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Region sown areas portfolio optimization taking into account crop production economic risk

P. Hrytsiuk[1], T. Babych[1,*], O. Mandziuk[2]

[1]Department of Economic Cybernetics, The National University of Water and Environmental Engineering, Rivne, Ukraine
[2]Department of Management, The National University of Water and Environmental Engineering, Rivne, Ukraine

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ABSTRACT

Grain production is one of the Ukrainian agro-industrial complex main branches. An indicator of the grain production efficiency is its profitability. It is characterized by significant annual fluctuations that induce risk. Redistribution of existing grain crops areas taking into consideration their profitability can bring to increase of production efficiency. The paper observes Markowitz's optimal portfolio theory appliance to grain branch. The central aim of this work is the development and justification of a new technique of sown areas portfolio risk evaluating. In this study, the annual profitability of four cereal crops cultivated in the Rivne region: wheat, barley, corn, and oats, have been analyzed. It is shown that the profitability of the cereals is not normally distributed. Under these conditions, the portfolio variance loses part of its informativity and can not serve as a good risk measure. It has been determined that the profitability of crops with good precision follows Laplace distribution (double exponential distribution). The analytical expression for Value-at-Risk measures has been obtained using the Laplace distribution function. Numerical risk assessments performed. Using a modified Markowitz model and obtained risk estimates the efficient frontiers of cereal sown areas portfolios in the Rivne region were constructed. Obtained results allow indicating ways for optimization the region grain industry structure.

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*Corresponding Author:
Email: *t.iu.babych@nuwm.edu.ua*
Phone: +380677614999

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INTRODUCTION

Due to its complexity, economic systems are constantly in a state of uncertainty. This uncertainty always gives rise to the risk (Mechler, 2013). This may be the risk of profit loss, risk of expenses, the risk of unused opportunities, etc. The causes of uncertainty and the resulting risk are accidental economic processes, inaccuracy, incompleteness and asymmetry of economic information. One of the important tools for risk management is diversification (Sharpe, *et al.,* 1995; Bjornson and Innes, 1992). In practice, diversification is often realized by building a portfolio of financial assets. The portfolio theory originates from the works of Markowitz (1952 and 1991). The main characteristics of portfolio in this theory are mathematical expectation of return and variance (as a risk measure). This method, known as the classical theory of portfolio, relies on hypotheses about the normality of returns distribution for assets included in the portfolio, and their non-autocorrelation. The hypotheses of classical portfolio theory are criticized in modern financial research. In works by R. Blattberg, T. Bollerslev, R. Engle the presence of "heavy tails" was discovered in the distribution of financial assets (Bollerslev, 1990; Engle, 1995). Under these conditions, variance loses some part of its informativity. At present, VaR is considered a more reliable indicator of risk and its expansion to a coherent risk of CVaR and its modification (Khokhlov, 2012; Emmer, *at al.,* 2015; Holton, 2014). In recent years, portfolio approach is widely used as a tool for improving the economic efficiency of agrarian production. In article by Bjornson and Innes (1992) was developed and estimated an explicit-factor Arbitrage Pricing Theory model for uncovering the systematic risk properties of agricultural assets returns. Wanli Ma in work by Ma (2011) studies how to achieve the maximum expected return from venture investment of agricultural engineering projects at the least investment portfolio risk. Mitter, *et al.* (2014) have estimated climate change impacts on level and variability of crop yields and profits. The optimal crop production portfolios capturing the tradeoff between profit expectation, variability of crop yields and risk aversion were identified. Crop yields was modeled with using biophysical model, alternative management methods and alternative climate change scenarios. In work by Pepelyaev and Golodnikova (2014) the question of sown areas optimization considering the risk of harvest wastage is reviewed. The authors propose solving of this problem through a mathematical model constructed on the basis of the portfolio optimization theory. Its essence is to maximize the average expected result with limiting the risk of losses. In paper by Tóth, *et al.* (2016) the alternative Markowitz portfolio theory approach was used, by replacing the stock return with return on equity, for estimation the risk and profitability of unquoted agricultural farms. In work by Hrytsiuk and Babych (2017) the problem the optimization of crops and vegetables growing structure in Ukraine, taking into consideration the accompanying risks is observed. The Markowitz's portfolio optimization theory was applied to agrarian production. An optimal portfolio of agricultural crops sown area for Ukraine has been formed. The technique of taking into account the overall effect of economic and climate-induced risks on the crop production is developed. In this paper the technique of financial portfolio optimization is used to find ways for increasing the efficiency of Rivne region crop production. The role of financial assets is played by the croplands, profitability of economic activity is determined by the profitability of cultivating various crops. Portfolio approach provides risk control through diversification of crop production (Hrytsiuk and Babych, 2017).

