term trends, wheat yields were analyzed for the time interval 1961–2019 for the USA and Germany and during 1992–2019 for Ukraine. To bring it to an equivalent time interval, the time series of yields of the former Soviet Union from 1961 to 1990 are extended with a series of yields in Ukraine in the interval 1992–2019. In addition, the time series of yields of the Soviet Union (1961–1991) and Ukraine (1992–2019) were considered separately. Due to that major costs in the total variable costs for grain production are taken by fertilizers and plant protection products, these factors were taken for the model development in the paper. The data of the fertilizers and plant protection products input in Ukraine are from FAOSTAT from 1992 till 2018–time interval.

Regarding the impact of weather conditions, the following factors were investigated: the impact of annual precipitation; the impact of precipitation between September and May (t0) January–May (t1) March–May (t2) in time interval 1992–2018.

Results and discussion. Over the last five years, the average yield of wheat in Ukraine has reached 45 hundreds kg/ha (Fig. 1), considerably lower than in Germany, but higher by 10 hundreds kg/ha than in the USA. The lowest yields were in 2003 as a result of climate risks in Ukraine. As a large proportion of the crop was not harvested, this resulted in food security risks and led to a grain export quota until 2012.

As far as the USA and Germany are concerned, there are stable yield trends, so this can be presented as a linear trend (1):

$$y(t) = \beta_0 + \beta_1(t - 1961) + \varepsilon, \qquad (1)$$

where $\beta_0 -$ expected yield, hundreds kg/ha in 1960, $\beta_1 -$ expected annual growth of yield of one hectare, $\varepsilon -$ error.

In reference to Ukraine, as the transition to market conditions was accompanied by a certain recession, this was also noticeable in the agricultural sector, so linear growth is replaced by a parabolic time dependence:

$$y(t) = \beta_0 + \beta_1(t - 1992) + \beta_2(t - 1992)^2 + \varepsilon \qquad (2)$$

Let us consider a general model of the profitability of the agricultural business in crop production. We assume that prices for final products and components of the production process (fertilizers, herbicides, pesticides) are fixed and known. Profit depends on soil conditions, given by a k-component vector $\bar{s}(s_1; s_2; \ldots; s_k)$ by an n-component vector of the components of the production process $\bar{x}(x_1; x_2; \ldots; x_n)$, and are considered to be known constants $\overline{w}(w_1;w_2;...;w_n)$. The production process results in profit, which in addition to soil conditions $\overline{s}(s_1;s_2;...;s_k)$ and production factors $\overline{x}(x_1;x_2;....;x_n)$ is affected by random factors determined by weather and climatic conditions ($Rnd(R_1;R_2;...;R_l)$):

$$\Pr(\overline{s};\overline{x};\overline{Rnd}) = p \cdot y(\overline{s};\overline{x};\overline{Rnd}) - \overline{w} \cdot \overline{x}\ , \qquad (3)$$

where *p* is the unit price of the Product; *y* is the yield per hectare, which depends on soil condition, fertilizer and pesticide application and the impact of weather conditions.

