
НАУКОВІ ГОРИЗОНТИ



Засновник, редакція, видавець
ПОЛІСЬКИЙ НАЦІОНАЛЬНИЙ УНІВЕРСИТЕТ

**Свідоцтво про державну реєстрацію
Серія KB № 24997-14937 ПР від 11.10.2021 р.**

Науковий журнал включено до категорії Б Переліку наукових фахових видань України, в яких можуть публікуватися результати дисертаційних робіт на здобуття наукових ступенів доктора і кандидата ветеринарних, економічних, сільськогосподарських та технічних наук зі спеціальностей – 071, 072, 073, 075, 076, 101, 133, 201, 202, 203, 204, 205, 206, 208, 211 (наказ МОН України № 1643 від 28.12.2019 р., наказ МОН України № 409 від 17.03.2020 р.).

Журнал включено до міжнародних наукометричних баз і каталогів наукових видань: Index Copernicus; Directory of Open Access Journals (DOAJ); Open Academic Journals Index (OAJI); Google Scholar; Crossref; Національна бібліотека України імені В.І. Вернадського, AGRICOLA, CAB Abstracts and Global Health (CABI), Open Academic Journals Index, Scopus.

Друкується за рішенням Вченої ради Поліського національного університету, протокол № 6 від 26.01.2022 р.

Підписано до друку 26.01.2022 р.
Формат 210×297. Ум. друк. арк. 12,8
Наклад 300 примірників

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ISSN: 2663-2144
e-ISSN: 2709-8877

SCIENTIFIC HORIZONS



Founder, Editorial and Publisher
POLISSIA NATIONAL UNIVERSITY

Certificate of state registration
KV No. 24997-14937 PR of October 11, 2021.

The scientific journal is included in category B of the List of scientific professional periodicals of Ukraine. It enables publishing the thesis results for Doctor and Candidate degrees in economic agricultural, technical and veterinary sciences (Order of the Ministry of Education and Science of Ukraine No 1643 of December 28, 2019; Order of the Ministry of Education and Science of Ukraine No 409 of March 18, 2020). It comprises the following specialties – 071, 072, 073, 075, 076, 101, 133, 201, 202, 203, 204, 205, 206, 208, 211.

The journal is included in the international scientific databases and catalogs of scientific publications: Index Copernicus; Directory of Open Access Journals (DOAJ); Open Academic Journals Index (OAJI); Google Scholar; Crossref; National Library of Ukraine named after V. I. Vernadskiy, AGRICOLA, CAB Abstracts and Global Health (CABI), Open Academic Journals Index, Scopus.

Recommended for publication by the decision of the Academic Council Polissia National University Minutes No. 6 of 26.01.2022.

ISSN: 2663-2144
e-ISSN: 2709-8877

Signed for publication 26.01.2022
Format 210×297. Conventional Printed Sheet 12.8
Circulation 300 copies
© Polissia National University, 2022

НАУКОВИЙ ЖУРНАЛ

Засновано 12 березня 1998 р.

Періодичність випуску: дванадцять разів на рік

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SCIENTIFIC HORIZONS

Vol. 24, No. 10 2021

SCIENTIFIC JOURNAL
Year of establishment: Since March 1998.
Publication frequency: Twelve times a year

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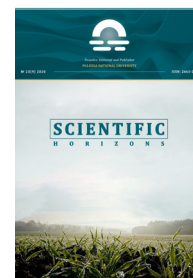
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SCIENTIFIC HORIZONS

Journal homepage: <https://sciencehorizon.com.ua>

Scientific Horizons, 24(10), 9-16



UDC 621.316

DOI: 10.48077/scihor.24(10).2021.9-16

Determination of the Concepts of Building a Solar Power Forecasting Model

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Article's History:

Received: 15.10.2021

Revised: 13.11.2021

Accepted: 15.12.2021

Suggested Citation:

Bosak, A., Matushkin, D., Dubovyk, V., Homon, S., & Kulakovskiy, L. (2021). Determination of the concepts of building a solar power forecasting model. *Scientific Horizons*, 24(10), 9-16.

Abstract. Since in Ukraine there are fines for imbalances in solar power generation in the "day-ahead" energy market, the forecasting of electricity generation is an important component of the solar power plant operation. To forecast the active power generation of photovoltaic panels, a mathematical model should be developed, which considers the main factors affecting the volume of energy generation. In this article, the main factors affecting the performance of solar panels were analysed using correlation analysis. The data sets for the construction of the forecasting model were obtained from the solar power plant in the Kyiv region. Two types of data sets were used for the analysis of factors and model building: 10-minute time interval data and daily data. For each data set, the input parameters were selected using correlation analysis. Considering the determining factors, the models of finding the function of reflecting meteorological factors in the volume of electricity generation are built. It is established that through models with a lower discreteness of climatic parameters forecast it is possible to determine the potential volume of electricity production by the solar power plant for the day-ahead with a lower mean absolute error. The best accuracy of the model for predicting electric power generation over the 10-minute interval is obtained in the ensemble random of a forest model. It is determined that models without solar radiation intensity parameters on the input have an unsatisfactory coefficient of determination. Therefore, further research will focus on combining a model of forecasting the day-ahead solar radiation with 10-minutes discreteness with a model for determining the amount of electricity generation. The determined predicted values of solar radiation will be the input parameter of the forecasting model described in the article

Keywords: solar power plant, solar radiation, regression analysis, regularisation, model accuracy, coefficient of determination



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INTRODUCTION

One of the largest sources of energy is the sun. Every year there is an increase in the exponential dependence of the electricity production of a solar power plant (SPP) in Ukraine [1]. According to [2], the main target parameters for the period up to 2035 include optimisation of the energy balance of the state, based on the requirements of security of energy supply and ensuring the share of renewable energy at 25%. A significant role is devoted to solar energy. However, with the development of renewable energy sources, there is a problem of ensuring the appropriate manoeuvrability of the power system. In [3], it is stated that the structure of the generating capacities of the Integrated Power System (IPS) of Ukraine in terms of ensuring effective frequency and power regulation in the power system is suboptimal. Among the reasons are the unregulated and variable operation of wind and solar power plants, aggravated by a lack of tools and approaches for forecasting electricity generation regimes.

According to the Law of Ukraine No. 1928-IX "Amendments to Certain Laws of Ukraine on Improving the Conditions for Supporting the Production of Electricity from Alternative Energy Sources" [4], in the day-ahead energy market, the fines for imbalances in the generation of SPP came into force since 2020. However, the Law does not provide a mechanism for short-term generation forecasting. There are no comments on databases, algorithms, techniques, and other grounds for effective day-ahead forecasting. In addition, Ukraine does not have an infrastructure base for a synoptic accurate short-term forecast for this field, which should be the basis for calculating the volume of generation, does not specify the degree of responsibility of third parties who provide data for forecasts, and there are no indications of the permissible accuracy of weather data for forecasting. At the same time, the Law imposes fines for actual hourly deviation from the projected schedules for the day-ahead and obliges the producer to be financially responsible for the imbalance of electricity to the Guaranteed Buyer.

That is why the issue of accurate forecasting of the possible electricity generation volume has become acute. However, solar energy forecasting is a rather difficult task, as it largely depends on climatic conditions that change over time. To overcome the above issues, it is important to use new intelligent methods to obtain reliable and accurate results.

Today, Machine Learning Methods have attracted considerable attention from many researchers and developers in solar radiance and power generation forecasting [5; 6]. Linear models based on the Autoregression method are mostly used to determine the radiation intensity. This method is simple but not flexible. An improved autoregressive integrated model with a moving average for determining the monthly solar radiation based on a set of radiation and temperature data for previous periods was proposed in [7]. A novel solar radiation prediction

approach that combines two models, the Auto Regressive Moving Average (ARMA) and the Nonlinear Auto Regressive with exogenous input (NARX) is presented in [8]. The effectiveness of combining a modification autoregression model and a convolutional neural network was studied in [9]. An empirical hybrid Autoregressive Integrated Moving Average (ARIMA) and Artificial Neural Network (ANN) approach shows a high correlation with experimental results and a relatively small error rate [10]. Deterministic and probabilistic forecasting of photovoltaic power based on a deep convolutional neural network is discussed in [11]. Also, recurrent neural networks are used for the hourly prediction of photovoltaic power output using meteorological information [12].

In addition, there are also some nonlinear methods based on time series. For example, a deep learning-based Photovoltaics (PV) power generation forecasting model based on Long Short-Term Memory (LSTM) model uses both outdated and forecast data by replacing the outdated weather data with the future weather forecast data during the testing phase for daily PV power generation forecasting [13]. In [14], the authors used a traditional recurrent artificial neural network and Support Vector Machine (SVM), based on a set of time series data, to increase forecasting accuracy for the next 24 hours. The special feature of time forecasting is that it considers the trend and seasonality of the predicted parameter. But the influence degree of the nature of changes in the values of climatic parameters in these models is mainly not considered. The question arises about the need in evaluating the application of other methods of Regression Analysis of Machine Learning, that will better account for the influence of disturbing factors on the further forecast through artificial neural networks. [15] presents Feature-Selective Ensemble Learning-Based Long-Term Regional PV Generation Forecasting. The Ensemble model that used simple multilayer perceptron and CNN with applied feature selection shows higher predictive power than the time series based single model.

The purpose of the study is to develop a concept and methodology for building a mathematical model for forecasting the amount of electricity generated by solar panels. It can be done by feature selection for active power generation parameters and selection of an adequate mathematical model for determining the target value of the energy generation function based on actual data.

MATERIALS AND METHODS

Data for the analysis of electricity generation by photovoltaic facilities and factors affecting the solar power plant (SPP) were obtained from Dymerska SPP in the village of Velyka Dymerka, Kyiv region. The data consisted of more than 26 thousand samples collected from July 1, 2020, to December 31, 2020, which characterize the operating conditions of solar panels with a capacity of 9 MW.

The data set consists of two types:

1. Weather condition data. The first part of the data consists of measured weather parameters such as temperature, humidity, solar radiation, atmospheric pressure, wind direction and wind speed.

2. Data from metering devices on the amount of electricity produced.

The analysed dataset consisted of the actual value of the output electric power for 10-minute intervals (the meter transfers the generation value to the monitoring point with the discreteness of 10 minutes) and the measured climatic parameters for the appropriate period. The data of 10-minute discreteness samples also need to be aggregated into daily samples for forecasting electric power generation on a day ahead.

To estimate the actual value of the influence of each parameter on the target function and separately on each of the input factors of the model, a correlation matrix is used. It is a structured approach to ranking the importance of predictors or input variables at the output. The correlation coefficient for the sample is determined from the equation [16]:

$$r_{xy} = \frac{\sum_{i=1}^n x_i y_i - n \bar{x} \bar{y}}{(n-1) s_x s_y} = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^n (y_i - \bar{y})^2}} \quad (1)$$

where n is the sample size; \bar{x} and \bar{y} are the sample means of the individual sample points x and y accordingly; s_x and s_y are the sample standard deviations for x and y accordingly.

The first task of this study was to determine the nature of the dependence of the output target function, i.e., the volume of electricity generation on the set of input parameters (climate conditions) and to build mathematical models based on them. Thus, it is necessary to determine the amount of electricity generated (Y):

$$Y = \sum_{k=1}^n \beta_{jk} \psi_k(X_1, \dots, X_N) \quad (2)$$

where β_{jk} is an unknown constant, when $\psi_k(\cdot)$ is the set of basic functions, at $k \in \{1, \dots, N\}$, X_1, \dots, X_N are the set of input parameters (temperature, humidity, solar radiation, wind speed etc.).

The determination of active power generation from solar panels is possible by the methods of linear regression, ridge regression, lasso regression and random forest regression. For linear regression, the relationship between the data was built using linear functions, and the unknown parameters of the model were estimated from inputs. Using the linear regression model, it is possible to obtain a process model:

$$y = \beta_0 + \beta_1 X_1 + \dots + \beta_i X_i + \varepsilon \quad (3)$$

where y is the target variable (the predicted value); X_1, \dots, X_i are independent variables; β_0 is the bias coefficient;

β_1, \dots, β_i are coefficients of independent variables; ε is the error term (the residual).

The coefficient β_0 is the predicted value of y when X is 0. The coefficients β_i of the model were selected by the least-squares method (LSQ). This method minimizes the sums of the squares of the regression residuals.

In the case of increasing the number of model parameters, the linear regression does not differentiate between "important" and "less important" predictions in the model. So, it includes all variants. The model will be retrained, and it will be difficult to find unique solutions after. There will also be issues with the multicollinearity of data.

One of the solutions to the multicollinearity issue is to use L_2 regularisation. Ridge regression belongs to a class of regression tools that uses L_2 regularisation. L_2 regularisation adds an L_2 penalty, which is equal to the square of the value of the coefficients. All coefficients are reduced by a coefficient (so none are excluded) [17]:

$$Ridge_{loss} = \underbrace{\sum_{i=1}^N (y_i - \hat{y}_i)^2}_{Loss} + \lambda \underbrace{\sum_{i=1}^k \omega_i^2}_{Penalty} \quad (4)$$

where y_i is the actual value; \hat{y}_i is the predicted value; λ is a non-negative tuning parameter; ω_j is the model weight.

Another modification of linear regression is lasso regression. In lasso regression, the loss function is modified to minimise the complexity of the model by limiting the sum of the absolute values of the model coefficients (the so-called L_1 -norm):

$$Lasso_{loss} = \underbrace{\sum_{i=1}^n (y_i - \hat{y}_i)^2}_{Loss} + \lambda \underbrace{\sum_{j=1}^k |\omega_j|}_{Penalty} \quad (5)$$

L_1 regularisation will lead to zero weights of some features. So, the features selection is the result of the L_1 regularisation, which produces sparse coefficients.

The influence of random fluctuations in a single dimension is weakened by averaging the results of observations. This can provide a more stable and reliable assessment. Algorithms of combining models present a similar concept. The construction of their ensembles is one of the most powerful methods of Machine Learning. They are often the best models for the quality of forecasts compared to other methods. One of the most common ensemble methods is the random forest method. Random Forest Regression builds several decision trees of a regression model during training and obtains an average forecast as input. The basic concept of a random forest is that a set of random trees find a solution independently of each other and act together, surpassing any solution obtained by a single decision tree [18].

The results of testing models obtained using the considered methods must be checked for the accuracy

of obtaining forecasts for the generation of electricity. For this purpose, authors applied such criteria as mean square error (MSE), root mean square error (RMSE), mean absolute error (MAE), mean absolute percentage error (MAPE) and coefficient of determination (R^2). The MAE measures the average distance between \hat{y}_i and y_i , i.e., directly describes the mean offsets. The R-squared (R^2) measures the level of correlation between \hat{y}_i and y_i [19]. The MSE is a function that corresponds to the expected value of the error loss square. The MAPE is widely used as a loss function for regression problems and in model evaluation, because of its very intuitive interpretation in terms of relative error. In the case of SPP, it is normalised by power. Mathematical equations of indicators are formulated as follows:

$$MSE = \frac{1}{N} \sum_{i=1}^N (y_i - \hat{y}_i)^2 \quad (6)$$

$$RMSE = \sqrt{MSE} \quad (7)$$

$$MAE = \frac{1}{N} \sum_{i=1}^N |\hat{y}_i - y_i| \quad (8)$$

$$MAPE = \frac{100}{N} \sum_{i=1}^N \left| \frac{y_i - \hat{y}_i}{P_0} \right| \quad (9)$$

$$R^2 = 1 - \left(\frac{\sum_{i=1}^N (y_i - \hat{y}_i)^2}{(y_i - \bar{y}_i)^2} \right) \quad (10)$$

where N is the sample size; y_i is the actual value; \hat{y}_i is the predicted value; \bar{y} is the sample mean; P_0 is the rated power of the SPP.

Sometimes, the equation (9) is normalised by the actual value, i.e., y_i , rather than P_0 , which has the disadvantage as a zero power value has a meaning when the SPP does not generate energy.

RESULTS AND DISCUSSION

The thermal parameter correlation matrix for the power generation data for the 10-minute intervals is shown in Figure 1a and for the daily intervals in Figure 1b. For daily intervals, the values of wind speed, temperature, humidity, and atmospheric pressure were averaged per day, and the total value per day was calculated for solar radiation and generation. Weather condition data on 10-minutes discreteness consists with measured wind direction parameters for each period. Otherwise, values of this parameter cannot be aggregated on a daily period. But for a daily active power generation can be used another parameter – the duration of daylight. It is a time duration from sunrise to sunset.

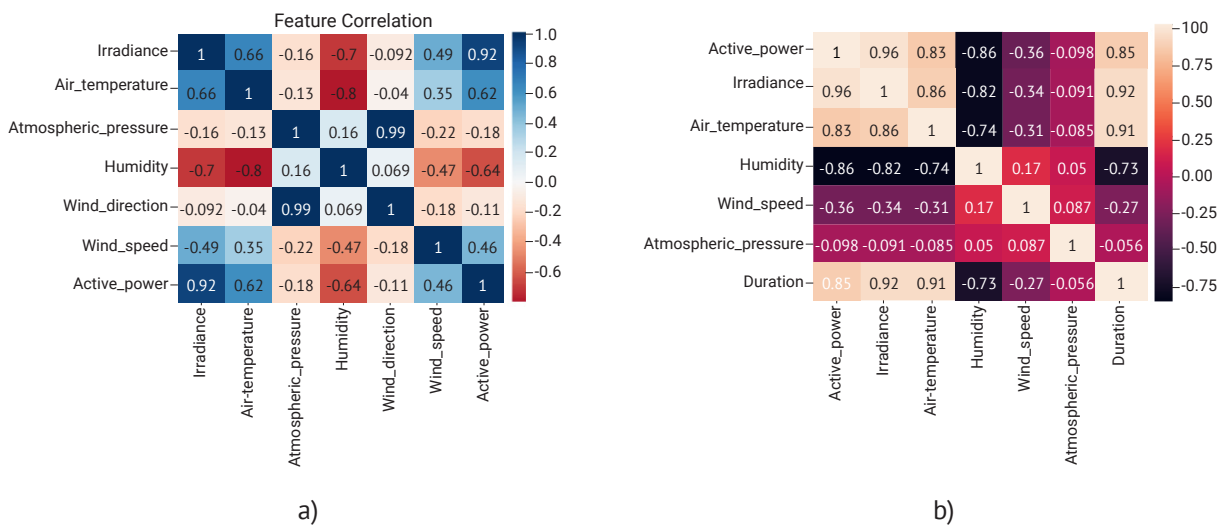


Figure 1. Correlation heatmaps for weather features and active power generation for a) 10-minutes intervals data; b) daily intervals data

According to the results of the calculation, two parameters had positive correlations with the output power, namely solar radiation, air temperature on each data time discreteness. Also, such parameter as the duration of daylight on daily data has a huge correlation with active power generation (85%) and the wind speed parameter on 10-minutes intervals has almost 50% correlation. Relative humidity had a negative correlation.