MATERIALS AND METHODS

Crop production risks

For crop production are inherent of various risks. Kay and Edwards (1999) work succinct list of such agrarian income risk main sources as: production, technical, marketing, price, financial, legal, and personal. According to Jian and Rehman (2016) most often the agriculture production risks consist of natural risks, economic risks, technical risks and policy risks. In our opinion, the most characteristic for crop production are natural (climate-induced) and economic risks. Climate-induced risk is associated with the onset of adverse natural phenomena and weather processes. Since these processes are not manageable, the correct strategy of agrarian production is adaptation to changing weather conditions in order to reduce risks and / or maximize economic benefits. The profitability of grain production depends to a large extent on the supply of grain on the domestic and world markets

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and fluctuates along with the volumes of this offer. These fluctuations are a source of economic risk to grain production. To estimate the value of aggregate crop production risk considering climate-induced and economic components, need to be used a ratio that as magnitudes of both risks takes into consideration, well as the correlation between them, using Eq. 1.

$$V=\sqrt{V_k^2+V_e^2+2V_kV_e\rho_{ke}} \quad (1)$$

Where, V– aggregate risk, V_e – economic risk, V_k – climate-induced risk, ρ_{ke} – coefficient of linear correlation between climate-induced and economic risk. From Eq. 1 it follows that different risks can as increasing the effect of each other in the case of the same direction, well as weaken the action of each other in the case of different orientations.

Sown areas portfolio

The main elements of the financial market are financial assets. The main elements of the grain production system are sown areas with one or another crop. Unlike the financial system, the configuration of which changes every minute due to changes in prices, demand, supply, configuration of the grain production system is determined once a year – after harvesting and its implementation.

The main criterion for the crop production economic efficiency is profit P derived from 1 ha of culture, or the culture profitability R, which reflects the ratio of profits to production costs. These values are linked using Eq. 2.

$$P=(R+1)\cdot Z \quad (2)$$

Where, V– production costs per 1 ha of culture. The definition of various crops optimal proportions in total sown areas provides the agrarian business economic efficiency growth. By changing the sown area under various cultures according to their profitability, you can increase the overall profitability of the grain production. We determine the expected profitability of a sown areas portfolio as a weighted sum of the expected profitability of its component (weights), using Eq. 3.

$$R_P=\sum_{i=1}^{k} w_i\cdot r_i \quad (3)$$

Where, $w_i=S_i/S_0;\ i=1.\ k$ – the relative share (weight) of the i-th sown area related to the total sown area S_0; $S_0=\sum_{i=1}^{k} S_i$ – the sum of all sown areas; r_i – the profitability of the i-th culture. The sum of all weights is described by Eq. 4.

$$\sum_{i=1}^{k} w_i=1 \quad (4)$$

Rivne region grain production

Rivne region is an investment-attractive region of Ukraine due to its geographically advantageous location. The grain production in Rivne region over the past 10 years has increased 2.5 times (from 500 thousand tons to 1.3 million tons). This

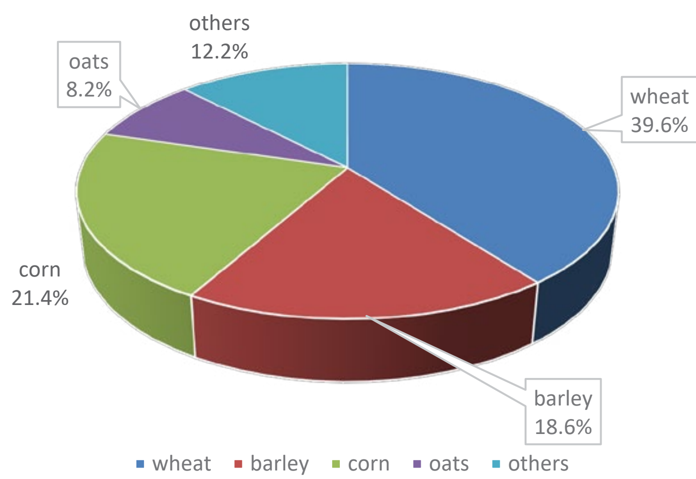

Fig. 1: The structure of grain crops areas in Rivne region (is based on the averaged values of the sown area for the period of 2012 - 2016 years) (State Statistic Service of Ukraine, 2010)