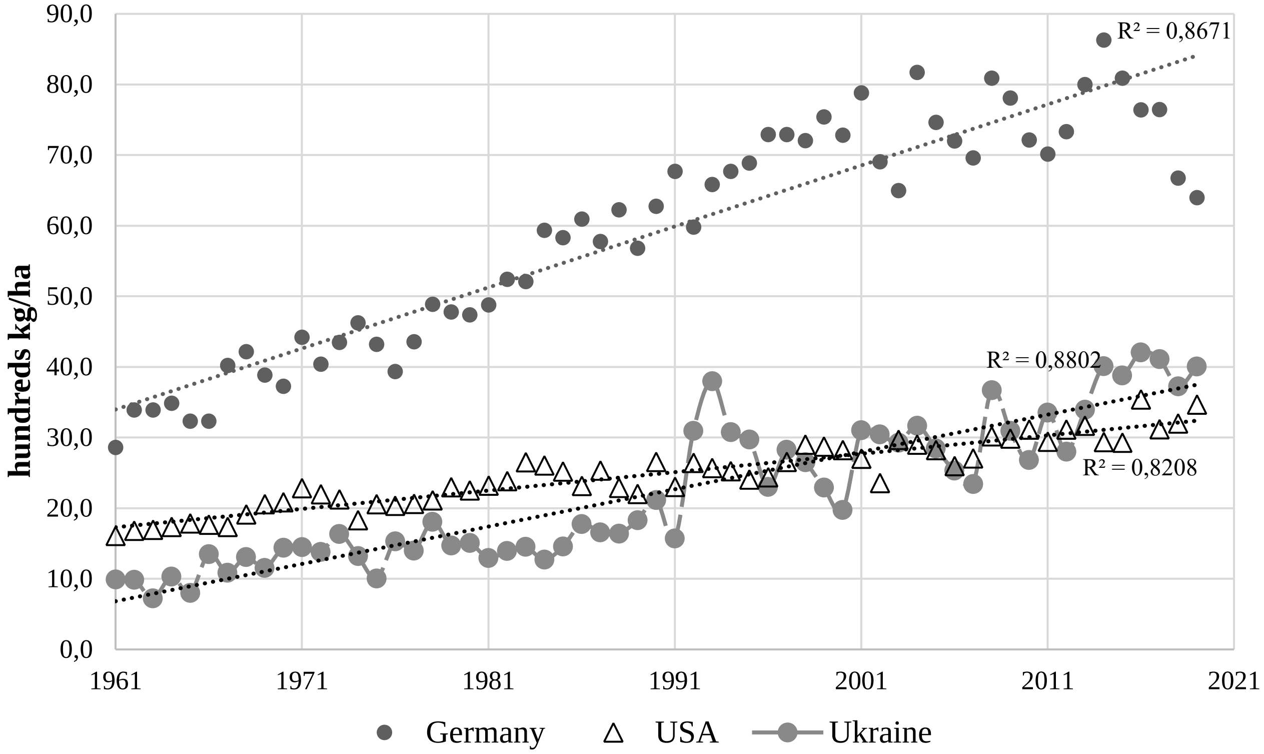

Fig. 1. Winter wheat yields in Germany, the USA and Ukraine in the time interval from 1961 to 2019

Source: calculated and built by the authors based on data FAOSTAT.

Since variation in pesticide and fertilizer inputs is the only mechanism that affects profit, a condition for profit growth is that the marginal utility (yield) of a particular component of the production process exceeds the price of that component in the product price:

$$\frac{\partial y}{\partial x_i} > \frac{w_i}{p} \qquad (4)$$

The non-linear interaction of the individual components of the production process, given the downward marginal utility, can be represented as:

$$y = \beta_0(\overline{s}) + \sum_{i=1}^{n} \beta_i x_i + \sum_{i=1}^{n}\sum_{j=1}^{n} \alpha_{ij} x_i x_j + \overline{\gamma'} \cdot \overline{Rnd} + \varepsilon(\alpha_{ii} < 0; i = 1,2,..n) \qquad (5)$$

The coefficients of equation (5) can be estimated over a long period with individual farm production cost data using a panel regression technique. The next step could be an optimization solution to maximize profits (3) or maximize yields (5). It should be emphasized that there are price fluctuations in the food grain market and prices for factor of production which have a significant impact on decisions about an individual farm's development strategy. Therefore, for simplicity, output prices and input costs are assumed to be constant.

If the marginal utility is assumed to be a constant, it is possible to increase the profitability of the business within a budget constraint by adjusting the price of the components of the production process. However, if yields are an increasing function of the components of the production process $\frac{\partial y}{\partial x_i} > 0; (i = 1,2,\ldots,n)$ then marginal utility is likely to be a decreasing function $\frac{\partial^2 y}{\partial x_i^2} < 0; (i = 1,2,\ldots,n)$

The simplest function corresponding to these properties, which is convenient to use (Green, 2021):

$$y = \beta_0 + \beta x + \alpha x^2 (\beta_0 > 0; \beta > 0; \alpha < 0) \tag{6}$$

The dependence of yields on natural, production and weather factors, given the descending marginal utility of production factors, can be represented in this form, assuming that the marginal utility of each component is known and a constant

$$y = \beta_0(\bar{s}) + \overline{\beta'} \cdot \bar{x} + \overline{\alpha'} \cdot \bar{x}^2 + \overline{\gamma'} \cdot \overline{Rnd} + \varepsilon, \tag{7}$$

where $\beta_0(\bar{s}) -$ is an estimate of natural yield, $\bar{\beta}, \bar{\alpha} -$ vectors characterizing influence of individual components of production process on yield, $\bar{\gamma} -$ vector of marginal influence of individual weather and climatic factors on yield, $\varepsilon -$ model error determined by unaccounted factors. In the case of yield dependency (6), there is already an optimal solution for the components of the production process that maximize profit (3):

$$x_i^* = (w_i / p - \beta_i) / 2\alpha_i (\beta_i > 0; \alpha_i < 0; i = 1,2,\ldots,n) \tag{8}$$

Existence condition for solution:

$$\beta_i > w_i / p \tag{9}$$

If we consider fertilizer application as the main production factor, the first order yield equation (6) will have the form:

$$x_1^* = -\beta / 2\alpha (\beta > 0; \alpha < 0; \tag{10}$$

To get a profit:

$$x_2^* = -\beta / 2\alpha + w/(2p\alpha); (\beta > 0; \alpha < 0; \tag{11}$$

Based on the above equations, maximum profitability is achieved with less fertilizer inputs than maximum yields: $x_1^* > x_2^*$.

Considering the long term effect of fertilizer application, previous years' fertilization should also be taken into account, then the yield will be as follows:

$$y(t) = \beta_0 + \sum_{i=0}^{T} \lambda_i \cdot x(t-i) + \sum_{i=1}^{T}\sum_{j-1}^{T} \lambda_{ij} \cdot x(t-i) \cdot x(t-j) + \varepsilon(t) \quad (12)$$

where λ_i coefficient with fertilizer application in the previous year with index i and, λ_{ij} – coefficient with fertilizer effect in years i and j, T is the period of maximum effect after fertilizer application.