It should be noted that the wind direction is correlated with an atmospheric pressure of 99% on 10-minute discreteness. This dependence means that the value of one parameter changes almost completely as the value of another. Thus, these factors in the model will be duplicated. Such a case could increase the error of the model and the possibility of retraining. Therefore, the “wind direction” parameter was excluded. If ensemble models

are built in combination with other climatic parameters, the atmospheric pressure factor can also affect them. However, there was no effect of atmospheric pressure on the model at a daily interval according to the correlation matrix and this factor was not included in the totality of output parameters. In this case, the degree of influence of most factors may vary depending on the season. Therefore, in further studies, both solar radiance and electricity generation values should consider seasonality and introduce the degree of importance of input parameters depending on the age of the data.

The data for the six months which were used in the experiment were divided into three segments: a training data set (60%), a validation data set (20%), and a test data set (20%). A training data set was used to train the models and a five-time test was performed as a resampling procedure. The experiments were implemented using the *scikit-learn library in Python 3.8* which allows implementing the Machine Learning Methods.

Construction models should be analysed on the accuracy of forecasting active power generation. MAE, MSE, RMSE could be used to characterise the difference in solar forecasting performance attributed to spatial aggregation [20]. A lower value of these indicators points to a higher quality of the forecast. For a day-ahead forecast,

the value of these errors is important, as in absolute terms it shows how real data may differ from the forecast. However, it is necessary to consider the variability of data in the short term. There can be a significant difference between the possible minimum and maximum value of absolute errors for certain climatic conditions. In particular, at night in the winter months, the generation of active electricity varies from 0 to 10 W per hour. At the same time, during daylight hours in the summer months, the generation can vary from a few hundred W to 50 W per hour. For this period, the absolute errors are higher. In this case, it is also advisable to use relative errors to assess the effectiveness of the model. Percentage errors have the advantage of being unit-free, so they are frequently used to compare forecast performances between data sets [21]. MAPE metric can be used to compare the results from different spatial and temporal scales of forecast errors. Firstly, attention should be paid to absolute errors and the coefficient of determination. Then it is necessary to determine the MAPE value (Table 1). In case the model has a bad or insufficient forecast error of MAPE then it is better to choose another model with lower absolute errors [22]. Table 2 shows the results of the calculation of accuracy for all models.

Table 1. Interpretation of typical MAPE values

MAPE, %	Forecast accuracy
Lower than 10%	High
10-20%	Good
21-40%	Satisfactorily
41-50%	Bad
More than 50%	Unsatisfactorily

Table 2. Comparison of errors criteria for the results obtained for each of the tests from the solar radiation forecast

Model	MAE, W	MSE, W	RMSE, W	MAPE, %	R ² , abs.un.
10-minute interval					
Linear regression	243.25	259514.05	509.43	11.12	0.912
Ridge regression	242.71	260008.21	509.91	10.86	0.915
Lasso regression	231.51	266892.45	516.62	11.56	0.916
Random forest regression	146.91	172864.78	415.77	9.34	0.941
Daily interval					
Linear regression	28979.11	1.24e+09	35227.21	15.19	0.947
Ridge regression	25719.42	1.21e+09	34734.32	13.43	0.949
Lasso regression	35520.55	1.77e+09	42024.57	34.92	0.925
Random forest regression	25509.59	1.41e+09	37557.94	17.99	0.94

The simulation results showed that in the dataset, where a better correlation of model parameters was

observed (more than 80%, and especially with the value of solar radiation of 0.96) with the target function, linear

regression and ridge regression had better quality. This is mainly attributable to the fact that the model did not require a combination of features, and the sample was smaller. Such results were obtained for daily intervals datasets. The best results in a sample of the 10-minute interval were obtained by the method of random forest regression, where the overall correlation was not so close. In this case, sorting features and randomly searching for

the optimal model by combining and crossing features allowed to get a more accurate model. The combined features were more correlated with the target function than when they were alone. The results of the forecast of active power generation on July 1st and July 2nd according to the initial parameters in the test sample and the real data are shown in Figure 2.

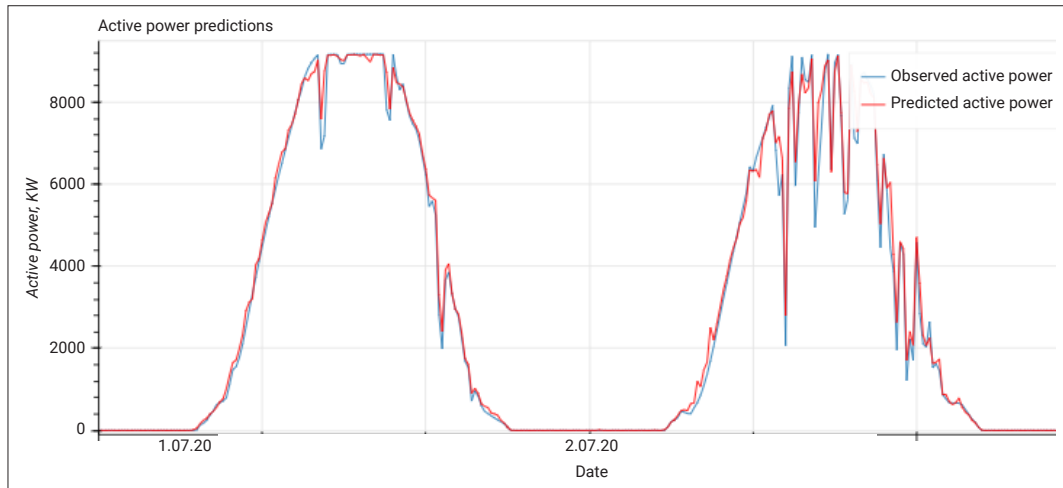


Figure 2. The forecast of active power generation by the method of random forest regression according to the initial parameters

Figure 2 shows that in general, the model predicts the amount of electricity generation accurately. The results in Table 2 also show that the models obtained at the daily interval have a higher coefficient of determination – 0.95 (ridge regression), while on the 10-minute interval the model obtained by the random forest method was

$$MAE_{day} = MAE_{10minute} \cdot 6 \cdot 24 = 146.9 \cdot 6 \cdot 24 = 21\,155[W], \quad (11)$$

because an hour has 60 minutes (six 10-minute intervals), and a day has 24 hours.

Obtaining accurate predictions of solar radiation can be quite a challenge for certain measurement sites. Therefore, models determining the amount of electricity generation according to the climatic data defined above, excluding the amount of solar radiation, were found. On

0.94. However, to determine which time period was more effective, it is necessary to compare the value of the obtained deviation of values of the original function. If in the random forest regression model for a 10-minute interval the MAE value is 146.9 W, then it can have the following maximum value per day:

the daily interval, instead of its value, it is possible to apply data on the duration of daylight (the correlation coefficient according to Figure 1b is 0.92). The 10-minute model excluded the parameter of radiation.

The values of the accuracy indicators of the models, excluding the solar radiation and including the duration of daylight at daily intervals, are given in Table 3.

Table 3. Comparison of criteria for results errors, excluding the solar radiation at 10-minute intervals and including the duration of daylight at a daily interval

Model	MAE, W	MSE, W	RMSE, W	MAPE, %	R ² , abs.un.
10-minute interval					
Linear regression	1290.65	3.19e+06	1787.89	62.34	0.494
Ridge regression	1288.024	3.2e+06	1788.72	61.47	0.494
Lasso regression	1476.25	3.86e+06	1963.55	72.64	0.39
Random forest regression	735.5	1.86e+06	1362.17	83.12	0.61
Daily interval					
Linear regression	36549.11	1.24e+09	35227.21	27.75	0.793
Ridge regression	34719.42	1.21e+09	34734.32	16.88	0.823
Lasso regression	42521.52	1.77e+09	42024.57	21.14	0.82
Random forest regression	35512.19	1.41e+09	37557.94	15.95	0.827

CONCLUSIONS

The forecast result shows that the complete elimination of the radiation parameter from the model did not allow obtaining an adequate accuracy of the target function ($R^2 < 0.75$ and MAPE is 50% higher). The daily chart shows that the presence of the duration of daylight parameter made it possible to obtain a model with $R^2 > 0.75$. However, it was significantly worse than the model with a solar radiation parameter ($R^2 = 0.827$ compared to $R^2 = 0.949$ for a model with a solar radiation factor at the input). Accordingly, the MAE value is also lower by about 26% and MAPE has a higher evaluation error. The results showed the need for a solar radiation parameter in the model, and the daylight indicator did not replace it completely. Therefore, it is needed to predict solar radiation for a short period ahead. These results should then be used in a model for predicting active power generation from the data sets used at 10-minute intervals.

The next step in the research involves a forecasting model based on neural networks of long short-term memory. This network may allow providing time series in conditions when there are time delays of unknown duration between important events and when it is necessary to take into account the seasonality of parameters [23]. So, obtaining a model by random forest method for obtaining active power generation amount on 10-minute intervals can be used for forecasting on a long short-term period by time series models.

It is established that the main factors for building a model of power generation forecasting are solar radiation, temperature, humidity, and wind speed. The obtained models by using both 10-minute and daily intervals were quite accurate, as the coefficient of determination was more than 0.94 for each of them. In addition, it was found that the models that used a 10-minute interval had a lower MAE value per day compared to the value from the daily interval. Therefore, the use of a model with a lower discreteness of the forecast of climatic parameters will determine the possible volume of electricity generation of SPP for the day-ahead with a lower forecast error. The best accuracy in models at a 10-minute interval was obtained in the ensemble model of a random forest, and among models, with daily interval, the best one was obtained based on linear regression and its regularisation. This results from the high correlation dependence of the main factors (solar radiation, temperature, and humidity) with the target function.

The models that did not use solar radiation as one of the input parameters had an unsatisfactory value of the coefficient of determination ($R^2 < 0.75$) and MAPE ($> 50\%$). By replacing the solar radiation parameter with the duration of daylight on the daily interval, it was possible to obtain an adequate model ($R^2 > 0.75$), although the MAE value increased by more than 25%. This indicated that the model should include solar radiation.

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Визначення концепції побудови моделі прогнозування сонячної енергії

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Анотація. Оскільки в Україні діють штрафи за дисбаланс виробництва сонячної енергії на ринку електроенергії «на добу вперед», то виникає необхідність прогнозування виробництва електроенергії сонячною електростанцією. Для прогнозування виробництва активної потужності фотоелектричних панелей потрібно розробити математичну модель з урахуванням основних факторів, що впливають на величину генерації енергії. В статті виділення основних факторів, що впливають на роботу сонячних панелей, було здійснено за допомогою кореляційного аналізу. Набір даних для побудови моделі прогнозування було отримано на сонячній електростанції в Київській області. Для аналізу факторів і побудови моделі використовувалися два типи наборів даних: дані 10-хвилинних інтервалів часу та добові дані. Для кожного набору даних за допомогою кореляційного аналізу були обрані відповідні вхідні параметри. З урахуванням визначених факторів побудовано моделі знаходження функції відображення метеорологічних факторів від обсягу вироблення електроенергії. Встановлено, що моделі з меншою дискретністю прогнозу кліматичних параметрів дозволяють визначити можливий обсяг виробництва електроенергії сонячною електростанцією на добу вперед з меншою середньою абсолютною похибкою. Найкращу точність моделі прогнозу виробітку електричної енергії на 10-хвилинному інтервалі отримано в ансамблевій моделі випадкового лісу. Встановлено, що моделі, що не містять на вході параметру інтенсивності сонячного випромінювання, мають незадовільний коефіцієнт детермінації. Тому подальші дослідження будуть зосереджені на поєднанні моделі прогнозування сонячного випромінювання з 10-хвилинною дискретністю на добу наперед із моделлю визначення кількості виробленої електроенергії. Визначені прогнозовані значення сонячного випромінювання будуть вхідним параметром описаної в статті моделі прогнозування

Ключові слова: сонячна електростанція, сонячне випромінювання, регресійний аналіз, регуляризація, точність моделі, коефіцієнт детермінації



UDC 619:19:616:98:579.873.21:631.153.7

DOI: 10.48077/scihor.24(10).2021.17-27

Influence of Ionizing Radiation on the Allergic Reactivity of Tuberculosis-Infected Laboratory Animals

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Article's History:

Received: 17.09.2021

Revised: 16.10.2021

Accepted: 19.11.2021

Suggested Citation:

Kassich, V., Kasianenko, O., Zazharskyi, V., Yatsenko, I., & Klishchova, Zh. (2021). Influence of ionizing radiation on the allergic reactivity of tuberculosis-infected laboratory animals. *Scientific Horizons*, 24(10), 17-27.

Abstract. Allergic examination using PPD-tuberculins is the main method of life-time tuberculosis diagnostics in farm animals and poultry. However, it is known about a decrease in the diagnostic value of allergic reactions after irradiation of animals, the occurrence of non-specific, pseudo-allergic reactions. One of the reasons for the manifestation of non-specific reactions may be autosensitisation (autoallergisation) of the body by the breakdown products of personal tissues, which is especially pronounced with radiation damage. Ionizing radiation affects the manifestation of tuberculin sensitivity, the course of tuberculosis and autoimmune processes in the body. Differential diagnostics of non-specific tuberculin reactions remains not yet a fully solved problem, although there are many tests for its implementation. After the accident at the Chernobyl nuclear power plant, a considerable number of animals remained in the adjacent territories contaminated with radioactive substances, including those infected with the causative agent of tuberculosis and atypical mycobacteria. It is known that irradiation leads to autosensitisation of the body by the breakdown products of its own tissues and the development of non-specific pseudoallergic reactions to heterologous allergens. Therefore, work was carried out to study the allergic reactivity of tuberculosis patients and laboratory animals sensitised with atypical mycobacteria irradiated with gamma radiation (200 guinea pigs). It was established that 14-60 days after infection with tuberculosis pathogens, 90-100% of covies developed allergic reactions to PPD-tuberculin for mammals and poultry, mainly to a homologous allergen. Allergic reactivity persisted until 90 days of the study. After exposure to sublethal (non-lethal) doses of gamma rays, infected and intact covies developed non-specific reactions to tuberculin and heterologous allergens: mallein and brucellin. In covies uninfected with the causative agent of tuberculosis, 7 days after gamma radiation exposure, non-specific reactions to mycobacterial allergens were observed at a dose load of 200 R in 16.6%; 150 R – 5.3% in the group, and after 27 days in irradiated doses of 50 R and 100 R in 25% and 33% of the studied animals, respectively. Isolated reactions to brucellin and mallein occurred in animals infected with the causative agent of tuberculosis and intact animals 60 days after irradiation with doses of 50 R, 100 R and 150 R. The manifestation of non-specific allergies in irradiated animals depended on the radiation dose rate and radiosensitivity of the animals

Keywords: tuberculin, heterologous allergens, gamma radiation, mycobacteria, allergic studies



INTRODUCTION

Tuberculosis has a special place among infectious diseases of farm animals since this disease not only causes considerable economic losses to animal husbandry but also poses a constant danger to human health. According to WHO, tuberculosis is currently the most common infection in the world [1-4]. Human and animal tuberculosis is widespread and is registered in many countries. Among domestic animals, tuberculosis most often occurs in cattle. The main method of intravital diagnostics of tuberculosis is an allergic study using PPD-tuberculin for mammals and poultry. Therewith, literature sources provide information indicating a decrease in the diagnostic value of allergic reactions after irradiation of animals [5; 6]. One of the reasons for the development of a non-specific allergy to tuberculin can be not only sensitisation by microorganisms of the genus *Mycobacterium* but also autoallergisation (autosensitisation) of the body by the breakdown products of its own tissues. Several researchers state that this is the reason for the simultaneous existence of specific and non-specific reactions in tuberculosis [7]. Tissue breakdown processes are observed when exposed to ionizing radiation, an indicator of which is an increase in urinary excretion of deoxycytidine [8-14]. The mechanism of changing the allergic reactivity of an irradiated organism is still poorly understood. It was proved that it is based on a violation of the general immunological state of the body, in particular, an increase in the appearance of autoantibodies [15; 16]. Non-specific reactions to tuberculin in animals sensitised by atypical mycobacteria are usually called paraallergic (paraspecific), and reactions caused by other factors (including unknown ones) are called pseudoallergic [17]. Differential diagnosis of non-specific tuberculin reactions remains not yet a completely solved problem, although there are several tests for its implementation (simultaneous allergic test, CSC, etc.). An important reason for the manifestation of non-specific reactions can be autoallergisation of the body by decay products of its own tissues, which is especially pronounced in radiation damage [18-21]. Ionizing radiation affects the manifestation of tuberculin sensitivity, the course of tuberculosis, and autoimmune processes in the body [22-26]. The widespread use of nuclear energy in the national economy is of great importance for the development of the domestic economy. However, radiation pollution of the biosphere as a result of the Chernobyl accident causes increasing exposure of populations of living organisms. Long-term contacts of humans, farm animals and other biological objects with sources of ionizing radiation of various nature have become a reality.

As a result of the Chernobyl accident, more than 144 thousand hectares of agricultural land were withdrawn from crop rotation. In total, about 10 million hectares are contaminated with radionuclides, of which more than 3 million are farm land [1]. In Ukraine, the territory of 17 regions is contaminated with radionuclides.