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Table 1: Statistic of Rivne region grain production profitability, % (State Statistic Service of Ukraine, 2010)

No	Year	Wheat	Barley	Corn	Oats	Cereals
1	2003	63.1	62.6	11.0	28.0	40.8
2	2004	33.3	33.7	64.6	22.3	31.2
3	2005	-5.5	16.8	3.5	-13.0	-1.5
4	2006	-0.1	-9.4	28.4	-16.7	-1.5
5	2007	25.6	59.1	40.1	12.7	32.4
6	2008	19.8	19.1	-17.4	15.3	13.0
7	2009	2.8	-9.1	-3.7	-8.6	-1.3
8	2010	8.8	14.8	16.5	-6.6	10.2
9	2011	-0.9	33.0	1.9	8.5	4.6
10	2012	10.6	29.2	7.5	6.4	11.3
11	2013	-11.9	8.8	11.8	5.7	3.4
12	2014	12.0	17.8	59.7	1.3	44.9
13	2015	28.9	26.1	83.0	17.8	55.1
14	2016	19.2	19.3	38.9	5.3	28.3

has been made possible through climate change (warming, decreasing rainfall), and through the new technologies and varieties of grain introduction that are most adapted to local conditions. The structure of grain crops areas in Rivne region is presented in Fig.1.

The main grain crops of Rivne region are wheat, corn and barley, their fraction in total crops areas is 80%. An indicator of the grain production efficiency is its profitability. It is characterized by significant annual fluctuations (Table 1) that induce economic risk.

Identification of the cereals profitability distribution

The first task of this work is the developing a technique for the risk measuring of sown areas portfolio. The annual profitability of four cereal crops cultivated in the Rivne region (wheat, barley, corn and oats) was investigated. First, it is necessary to establish the profitability distribution function of grain crops.

The main prerequisite for the economic risk estimation with applying the quantile zones method is the identification of the cereals profitability distribution. If profitability values obey the normal distribution, the most expected value of profitability coincides with the sample mean and with median value.

When the observation period (and hence the sample size) for individual assets is small, the profitability distribution for a separate sample cannot be established. If various samples are homogeneity, all samples can be combine and explores the properties of combined sample. If there is reason to believe that the profitability distribution differs from the normal, to test the homogeneity hypothesis uses the nonparametric Kruskal-Wallis H-test (Balakrishnan, 2010; Corder and Foreman, 2014). This test checks the null hypothesis that the sample medians for all samples are equal, i.e. samples originate from the same distribution. In our case the test statistic H equal 6.42, the critical value Hc equal 7.81 for alpha level $\alpha = 0.05$. Because H is not bigger than Hc, the null hypothesis is not rejected, and homogeneity property of samples is satisfied. Thus, a combined sample containing 56 values of profitability will be investigated. Markowitz model is based on the assumption of a normal distribution of financial assets profits. The probability density of the normal distribution is based on Eq. 5.

$$f(r) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(r-\mu)^2}{2\sigma^2}} \tag{5}$$

Where, μ is the mean or expectation of the profit distribution, σ is the standard deviation, and σ^2 is the variance.