Studies show that yields are steadily increasing each year in both Germany and the USA. However, the marginal yield (β1) is much higher in Germany than in the USA: 0.86 hundreds kg/ha and 0.26 hundreds kilograms per hectare (Table 1). In addition, the initial grain yield, which characterized soil quality, was higher in Germany (32 hundreds kilograms per hectare) than in the USA (17 hundreds kilograms per hectare). That is, at the beginning of the interval, the yield difference was at the expected value of 15 hundreds kilograms per hectare; hence, at the end of the interval it was 52 hundreds kilograms per hectare for a significant difference in the rate of increase.

Table 1

Regression models for grain yield growth over time

Grain yield, hundreds kilograms per hectare	Confirmatory Specification		Regression Coefficients			Significant testing		
	Coefficient of Determination, (*R2*)	Standard error of the estimate	β_0	β_1	β_2	*t0*	*t1*	*t2*
Germany 1961–2019	0.87	5.9	33.1	0.86	-	21.4	19.3	-
USA 1961–2019	0.82	1.7	17.0	0.26	-	38.8	20.5	-
USSR+Ukraine 1961–2019	0.88	3.2	6.8	0.53	-	8.2	9.1	-
USSR 1961–1991	0.77	2.0	9.6	0.26	-	13.0	6.5	-
USA 1961–1991	0.86	0.9	16.8	0.25	-	40.0	25.6	-
Ukraine 1992–2019	0.57	4.0	34.0	-1.4	0.06	13	3	4

Source: calculated by the authors based on data FAOSTAT (http://www.fao.org/faostat).

The yield of the grain since 1961 during the existence of the Soviet Union shows that the marginal yield is almost at the level of the USA (0.26 hundreds kilograms per hectare), but the expected initial value of 9 hundreds kilograms per hectare is much less than in the USA (16.8 hundreds kilograms per hectare), and the deviation from the trend (standard error) is much higher. Due to the fact that the consumption of bread and bakery products took much larger share of the society nutrition in the former Soviet Union than the USA, it is easy to explain how the continuously deviation from the trend towards low yields in time interval form 1981 till 1984 led to the need to import grain in large quantities.

Regarding the dynamics of grain yield in Ukraine during the years of its independence and on the initial interval of transformation to the market economy, there is a decrease of grain yield, so we used a parabolic profile of yield dynamics with the expected minimum in 2003. Around 2012, yields in Ukraine exceeded the USA level. However, it is still a long way from the current German level, as the 2020 level (84 hundreds kilograms per hectare) can only be achieved in 40 years, assuming that current growth tendency remain unchanged.

For a comparative analysis of the risks of grain production in each of the three countries, estimates of variability (standard errors) and estimated values of yield for 2020 are used. The coefficient of variation, which for Ukraine turned out to be significantly higher than for Germany or the USA (Table 2), is considered as the main indicator of risk (probability of reduction of the gross fee indicator beyond the established consumption limits).

Table 2

Risk assessment of wheat yields in 2020 (hundreds kilograms per hectare)

Country	Germany	The USA	Ukraine
Mathematical expectation	84.7	32.6	41.8
Standard error	5.9	1.7	4.0
The coefficient of variation, %	7.0	5.2	9.6

Source: calculated by the authors based on data FAOSTAT.

The higher the yield increase, the higher the variability index (standard error). This is also true for the relative risk index (coefficient of variation). That means, the share of variability in the expected grain yield is much higher in Germany than in the USA, but in Ukraine it is even higher. From this it can be concluded that an increase in yields is accompanied by an increase in absolute and relative risk indices.

This assumption is confirmed by estimating the variance by the moving average method for 9-year intervals with a step of 1 year (Fig. 2). The variance over the entire time interval (1965–2015) in Germany is considerably higher than in the USA, it has a clearly pronounced tendency for the amplitude to grow over time. It is possible that the absolute and significant variability in yields in Ukraine is due to the lack of warning about weather risks, and non-usage of weather-resistant technologies. Therefore, the issue of weather risk is increasing due to climate change and this factor must be taken into account in the further analysis.

However, an increase in yields is not the main factor for increasing profits. An interesting fact is that while there has been a steady increase in mineral use per hectare in Ukraine, a steady increase in yield occurs against a downward trend in Germany, and conversely, a significant increase in use does not contribute to an increase in yield in the USA. It is interesting to analyze the relationship between yields and inputs in individual farm enterprises, following econometric models (5, 12).

In our study, we used data on the domestic value and import value of inputs (mineral fertilizers and chemicals) for crop production in Ukraine from FAOSTAT. It is assumed that import of inputs is an exogenous variable (x1) and grain yield is an endogenous variable (y) (the impact of fertilizer application in previous years is not considered). Let us formalize the dependence of average grain yield on application of imported inputs per 1 ha in USD:

$$y_i = \beta_0 + \beta_1 X_i + \varepsilon_i, i = 1,2,\dots,n \quad (13)$$

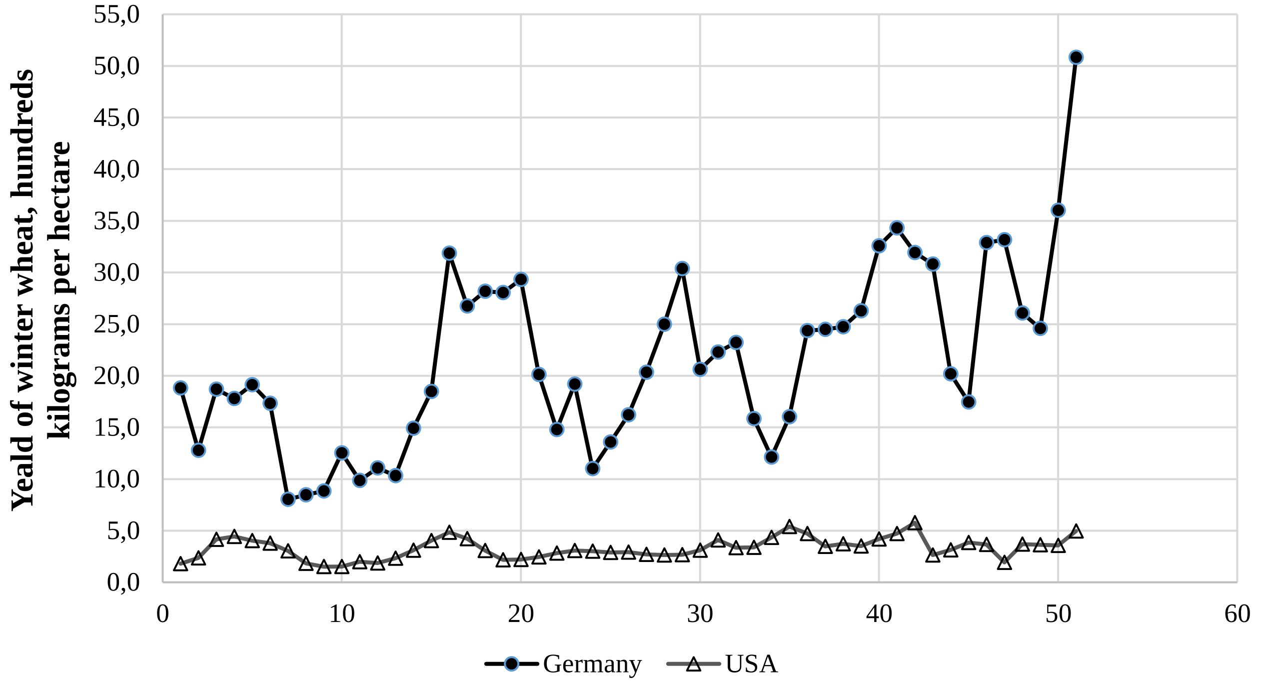

Fig. 2. Variance of wheat yield in Germany and the USA during 1962–2019

Source: built by the authors based on data [24].

Parameters for estimating regression relationship models are shown in Table 3:

$$\hat{y} = 19.57 + 0.05x_1 \quad (14)$$

Table 3

Dependence of grain yields on input factors of production and weather conditions

Model	Coefficient of variation	t_0	t_1	t_2	F	Standard deviation
$y_1=19.86+0.10x_1$	0.40	13.69	3.98	-	15.84	4.16
$y_2=20.12+0.05x_1+6.12x_2$	0.88	31.27	8.27	9.81	87.52	1.87
$y_3=11.99+0.05x_1+0.06x_3$	0.46	2.81	4.07	1.90	9.42	3.93

Source: calculated by the authors based on data FAOSTAT.

As for the regression coefficients, the null hypothesis for them is rejected at an extremely low level of significance, i.e. we can consider the free term (≈20 hundreds kilograms per hectare) as a natural yield, while the coefficient of imported costs of input factors of production suggests that an increase in the cost of imported inputs by 20 USD will increase in the value of imported inputs, increasing the expected yield by 1 hundred kilograms per hectare. A scatter plot and a plot of the linear dependence of grain yield on the value of imported inputs for their cultivation are shown in Fig. 3.

However, there are a number of points in the scatter plot that deviate significantly from the model plot. Assume that all deviations are greater than $\hat{y} \pm \sigma\_\varepsilon$ due to favourable or unfavourable weather conditions. From here, we determine the weather effect of yields using additional data in the form of a modified imaginary variable:

$$x_2 = \begin{cases} -1 & y < \hat{y} - \sigma_\varepsilon \\ 0 & \hat{y} - \sigma_\varepsilon \le y \le \hat{y} + \sigma_\varepsilon \\ 1 & y > \hat{y} + \sigma_\varepsilon \end{cases} \quad (15)$$