The contaminated areas contain a considerable number of farm animals, including those with tuberculosis or sensitised by atypical mycobacteria. Ionizing radiation can affect both the causative agent of an infectious disease and the susceptible organism. The degree of such exposure depends on the character of the radiation, the dose, its power, and many other factors. Therefore, the situation that arose after the Chernobyl accident required a deep study since the effect of radiation on the links of the epizootic process could lead to unforeseen changes in the epizootic and epidemic situation. In this regard, the determination of the epizootic value of mycobacteria (pathogens of tuberculosis of animals, poultry, humans and atypicals) under the influence of ionizing radiation, the study of the features of the biological effect of ionizing radiation of different intensities on the animal body, the introduction of optimal measures and means for the diagnostics and control of tuberculosis in radioactively contaminated territories have gained particular importance. Information on changes in allergic reactivity and features of clinical and immunological manifestations of animal tuberculosis against the background of ionizing radiation exposure is limited and is usually obtained in experiments on experimental models of laboratory animals. Until recently, the epizootic situation of animal tuberculosis in radioactively contaminated regions of Ukraine was not monitored. Methods for diagnosing tuberculosis in livestock kept in radioactively contaminated regions of the country have not been optimised.

Nowadays, when man-made disasters are a reality, the study of allergic diagnostics of animal tuberculosis is relevant, especially for Ukraine, on the modern territory of which the Chernobyl nuclear power plant is located with the adjacent exclusion territory and radionuclide-contaminated regions where productive animals are kept and used.

The purpose of the paper is to study the effect of irradiation on the allergic reactivity of laboratory animals.

MATERIALS AND METHODS

To study the effect of ionizing radiation on the specificity of allergic reactions, an experiment was conducted on 200 cavies weighing 300-350 g, selected according to the analogue method. The animals were divided into 5 groups of 40 heads each. To exclude natural tuberculosis of all animals, an allergic sample with mammalian PPD-tuberculin and an allergen from atypical mycobacteria was previously studied (30 days before irradiation) [27]. At the same time, brucellin (produced by Kherson biological factory) and mallein (produced by Kursk biological factory) were administered at a dose of 0.1 cm³ intradermally. The purpose of introducing allergens that are not specific to tuberculosis and animal species (cavies), whose body cannot be sensitised to brucellosis and equinia pathogens by natural or experimental infection,

was to study the possibility of developing non-specific pseudoallergic reactions in irradiated animals against the background of autosensitisation of their body by decay products of their own tissues due to radiation damage. In addition, the purpose was to establish whether irradiation and the resulting immunodeficiency state will contribute to the occurrence and development of characteristic pathoanatomical changes in cavies infected with poultry tuberculosis pathogen (*M. avium*). *M. avium*, according to the Ranion classification (1959), is classified as atypical mycobacteria of the third group: non-photochromogenic mycobacteria (achromous or have a yellow tint regardless of lighting). *M. avium* is pathogenic for poultry, rabbits and pigs, not pathogenic for cavies, cattle, but when administered to immune animals causes an immunobiological restructuring of the body, sensitisation and the occurrence of paraallergic reactions to mycobacterial allergens (PPD-tuberculin for mammals, PPD-tuberculin for poultry, and an allergen from atypical mycobacteria (AAM), differentiation of which is carried out using a simultaneous allergic test [27].

To solve the objectives set in the work, four groups of animals were separately irradiated with total gamma radiation in doses of 0.0129 C/kg (50 R); 0.0258 C/kg (100 R); 0.0387 C/kg (150 R), and 0.0516 C/kg (200 R) with a dose rate of 2.85 R/sec on the IGUR gamma emitter (radiation source ^{137}Cs). Irradiated and intact (unirradiated) cavies were divided into two equal groups of 100 animals each. Animals of the first group were examined one day after radiation treatment by a simultaneous allergic sample with mammalian PPD-tuberculin and an allergen from atypical mycobacteria [27]. 7 days after irradiation, animals of this group (5-6 irradiated doses of 0.0129 C/kg (50 R); 0.0258 C/kg (100 R); 0.0387 C/kg (150 R), and 0.0516 C/kg (200 R) and intact) were infected with mycobacterium cultures. Cultures of bovine (*M. bovis* No. 8), human (*M. tuberculosis*, strain M), and bird (*M. avium* 780) species of mycobacteria from the Museum of the tuberculosis laboratory of the VIEV were used. Infectious material was administered subcutaneously to each laboratory animal (cavies) in the groin area according to the generally accepted method of 1 mg of raw bacterial mass suspended in 1 ml of sterile isotonic solution of NaCl. Infected animals and cavies of the other group (not infected, irradiated and intact) were examined with a simultaneous allergic test 7 days after exposure to ionizing radiation. 14 days after irradiation, uninfected animals (5 cavies from each group exposed to the specified doses and intact) were inoculated with the same cultures of tuberculosis pathogens (*M. bovis*, *M. tuberculosis* and *M. avium*) in the same doses.

That is, after total gamma radiation exposure in doses of 0.0129 C/kg (50 R), 0.0258 C/kg (100 R), 0.0387 C/kg (150 R), and 0.0516 C/kg (200 R), experimental animals were infected with cultures in two stages: 7 and 14 days after radiation exposure (75 animals each) were infected with *M. bovis*, *M. tuberculosis* and *M. avium*. 50 cavies

(10 irradiated with doses of 50 R (0.0129 C/kg); 100 R (0.0258 C/kg); 150 R (0.0387 C/kg), and 200 R (0.0516 C/kg) and intact) were not infected with mycobacteria and were used as a control group. Before the infection (1 and 7 days after irradiation), experimental animals were examined by a simultaneous allergic test with PPD-mammalian tuberculin and an allergen from atypical mycobacteria.

14, 45 and 90 days after infection, experimental animals were examined with simultaneous allergic testing, as well as brucellin and mallein (to study the possibility of non-specific pseudoallergic reactions against the background of autosensitisation of the body of irradiated laboratory animals with decay products of their own tissues during radiation damage), which were administered intradermally in a dose of 0.1 ml using separate labeled syringes in the centres of depilated (hairless) skin areas on the sides of cavies. The results of allergic tests were considered 24 and 72 hours after drug administration, entered in the table and analysed using statistical methods.

The work was carried out based on VIEV (Moscow) and the All-Russian Research Institute of Farming Radiology and Agroecology (Obninsk). The results are submitted for printing for the first time. All the experiments described in the paper were conducted in accordance with the current legislation of Ukraine and general international ethical rules and requirements for the use of vertebrates in medical experiments – conclusion of the SNAU Bioethics Commission, Protocol No. 5 dated May 17, 2021 [28-30].

RESULTS AND DISCUSSION

During allergic studies with a simultaneous allergic test 7 days after exposure to ionizing radiation, 2 out of 19 uninfected animals irradiated with doses of 150 R (0.0387 C/kg) and 3 out of 18 irradiated with a dose of 200 R (0.0516 C/kg) showed reactions at the site of administration of mycobacterial allergens. Therewith, reactions to tuberculin were: in the group irradiated with a dose of 150 R (0.0387 C/kg) – in one animal (5.3% of the studied); 200 R (0.0516 C/kg) – 1 (5.5%). The reaction to an allergen from atypical mycobacteria was noted: in the group irradiated with a dose of 150 R (0.0387 C/kg) – 1 animal (5.3% of the studied), 200 R (0.0516 C/kg) – 2 animals (11.5%).

Notably, 72 hours after the administration of allergens in two cavies with an irradiated dose of 200 R (0.0516 C/kg) at the site of administration of an allergen from atypical mycobacteria, cold, painless swellings of dense consistency in the form of peas with a diameter of 9x9 and 5x5 mm were observed, respectively, which indicates the possibility of developing non-specific reactions to mycobacterial allergens in irradiated animals at a later time compared to specific tuberculin ones.

14 days after infection (20 days after irradiation), an allergic study of cavies infected 7 days after general gamma radiation was conducted. Therewith, it was established that among cavies irradiated with a dose of

0.0129 C/kg (50 R), infected with *M. bovis* and *M. tuberculosis*, isolated reactions to mammalian PPD-tuberculin were reported after 24 and 48 hours (16.7 and 33% \pm 0.2 mm responded, respectively). The diameter of the papule at the injection site in cavies infected with *M. bovis* was 9.0 ± 3.0 mm, in infected with *M. tuberculosis* – 9.9 ± 2.5 mm. For those infected with *M. avium*, no allergic reactions to allergens were observed in infected and uninfected animals exposed to a dose of 0.0129 C/kg (50 R).

Among cavies irradiated with a dose of 0.0258 C/kg (100 R) and infected with *M. bovis*, no allergic reactions to tuberculin were recorded. In single animals (20% of the studied) infected with *M. tuberculosis* and *M. avium*, reactions to tuberculin with a papule diameter of 7.1-9.2 mm were observed after 24 hours. There were no allergic reactions in uninfected animals exposed to this dose.

In the groups irradiated with doses of 150 R (0.0387 C/kg) and 200 R (0.0516 C/kg), mass death of animals was noted (from 66.7 to 100%). At the autopsy, hemorrhagic diathesis was noted in the form of extensive hemorrhages of various forms in the mucous and serous membranes of the thoracic and abdominal cavities and parenchymal organs, as well as the serous-hemorrhagic

exudate in the cavities. No allergic reactions to the administration of allergens were observed in animals.

Isolated allergic reactions were observed among unirradiated infected animals:

- in 10% of cavies infected with *M. bovis* – on PPD-tuberculin for mammals (papule diameter from 15 to 29 mm);
- in 50% of those infected with *M. tuberculosis* (papule diameter 17 ± 1.25 mm);
- in 30% of infected with *M. avium* (papule diameter 8.0 ± 2.0 mm).

No reactions to the allergen were observed in uninfected animals. That is, 14 days after infection, animals infected with tuberculosis pathogens 7 days after irradiation in doses of 0.0129 C/kg (50 R) and 0.0258 C/kg (100 R) and not irradiated developed isolated reactions to mycobacterial allergens. Infected animals exposed to doses of 150 R (0.0387 C/kg) and 200 R (0.0516 C/kg), as well as uninfected, both irradiated and intact, did not respond to the administration of allergens.

The results of accounting for a simultaneous allergic test of infected cavies 14 days after irradiation are shown in Table 1.

Table 1. Results of an allergic study of cavies 14 days after infection and 28 days after irradiation

Radiation dose (R/C/kg)	Type of pathogen	Number of animals with allergic reactions	Reaction intensity (mm) to:	
			PPD-tuberculin for mammals	KAM
1	2	3	4	5
50/0.0129	<i>M. bovis</i>	5	10.0 \pm 0.5	
		3		6.3 \pm 2.5
50/0.0129	<i>M. tuberculosis</i>	3	10.0 \pm 0.5	
		2		6.3 \pm 2.5
50/0.0129	<i>M. avium</i>	2	8.0 \pm 1.2	
		3		8.8 \pm 1.1
50/0.0129	Not infected	1	9 \times 9	
		–		
100/0.0258	<i>M. bovis</i>	4	10.1 \pm 0.5	
		2		6.1 \pm 1.6
100/0.0258	<i>M. tuberculosis</i>	3	9.0 \pm 1.5	
		2		6.4 \pm 2.2
100/0.0258	<i>M. avium</i>	2	8.0 \pm 1.1	
		3		8.8 \pm 1.2
100/0.0258	Not infected	1	8 \times 6	
		–		
150/0.0387	<i>M. bovis</i>	1	10 \times 10	
		–		
150/0.0387	<i>M. tuberculosis</i>	2	8.2 \pm 1.7	
		1		6 \times 6
150/0.0387	<i>M. avium</i>	–		
		–		
150/0.0387	Not infected	–		
		–		

Table 1, Continued

Radiation dose (R/C/kg)	Type of pathogen	Number of animals with allergic reactions	Reaction intensity (mm) to:	
			PPD-tuberculin for mammals	KAM
200/0.0516	<i>M. bovis</i>	1	5×5	
		–		
200/0.0516	<i>M. tuberculosis</i>	–		
		–		
200/0.0516	<i>M. avium</i>	–		
		–		
200/0.0516	Not infected	–		
		–		
Not irradiated	<i>M. bovis</i>	4	7.7±1.3	
		1	7×7	
	<i>M. tuberculosis</i>	2	6.8±1.2	
		–		
	<i>M. avium</i>	–		
		–		
	Not infected	–		
		–		

The study was conducted 14 days after infection (28 days after irradiation of animals). From the table materials, it can be seen that cavies irradiated with doses of 50 R (0.0129 C/kg) and 100 R (0.0258 C/kg) and infected with *M. bovis* and *M. tuberculosis*, had intense reactions to the introduced allergens in the form of hyperemia and extensive infiltrates. Animals mainly reacted to mammalian tuberculin (75-100%), while reactions to an allergen from atypical mycobacteria were observed in 50-66% of cases or were absent. In terms of the intensity of manifestation, reactions to tuberculin were larger (papule diameter 10.0±0.5 mm) than to an allergen from atypical mycobacteria (6.3±0.25 mm).

In the groups of uninfected animals exposed to total gamma radiation at doses of 50 R (0.0129 C/kg) and 100 R (0.0258 C/kg), two cavies (one in each group) responded to tuberculin after 48 hours. Reactions were dense consistency, painless infiltrates at the injection site (papule diameter 9x9 and 8x8 mm, respectively), skin hyperemia was not noted. In cavies irradiated at doses of 50 R (0.0129 C/kg) and 100 R (0.0258 C/kg) and infected *M. avium*, positive reactions were observed mainly on KAM. Reactions were observed in 66.7-80% of the experimental animals, with a papule diameter of 8.8±1.1 mm. Positive reactions to mammalian tuberculin were observed in 33.3-40% of the studied animals, the infiltrate diameter was 8.0±1.2 mm.

Among animals irradiated with doses of 150 R (0.0387 C/kg) and 200 R (0.0516 C/kg), deaths were recorded (from 33.3 to 100% in the group). At the autopsy, the hemorrhagic syndrome was observed with the serous effusion in the body cavities. In groups of animals irradiated with doses of 150 R (0.0387 C/kg) and 200 R (0.0516 C/kg), infected with *M. bovis*, positive reactions to mammalian PPD-tuberculin were noted. Therewith, in

the group irradiated with a dose of 150 R (0.0387 C/kg), one cavy remained and reacted during the study (papule diameter – 10.0 mm). In the group irradiated with a dose of 200 R (0.0516 C/kg), the reaction was observed in one of the three studied animals (papule diameter – 5.0 mm).

In the group of irradiated cavies with a dose of 150 R (0.0387 C/kg) and infected with *M. tuberculosis* at the time of the study, two animals remained alive. Both responded positively to mammalian administration of PPD-tuberculin (papule diameter – 8.2±1.2 mm). One cavy reacted to KAM (papule diameter – 6.0 mm). In the group of irradiated with a dose of 150 R (0.0387 C/kg) and infected with *M. avium*, one of the two animals left alive on the day of the study responded to KAM with a papule diameter of 5.0 mm.

Among the unirradiated cavies infected with *M. bovis* and *M. tuberculosis*, positive reactions to tuberculin were observed. In animals infected with *M. avium*, no allergic reactions were observed. Thus, from 50 to 100% of infected animals reacted to specific allergens 14 days after exposure to various doses of gamma radiation (with the exception of those infected with *M. avium*). At the same time, uninfected cavies irradiated with doses of 150 R (0.0387 C/kg) and 200 R (0.0516 C/kg) had single 150 R (0.0387 C/kg) and 200 R (0.0516 C/kg), non-specific reactions to tuberculin.

Based on a comparison of the results of an allergic study of experimental animals infected at intervals of 7 and 14 days after exposure to ionizing radiation, it can be argued that 2 weeks after the administration of infectious material, contaminated animals, both irradiated and intact, showed an infectious allergy to specific allergens. Therewith, in groups of animals infected with mycobacteria 7 days after irradiation, 16.7-50% reacted positively, while among animals infected 14 days after

irradiation – 50-100%, which indicates a faster development of the infectious process in animals infected 2 weeks after irradiation, when the symptom complex of pronounced clinical signs of radiation sickness manifests itself more intensively, as evidenced by the mass death of cavies (up to 100% in groups irradiated 150 R (0.0387 C/kg) and 200 R (0.0516 C/kg)) with a picture of hemorrhagic syndrome and progressive changes in the hematopoietic organs.

That is, 14-21 days after irradiation among cavies irradiated with doses of 150 R (0.0387 C/kg) and 200 R (0.0516 C/kg), mass death of animals was noted (from 66.7 to 100% in the group). At the autopsy, pathoanatomical changes characteristic of radiation damage were

noted: hemorrhagic diathesis in the form of extensive hemorrhages on the mucous membranes and in the serous membranes of the thoracic and abdominal cavities, as well as the presence of serous-hemorrhagic exudate in the cavities.

Starting from 21 days after infection in dead irradiated and unirradiated cavies infected with *M. bovis* and *M. tuberculosis*, tuberculosis-specific lesions of varying intensity were noted: exhaustion, ulcers at the culture injection site, and at autopsy, a considerable increase in the liver and spleen was observed with the presence of foci of caseous necrosis in them (Fig. 1-4). Among the cavies infected with *M. avium*, no such lesions were observed.