A significant divergence between the sample mean (17.00) and the sample median (13.80) calls into question the hypothesis on sample normal distribution. To test the hypothesis of normal distribution for combined sample of profitability, Kolmogorov-Smirnov criterion, Shapiro-Wilk test (Fig. 2) and Jarque-Bera test were used. According to results of the first two tests, the sample dataset

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is significantly different than the normal one ($p < 0.05$). The Jarque-Bera statistic was compared to the χ^2 distribution with 2 degrees of freedom to determine the critical value *JBc*. In our case the test statistic *JB* equal 8.00, the critical value *JBc* equal 5.99 for alpha level $\alpha = 0.05$. Because *JB* is bigger than *JBc*, the null hypothesis of normal distribution was rejected. The main reason for the deviation from the normal distribution is the presence of "heavy tails" in profitability distribution. This means that the probability of occurrence of extreme (very large or very small) values of profitability is much higher than assumed by the normal distribution. Consequently, Markowitz model to optimize the sown areas portfolio can not applied. To construct a new portfolio model, it is necessary to identify profitability distribution and choose an adequate risk measure. Computer experiments showed that the profitability of all four crops are described with good precision by Laplace distribution (double exponential distribution) (Härdle and Simar, 2015; Balakrishnan, 2014). The random variable with Laplace distribution has a density using Eq. 6.

$$f(r) = \frac{b}{2}\exp\left(-b\left|r - m\right|\right) \qquad (6)$$

Where, *r*– profitability, *m* – the mathematical expectation (median) of the profitability, b – the coefficient that determines the excess distribution. Given the distribution asymmetry of the sample, the median was used as a mathematical expectation. Laplace distribution density is similar to the normal one, but the Laplace distribution has thicker tails (Fig. 3).

The graph is based on calculations performed using statistical data (State Statistic Service of Ukraine, 2010). To test the hypothesis of the Laplace distribution of profitability, Pearson's chi-squared test was used (Downey, 2011). The range of random variables *r* is divided into *k* intervals. To apply Pearson's criterion, it is necessary to calculate Pearson statistics using Eq. 7 and to compare it with tabular values $\chi_c^2(\alpha, k-3)$.

$$Q^2 = \sum_{i=1}^{k} \frac{(n_i - m_i)^2}{m_i} \qquad (7)$$

Here, m_i- the theoretical number of the random variable values in the i-th interval, n_i- the actual number of the random variable values in the i-th interval, $\alpha = 0.05$- the level of significance of the test. In this case $\chi_c^2(0.05, 8-3) = 11.07$, $Q^2 = 5.31$ since $Q^2 < \chi_c^2$, the hypothesis of the Laplace distribution is not rejected.

Samples of profitability values for different crops have different medians, and therefore they have different economic risk values. It is necessary to build separate distributions for each of the crops. The task of the distribution identification is reduced to determine the median *m* and the optimal choice of

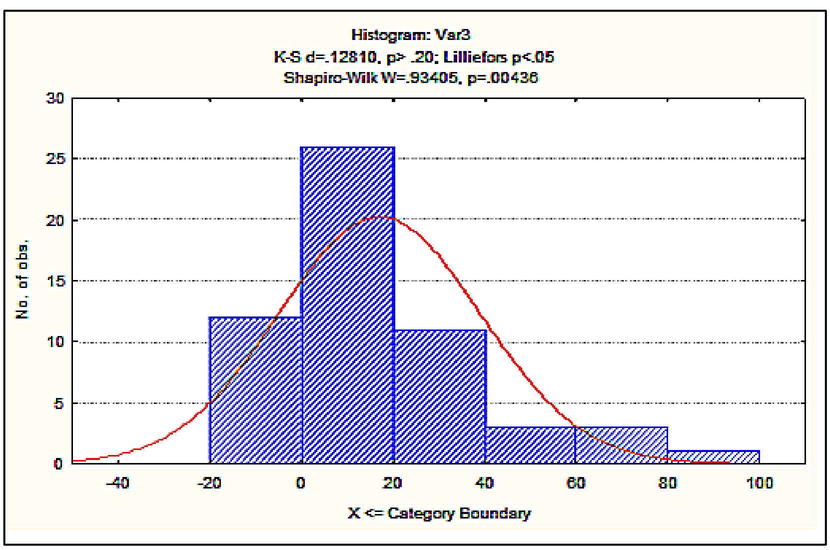

Fig. 2: Testing the hypothesis of normal distribution of combined sample

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parameter *b*. The parameter *b* of Laplace distribution has been selected by minimizing Pearson statistics Q^2. Checking the hypothesis about the Laplace distribution for various crops profitability according to Pearson's criterion has confirmed the validity of the hypothesis (Table 2).