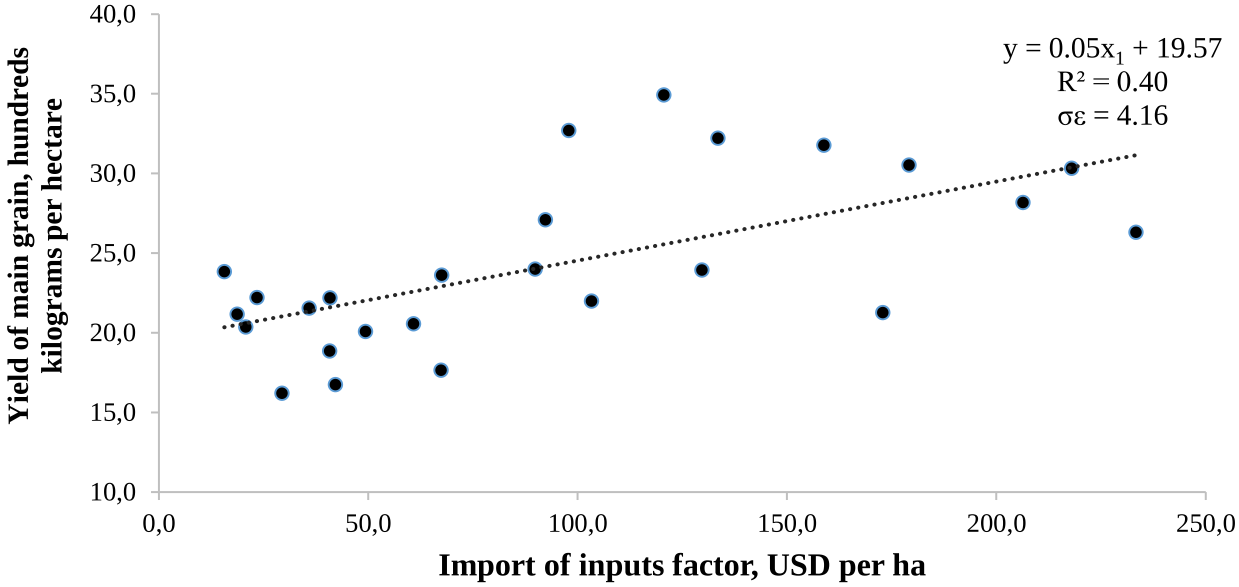

Fig. 3. Scatterplot and linear dependence of grain yield on the value of input of production factors in Ukraine, 1992–2018

Source: calculated and built by the authors based on data UKRSTAT.

This results in the following equation for the dependence of grain yields on inputs and climate effects (x2):

$$\hat{y} = 20.12 + 0.05x_1 + 6.12\,x_2 \quad (16)$$

All the coefficients are significant and the model adequacy parameters are significantly improved. The standard error is halved from 4.16 to 1.87 hundreds kilograms per hectare (Table 3). It is important to note that the regression coefficients for natural yield and dependence on inputs remain virtually unchanged, while adverse weather conditions can reduce yields by 6 hundreds kilograms per hectare. However, while weather risks were able to induce food insecurity at the beginning of the research interval, such yield changes have almost no effect on food security, as the overall positive yield trend after 2003 has significantly improved the situation

The model showed a significant positive contribution to grain yield (Table 3) of average precipitation in the March-May time interval, namely during the second growing season (x3). The null hypothesis (absence of this effect) is rejected at a significance level of 0.05 and a 1 per cent increase in precipitation leads to a yield increase of 0,06 hundreds kilograms per hectare:

$$\hat{y} = 11.99 + 0.05x_1 + 0.06\,x_3 \quad (17)$$

The practically oriented case of decreasing marginal utility of an agricultural input factors of production is considered (6, 7). The econometric models are based on data on grain yields and the value of input factors of production (fertilizers, chemicals) for 1992–2017 (Table 4). The results confirmed the hypothesis that the marginal utility value of inputs decreases. If the unit price is known, the question of optimizing yields and profits per hectare can be solved as follows:

$$y(x) = \beta_0 + \beta x + \alpha x^2 \tag{18}$$

$$\Pi p(x) = p(\beta_0 + \beta x + \alpha x^2) - x \tag{19}$$

The maximum profit is achieved: $x_1^* = -\dfrac{\beta}{2\alpha}$.

The cost at which the profit is maximized, is determined: $x_2^* = -\dfrac{\beta}{2\alpha} + \dfrac{1}{2p\alpha}$.

Given the conditions of diminishing marginal utility $(\alpha < 0)$, the maximum yield is achieved at a higher cost than the maximum profit $x_1^* > x_2^*$.

Table 4

Non-linear equations of the relationship between grain yield and resources based on annual data for 1992–2017

Model	Coefficient of variation	t_0	t_1	t_2	F	Standard error
$y = 19.71 + 0.14x_1 - 0.0005\,x_1{}^2$	0.43	12.67	2.07	-1.17	8.26	4.04
$y = 19.26 + 0.35x_2 - 0.003\,x_2{}^2$	0.60	17.76	2.25	-1.26	14.71	2.90
$y = 18.43 + 0.35x_3 - 0.002\,x_3{}^2$	0.52	10.70	2.55	-1.82	11.79	3.72

Source: calculated by the authors based on data FAOSTAT.

y – grain yield, hundreds kilograms per hectare;

x_1 – total value of inputs import, USD per ha;

x_2 – value of fertilizers import, USD per ha;

x_3 – value of plant protection products import, USD per ha.

The calculation of costs is based on maximum yield or maximum (optimum) profit (Table 5). As expected, the maximum grain yield is achieved at the expense of higher costs, which are not compensated by increased profits. If other costs (wages, depreciation of equipment, transportation costs, etc.) are added to the cost of fertilizer and chemicals, the predicted yield index will be much better in the case of profit maximization rather than yield maximization.