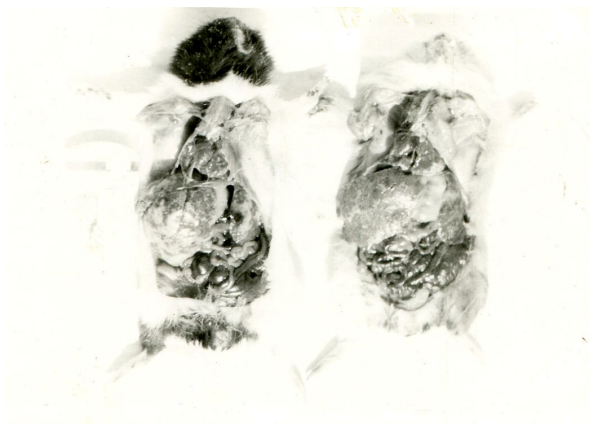


Figure 1. Generalised tuberculosis of cavies that died 25 days after infection with *M. bovis*, irradiated with gamma radiation at a dose of 150 R (0.0387 C/kg). Considerable enlargement of the liver, spleen, foci of caseous necrosis



Figure 2. Considerable enlargement of the spleen, miliary tuberculosis in cavy exposed to a dose of 200 R (0.0516 C/kg), which died 25 days after an infection with *M. tuberculosis*

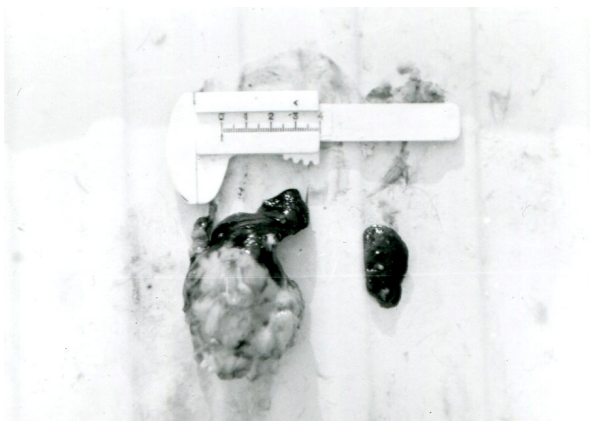


Figure 3. The spleen of the cavy deceased 31 days after an infection with *M. bovis* (left). On the right is the spleen of a cavy infected with *M. avium* at the same time. Irradiation with a dose of 150 R (0.0387 C/kg)

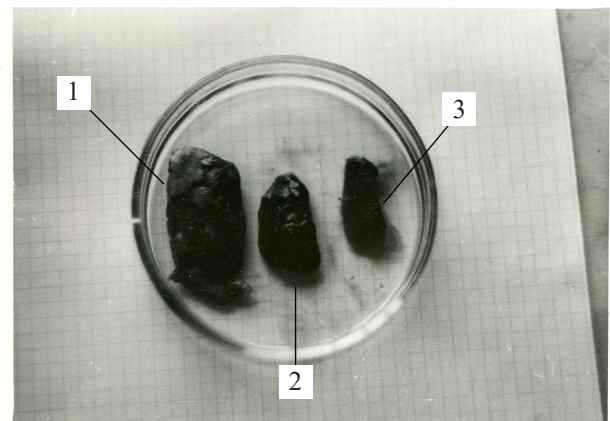


Figure 4. Spleens of cavies irradiated with a dose of 50 R (0.0129 C/kg), who died after the twentieth day after infection: 1 – *M. bovis*; 2 – *M. tuberculosis*; 3 – *M. avium*

Figure 4 shows that the seals, the appearance of tubercles and necrotic foci with caseous contents are noticeable in the first two cases. In the third case, there are no tuberculosis lesions.

Notably, 25-33.3% of uninfected animals exposed to doses of 50 R (0.0129 C/kg) and 100 R (0.0258 C/kg) had pseudoallergic reactions to tuberculin (non-specific allergy) 27 days after irradiation.

60 days after the beginning of an experiment allergic reactions to mammalian PPD-tuberculin were observed among animals irradiated with a dose of 50 R (0.0129 C/kg) in groups infected with *M. bovis* and *M. tuberculosis*. Out of the nine cavies infected with *M. bovis*, reactions were observed in six (66.7%), the papule diameter was 11.8 ± 1.1 mm. Out of eight animals infected with *M. tuberculosis*, 7 reacted positively to tuberculin, the papule diameter was 21.3 ± 1.6 mm. In the group contaminated with *M. avium*, seven of the eight cavies that remained alive at the time of the study showed reactions to PPD-tuberculin for poultry, the papule diameter was 13.6 ± 1.2 mm. Therewith, isolated pseudoallergic reactions to brucellin and mallein (non-specific allergy) were noted in the studied animals. Therewith, in the group of animals infected with *M. tuberculosis*, three cavies with a papule diameter of 9.7 ± 0.2 mm reacted to brucellin. In the group infected with *M. avium*, two cavies reacted to brucellin, the papule diameter was 8×8 mm, and three reacted to mallein (diameter 7.0 ± 0.7 mm). In the group of uninfected animals irradiated with a dose of 50 R (0.0129 C/kg), one of the ten cavies had a reaction to brucellin (diameter 10 mm).

In the group of cavies exposed to radiation at a dose of 100 R (0.0258 C/kg) and infected with *M. bovis*, two out of five animals responded positively to mammalian tuberculin (papule diameter 13.0 ± 0.2 mm). In the group infected with *M. tuberculosis*, all animals responded to drug administration (papule diameter 17.5 ± 0.7 mm). Among those infected with the poultry tuberculosis pathogen, all animals responded to PPD-tuberculin for poultry. One cavy had a reaction in the form of an infiltrate with skin redness with a diameter of 10 mm at the brucellin injection site. No allergic reactions were observed in control (uninfected) animals exposed to a dose of 100 R (0.0258 C/kg).

Among those irradiated with a dose of 150 R (0.0387 C/kg) from the group of animals infected with *M. bovis* on the day of the study, one guinea pig remained alive, which developed an allergic reaction in the form of an infiltrate with erythema of the skin with a diameter of 5 mm 48 hours after the administration of PPD-tuberculin for mammals. Out of those infected with *M. tuberculosis*, two cavies that reacted to mammalian tuberculin (papule diameter 20.0 ± 1.6 mm) remained alive. One of these animals had a skin allergic reaction to brucellin in the form of an infiltrate with skin redness of size 8×6 mm.

All studied cavies infected with *M. avium* reacted to PPD-tuberculin for poultry (papule diameter 17.1 ± 0.8 mm). One animal showed a reaction to brucellin (infiltrate with a diameter of 5 mm). All control (uninfected) animals exposed to a dose of 150 R (0.0387 C/kg) died during the study. In the group irradiated with a dose of 200 R (0.0516 C/kg) and infected with *M. bovis* on the day of the study, no cavies remained alive. In the group of cavies infected with *M. tuberculosis*, only one remained alive. The animal was exhausted, an open abscess was

observed at the site of infection. The animal did not respond to the administration of allergens (a state of anergy).

In the group of cavies irradiated with a dose of 200 R (0.0516 C/kg) and infected with *M. avium*, two animals remained alive. One of them showed a reaction to PPD-tuberculin for poultry, the papule diameter is 20 mm. All uninfected animals from the group exposed to a dose of 200 R (0.0516 C/kg) on the day of the study died.

In the group of unirradiated, infected with *M. bovis* at the time of the allergic study, only one cavy remained alive, which responded to the administration of PPD-tuberculin for mammals, with a papule diameter of 16 mm.

Out of nine animals infected with *M. tuberculosis*, skin allergic reactions in the form of large infiltrates with a diameter of 22.0 ± 2.2 mm with areas of ischemia and necrosis in the centre were observed in eight unirradiated animals at the site of tuberculin administration. In 40% of the studied animals, skin lesions were observed in the form of abscesses and ulcers at the site of administration of infectious material.

In the group of unirradiated animals, contaminated with *avium*, allergic skin reactions with a diameter of 13.0 ± 2.1 mm were observed in 6 out of 7 studies at the injection site of PPD-tuberculin for poultry. All the cavies were well-fed and active. No allergic reactions were recorded in the group of unirradiated and uninfected animals.

Thus, reactions to homologous allergens were observed 60 days after exposure (48-53 days after infection) and most (50-100%) infected irradiated and intact animals. Reactions were intense in the form of hyperemia and extensive infiltrates, often with areas of ischemia and necrosis. Exhausted animals with noticeable skin lesions in the form of ulcers or abscesses did not respond to allergens (a state of anergy).

In infected and intact animals exposed to doses of 50 R (0.0129 C/kg), 100 R (0.0258 C/kg) and 150 R (0.0387 C/kg), isolated reactions to the administration of heterologous bacterial allergens (brucellin and mallein) were observed. Therewith, 12.5% of the total number of animals exposed to brucellin reacted, including 20% of those exposed to a dose of 50 R (0.0129 C/kg), 3.5% of those infected with a dose of 100 R (0.0258 C/kg), and 30% of those exposed to a dose of 150 R (0.0387 C/kg) in groups infected with *M. tuberculosis* and *M. avium*. 8.3% of irradiated animals reacted to mallein, while reactions were observed only in the group of cavies exposed to a dose of 50 R (0.0129 C/kg).

Thus, after the infection with tuberculosis pathogens, laboratory animals developed allergic reactions to homologous allergens (PPD tuberculin and an allergen from atypical mycobacteria). Non-specific reactions to mycobacterial allergens were observed in 5.6-33% of animals not infected with the causative agent of

tuberculosis after irradiation. Cavies infected with the causative agent of tuberculosis experienced isolated reactions to heterologous allergens: brucellin and mallein 60 days after irradiation. The manifestation of non-specific allergies in irradiated laboratory animals depended on the radiation dose. After infection of cavies irradiated with various doses of radiation and not irradiated with the causative agent of poultry tuberculosis, starting from 14 days after the administration of infectious material, the animals developed delayed-type hypersensitivity to mycobacterial allergens, which persisted until the end of the experiment. Clinical and pathoanatomical manifestations of the disease were not observed in irradiated and intact animals.

The results of previous researchers in the area of studying the allergic reactivity and state of delayed hypersensitivity of irradiated and infected animals with tuberculosis convincingly prove that ionizing radiation affects the manifestation of tuberculin sensitivity, the course of tuberculosis infection, and autoimmune processes in the body. The works of B.A. Egorov, A.A. Kirstner [31]; P.A. Kartashov et al. [32; 33]; N.N. Klemparskaya et al. [34-39]; R.V. Petrov [40; 41]; A.Yu. Kassich [42] and other authors showed that the effect of ionizing radiation is not the same depending on the value of the radiation dose. One of the reasons for the manifestation of non-specific reactions may be autoallergisation of the body by the decay products of the tissues of the irradiated body, which is especially pronounced with radiation damage. When studying the specificity of allergic reactions in tuberculosis in irradiated animals, it was determined that the occurrence of pseudoallergic ("false") reactions depends on the level of autosensitisation of the body, which, in turn, depends on the total radiation dose received. Thus, researchers believe that the main role in the pathogenesis of radiation damage is played by activated oxygen metabolites – products of lipid peroxidation, which cause the development of autoimmune processes in the macroorganism. After radiation exposure, autosensitisation of the body occurs due to a violation of the antigenic specificity of proteins. The resulting autoantibodies have cytolytic activity. N.N. Klemparskaya et al. [43] believe that autoimmune reactions in the irradiated body proceed according to the type of auto-allergic processes, the side effect of which is the occurrence of non-specific (pseudoallergic) reactions to the administration of homologous and heterologous allergens. Therewith, if autoantibodies completely neutralise the products of cellular destruction, the pathological process with the development of large amounts of cytotoxic autoantibodies does not occur. With incomplete neutralisation of products, clinical signs of radiation damage develop. Some researchers believe that autoantibodies formed in the irradiated body are involved in increasing its radioresistance with

single sublethal doses and with chronic low-dose radiation. It is also known that in irradiated animals that are not infected with pathogens of infectious diseases, due to autosensitisation by decay products of their own tissues, skin allergic reactions can occur to the administration of various non-specific stimuli [1; 4; 10; 12; 15]. The authors have suggested that this phenomenon can be used to differentiate pseudoallergic reactions in animals, in particular those kept in the zone of radioactive contamination. The conducted experiments proved that when using non-specific heterologous allergens at the same time with specific diagnosticums when conducting allergic studies for tuberculosis, it is possible to assert the specificity of allergic reactions to tuberculin and allergen from atypical mycobacteria and the degree of autosensitisation of the body. If skin reactions develop simultaneously to the administration of different allergens (PPD-tuberculin for mammals, poultry, an allergen from atypical mycobacteria, brucellin and mallein), then this refers to an autoallergic state of the body caused by non-specific (non-infectious) agents, in particular, the action of ionizing radiation.

CONCLUSIONS

The effect of irradiation on the allergic reactivity of laboratory animals experimentally infected with tuberculosis pathogens was determined.

1. 14-60 days after infection with tuberculosis pathogens *M. bovis*, *M. tuberculosis* and *M. avium*, 90-100% of laboratory animals developed allergic reactions to mammalian and poultry PPD-tuberculin, mainly to a homologous allergen. Allergic reactivity persisted until 90 days of the study.

2. After irradiation with sublethal doses of gamma rays, cavies developed non-specific reactions to tuberculin, mallein, and brucellin. In cavies not infected with the causative agent of tuberculosis, non-specific reactions to mycobacterial allergens were observed 7 days after gamma radiation exposure at a dose load of 200 R in 16.6%; 150 R – 5.3% in the group, and after 27 days in those irradiated with doses of 50 R and 100 R in 25% and 33% of the studied animals, respectively. Reactions manifested themselves in the form of infiltrates at the allergen injection site with necrosis in the centre and developed over time at the same time as specific tuberculin reactions.

3. Isolated reactions to brucellin and mallein occurred in animals infected with the causative agent of tuberculosis and intact animals 60 days after irradiation with doses of 50 R, 100 R and 150 R. The manifestation of non-specific allergies in irradiated laboratory animals depends on the radiation dose rate and radiosensitivity of the animals. Further studies of the allergic reactivity of farm animals exposed to tuberculosis are required.

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Вплив іонізуючої радіації на стан алергічної реактивності інфікованих туберкульозом лабораторних тварин

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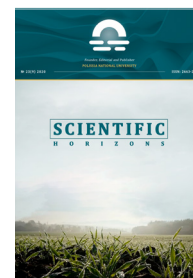
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Анотація. Алергічне дослідження з використанням ППД-туберкулінів є основним методом прижиттєвої діагностики туберкульозу сільськогосподарських тварин та птиці. Проте відомо про зниження діагностичної цінності алергічних реакцій після опромінення тварин, появу неспецифічних, псевдоалергічних реакцій. Однією з причин прояву неспецифічних реакцій може бути аутосенсibiliзація (аутоалергізація) організму продуктами розпаду особистих тканин, що особливо виражено за променевого ураження. Іонізуюча радіація впливає на прояв туберкулінової чутливості, перебіг туберкульозу та аутоімунні процеси в організмі. Диференціальна діагностика неспецифічних туберкулінових реакцій лишається поки що не повністю вирішеною проблемою, хоча існує цілий ряд тестів для її здійснення. Після аварії на Чорнобильській АЕС на прилеглих забруднених радіоактивними речовинами територіях лишилося значне поголів'я тварин, у тому числі інфікованих збудником туберкульозу та атипovими мікобактеріями. Відомо, що радіаційне опромінення призводить до аутосенсibiliзації організму продуктами розпаду власних тканин і розвитку неспецифічних псевдоалергічних реакцій на гетерологічні алергени. Тому була проведена робота з вивчення алергічної реактивності хворих на туберкульоз і сенсibiliзованих атипovими мікобактеріями опромінених гамма-радіацією лабораторних тварин (200 морських свинок). Було встановлено, що через 14–60 діб після зараження збудниками туберкульозу у 90–100 % мурчаків розвивались алергічні реакції на ППД-туберкулін для ссавців та птиці, переважно на гомологічний алерген. Алергічна реактивність зберігалась до 90 доби дослідження. Після опромінення сублетальними (не летальними) дозами гамма-променів у заражених та інтактних морських свинок розвивались неспецифічні реакції на туберкулін і гетерологічні алергени: малеїн та бруцелін. У незаражених збудником туберкульозу мурчаків через 7 діб після опромінення гамма-випромінюванням спостерігали неспецифічні реакції на мікобактеріальні алергени при дозовому навантаженні 200 Р у 16,6 %; 150 Р – 5,3 % по групі, а через 27 діб у опромінених дозами 50 Р та 100 Р у 25 % та 33 % досліджених тварин, відповідно. У інфікованих збудником туберкульозу та інтактних тварин через 60 діб після опромінення в дозах 50 Р, 100 Р та 150 Р виникали поодинокі реакції на бруцелін та малеїн. Прояв неспецифічної алергії у опромінених тварин залежала від потужності дози опромінення та радіочутливості тварин

Ключові слова: туберкулін, гетерологічні алергени, гамма-опромінення, мікобактерії, алергічні дослідження



UDC 631.862:636.52/58:504.05

DOI: 10.48077/scihor.24(10).2021.28-34

Reducing Greenhouse Gas Emissions from Chicken Droppings for the Use of Inorganic and Biologically Active Substances

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Article's History:

Received: 18.10.2021

Revised: 16.11.2021

Accepted: 15.12.2021

Suggested Citation:

Vorobel, M., Kaplinskyi, V., Klym, O., Pinchuk, V., & Dmytrotsa, A. (2021). Reducing greenhouse gas emissions from chicken droppings for the use of inorganic and biologically active substances. *Scientific Horizons*, 24(10), 28-34.