Risk assessment technique

Markowitz (1952) was the first who pointed out that in constructing the portfolio of assets it is necessary to take into account not only the portfolio return but also the portfolio risk. In Markowitz model, the risk of i-th asset is considered as the mean-square deviation σ_i of profits from its mathematical expectation. To assess the portfolio risk, it is necessary to evaluate the correlation between its components. Financial assets with high positive correlation increase the portfolio risk; financial assets, between which the correlation is weak or negative reduce the portfolio risk. The portfolio risk σ_p is determined by the function of mean-square deviation using Eq. 8.

$$\sigma_p = \sqrt{\sum_{i=1}^{T}\sum_{j=1}^{T}\left(w_i \times \sigma_i \times w_j \times \sigma_j \times \rho_j\right)} \quad (8)$$

Where, w_i, w_j – the percentage of assets in the portfolio; σ_i, σ_j – risk of assets (standard deviation of profit); ρ_{ij} – Pearson correlation coefficient between the profits of two assets. In our research we follow Markowitz techniques. But the rejection of the normal distribution requires a different risk measure, that is different from the variance. In modern financial practice better risk measures are quantile-based measures. The most popular of them is the so-called Value-at-Risk (VaR) (Kisiala, 2015; Khokhlov, 2012). VaR shows the maximal level of losses with the probability a. The parameter a is known as a confidence level. For estimates in this paper, the value a=0.95 have been chosen. To calculate the exact quantile value, it is necessary to know the distribution function of profitability F(x). The integral Laplace distribution function is based on Eq. 9 (Fig. 4).

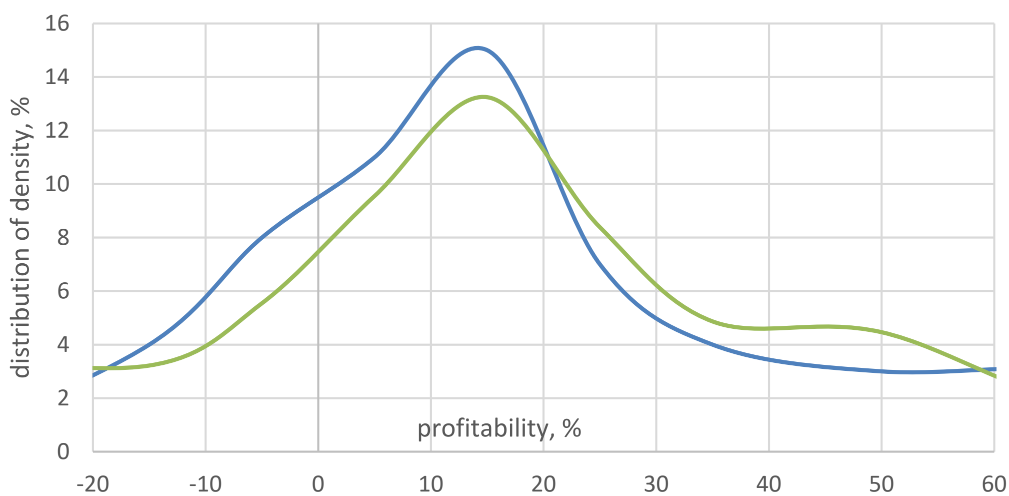

Fig. 3: Identification of crop production profitability distribution (according to the combined sample). Blue line - actual distribution, gray line -Laplace distribution

Table 2: Checking the hypothesis about Laplace distribution according to Pearson criterion

Parameters	Wheat	Barley	Corn	Oats
b	0.078	0.056	0.070	0.087
m	11.30	19.20	14.15	6.05
Q^2	3.81	9.70	7.03	3.15
X_{cr}^2	11.07	11.07	11.07	11.07

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$$F(r)=\begin{cases}\frac{1}{2}e^{b(r-m)}, r\le m\\ 1-\frac{1}{2}e^{-b(r-m)}, r>m\end{cases} \quad (9)$$

At a certain confidence level of α for VaR, the risk of a financial asset with a return of X_t is according to Eq. 10 (Kisiala, 2015; Zabolotskyy, 2016).