Table 5

Costs, yields and profits for different values of the target functions

Model	Cost for max yield / profit (€)	Max./optimal yield (hundreds kilograms/ha)	Profit based on max / optimal yield (€)
$y_2 = 19.71 + 0.14x_1 - 0.0005\,x_1{}^2$	140.0 / 82.7	29.5 / 27.9	374.8 / 403.5
$y_2 = 19.26 + 0.35x_2 - 0.003\,x_2{}^2$	58.3 / 48.8	29.5 / 29.2	455.8 / 460.5
$y_2 = 18.43 + 0.35x_3 - 0.002\,x_3{}^2$	87.5 / 73.2	33.7 / 33.3	501.2 / 580.3

Note. The average price for 1 hundred kilograms of grain is equal 17.65 USD.
Source: calculated by the authors based on data FAOSTAT.

It should be emphasized that the component use of equations (18; 19) is not quite correct, in our view it would be more appropriate to represent income in form (5) and profit in form (3). This model more adequately reflects all the components of the production process, including the interaction of individual production factors (new varieties, innovation, mechanization and features of economic activity). However, in this case, regression analysis techniques have to estimate 6 rather than 3 regression coefficients, which is insufficient for the time interval series.

Conclusions. After a long period of growth in wheat yields due to imported technologies and production components, in Ukraine, there is a steady increase in the expected yield averaging 1 hundred kg/ha per year against the background of weather risks (8 hundreds kg/ha loss due to adverse weather conditions). Estimates of wheat yield fluctuations due to weather risks suggest that they will not significantly affect the food security factor, eliminating the need to impose restrictions on grain exports.

An analysis of the variability of wheat yields in Germany and the USA shows a characteristic interdependence between yields and risk. This means that as productivity increases, its variability will also increase, so there is a need to implement a long-term strategy that can ensure sustainable growth of agro-industry in Ukraine.

When choosing an optimal strategy, based on analysis using econometric model of decreasing marginal utility of production resources, it is proved that the maximization of yields is achieved at lower costs than profit maximization. Optimal yields can be used to estimate the potential value of land. When analyzing the long-term strategy for agricultural development, lagging changes in the production process must be taken into account. Further development of crop production in Ukraine is likely to choose the intensive way of development (increasing yields), with the simultaneous allocation of parts of the area to implement the global requirements of greening and increasing forest cover. Practical value based on the above calculations, is that the Ukrainian agrarian business (in particular, crop production) is developing its own way, not following the development path of Germany or the USA. However, some peculiarities of the development can be highlighted. After a rather long recession, the agricultural sector has embarked on a path of stable growth with an annual increase in wheat yields of around 1 hundred kg/ha. At the same time, wheat production in Ukraine has the highest relative variability relative to its counterparts in the USA and Germany. Rather, the overall aim of the agricultural business in Ukraine is to make a profit in the shortest possible time, apart from the environmental component. Therefore, a long-term development strategy is lacking. This may well change after the introduction of the land market, when the tenant-owner ratio will gradually change in favor of the second one.

Furthermore, the extremely low proportion of forested land in Ukraine by European standards significantly increases the impact of weather and climate risks. Therefore, a further intensification of crop production while increasing the share of forested land at the expense of less productive land is probably the way to an ecologically balanced development of agriculture. Transition to the land market, provided and available state land can accelerate the solution of these issues. By the way, to implement the proposal of the World Economic Forum in Davos (1 trillion trees) we need to plant about 4 billion trees in Ukraine (proportional to the size of the country). If we plant one tree per 4 m^2 area, the total area will be 16 thousand m^2, which is 2.6 % of Ukraine. Such results could be useful both for global climate change mitigation and for reducing weather and climate risks in agricultural production in Ukraine.

References

1. Ahrends, H., Eugster, W., Gaiser, T., Rueda-Ayala, V., Hüging, H., Ewert, F., and Siebert, S. (2018), Genetic yield gains of winter wheat in Germany over more than 100 years (1895–2007) under contrasting fertilizer applications. *Environmental Research Letters*, vol. 13, no. 10, 104003. https://doi.org/10.1088/1748-9326/aade12.

2. Altieri, M., and Toledo, V. (2011), The agroecological revolution in Latin America: rescuing nature, ensuring food sovereignty and empowering peasants. *Journal of Peasant Studies*, vol. 38, no. 3, pp. 587–612. https://doi.org/10.1080/03066150.2011.582947.

3. Altieri, M., Funes-Monzote, F. and Petersen, P. (2011), Agroecologically efficient agricultural systems for smallholder farmers: contributions to food sovereignty. *Agronomy for Sustainable Development*, vol. 32, no. 1, pp. 1–13. https://doi.org/10.1007/s13593-011-0065-6.

4. Andrieu, N., Sogoba, B., Zougmore, R., Howland, F., Samake, O., Bonilla-Findji, O., Lizarazo, M., Nowak, A., Dembele, C., and Corner-Dolloff, C. (2017), Prioritizing investments for climate-smart agriculture: lessons learned from Mali. *Agricultural Systems*, vol. 154, pp. 13–24. https://doi.org/10.1016/j.agsy.2017.02.008.

5. Angelsen, A., and Kaimowitz, D. (2001), Agricultural Technologies and Tropical Deforestation, Cabi Publishing, New York, USA.