Abstract. The leading place in the structure of livestock production is occupied by poultry farming. The intensive development of this industry poses a problem in maintaining the cleanliness of the environment since, in addition to the main products, there is a considerable amount of waste. The latter serves as a source of greenhouse gases entering the atmosphere, which are one of the main causes of negative changes in the climatic balance of the planet. Therefore, determining the level of greenhouse gas emissions under the influence of inorganic and biologically active substances was the basis of the planned research. As a result of the conducted studies, the effectiveness of the studied substances – perlite, glauconite, saponite, vermiculite, biopreparations Kapeliukhiv Yarok and Scarabei, magnesium acetate and superphosphate – was established to reduce the level of methane (CH₄), carbon dioxide (CO₂) and nitric oxide (NO) release from poultry litter (*in vitro*). In particular, it was determined that vermiculite, which most effectively affects greenhouse gas emissions from poultry litter from natural sorbents, reduces the level of CH₄ and CO₂ by 10.5-14.4%, and NO – 9.6-11.2%. The biological product of Kapeliukhiv Yarok more effectively reduces the emission of CH₄ and CO₂ from the test substrate by 12.9-17.3%, and Scarabei – NO by 11.8-13.3%. The introduction of magnesium acetate and superphosphate into fermented poultry litter helps to reduce the level of CH₄ and CO₂ release by 14.8-18.7% and 14.0-17.4%, respectively, and NO – by 15.3-16.1% and 12.4-14.7%. Studied substances that reduce greenhouse gas emissions to the greatest extent (*in vitro*) – magnesium acetate, superphosphate, biopreparations Kapeliukhiv Yarok and Scarabei, vermiculite from the studied substrate, and at the same time provide the lowest pH level – 6.55-7.15 units. Thus, the determination of the effectiveness of the studied inorganic and biologically active substances on reducing greenhouse gas emissions from poultry litter (*in vitro*) indicates the prospects of their use to prevent environmental pollution in the intensive management of the poultry industry

Keywords: poultry farming, waste, methane, carbon dioxide, nitric oxide



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INTRODUCTION

The agricultural sector with its basic component, agriculture, is system-forming in the national economy and provides stability, food independence, and security of the state [1; 2]. The most dynamic branch of agriculture, which began to revive one of the first and has already achieved high technological and economic results is the poultry industry, which provides high-quality food to the population of Ukraine and allows exporting some products abroad [3]. It is known that one kilojoule of energy from eggs and poultry requires twice less energy than milk production and three times less than pork and beef [4]. Intensive development of the poultry industry faces the problem of excessive environmental pollution, as along with the main products (meat, eggs, products of slaughter and processing, down, feathers, etc.) there is an accumulation of considerable by-products of animal origin, including large quantities of poultry litter [5; 6]. Thus, the average anthropogenic load from poultry waste on the territory of Ukraine is 0.22 million tonnes/km², that is, 3000 tonnes for every thousand of population [4; 7].

The accumulation of considerable amounts of waste causes various types of atmospheric pollutions, including greenhouse gases such as methane, carbon dioxide, nitrogen oxide, etc., which serve as a source of air, soil, and water pollution and thus lead to air temperature increase on the planet, emergence of acid rain, droughts, floods, declining of drinking water supplies, formation of atmospheric aerosols [8; 9]. Greenhouse gases are the driving factors of climate change that have befallen humanity over the last century [8]. According to the Food and Agriculture Organisation of the United Nations (FAO), greenhouse gas emissions from agriculture, forestry and fisheries have almost doubled over the past 50 years and tend to increase by 30% by 2050 if a number of effective measures will not be implemented to improve environmental situation [10]. In terms of the greenhouse gas emissions scale, agriculture, although inferior to energy and industry, is still a powerful source of pollution both in Ukraine and worldwide [11; 12]. Agriculture, which often suffers from climate change, is simultaneously one of the reasons for this change [13]. Given the above, a necessary condition for the development of the poultry industry is maintaining a balance between increasing production and effective rational disposal of waste, which will minimise the negative effect of agriculture on the environment [14-16]. The research of many scientists has been devoted to the problems of environmental pollution caused by the activities of poultry farms [17-19]. However, the available literature provides information mainly on reducing emissions of certain gases from the waste, in particular, ammonia or hydrogen sulfide [20-22]. The task of developing measures to reduce the emission of greenhouse gases – methane, carbon dioxide, nitrogen oxide from animal by-products remains unsolved.

Thus, minimising greenhouse gas emissions from poultry litter is an extremely important task today due to the active development of the poultry farming and the intensive accumulation of a considerable amount of waste. Therefore, the search for effective means and ways to

reduce greenhouse gas emissions from poultry litter without harming the environment is an important scientific and practical issue to solve.

The purpose of the study was to establish the effect of inorganic and biologically active substances on the emission of greenhouse gases from poultry litter – CH₄, CO₂, NO during anaerobic fermentation (*in vitro*) to prevent their entry into the environment.

MATERIALS AND METHODS

Research for establishing the effectiveness of inorganic and biologically active substances on the level of such greenhouse gases emission as methane, carbon dioxide, nitrogen oxide from poultry litter was carried out using experimental-laboratory, statistical-mathematical, and analytical methods. To conduct the experiment, samples of poultry litter without additions were taken at the farm “Zahid-Ptytsia” in Pustomyty district, Lviv region. The study was performed *in vitro* according to the method of O.G. Skliar et al. [23]. Closed tanks were used in the experiment for anaerobic conditions. To stabilise the process of anaerobic fermentation, poultry litter was diluted with water and the substrate humidity was adjusted to 92%. Each option of the experiment was repeated three times. During the experimental studies, the substrate was periodically shaken. Similar conditions of the biofermentation process were in the control option of the study, where anaerobic fermentation of the substrate occurred due to the natural microflora of litter, as well as in experimental analogues using the studied inorganic and biologically active substances. In the experiment, at each stage of biofermentation (hydrolysis, oxidation, acetogenesis, methanogenesis), the temperature regime was maintained. The study was conducted under the mesophilic regime at a temperature within 33°C since the mesophilic regime is characterised by the highest stability of the biofermentation process and small temperature fluctuations are allowed without disrupting fermentation. It is known that biofermentation can be carried out in a wide range of temperatures, but not below 6°C since there is a cessation of the microorganisms' activity at this temperature [24]. One of the important factors is also the time of biomass fermentation. Depending on the temperature, the fermentation exposure is set in the following intervals: at 10-25°C up to 30 days, at 25-40°C – from 10 to 20 days, at 45-55°C – from 4 to 8 days [25]. In this experiment, the exposure to biomass fermentation was 17 days.

To achieve the reduction of greenhouse gas emissions from poultry litter, on the 17th day from the beginning of anaerobic fermentation, inorganic and biologically active substances were added to the fermented substrate in optimal pre-established and economically substantiated doses: Option I – control (without substances); Option II – perlite, 3%; Option III – glauconite, 3%; Option IV – saponite, 3%; Option V – vermiculite, 3%; Option VI – Kapeliukhiv Yarok, 150 g/m³; Option VII – Scarabei, 40 g/m³; Option VIII – magnesium acetate, 3%; Option IX – superphosphate, 3%. In addition, the

level of greenhouse gases – methane, carbon dioxide, nitrogen oxide in the control and experimental variants was measured. Subsequently, during the experiment, every three days, the measurement of greenhouse gases level was performed using a portable alarm-analyser Dozor C-M-5 (certificate of the device verification type UA.TR.001 212-18 and certificate of conformity UA.TR.002.CB.1234-19). The key factor determining the area of anaerobic fermentation is the hydrogen index (pH). That is why the experiment also determined the acid of the test substrate (at the beginning of the experimental studies and their completion) using a pH-meter Tour N5170. Statistical and mathematical analysis of the obtained research results was performed using the methods of variation statistics and Student's t-test standard package *Microsoft EXCEL* and *AtteStat*. Arithmetic mean values (M) and arithmetic mean errors (m) were calculated. Differences between arithmetic means were considered statistically significant by: * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

RESULTS AND DISCUSSION

Based on the studies, it was established that the pH

of poultry litter in hydrogen substrates in the control options (without the introduction of substances) before and at the end of the study (*in vitro*) was in the range of 8.35-8.55 units (Fig. 1), that is, had an alkaline reaction. After the introduction of inorganic and biologically active substances into the fermented poultry litter, the processes of anaerobic fermentation decreased and at the end of the study, there was a change in the hydrogen substrates of poultry litter in pH to the acidic side with the use of perlite – up to 7.38 units, glauconite – 7.3, saponite – 7.6, vermiculite – 7.15, biologically active substances – Kapeliukhiv Yarok – 6.55, Scarabei – 6.7, magnesium acetate – 6.65, superphosphate – 6.75 units, compared with the control – 8.55 units, which indicates inhibition of the activity of microorganisms due to increasing concentrations of H^+ ions.

The obtained experimental data indicate that the studied substances, which caused the greatest decrease in pH, were at the same time the most effective in reducing the emission of studied greenhouse gases – CH_4 (Fig. 2), CO_2 , NO from the substrate of poultry litter (*in vitro*).

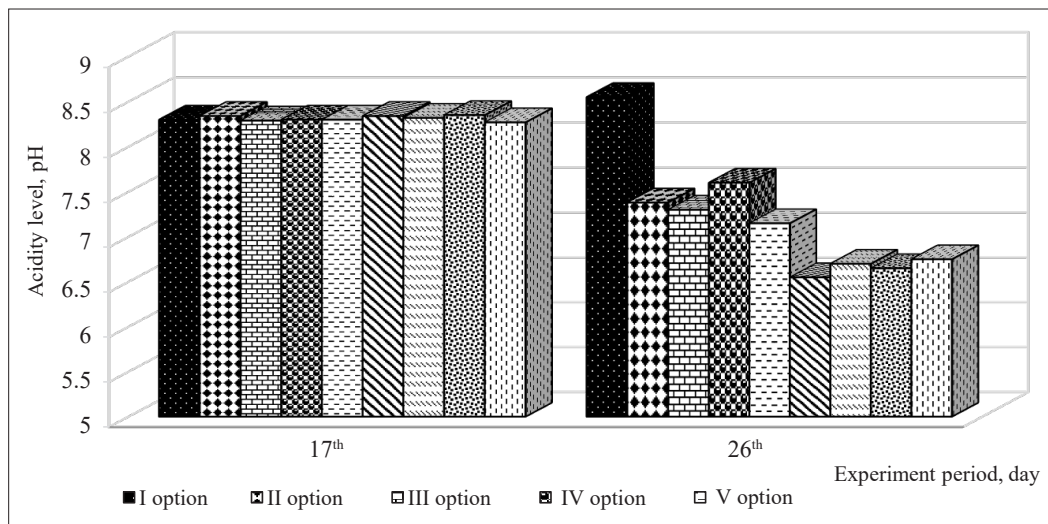


Figure 1. Acidity level in options using inorganic and biologically active substances

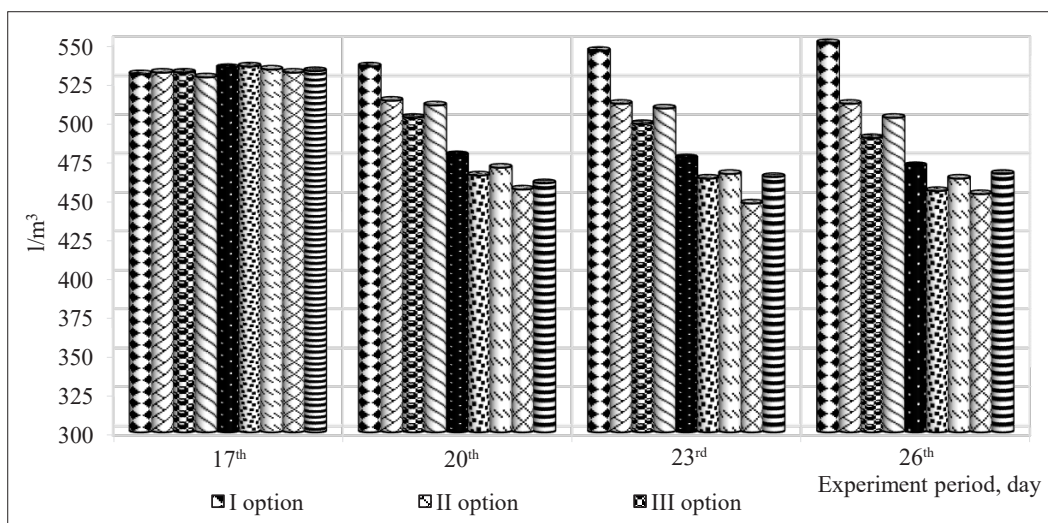


Figure 2. The level of methane emission in options using inorganic and biologically active substances

Analysis of the results showed that the intensity of anaerobic fermentation and the processes of greenhouse gases emission in the substrate of poultry litter depend on the duration of the experiment. The introduction of natural sorbents into the fermented poultry litter – perlite, glauconite, saponite, and vermiculite helps to reduce the level of methane and carbon dioxide (Fig. 3). In particular, when perlite is added to the studied substrate, methane and carbon dioxide emissions are reduced by 20-26th days, respectively, by 22-39 l/m³ and 15-28 l/m³, that is 3.9-7.1% (P<0.05-0.001) regarding control. The use of glauconite causes a decrease in the level of CH₄ and CO₂ from fermented poultry litter, depending on the day of the experiment, respectively, by 33 l/m³ and 24 l/m³ – 6.2% (P<0.01-0.001) – 20th day; by 47 l/m³ and 33 l/m³ or 8.5% (P<0.01-0.001) – 23rd day; by 61 l/m³

and 44 l/m³, that is 11.1% (P<0.001) – 26th day, compared to the control options. It was also established that in the options with the addition of saponite there is a decrease in methane and carbon dioxide emissions from the studied substrate, namely: on the 20th day – 25 l/m³ and 18 l/m³ – 4.6% (P<0.01); on the 23rd day – 37 l/m³ and 26 l/m³ or 6.7% (P<0.05-0.001); on the 26th day – 48 l/m³ and 34.5 l/m³, that is 8.7% (P<0.001), relative to control. During the same study period (20-26 days), the level of CH₄ and CO₂ emissions from fermented poultry litter when using vermiculite was lower than the control, respectively, by 57-79 l/m³ and 41-57 l/m³, which was the percentage – 10.5-14.4% (P<0.01-0.001). Thus, the natural sorbent – vermiculite – had the most pronounced effect on reducing the emission of methane and carbon dioxide from the substrate of poultry litter in the above period.

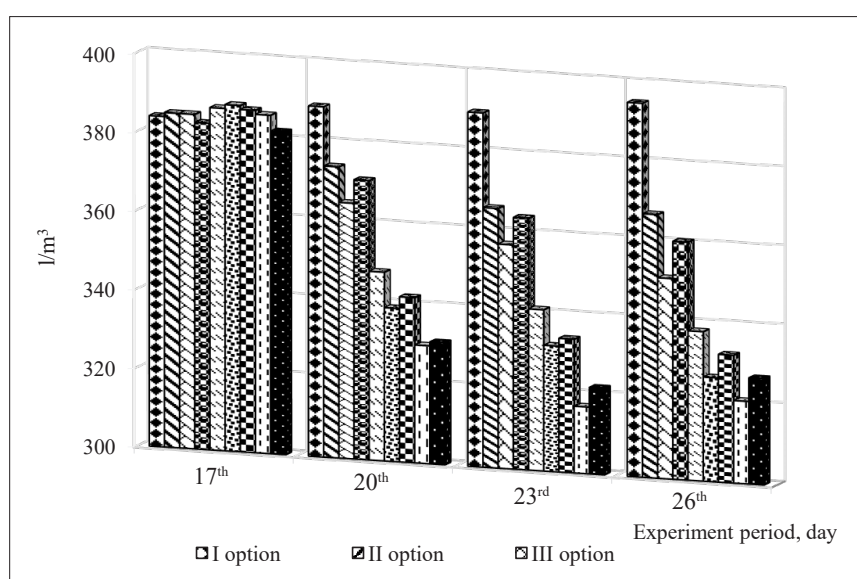


Figure 3. The level of carbon dioxide emission in options using inorganic and biologically active substances

The use of biological products – Kapeliukhiv Yarok and Scarabei – also have a positive effect on the emission of greenhouse gases from the substrate of poultry litter. The application of the biological product Kapeliukhiv Yarok to the substrates helps to reduce the level of methane and carbon dioxide from the studied substrate during anaerobic fermentation, respectively, on the 20th day – 70 l/m³ and 50 l/m³, that is 12.9-13.1% (P<0.05-0.001), compared to control; on the 23rd day – 82 l/m³ and 58 l/m³ or 14.9-15.1% (P<0.001) and on the 26th day – 95 l/m³ and 68.5 l/m³ – 17.3% (P<0.001). The use of the biological product Scarabei reduces the emission of CH₄ and CO₂ from fermented poultry litter by 20-26 days, respectively, by 65-87 l/m³ and 47-62.5 l/m³ relative to the control, which in percentage was 12.1-15.8% (P<0.001).

According to the obtained research results, it was established that the introduction of magnesium acetate into the studied substrate helps to reduce the level of methane and carbon dioxide emissions, depending on the day of the study, respectively: on the 20th day – 79 l/m³ and

59 l/m³ or 14.8% and 15.2% (P<0.001); on the 23rd day – 98 l/m³ and 73 l/m³ – 18.0% and 18.7% (P<0.001), and on the 26th day of the study – 97 l/m³ and 74 l/m³, that is 17.6% and 18.7% (p<0.001).

In the options using superphosphate, the emission of CH₄ and CO₂ from fermented poultry litter is reduced on 20-26th days of the study, respectively, by 75-84 l/m³ and 58-68 l/m³, which in terms of percentage was 14.0-15.3% and 14.9-17.4% (P<0.001). Thus, analysing the obtained results, it should be noted that the lowest level of methane and carbon dioxide emissions from poultry litter substrate in all experimental options using inorganic and biologically active substances was observed on the 26th day of the experiment – 7.1-18.7%.

The obtained results testify that at the introduction of perlite in the investigated substrate there was a decrease in emission of nitrogen oxide (Fig. 4), depending on days of the experiment, accordingly: on the 20th day – 12.5 mg/m³, that is 9.9%; on the 23rd day – 8.7 mg/m³ – 8.3% (P<0.01), and on the 26th day – 6.7 mg/m³ or

8.2% ($P < 0.05$) relative to control. The use of glauconite helps to reduce the level of NO emission from fermented poultry litter, respectively, by 14.6 mg/m^3 or 11.5% ($P < 0.01$) – 20th day; by 10.9 mg/m^3 , that is 10.4% ($P < 0.01$) – 23rd day; by 8.0 mg/m^3 – 9.7% – 26th day, compared to the control analogue. The introduction of saponite into the studied substrate causes a decrease in nitrogen oxide emission by

20th day – 9.1 mg/m^3 – 7.2%; on the 23rd day – 6.2 mg/m^3 or 5.9% ($P < 0.05$), and on the 26th day – 4.3 mg/m^3 , that is 5.2%. The level of NO emission from fermented poultry litter was lower in the options with vermiculite, relative to control, respectively, by 14.2 mg/m^3 – 11.2% ($P < 0.05$) – 20th day; by 11.1 mg/m^3 , that is 10.6% ($P < 0.05$) – 23rd day and by 7.9 mg/m^3 or 9.6% ($P < 0.05$) – 26th day.