$$VaR_{\alpha}(X_t)=-sup\{x\in\Re : F_X\le 1-\alpha\} \quad (10)$$

Using the form of Laplace distribution function (Eq. 9), it can be found an analytic expression for risk degree at a given comfidence level a. From equality $e^{b(r-m)}=2\alpha$, it is defined as Eq. 11.

$$VaR_{\alpha}=m+\ln 2\alpha / b \quad (11)$$

The value VaR_a specifies the limit value of the random variable *r*, below which the risk zone is located. To estimate the risk measure, the distance is chosen from the median of profitability to the limit of the risk zone, it is written as Eq. 12.

$$V=-\frac{\ln 2\alpha}{b} \quad (12)$$

The values of the risk zone limit (VaR) and the risk measure V calculated in this work are shown in Table 3.

RESULTS AND DISCUSSION

Portfolio optimization

If assuming that profitability $r_i(t)$ are poorly stationary random processes, each of which is characterized by mathematical expectations (median) m_i and a degree of risk V_i, then for portfolio optimization, a modified Markowitz model can be used. In this model an approach similar to Markowitz's approach to portfolio risk assessment was used. But instead of profitability standard deviation (as a risk measure), VaR measure was used, which estimates the risk as deviation from VaR to median of profitability. The correctness of such approach to optimizing the portfolio is analyzed in detail in the monograph of Zabolotskyy (Zabolotskyy, 2016). Thus, the mathematical description of the problem at the maximum portfolio profiability will have the form as Eq. 13.

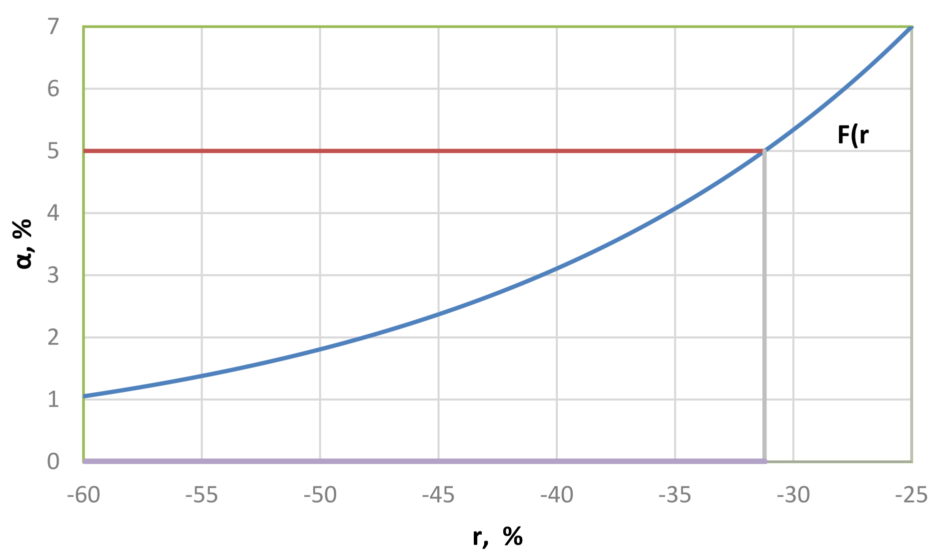

Fig. 4: Determination of bound for risk zone $VaR_{\alpha \text{ at level}}$ α = 5% (Wheat)

Table 3: Estimation of economic risk by quantile zones method (α = 0.05)

Estimates	Wheat	Barley	Corn	Oats
VaR	-31.22	-21.75	-18.88	-20.55
V_{VaR}, %	42.52	40.95	33.03	26.60

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$$\begin{cases} R_p = \sum_{i=1}^{4} w_i \times m_i \to \max; \\ V_p = \sqrt{\sum_{i=1}^{4}\sum_{j=1}^{4}\left(w_i \times V_i \times w_j \times V_j \times \rho_j\right)} \le V_{req}; \\ 0.7w_{i0} \le w_i \le 1.3w_{i0}; \\ w_i \ge 0; \sum w_i = 1. \end{cases} \quad (13)$$