6. Aramburu, M., Monzon, J., Mercau, J., Taboada, M., Andrade, F., Hall, A., Jobbagy, E., Cassman, K., and Grassini, P. (2015), Potential for crop production increase in Argentina through closure of existing yield gaps. *Field Crops Research*, vol. 184, pp. 145–154. https://doi.org/10.1016/j.fcr.2015.10.001.

7. Babenko, V., Zomchak, L. and Nehrey, M. (2021), Ecological and economic aspects of sustainable development of Ukrainian regions. *E3S Web of Conferences*, vol. 280, 02003. https://doi.org/10.1051/e3sconf/202128002003.

8. Behnke, G., Zuber, S., Pittelkow, C., Nafziger, E., and Villamil, M. (2018), Long-term crop rotation and tillage effects on soil greenhouse gas emissions and crop production in Illinois, USA. *Agriculture, Ecosystems and Environment*, vol. 261, pp. 62–70. https://doi.org/10.1016/j.agee.2018.03.007.

9. Börjeson, L. (2007), Boserup backwards? Agricultural intensification as ‘its own driving force’ in the mbulu highlands. *Geografiska Annaler: Series B, Human Geography*, vol. 89, no. 3, pp. 249–267. https://doi.org/10.1111/j.1468-0467.2007.00252.x.

10. Bustos, P., Caprettini, B., and Ponticelli, J. (2016), Agricultural productivity and structural transformation: evidence from Brazil. *American Economic Review*,

vol. 106, no. 6, pp. 1320–1365. https://doi.org/10.1257/aer.20131061.

11. Chrzan, J. (2004), Slow food: what, why, and to where? *Food, Culture and Society*, vol. 7, no. 2, pp. 117–132. https://doi.org/10.2752/155280104786577798.

12. FAO, IFAD, UNICEF WFP and WHO (2018), The state of food security and nutrition in the world 2018. Building climate resilience for food security and nutrition. FAO, Rome, Italy.

13. Foley, J., Ramankutty, N., Brauman, K., Cassidy, E., Gerber, J., Johnston, M., Mueller, N., O'Connell, C., Ray, D., West, P., Balzer, C., Bennett, E., Carpenter, S., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S. and Zaks, D. (2011), Solutions for a cultivated planet. *Nature*, vol. 478, no. 7369, pp. 337–342. https://doi.org/10.1038/nature10452.

14. Green, W. (2018), Econometric analysis. Stern School of Business, New York University, USA.

15. Haddad, L., Hawkes, C., Webb, P., Thomas, S., Beddington, J., Waage, J. and Flynn, D. (2016), A new global research agenda for food. *Nature*, vol. 540, pp. 30–32. https://doi.org/10.1038/540030a.

16. Hinrichs, C. (2003), The practice and politics of food system localization. *Journal of Rural Studies*, vol. 19, no. 1, pp. 33–45. https://doi.org/10.1016/s0743-0167(02)00040-2.

17. Ickowitz, A., Powell, B., Rowland, D., Jones, A. and Sunderland, T. (2019), Agricultural intensification, dietary diversity, and markets in the global food security narrative. *Global Food Security*, vol. 20, pp. 9–16. https://doi.org/10.1016/j.gfs.2018.11.002.

18. Jarosz, L. (2014), Comparing food security and food sovereignty discourses. *Dialogues in Human Geography*, vol. 4, no. 2, pp. 168–181. https://doi.org/10.1177/2043820614537161.

19. Kadiyevskyy, V. and Klymenko, N. (2014), Systemic vision of ecological and economic interaction of land use factors in modern agrosphere. *Actual Problems of Economics*, vol. 152, no. 2, pp. 313–320.

20. Kaminskyi, V., Shevchenko, I. and Kolomiiets, L. (2018), Scientific-and-methodical maintenance of protection of lands of agricultural assignment as a precondition for sustainable development of agribusiness industry of Ukraine. *Bulletin of Agricultural Science*, vol. 96, no. 1, pp. 5–10. https://doi.org/10.31073/agrovisnyk201801-01.

21. Kaminskyi, A., Nehrey, M. and Zomchak, L. (2021), COVID-19: crisis or new opportunities time for the agricultural sector of Ukraine. IOP Conference Series: Earth and Environmental Science, 8th International Scientific Conference on Sustainability in Energy and Environmental Science, 21–22 October 2020, Ivano-Frankivsk, vol. 628, no. 1, 012031. https://doi.org/10.1088/1755-1315/628/1/012031.

22. Karpenko, L., Chunytska, I., Oliinyk, N., Poprozman, N. and Bezkorovaina, O. (2020), Consideration of risk factors in corporate property portfolio management. *Journal of Risk and Financial Management*, vol. 13(12), 299. https://doi.org/10.3390/jrfm13120299.

23. McArthur, J. and McCord, G. (2017), Fertilizing growth: agricultural inputs and their effects in economic development. *Journal of Development Economics*, vol. 127, pp. 133–152. https://doi.org/ 10.1016/j.jdeveco.2017.02.007.