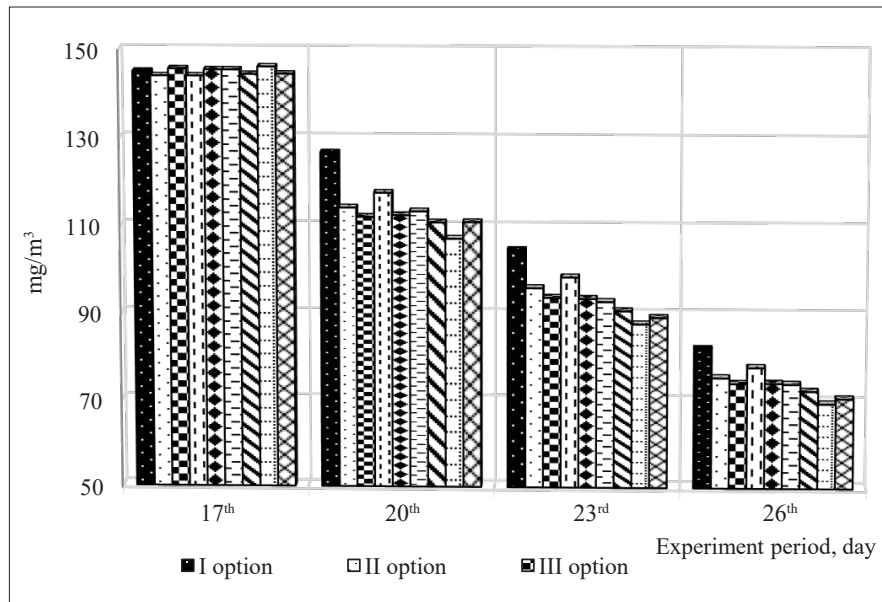


Figure 4. The level of nitrogen oxide emission in options using inorganic and biologically active substances

Reduction of nitrogen oxide emission from the studied substrate is also observed by the use of biological products Kapeliukhiv Yarok and Scarabei, respectively, on the 20th day – 13.3 mg/m^3 and 15.8 mg/m^3 , that is 10.5% and 12.5% ($P < 0.05$); on the 23rd day – 11.8 mg/m^3 and 13.9 mg/m^3 or 11.3% and 13.3%; on the 26th day – 8.1 mg/m^3 and 9.7 mg/m^3 – 9.9% and 11.8% ($P < 0.05$), compared to the control options.

When magnesium acetate and superphosphate were added to the fermented poultry litter, the level of NO emission was lower, respectively, by 19.5 mg/m^3 , that is 15.4% ($P < 0.05$) and 15.7 mg/m^3 – 12.4% ($P < 0.05$) – 20th day; by 16.9 mg/m^3 or 16.1% ($P < 0.001$) and 15.4 mg/m^3 – 14.7% ($P < 0.01$) – 23rd day; by 12.6 mg/m^3 or 15.3% ($P < 0.01$) and 11.4 mg/m^3 that is 13.9% ($P < 0.001$) – 26th day.

The most effective in reducing nitrogen oxide emissions in the process of biofermentation of the studied substrate using natural sorbents – perlite, glauconite, saponite and vermiculite were set on the 20th day, and biological products – Kapeliukhiv Yarok and Scarabei; magnesium acetate and superphosphate – on the 23rd day of research. The obtained research of results in reducing the level of greenhouse gases emission from chicken manure is consistent with studies of W. Qasim et al. who used aluminum sulfate and ferric chloride blend in different ratios in vitro, which caused a pH decrease of the tested substrate and hence a decrease in gas emissions [26]. Researchers K. Anderson et al. [27], B. Eugene et al. [28],

J. Sims et al. [29], M. Spiehs et al. [30] also obtained similar results in reducing the level of greenhouse gases emission from litter of the poultry industry using various substances of organic and inorganic origin. Thus, it is experimentally proved that the studied substances – perlite, glauconite, saponite, vermiculite, biological products – Kapeliukhiv Yarok and Scarabei, magnesium acetate and superphosphate have an effect on reducing the level of greenhouse gases – CH_4 , CO_2 and NO from the substrate of poultry litter during mesophilic fermentation.

The most effective of natural sorbents (perlite, glauconite, saponite, vermiculite) in reducing the level of greenhouse gases – methane, carbon dioxide and nitrogen oxide from the studied substrate in anaerobic fermentation is vermiculite (9.6-14.4%), and from biological products (Kapeliukhiv Yarok, Scarabei) – Kapeliukhiv Yarok – on CH_4 , CO_2 , and Scarabei – on NO, respectively, by 12.9-17.3% and 11.8-13.3%. The introduction of magnesium acetate and superphosphate in the fermented poultry litter helps to reduce the emissions of the studied gases – CH_4 , CO_2 and NO, respectively, by 14.8-18.7% and 12.4-17.4%.

Therefore, out of the studied inorganic and biologically active substances, the most effective in reducing the emission level of greenhouse gases – CH_4 , CO_2 and NO from the substrate of poultry litter was found in the options using magnesium acetate. The effectiveness of others decreases in the following sequence: magnesium

acetate – superphosphate – biological product Kapeliukhiv Yarok – biological product Scarabei – vermiculite – glauconite – saponite – perlite.

CONCLUSIONS

The study theoretically substantiated the effectiveness of the use of inorganic and biologically active substances, in particular natural sorbents (perlite, glauconite, saponite, vermiculite), biopreparations (Kapeliukhiv Yarok, Scarabei), as well as magnesium acetate and superphosphate in reducing the emission of the studied greenhouse gases – CH₄, CO₂, and NO from poultry litter (*in vitro*) due to changes in substrate pH. It was experimentally proved

that the most effective substances in reducing the level of methane, carbon dioxide and nitrogen oxide from poultry litter (9.6-18.7%) are magnesium acetate, superphosphate, biopreparation Kapeliukhiv Yarok, and vermiculite, which indicates the feasibility of their use to prevent environmental pollution in the intensive management of the poultry farming. A promising area of further research is establishing the influence of studied substances on reducing greenhouse gases emission directly in the premises where poultry are kept and in manure storages (lagoons) during keeping animal by-products, which is important for solving environmental problems of the agro-industrial complex.

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Зменшення емісії парникових газів з курячого посліду за використання неорганічних та біологічно активних речовин

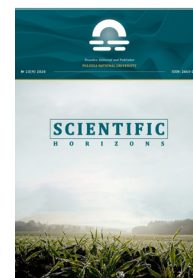
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Анотація. Провідне місце у структурі виробництва продукції тваринництва займає птахівництво. Інтенсивний розвиток цієї галузі становить проблему щодо збереження чистоти довкілля, оскільки крім основної продукції накопичується значний обсяг відходів. Останні слугують джерелом надходження в атмосферу парникових газів, які є однією із основних причин негативних змін у кліматичному балансі планети. Тому, встановлення рівня емісії парникових газів за впливу неорганічних і біологічно активних речовин були основою запланованих досліджень. У результаті проведених досліджень встановлено ефективність дії досліджуваних речовин – перліту, глауконіту, сапоніту, вермикуліту, біопрепаратів Капелюхів Ярок й Скарабей, ацетату магнію та суперфосфату на зменшення рівня виділення метану (CH₄), вуглекислого газу (CO₂) і оксиду азоту (NO) із курячого посліду (*in vitro*). Зокрема, визначено, що найефективніше на зниження емісії парникових газів із курячого посліду з природних сорбентів впливає вермикуліт, який зменшує рівень виділення CH₄ і CO₂ на 10,5–14,4 %, а NO – 9,6–11,2 %. Біопрепарат Капелюхів Ярок більш ефективно обумовлює зниження емісії з досліджуваного субстрату CH₄ та CO₂ на 12,9–17,3 %, а Скарабей – NO на 11,8–13,3 %. Внесення ацетату магнію та суперфосфату в зброжений курячий послід сприяє зменшенню рівня виділення CH₄ та CO₂, відповідно на 14,8–18,7 % та 14,0–17,4 %, а NO – на 15,3–16,1 % й 12,4–14,7 %. Досліджувані речовини, які в найбільшій мірі зменшують емісію парникових газів (*in vitro*) – ацетат магнію, суперфосфат, біопрепарат Капелюхів Ярок та Скарабей, вермикуліт із досліджуваного субстрату, забезпечують водночас і найменший рівень pH – 6,55–7,15 од. Отже, встановлення ефективності впливу досліджених неорганічних та біологічно активних речовин на зниження емісії парникових газів з курячого посліду (*in vitro*) вказують на перспективність їх застосування для запобігання забруднення довкілля при інтенсивному веденні галузі птахівництва

Ключові слова: птахівництво, відходи, метан, вуглекислий газ, оксид азоту



UDC 633.11:632.954

DOI: 10.48077/scihor.24(10).2021.35-42

Effectiveness of Herbicides in Winter Wheat Crops

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Article's History:

Received: 22.09.2021

Revised: 20.10.2021

Accepted: 21.11.2021

Suggested Citation:

Gurmanchuk, O., Plotnytska, N., Nevmerzhytska, O., Pavlyuk, I., & Moshkivska, A. (2021). Effectiveness of herbicides in winter wheat crops. *Scientific Horizons*, 24(10), 35-42.

Abstract. To obtain high yields of winter wheat, it is important to control the contamination of crops with weeds. It is known that yield losses can be 30% or more due to the presence of segetal vegetation in wheat crops. With intensive technology of growing winter wheat, the chemical method of protection against weeds is an extremely important element. The paper highlights data on the species composition and class of contamination of winter wheat agrocenosis. The effectiveness of herbicides and their tank mixtures in winter wheat crops to reduce the presence of the weed component, increase grain yield and quality in the conditions of Luginsky District of Zhytomyr region on sandy loam soils during 2019-2021 was studied. It is established that the structure of the weed component of agrophytocenosis of winter wheat in farm conditions is dominated by dicotyledonous weed species, namely: field mustard (*Sinapis arvensis* L.), wild radish (*Raphanus raphanistrum* L.), wild pansy (*Viola tricolor* L.), shovelweed (*Capsella bursa-pastoris* L.), toadpipe (*Equisetum arvense* L.), and blue bottle flower (*Centaurea cyanus* L.), the share of which is 64.8%. Gramineous species of weeds are represented by silky bent grass (*Apera spica-venti* L.), couch-grass (*Elytrigia repens* L.), rye brome grass (*Bromus secalinus* L.). The technical efficiency of the studied herbicides with the separate and joint application was in the range of 60.8-94.6%. The highest indicator of technical efficiency of herbicides in winter wheat crops, which is 94.6%, was obtained in an experiment using a tank mixture of Granstar Pro 75 + Apiros 75 preparations, with norms of 0.025+0.013 kg/ha, as well as an increase in wheat grain yield by 2.0 t/ha compared to the contaminated control. Spraying winter wheat crops with herbicides during the growing season allows improving the quality indicators of the grain yield structure. In particular, the content of protein and fibrin increases by 1.1 times; the moisture content of grain decreases by 1.0-1.1 times, and the content of dirt impurity decreases by 2.8-6.7 times, compared to the control version

Keywords: winter grains, weeds, chemical protection, yield, technical efficiency, agrophytocenosis



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INTRODUCTION

Among all field crops grown in Ukraine, winter wheat is the most important and popular among both farmers and the private sector. This is evidenced, first of all, by the areas under this grain crop, which in recent years occupy an average of 6.3 million hectares, which is approximately 23% of the total area of crops [1].

The popularity of winter wheat is conditioned upon a number of factors: it is used for making flour, cereals, pasta, for feeding livestock and poultry, etc. High protein content, which can be up to 15% in soft wheat varieties, a considerable amount of carbohydrates and starch, vitamins A, B, D, E, PP, essential amino acids, etc. increase the value of winter wheat grain compared to other cereals. The most important thing in economic terms is that winter wheat is in great demand as an export crop. Ukraine occupies an important place in this regard, as it is one of the top ten wheat exporting countries in the world. Every year, the export of the main grain crop from the country accounts for about 17-19 million tonnes. Winter wheat is a crop that produces large yields on soils with a high agricultural background and slightly smaller ones with a low one, but at the same time remains highly profitable. Its average yield on soils with a high bonus is 5-7 t/ha, while on less fertile soils it is possible to get 3-4 t/ha [2].

The soil and climatic conditions of all regions of Ukraine are mainly suitable for growing winter wheat. However, some annual temperature fluctuations during certain periods of wheat growth, as well as changes in moisture supply, force producers to resort to certain adjustments in the technology of growing crops in different zones. This crop produces good yields using various cultivation technologies, in particular conventional, minimal or zero. Important techniques in the technological process of growing winter wheat are the selection of varieties, sowing dates, balanced nutrition, and protection from harmful organisms. The varietal resource of winter wheat, which is currently formed in Ukraine and recommended for production, consists of almost 80% of varieties of Ukrainian selection. They are characterised by above-average and increased winter hardness, high drought resistance, resistance to lodging, etc. Sowing dates are also of great agrotechnical importance and affect the size of the resulting crop. In recent years, the terms of sowing in various soil and climatic zones of Ukraine deviate from the recommended ones. This indicator is influenced by weather conditions, soil moisture reserves, the quality of seed material, and a number of other factors. Depending on the ecological zone of winter wheat cultivation in Ukraine, the recommended sowing dates are from the first decade of September to the first decade of October [1; 2].

Another factor affecting the growth, development and yield of winter wheat is the fertilizer application system and the correct application of nitrogen fertilizers. To obtain high yields of winter wheat, a considerable

role is given to controlling the contamination of crops [3]. It is known that crop losses due to the considerable presence of segetal vegetation in wheat crops can be 30% or more. Contaminated winter wheat crops cannot fully provide themselves with moisture and nutrients, and they also receive a limited amount of light [4]. In addition, the area of nutrition decreases, which limits the growth of the root system and thickens crops due to weeds, which leads to a decrease in air movement between plants and, accordingly, a deterioration in the overall phytosanitary state of agrocenosis. Weeds can also be used as reserves of many pathogens and pests, which also leads to a negative impact on the yield of winter wheat [5].

Sowing of winter wheat is mainly carried out by seeders designed for continuous sowing with row spacing of 15-19 cm, but in recent years, many farms have experienced wider row spacing of 20-50 cm, which, in turn, requires more attention to control the contamination of crops [6]. Increasing the width of row spacing creates more favourable conditions for weed germination, that is, a "free ecological niche" appears [7]. Therefore, regulating the level of presence of the weed component in the agrocenosis of winter wheat at all stages of its organogenesis is one of the factors for preserving grain yield and quality. The use of agrotechnical measures to destroy weeds in winter wheat crops does not always allow getting the maximum result. For effective control of segetal vegetation in the agrocenosis of winter wheat, a comprehensive approach to solving this problem is necessary, including the use of herbicides [3; 8].

The purpose of the research was to establish the effectiveness of herbicides and their tank mixtures in the agrocenosis of winter wheat in the conditions of Ukrainian Polissia. The objectives of the study were to establish the species composition of segetal vegetation, select suitable herbicides, and determine their effectiveness against the most common types of weeds, as well as their impact on the yield and quality of winter wheat grain in the conditions of Ukrainian Polissia.

LITERATURE REVIEW

With intensive technology of growing winter wheat, the chemical method of protection against weeds is an extremely important element. With the correct selection of herbicides, their timely use in compliance with all the requirements on this crop, the presence and negative impact of the weed component can be minimised [5]. The range of drugs that are presented on the Ukrainian market for regulating the number of weeds in wheat crops is sufficient and can meet the needs of almost any farm. Wheat can be attributed to crops on which the widest "line" of herbicides can be applied. It is represented, in the vast majority, by chemicals for the destruction of dicotyledonous weed species, but there are a certain number of chemicals that have a detrimental effect on

grain species. There are herbicides that combine the ability to destroy dicotyledonous and grain weed species. In addition, there are preparations with a soil effect or a weakly expressed soil effect on weeds.

The most popular herbicides on winter wheat are chemicals based on active ingredients: tribenuron-methyl, dicamba, florasulam, etc. [9]. To regulate the number of dicotyledonous perennial weed species in the agroecosis of winter wheat, mixtures of several active substances from the group of sulfonylureas and synthetic auxins are used [10]. Among the drugs that negatively affect the development of grain weeds in the agroecosis of winter wheat, manufacturers often use monitor 75 WG, Axial 045 EC, Puma super 144 EW [11].

In recent years, the use of herbicides in the autumn period has been quite popular, but not all of the chemicals allowed for use on winter wheat are suitable for this purpose. When using some chemicals in the autumn period, there may be a negative impact on wheat plants and, accordingly, on the future harvest [12]. In addition, a combination of two chemicals Grodil maxi 375 OD and Zenkor liquid 600 SC with norms of 0.11 and 0.3-0.4 l/ha, respectively, is recommended for use in the autumn period in agroecosis of winter wheat. The use of this mixture is quite effective, but it is impractical on light sandy soils and soils with low humus content. The advantage of the mixture of these drugs is their long-term protective effect, which, under optimal conditions in winter, continues in spring, while ensuring the initial spring growth with almost no weeds [13].

More effective and widespread is the use of chemicals in the agroecosis of winter wheat in the spring after the resumption of crop vegetation. The positive side of using herbicides in spring is that winter, wintering and early spring weed species germinate in wheat agroecosis, which allows more carefully selecting herbicides or their tank mixtures. Therewith, if the treatment is carried out as late as possible but within the permissible phase of crop development, a very high efficiency of controlling the number of weeds in winter wheat crops can be obtained. Although with the later use of herbicides, it is possible to lose the crop due to the competition of weeds with winter wheat plants for solar energy, moisture, and nutrients at the beginning of its growth and development. In addition, there is a possibility of overgrowth of segetal vegetation in the wheat agrophytocenosis, which also negatively affects the effectiveness of herbicides [14]. Considering the fact that the effect of chemical preparations may vary slightly depending on soil and weather conditions, the authors of this paper conducted special studies to determine the effectiveness of herbicides in regulating the amount of segetal vegetation of winter wheat agroecosis.