Where, R_P – the total profitability of crop production in Rivne region (in terms of crops it was considered), w_i – relative share of i-th crop in the portfolio of land (weight of i-th asset), m_i – expected profitability of i-th crop production (median of profitabilities according to data of 2003-2016), V_i – the i-th asset risk measure, which was calculated previously by the quantile zones method for the period under research, V_p – actual portfolio risk, V_{req} – the recommended portfolio risk, ρ_{ij} – the Pearson correlation coefficient between two time series of profitability, w_{i0} – the current share of area i-th crop prior to start of optimization. The first ratio of system (13) describes the target function, which involves maximizing the overall crop production profitability in the region by redistribution the structure of crop areas. The second ratio sets the permissible level of risk. Since the crop production is an important component of the region's population food supply, the area under crops cannot be reduced below a certain minimum. Third restriction in order to prevent abrupt changes in areas under crop was added. Fourth and fifth ratios describe the condition of non-negativity areas and invariability total area. Current values of area under crops were determined by averaging according to the data for 2012–2016. The mathematical description of the problem for a minimum portfolio risk will have as Eq. 14.

$$\begin{cases} V_p = \sqrt{\sum_{i=1}^{4}\sum_{j=1}^{4}\left(w_i \times V_i \times w_j \times V_j \times \rho_j\right)} \to \min; \\ R_p = \sum_{i=1}^{4} w_i \times m_i \ge R_{req}; \\ 0.7w_{i0} \le w_i \le 1.3w_{i0}; \\ w_i \ge 0; \sum w_i = 1. \end{cases} \quad (14)$$

The first ratio of Eq. 14 describes the condition that the risk of crop production after re-planning of the areas should be minimal. The second ratio provides the lowest acceptable margin of the sown areas portfolio profitability, established expert way. The third, fourth and fifth ratios establish boundaries for permissible changes in areas under crops. Let's show the difference between the existing formed portfolio and an optimal sown areas portfolio. The calculations performed on the Eqs. 13 and 14 (with using of risk measure VaR) showed that under the existing distribution of sown areas between crops in Rivne region, the overall level of crop production risk is $V_0 = 25.91\%$, and the total level of profitability of crop production is $r_0 = 13.16\%$ (the square point on the graph – fig. 5). However these characteristics will not be optimal. Indeed, using Eqs. 13 and 14 and recommended risk level $V_{req} = 25.91\%$, may be get the maximum possible portfolio profitability $R_p = 13.93\%$. In order to increase the crop production profitability in Rivne region on $\Delta r = 0.77\%$, it is necessary to reduce the sown area for wheat (10%) and oats (2.8%) and

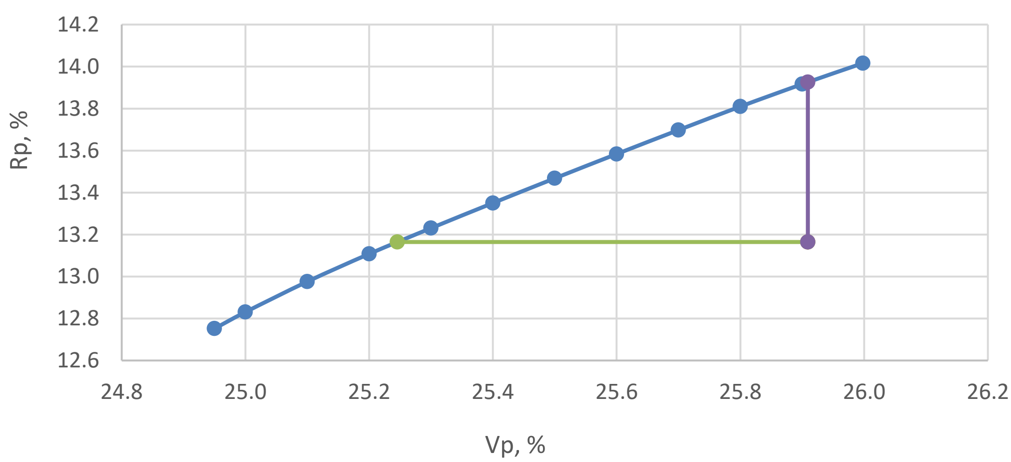

Fig. 5: The set of optimal portfolios. A square point represents a portfolio existing distribution of sown areas

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Table 4: The set of optimal portfolios