24. McMichael, A. and Lindgren, E. (2011), Climate change: present and future risks to health, and necessary responses. *Journal of Internal Medicine*, vol. 270, no. 5, pp. 401–413. https://doi.org/10.1111/j.1365-2796.2011.02415.x.

25. Mesel-Veseliak, V. (2018), Cereal production in Ukraine: potential opportunities. *Economika APK*, vol. 5, pp. 5–14.

26. Muller, D., Jungandreas, A., Koch, F. and Shirhorn, F. (2016). The impact of climate change on wheat production in Ukraine. Report on agricultural policy (APD/APR/02/2016). Institute for Economic Research and Policy Consulting, available at: https://www.apd-ukraine.de/images/APD_APR_05-2016_impact_on_wheat_ukr_fin.pdf.

27. Oerke, E.-C. (200), Crop losses to pests. *The Journal of Agricultural Science*, vol. 144, no. 1, pp. 31–43. https://doi.org/10.1017/s0021859605005708.

28. Oliinyk, O., Makohon, V. and Brik, S. (2019), Maximum yield or profitability: priorities of choice in terms of innovative development. *Economika APK*, vol. 7, pp. 50–58. https://doi.org/10.32317/2221-1055.201907050.

29. Pimentel, D. (2009), Pesticides and pest control In *Integrated Pest Management: Innovation-Development Process*, eds R. Peshin, A. K. Dhawan. Springer, Dordrecht, Netherlands. https://doi.org/10.1007/978-1-4020-8992-3_3.

30. Pingali, P. (2012), Green revolution: impacts, limits, and the path ahead. *Proceedings of the National Academy of Sciences*, vol. 109, no. 31, pp. 12302–12308. https://doi.org/10.1073/pnas.0912953109.

31. Pretty, J. and Bharucha, Z. (2014), Sustainable intensification in agricultural systems. *Annals of Botany*, vol. 114(8), pp. 1571–1596. https://doi.org/10.1093/aob/mcu205.

32. Scherr, S. and McNeely, J. (2007), Biodiversity conservation and agricultural sustainability: towards a new paradigm of ‘ecoagriculture’ landscapes. *Philosophical Transactions of the Royal Society B: Biological Sciences*, vol. 363, no. 1491, pp. 477–494. https://doi.org/10.1098/rstb.2007.2165.

33. Silva, V., Mol, H. G. J., Zomer, P., Tienstra, M., Ritsema, C. and Geissen, V. (2019), Pesticide residues in European agricultural soils – a hidden reality unfolded. *Science of The Total Environment*, vol. 653, pp. 1532–1545. https://doi.org/10.1016/j.scitotenv.2018.10.441.

34. Skrypnyk, A., Klymenko, N., Talavyria, M., Goray, A. and Namiasenko, Y. (2019), Bioenergetic potential assessment of the agricultural sector of the Ukrainian economy. *International Journal of Energy Sector Management*, vol. 14, no. 2, pp. 468–481. https://doi.org/10.1108/IJESM-04-2019-0015.

35. Skrypnyk, A., Zhemoyda, O., Klymenko, N., Galaieva, L. and Koval, T. (2021), Econometric analysis of the impact of climate change on the sustainability of agricultural production in Ukraine. *Journal of Ecological Engineering*, vol. 22, no. 3, pp. 275–288. https://doi.org/10.12911/22998993/132945.

36. Strydhorst S., King, J., Lopetinsky, K. and Harker, K. (2008), Forage potential of intercropping barley with faba bean, lupin, or field pea. *Agronomy Journal*, vol. 100, no. 1, pp. 182–190. https://doi.org/10.2134/agronj2007.0197.

37. Tscharntke, T., Clough, Y., Wanger, T., Jackson, L., Motzke, I., Perfecto, I., Vandermeer, J. and Whitbread, A. (2012), Global food security, biodiversity conservation and the future of agricultural intensification. *Biological Conservation*, vol. 151, no. 1, pp. 53–59. https://doi.org/10.1016/j.biocon.2012.01.068.

38. Voronenko, I., Skrypnyk, A., Klymenko, N., Zherlitsyn, D. and Starychenko, Y. (2020), Food security risk in Ukraine: assessment and forecast. *Agricultural and Resource Economics*, vol. 6, no. 4, pp. 63–75. https://doi.org/10.51599/are.2020.06.04.04.

39. Zaburanna, L. and Poprozman, N. (2015), Factors of impact on the process of economic development strategies formation for agribusiness. *Actual Problems of Economics*, vol. 170, no. 8, pp. 111–118.

Citation:

Стиль – ДСТУ:

Skrypnyk A., Klymenko N., Tuzhyk K., Galaieva L., Rohoza K. Prerequisites and prospects for sustainable development of grain production in Ukraine. *Agricultural and Resource Economics*. 2021. Vol. 7. No. 3. Pp. 90–106. https://doi.org/10.51599/are.2021.07.03.06.

Style – APA:

Skrypnyk, A., Klymenko, N., Tuzhyk, K., Galaieva, L. and Rohoza, K. (2021), Prerequisites and prospects for sustainable development of grain production in Ukraine. *Agricultural and Resource Economics*, vol. 7, no. 3, pp. 90–106. https://doi.org/10.51599/are.2021.07.03.06.