MATERIALS AND METHODS

Field studies were conducted during 2019-2021 in the conditions of farm "Obriy" of Luginsky District of Zhytomyr region. On the farm, sandy loam, sod-podzolic soils are

characterised by the following indicators: humus (according to Tyurin and Kononova) – 1.10-1.23%, easily hydrolysed nitrogen (according to Cornfield) – 57-66 mg/kg of soil, mobile phosphorus (according to Chirikov) – 108-170 mg/kg of soil, exchange potassium (according to Chirikov) – 76-104 mg/kg of soil, pH_{sol} – 5.7-6.4. Weather conditions during the study period were somewhat different in terms of indicators from long-term data but did not cause a considerable negative impact on the development of winter wheat.

Winter wheat in the experiment was grown using minimal soil treatment technology. The previous crop in the experiment was soy. After collecting the previous crop, the soil was treated with the DAN 2.1 unit (discolp with a roller), pre-sowing cultivation, and sowing. The Kraevid wheat variety, characterised by increased resistance to pathogens and stress factors, was sown at the experimental sites. The seeding rate was 4.5 million tonnes of grain per 1 hectare. Sowing was carried out with a row spacing of 15 cm. The seed material was used well cleaned and calibrated with mandatory pickling before sowing with fungicidal and insecticidal chemicals. In all variants of the experiment, mineral fertilizers were used, in particular, during sowing, 100 kg of physical weight of ANP fertilizer NPK was locally applied to the rows at the rate of 16:16:16+6S per hectare; 100 kg per hectare of ammonium nitrate was superficially scattered on frozen-thawed soil, and another 50 kg of physical weight of the same fertilizer was applied in the phase of the beginning of stem elongation. Spraying of wheat plants with the studied herbicides and tank mixtures was carried out in the tillering phase before the stem elongation using a mounted sprayer OGN 600 with a working fluid consumption rate of 200 l/ha. During the growing season of wheat, crops were protected from pests and pathogens. Harvesting was carried out by direct combining using the Niva SK-5m combine.

The species composition of weeds in wheat agroecosis was determined using atlases and reference books [15]. Studies on the effectiveness of herbicides were conducted according to the following scheme: 1. Contamination control (water treatment); 2. Granstar Pro 75, v.g. (d.r. tribenuron-methyl – 750 g/kg) – 0.025 kg/ha; 3. Prima, s. e. (d. r. florasulam 6.25 g/l + 2-ethylhexyl ether 2.4-D 452.5 g/l) – 0.5 l/ha; 4. Apiros 75, v. g. (d. r. sulfosulfuron – 750 g/kg) – 0.026 kg/ha; 5. Granstar Pro + Apiros, 0.025 kg/ha+0.013 kg/ha; 6. Granstar Pro + Prima, 0.025 kg/ha+0.3 l/ha. The size of the experimental site was 0.5 hectares. The experiment is repeated three times, and the placement of sites is systematic. Records of contamination of winter wheat crops were carried out three times during the growing season: the first – before the use of herbicides; the second – on the 30th day after application; the third – before harvesting. The level of contamination of winter wheat agroecosis was assessed on a five-point scale, where 1 point is a very weak degree of contamination (1-5 pcs/m²), and 5 points – a very strong degree of contamination (more than 100 pcs/m²) [16].

The technical effectiveness of herbicides was calculated 30 days after their application, in comparison with the initial contamination and with a mandatory adjustment for control according to the generally accepted method. After harvesting wheat, its quality indicators were studied according to the methods [17]. Mathematical processing of the obtained research results was carried out by the method of variance analysis according to methodology B.A. Dospekhov [18].

RESULTS AND DISCUSSION

Over the years of research, the specific and quantitative composition of weeds in winter wheat crops has been studied. When studying the species belonging of segetal vegetation in winter wheat crops in the conditions of farm "Obriy" of the Luginsky District of Zhytomyr region, it was established that dicotyledonous weed species are dominant, the share of which in the overall structure of contamination was 64.8% (Fig. 1).

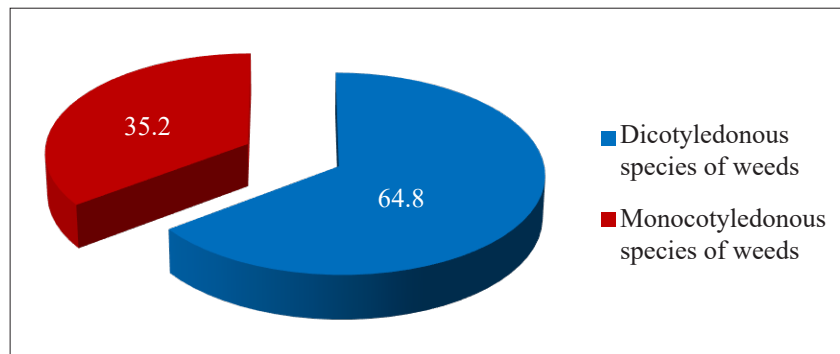


Figure 1. Ratio of single- and dicotyledonous weed species in winter wheat crops under the conditions of farm "Obriy", 2019-2021

Among dicotyledonous weeds, the dominant species were: field mustard (*Sinapis arvensis* L.), wild radish (*Raphanus raphanistrum* L.), wild pansy (*Viola tricolor* L.), shovelweed (*Capsella bursa-pastoris* L.), toadpipe (*Equisetum arvense* L.) and blue bottle flower (*Centaurea cyanus* L.) (Fig. 2). In the agrocenosis of winter wheat, the following types of cereal weeds prevailed: silky bent grass (*Apera spica-venti* L.), couch-grass (*Elytrigia repens* L.), rye brome grass (*Bromus secalinus* L.)

In winter wheat crops, when accounting, 24.9% of the detected weed species were only 1-2 specimens

on the accounting site. In particular, these are such cereal types of weeds as common oatmeal (*Avena fatua* L.), annual bluegrass (*Poa annua* L.), black grass (*Alopecurus myosuroides* L.), etc. Single specimens of pig weed (*Chenopodium album* L.), canada thistle (*Cirsium arvense* L.), purple deadly (*Lamium purpureum* L.), doorweed (*Polygonum aviculare* L.), water pepperwort (*Polygonum hydropiper* L.), small-flower galinsoga (*Galinsoga parviflora* L.), wild chamomile (*Chamomilla suaveolens* L.) have been identified from dicotyledonous species of segetal vegetation.

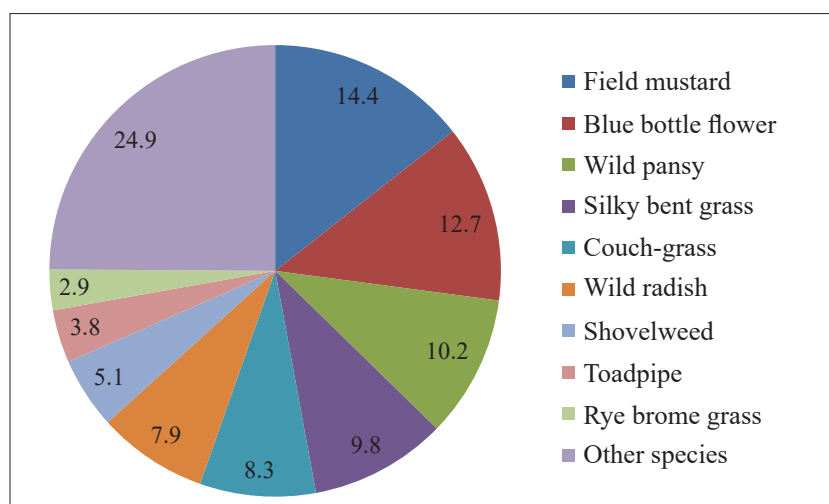


Figure 2. Structure of winter wheat crops contamination in the conditions of farm "Obriy", 2019-2021

According to the results of monitoring the phytosanitary condition of winter wheat crops in the Polissia

zone of Ukraine, conducted by N.V. Hrytsiuk et al., the synusia weed is represented by nine species from six

families. The largest percentage of the detected weeds were rye brome grass and silky bent grass, belonging to annual winter crop species [10].

To ensure high and stable yields of winter wheat on poor sod-podzolic soils of Polissia, one of the main methods in the technology of its cultivation is the control of the weed component. Analysis of the structure of winter wheat crops contamination showed that the agrophytocenosis of this crop was characterised by a mixed class of contamination, namely dicotyledonous-monocotyledonous. That is, dicotyledonous species predominate in the composition of the weed synusia of winter wheat agrocenosis, which must be considered when using chemicals in regulating the number of weeds.

In certain soil and climatic conditions, studies are conducted to determine the effectiveness of chemicals against various types of weeds in winter wheat crops. In particular, the effectiveness of diflufenican, clopiralide, and fluroxypir against broad-leaved weed species and

their impact on wheat yield was confirmed in Iran [9]. In addition, the use of a mixture of fluroxypir and 2,4 D after germination is effective in controlling the number of *Viola arvensis* in spring wheat crops [14]. The use of a post emergence herbicide based on the active substance isoproturon in Pakistan allows regulating the number of *Avena fatua*, *Convolvulus arvensis*, *Melilotus indica*, *Cirsium arvense*, and *Fumaria indica* in wheat crops [13].

That is why in the conditions of Ukrainian Polissia, a study was conducted to determine the effectiveness of herbicides and their tank mixtures for a comprehensive solution to the problem of contamination of winter wheat crops. The initial contamination of crops before the use of the studied chemicals was in the range of 48.9-51.1 pcs/m² (Table 1). The obtained results of the study allow asserting the expediency of using herbicides separately and in mixtures to control the amount of segetal vegetation in winter wheat crops.

Table 1. Effectiveness of herbicides in winter wheat crops (2019-2021)

Research variant	Number of weeds, initial, pcs/m ²	Number of weeds, 30 days after application of the chemical, pcs/m ²	Technical efficiency, %	Number of weeds, before harvesting, pcs/m ²
Contamination control (water treatment)	48.9	51.7	–	60.2
Granstar Pro 75, v. g., 0.025 kg/ha	49.8	17.7	66.4	27.8
Prima, s. e., 0.5 l/ha	51.1	21.2	60.8	29.3
Apiros 75, v. g., 0.026 kg/ha	50.4	20.1	62.3	23.4
Granstar Pro 75 + Prima, 0.025+0.3 kg, l/ha	49.9	8.7	83.5	25.4
Granstar Pro 75 + Apiros 75, 0.025+0.013 kg/ha	50.5	2.9	94.6	8.5
HIP ₀₅	0.11	0.02	–	0.03

In particular, the use of herbicides Granstar Pro 75, v. g. (0.025 kg/ha), Prima, s. e. (0.5 l/ha), Apiros 75, v. g. (0.026 kg/ha) contributed to a decrease in the number of weeds on the 30th day after the use of chemicals by 2.4-2.8 times compared to the initial contamination. Mixtures of Granstar Pro+Apiros, 0.025 kg/ha+0.013 kg/ha and Granstar Pro+Prima, 0.025 kg/ha+0.3 l/ha showed high efficiency against weed synusia in winter wheat agrocenosis and contributed to a decrease in its number by 5.7-17.4 times compared to the initial contamination of experimental plots.

In the variants of the experiment using each of the studied herbicides with their separate application (Granstar Pro 75, Prima, s. e., Apiros 75), technical efficiency was obtained at the level of 60.8-66.4%. When studying the effect of a tank mixture of Granstar Pro 75 + Prima preparations with norms of 0.025+0.3 kg, l/ha, the decrease in the presence of the weed component

in crops was 83.5%, compared with the contamination control. The use of a tank mixture of herbicides Granstar Pro 75 + Apiros 75 at a rate of 0.025+0.013 kg/ha, respectively, contributed to the reduction of weeds in the agrophytocenosis of winter wheat by 94.6%, which was the most effective option in the experiment. The high effectiveness of this combination of chemicals can be explained by the fact that it can control grain species of weeds, the share of which is about 35% of the total, due to the herbicide Apiros 75.

After considering the number of segetal vegetation before harvesting, 60.2 weeds per 1 m² were recorded in the control version of the experiment. In three variants of the experiment using each of the studied herbicides separately, as well as when using the Granstar Pro 75 + Prima tank mixture before harvesting winter wheat, the number of weeds in crops was in the range of 23.4-29.3 pcs/m². The smallest number of weeds before harvesting, which

was 8.5 pcs/m², were observed in a variant of the experiment using a mixture of Granstar pro 75 + Apiros 75 chemicals with appropriate standards.

With a decrease in the presence of the weed component in the agrophytocenosis of winter wheat, a positive effect on crop yield indicators was noted (Table 2). In the control version of the experiment (water treatment), the lowest yield of winter wheat grain was obtained, which was 1.4 t/ha. In the variants of the experiment

using the studied herbicides, the yield was preserved separately at the level of 1.4-1.5 t/ha. For the use of a tank mixture of Granstar Pro 75 + Prima chemicals, an increase in the yield of winter wheat grain in the range of 1.6 t/ha was obtained. The largest preserved grain yield of the studied crop (2.0 t/ha) was obtained when using a mixture of Granstar Pro 75 + Apiros 75 preparations with norms of 0.025+0.013 kg/ha, respectively.

Table 2. Influence of herbicides on the yield of winter wheat grain (2019-2021)

Research variant	Chemicals consumption rate, l/ha, kg/ha	Yield, t/ha	Preserved harvest	
			t/ha	% to contamination control
Contamination control (water treatment)	–	1.4	–	–
Granstar Pro 75, v. g.	0.025	2.9	1.5	107.1
Prima, s. e.,	0.5	2.8	1.4	100.0
Apiros 75, v. g.,	0.026	2.8	1.4	100.0
Granstar Pro 75 + Prima	0.025+0.3	3.0	1.6	114.3
Granstar Pro 75 + Apiros 75	0.025+0.013	3.4	2.0	142.9
HIP ₀₅	–	0.03	0.01	–

The study of the effectiveness of herbicide use and their tank mixtures on winter wheat allows drawing conclusions about the feasibility of their use. In particular, if the studied herbicides are used singly, then their technical efficiency is 60.8-66.4%, and when using tank mixtures of these same chemicals, it increases from 83.5% to 94.6%.

After analysing the study data, it should be noted that the highest efficiency in the use of herbicides was obtained in the version with the Granstar Pro 75 + Apiros 75 tank mixture. In the authors' opinion, this is explained by the ability of the active substances of these two herbicides to control both dicotyledonous and grain species of weeds in winter wheat crops.

For the sale of winter wheat grain, quality indicators are of great importance, in particular: protein content, fibrin content, nature, humidity, and dirt admixture.

It is known that grain quality largely depends on the genotype of the variety [2], and the effect of herbicide treatments is not fully studied. That is why the main quality indicators of the resulting winter wheat grain were evaluated. The conducted studies established that the use of herbicides allows improving the quality indicators of grain yield, in comparison with the contaminated control (Table 3). In particular, the content of protein and fibrin increases by 1.1 times. The highest levels of protein and fibrin content were obtained in the experiment version using the Granstar Pro 75 + Apiros 75 tank mixture, which amounted to 13.9% and 31.3%, respectively. Grain humidity in all the studied variants was within the normal range and did not exceed 13.7-14.0%. In the control version, this indicator was 14.6%, which required drying the resulting crop to remove excess moisture.

Table 3. Influence of herbicides on the quality indicators of winter wheat grain (2019-2021)

Research variant	Protein content, %	Fibrin content, %	Grain size, g/l	Grain humidity, %	Dirt admixture, %
Contamination control (water treatment)	12.8	28.5	748.3	14.6	4.7
Granstar Pro 75, v. g., 0.025 kg/ha	13.8	30.7	757.5	13.9	1.4
Prima, s. e., 0.5 l/ha	13.8	30.9	756.5	13.9	1.5
Apiros 75, v. g., 0.026 kg/ha	13.8	30.8	755.9	14.0	1.7
Granstar Pro 75 + Prima, 0.025+0.3 kg, l/ha	13.9	31.1	758.7	13.7	0.9
Granstar Pro 75 + Apiros 75, 0.025+0.013 kg/ha	13.9	31.4	764.9	13.7	0.7
HIP ₀₅	–	–	21.4	–	–

Dirt admixture in the control variant was the largest and amounted to 4.7%, which required additional measures for post-treatment of grain. When using herbicides singly, the indicator of dirt admixture decreased by 2.8-3.4 times, and when using tank mixtures of chemicals – by 5.2-6.7 times, compared to the control.

CONCLUSIONS

The structure of the weed component of winter wheat agroecosystem in the conditions of farm "Obriy" in Luginsky District of Zhytomyr region is dominated by dicotyledonous weed species, the share of which is 64.8%. Dicotyledonous weeds are represented by the following dominant species: field mustard (*Sinapis arvensis* L.), wild radish (*Raphanus raphanistrum* L.), wild pansy (*Viola tricolor* L.), shovelweed (*Capsella bursa-pastoris* L.), toadpipe (*Equisetum arvense* L.) and blue bottle flower (*Centaurea cyanus* L.). Among the grain species, the following were most often found: silky bent grass (*Apera spica-venti* L.), couch-grass (*Elytrigia repens* L.), rye brome grass (*Bromus secalinus* L.).

The use of herbicides Granstar Pro 75, v.g. (0.025 kg/ha), Prima, s. e. (0.5 l/ha), Apiros 75, v. g. (0.026 kg/ha) reduces the number of weeds by 30 days after the use of chemicals

by 2.4-2.8 times, and mixtures of chemicals Granstar Pro+Apiros, 0.025 kg/ha+0.013 kg/ha and Granstar Pro + Prima, 0.025 kg/ha+0.3 l/ha – 5.7-17.4 times, compared to the initial contamination. The highest indicator of technical efficiency of herbicide use in winter wheat crops, which is 94.6%, was obtained in a variant of the experiment using a tank mixture of Granstar Pro 75 + Apiros 75, with norms of 0.025+0.013 kg/ha. The use of herbicides Granstar Pro 75, v. g. (0.025 kg/ha), Prima, s. e. (0.5 l/ha), Apiros 75, v. g. (0.026 kg/ha) contributes to an increase in the yield of winter wheat grain in the range of 1.4-1.5 t/ha. The use of a mixture of herbicides Granstar Pro 75 + Apiros 75, with norms of 0.025+0.013 kg/ha contributes to an increase in wheat grain yield by 2.0 t/ha, compared to the contamination control. Treatment of wheat crops with herbicides allows improving the quality indicators of the crop structure, in particular, the protein and fibrin content increases by 1.1 times; grain moisture decreases by 1.0-1.1 times, and the content of dirt admixture decreases by 2.8-6.7 times compared to the control variant. The highest quality indicators of the crop structure were obtained in a variant of the experiment using the Granstar Pro 75 + Apiros 75 tank mixture.