No	w_1	w_2	w_3	w_4	R_p	V_p
1	0.402	0.144	0.334	0.121	12.752	24.950
2	0.392	0.154	0.334	0.121	12.831	25.000
3	0.374	0.172	0.334	0.121	12.976	25.100
4	0.357	0.189	0.334	0.121	13.108	25.200
5	0.350	0.201	0.334	0.116	13.231	25.300
6	0.353	0.208	0.334	0.104	13.350	25.400
7	0.358	0.216	0.334	0.093	13.468	25.500
8	0.361	0.223	0.334	0.082	13.584	25.600
9	0.365	0.230	0.334	0.071	13.698	25.700
10	0.361	0.240	0.334	0.065	13.810	25.800
11	0.347	0.254	0.334	0.065	13.917	25.900
12	0.335	0.267	0.334	0.065	14.016	25.998

to increase it for barley (5%) and corn (7.7%). When using the Eq. 14 and recommended profitability level $R_p = 13.16\%$, may be obtained the minimum possible risk level $V_p = 25.25\%$. In order to reduce the crop production risk level in Rivne region on $\Delta V = 0.66\ \%$, it is necessary to increase the sown area for wheat (9.6%) and barley (0.9%) and to reduce it for corn (7.7%) and oats (2.8%).

The set of optimal portfolios

The set of optimal portfolios (the efficient frontier) using the obtained above croplands risk estimates was constructed (Table 3). Each such portfolio gives maximum profitability at the established risk level. For the first time, the concept of optimal portfolios set was introduced by Markowitz (1952). The following technique for constructing the set of optimal portfolios was proposed. Initially, a portfolio structure with a minimum risk level and a minimum portfolio profitability was determined (Eq. 14).

In the second step, the portfolio structure with maximum portfolio profitability and maximum portfolio risk was determined (Eq. 13). Then, the set of optimal portfolios was received by changing the risk value from the minimum value to the maximum one in step 0.1 and using the Eq. 13. The graphic illustration of this set is shown in Fig. 5. The Table 4 presents the portfolio structure for each of the optimal solutions obtained using annually profitability of crop production in Rivne region (State Statistic Service of Ukraine, 2010). The graph and the table confirm the well-known statement that a higher return level always requires a higher risk degree.

CONCLUSION

In this study, the optimization of the region sown areas structure on the basis of the optimal portfolio theory was performed. The source of the grain production economic risk is profitability fluctuations. The model for assessing of grain production economic risk, proposed in this paper, based on quantitative estimates obtained using the grain production profitability distribution. It is determined that the profitability of four cereal crops is not subject to the normal distribution. But it can be described by the Laplace distribution. Using the Laplace distribution function, the analytical expression for VaR risk measures was obtained and performed of the risk assessment calculations according to this approach. Taking into consideration the obtained estimations, modified Markowitz models were constructed. The principal difference between these models from Markowitz's classic models is a different risk estimation, which considers the deviation of profitability distribution from the normal one. Using these models, it is possible to optimize the region sown areas structure. As a result of optimization, the efficient frontier of cereals sown areas portfolios of Rivne region was built. Consequently, modified Markowitz models that take into account deviation

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of profitability distribution from the normal one are proposed. In this way, the scope of the portfolio theory for agribusiness was expanded.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

ABBREVIATIONS

%	Percentage
CVaR	Conditional Value-at-Risk
Eq.	Equation
Fig.	Figure
Ha	Hectare
JB	Jarque-Bera statistic
JBc	Jarque-Bera statistic critical value
K-S d	Kolmogorov-Smirnov criterion
Sup	Supreme
VaR	Value-at-Risk
VaRα	Value-at-Risk at level α

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AUTHOR (S) BIOSKETCHES

Hrytsiuk, P., Dr.Sci. in Economic Sciences, Professor, Chief of Economic Cybernetics Department, The National University of Water and Environmental Engineering, Rivne, Ukraine. Email: *gritsukp@ukr.net*

Babych, T., Candidate of Economic Sciences, Economic Cybernetics Department, The National University of Water and Environmental Engineering, Rivne, Ukraine. Email: *t.iu.babych@nuwm.edu.ua*

Mandziuk, O., Candidate of Economic Sciences, Department of Management, The National University of Water and Environmental Engineering, Rivne, Ukraine. Email: *o.m.mandziuk@nuwm.edu.ua*

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