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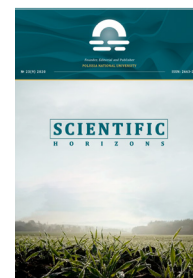
Ефективність гербіцидів у посівах пшениці озимої

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Анотація. Для отримання високих урожаїв пшениці озимої важливим є контроль забур'яненості посівів. Відомо, що втрати урожайності за значної присутності сеgetальної рослинності у посівах пшениці можуть становити 30 % і більше. При інтенсивній технології вирощування пшениці озимої хімічний метод захисту від бур'янів є надзвичайно важливим її елементом. У статті висвітлено дані щодо видового складу, класу забур'яненості агроценозу пшениці озимої. Досліджено ефективність гербіцидів і їх бакових сумішей у посівах пшениці озимої на зменшення присутності бур'янового компоненту, збільшення урожайності та якості зерна в умовах Лугинського району Житомирської області на супіщаних ґрунтах протягом 2019–2021 рр. Встановлено, що у структурі бур'янового компоненту агрофітоценозу пшениці озимої в умовах господарства переважають дводольні види бур'янів, а саме: гірчиця польова (*Sinapis arvensis* L.), редька дика (*Raphanus raphanistrum* L.), фіалка триколірна (*Viola tricolor* L.), грицики звичайні (*Capsella bursa-pastoris* L.), хвощ польовий (*Equisetum arvense* L.) та волошка синя (*Centaurea cyanus* L.), частка яких становить 64,8 %. Злакові види бур'янів представлені метлюгом звичайним (*Apera spica-venti* L.), пирієм повзучим (*Elytrigia repens* L.), бромусом житнім (*Bromus secalinus* L.). Технічна ефективність досліджуваних гербіцидів за роздільного та сумісного їх внесення становила у межах 60,8–94,6 %. Найвищий показник технічної ефективності гербіцидів у посівах пшениці озимої, що становить 94,6 %, отримано у варіанті досліді з застосуванням бакової суміші препаратів Гранстар Про 75 + Апірос 75, з нормами 0,025+0,013 кг/га, а також отримано зростання урожайності зерна пшениці на 2,0 т/га, порівняно із забур'яненим контролем. Обприскування посівів пшениці озимої гербіцидами у період вегетації дає можливість покращити якісні показники структури врожаю зерна. Зокрема, вміст білку та клейковини зростає у 1,1 раза; вологість зерна знижується у 1,0–1,1 раза, а вміст сміттевої домішки знижується в 2,8–6,7 рази, у порівнянні із контрольним варіантом

Ключові слова: озимі зернові, бур'ян, хімічний захист, урожайність, технічна ефективність, агрофітоценоз



UDC 582.661.21:631.559

DOI: 10.48077/scihor.24(10).2021.43-51

Yield of Amaranth (*Amaranthus*) Depending on the Cultivar in the Conditions of Ukrainian Western Forest-Steppe

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Article's History:

Received: 14.11.2021

Revised: 12.12.2021

Accepted: 15.01.2022

Suggested Citation:

Tyrus, M., & Lykhochvor, V. (2021). Yield of Amaranth (*Amaranthus*) depending on the cultivar in the conditions of Ukrainian Western Forest-Steppe. *Scientific Horizons*, 24(10), 43-51.

Abstract. Amaranth is called the culture of the future due to its unique food, feeding and medicinal properties. The acreage of Amaranth in Ukraine is very small, which can be explained by the lack of adaptive cultivation technologies, especially for growing this crop for grain. The purpose of the research was to establish the most productive cultivars for growing in the conditions of excessive and sufficient moisture in the western forest-steppe on dark grey soil. For this purpose, field research was conducted in the experimental field of Lviv National Agrarian University. The total area of the site was 30 m², recording – 20 m². The studies were conducted in three repetitions. The authors studied seven of the most common cultivars of Amaranth in Ukraine: Kharkivskiyi 1, Lera, Sam, Studentskyi, Polishchuk, Aztec, Ultra. It was established that the yield of amaranth considerably depended on the hydrothermal conditions of the year. It was lower in years with excessive rainfall in the first half of vegetation (2019 and 2020). The highest grain yield (2.46-4.35 t/ha) was formed in 2021 when the amount of precipitation in May, June and July was within the normal range. A strong inverse correlation was established ($r=-0.82$ – $r=-0.95$) between the yield of amaranth cultivars and the amount of precipitation. The highest grain yield (4.03 t/ha) among the studied amaranth cultivars was obtained in Kharkivskiyi 1. The lowest yield was formed in the Ultra cultivar (1.97 t/ha), which is less than in the Kharkivskiyi 1 cultivar by 2.06 t/ha. The study of elements of the yield structure showed that the height of the plant had a positive effect ($r=0.63$) on the level of amaranth grain yield, while average relationship was observed between panicle length and yield ($r=-0.36$). The weight of 1000 seeds in the cultivars ranged from 0.74-0.88 g. The low mass of seeds per plant had the greatest impact on yield ($r=0.99$). The highest yield of amaranth of the Kharkivskiyi 1 cultivar was formed with the following ratio of the main elements of the crop structure: the number of plants – 21 p/m² and the mass of seeds from the plant – 19.2 g. To obtain a high stable yield of amaranth grain, additional research is required to clarify the main elements of cultivation technology for these soil and climatic conditions

Keywords: amaranth, cultivars, yield gain, weight of 1000 seeds, hydrothermal conditions, structural elements



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INTRODUCTION

Amaranth is grown as a grain, feeding, vegetable, medicinal, and ornamental crop. It has considerable prospects for growing in Ukraine. V.V. Saratovsky [1] notes that even the climatic conditions of the Carpathian region are suitable for growing amaranth. Its yield can reach 30 dt/ha, amaranth seeds contain 12-18% of protein and 5-17% of oil [2]. Its main value is the ability to accumulate a lot of protein in the grain and leaves. Amaranth protein has a high nutritional value and is estimated at 75-80 points, while cow's milk protein – 72, wheat – 57, corn – 44, soy – 68 points [3]. The value of amaranth oil lies in the fact that it contains squalene (8%), which in combination with tocopherol regulates lipid metabolism. Amaranth is considered a “natural biopharmaceutical” plant [4].

Amaranth products prevent various diseases. It can increase immunity, which is very important now, in the era of coronavirus. Amaranth oil is not inferior in quality to sea buckthorn oil and is widely used for the treatment of radiation sickness, burns, etc. [2]. Production areas in Europe are quite low, only about 1000 hectares. Amaranth is grown in Slovakia, Hungary, and Italy [5]. Accurate statistics on amaranth acreage in Ukraine are not available. Various figures are given – from 1000 thousand ha to 5000 thousand ha.

To expand amaranth crops in Ukraine, it is necessary to study and develop intensive cultivation technologies focused on particular soil and climatic zones [6]. For this relatively new culture, it is necessary to study and refine most of the elements of technology [4]. In particular, the impact of climate change and irrigation [7]. The study of sowing methods has shown the advantage of row spacing of 18 cm over row spacing of 60 cm [8]. There are recommendations to place amaranth according to the scheme of 15x15 cm [9]. In the conditions of the southern steppe, when growing amaranth for grain, it is proposed to sow with a seeding rate of 2.25 million/ha with a row spacing of 60 cm [10]. S.G. Kohut [11] studied the issue of seeding depth. There are recommendations to sow amaranth to a depth of 1 cm to 3 cm in the absence of moisture.

There is little data on determining the effect of fertilisers on amaranth yields, which is often contradictory. Notably, it is advisable to apply the calculated amount of fertilisers [12], or that the most important fertilisers are nitrogenous ones [13]. It was established that the application of complete mineral fertiliser ($N_{90}P_{90}K_{30}$) in the conditions of the northern steppe of Ukraine caused an increase in the yield of amaranth grain (*Amaranthus paniculatus*) by 0.42 t/ha, compared to the control without fertilisers [14]. According to the authors, this is a low gain in yield. There is practically no data on the use of macroelements such as magnesium, sulfur, and calcium in amaranth cultivation technology. There are no recommendations for the introduction of microelements. Namely, a scientifically based fertiliser system allows increasing the yield to 4.0-5.0 t/ha.

In the technology of growing amaranth, the possibility of using plant protection products has almost not been studied. Amaranth, with the existing small areas of sowing, is almost not affected by diseases but there are many problematic issues with weed and pest control. Amaranth grows very slowly at the early stages and can become infested with weeds. Areas intended for medicinal purposes use agrotechnical methods of weed control: several surface treatments before sowing, harrowing, inter-row aeration, manual weeding. In large industrial areas, these methods will not be effective and it will be impossible to obtain high yields without the use of plant protection. Therefore, it is necessary to study the possibility of using herbicides, their effectiveness, and the cultivar reaction of amaranth to them. There are data on the study of Betanal Max Pro, Dual Gold, Caribou, Lontrel Grand, Piramin Turbo, Frontier Optima, Fusilad Forte, Aramo 45 herbicides on amaranth [15]. The most dangerous and mass pests on amaranth are the following two types: been aphid (*Aphisfabae Scop.*) and amaranth stem borer (*Lixus subtilis Boh.*). To control them on crops that are not intended for medicinal purposes, it is recommended to use insecticides Aktara, Ampligo, Engio, Karate Zeon, Nurel D, Fastak, Mospilan [16].

The purpose of this research was to study the influence of soil and climatic conditions of the Western Forest-Steppe on the adaptive potential and productivity of plants of grain amaranth cultivars.

LITERATURE REVIEW

The use of amaranth cultivars adapted to the growing conditions is important in terms of ensuring high yields of this promising crop. Breeding work with amaranth began relatively recently [17]. Breeding can considerably improve the quality of amaranth grain and increase its yield. New cultivars are of great value, which in certain soil and climatic conditions exceed the yield of the cultivars grown here, given that the cost of producing amaranth seeds is minimal.

The research of I.T. Hoptsi et al. [18] determined a particular morphotype of plants of this culture, which corresponds to a certain area of use. Grain-type cultivars have the following characteristics: low-growing plants (up to 1 m), unbranched, with a large dense or semi-dense panicle, with a high percentage of female flowers, even maturing; white, golden or pink seeds with a mass of 1000 seeds up to 1 g, crude protein content up to 18.0 – 19.0%, starch – 58.0-59%, grain yield up to 30 dt/ha; suitable for mechanised harvesting. The grain group of amaranths is also characterised by such features as panicle length, panicle productivity, seed moisture during harvesting, and seed nutritional qualities.

To determine the economically valuable cultivars for the conditions of the left-bank forest-steppe of Ukraine, 19 types of amaranth were analysed according to a complex of economically valuable features and distributed

according to their economic purpose and practical significance. The species *Amaranthus hypochondriacus* had the highest seed yield (1.70 t/ha) [18].

The creation of highly productive cultivars for various soil and climatic conditions will also contribute to the expansion of amaranth acreage. A considerable amount of research in this area was carried out in the M.M. Hryshko National Botanical Garden of the National Academy of Sciences of Ukraine (Sterkh, Early Cream, Carmine), Podillia Institute of Feeding and Agriculture of the National Academy of Sciences of Ukraine (Legin, Aztec, Orchid, Kotyhoroshok), V.V. Dokuchaev Kharkiv National Research University (Ultra, Kharkivskiyi 1, Nadiia, Studentskyi, Sam, Roganskyi) [19].

Amaranth belongs to plants of tropical origin with C_4 -type of photosynthesis and is characterised by more efficient use of water and high productivity [5; 20]. Therefore, the potential capabilities of modern cultivars of this crop range from 8-15 t/ha, but the average grain yield in Ukraine is 2.8-3.5 t/ha [6]. The yield of amaranth grain is often even lower. Thus, in the conditions of the northern steppe of Ukraine against the background of $N_{90}P_{90}K_{30}$ for sowing with row spacing of 45 cm and a seeding rate of 1 kg/ha, a yield of 1.77 t/ha was obtained [14; 21]. In the southern steppe, the yield was only 5.5-8.7 st/ha [13]. The Dnipro 1 cultivar, depending on the fertiliser standards, formed a yield of 9.4-14.7 dt/ha [22].

In Romania, amaranth cultivars of the *Amaranthus cruentus* species formed the following yields: the Golden Giant cultivar – 2.65 t/ha and the Bolivia cultivar – 2.38 t/ha [23]. However, there are also high yield indicators. Thus, it was established that in favourable conditions of the year, amaranth provided the highest yield for sowing in the first decade of May and the wide-row method (45 cm), the Ultra cultivar – 4.9 t/ha and the Studentskyi cultivar – 5.1 t/ha [6]. In other studies, the Ultra cultivar is also recommended for growing for grain [11]. As of 2021, 19 cultivars of amaranth were registered in Ukraine [19].

MATERIALS AND METHODS

The research was conducted in the experimental field of Lviv National Agrarian University. The soil of the experimental site is dark grey podzolic light loam, which was characterised by the following indicators: humus content (according to the Tyurin method) – 2.10%, pH – 6.08, easily hydralised nitrogen – 110 mg/kg of soil, mobile forms of phosphorus (according to the Chirikov method) – 128 mg/kg of soil, mobile forms of potassium (according to Chirikov) – 114 mg/kg of soil, copper content – 1.25 mg/kg and zinc – 1.06 mg/kg, manganese (according to the Peive and Rinkis method) – 16.0 mg/kg, boron (according to the Rinkis method) – 0.94 mg/kg, iron – 128.0 mg/kg.

Hydrothermal conditions differed from the long-term average data. It was warmer and more precipitation fell. In 2019, the average temperature for the vegetation

was 16.1°C, which is 1.3°C higher than long-term data. In 2020, these figures were 15.3°C and 0.5°C, respectively, and in 2021, 14.8°C, which corresponded to the long-term average data. In 2019, during the vegetation, the precipitation was 53 mm above normal, in 2020 – by 129 mm, in 2021 – by 73 mm. The total area of the site was 30 m², recording – 20 m². The studies were conducted in three repetitions. The cultivation technology in the experiment was as follows. The predecessor of amaranth is winter wheat. After harvesting the predecessor, the field was disked and winter plowing was carried out. In spring, soil treatment consisted of closing the moisture, 2 cultivations, and pre-sowing treatment using a combined Compactor tool. Mineral fertilisers were applied according to the norm $N_{120}P_{80}K_{120}$. Phosphorous and potassium fertilisers were applied for plowing. Nitrogenous fertilisers in spring for pre-sowing treatment. Sowing was conducted in a wide-row way with row spacing of 45 cm to a depth of 1 cm. A Horsh Pronto 4 DS seed drill was used. The sowing period is April 25, the seeding rate is 0.8 kg/ha. Row-to-row treatments and Fusilad Forte herbicide (1.0 l/ha) were used to control weeds. Mowing of amaranth was carried out in the phase of full ripeness of seeds in the lower and middle parts of the panicle, amaranth was threshed after drying. Statistical data processing was performed using Microsoft Excel and Statistica 6.0 programmes.

Cultivars. Seven cultivars of amaranth were studied.

Sam. The cultivar was created by individual selection from a sample *A. hypochondriacus* (Panishmen). Entered in the Register of Plant Varieties of Ukraine in 2002. The plant is up to 128 cm tall, the stem and leaves are red, the seeds are white. Panicle red spreading, up to 47 cm long. Drought resistance – 7 points, resistance to shedding and lodging – 9 points. Mid-season – 110 days. The protein content in seeds is 19.5%. The oil content is 6.7%. Seed yield is up to 25 td/ha. The anti-inflammatory activity and protective effect of the cultivar's oil on the development of experimental insulin resistance were established.

Lera. The cultivar was created by individual selection from a sample *A. hypochondriacus* (K-14). Entered in the Register of Plant Varieties of Ukraine in 2002. Plants up to 170-220 cm tall. The stem is green, the leaves are green with red veins. Panicle up to 54 cm long, red, compact. White seeds, weight of 1000 seeds – 0.7 g. Resistance to lodging – 9 points, resistance to shedding – 8 points. The cultivar is mid-season – 105 days. The protein content in seeds is 20.6%, oil – 7.0%. The seed yield is up to 22 td/ha. The grain is suitable for making flour and oil.

Kharkivskiyi 1. The cultivar was created by individual selection from the population *A. hypochondriacus* (K-7). Entered in the Register of Plant Varieties of Ukraine in 2001 as a medicinal plant. Plants up to 160 cm tall. The stem and leaves are green, the panicle is white, compact, up to 60 cm long. White seeds, weight of 1000 seeds – 0.65 g, oil content – up to 8% with a high

squalene content – up to 10%. The vegetation is 110 days. Grain is used for the production of butter, flour, and oil cake. Based on the results of medicinal properties testing at the V.Ya. Danilevsky Institute of Endocrine Pathology Problems, amaranth seed oil of the Kharkivskiyi 1 cultivar is recommended for further study in medical institutions for possible clinical use to prevent and treat Type 2 diabetes mellitus and stomach ulcers. Seed yield is up to 50 dt/ha.

Studentskyi. Created by individual selection from a sample *A. hypochondriacus* (K-1267). Entered in the Register of Plant Varieties of Ukraine in 2009. Mid-season. Plants up to 125 cm tall. The stem is red, the leaves are green with red veins. Panicle up to 40 cm long, red, compact. White seeds, weight of 1000 seeds – 0.8 g. Resistance to lodging – 9 points, resistance to shedding – 9 points. The cultivar is mid-season – 100-125 days. The oil content is 6-10%, and the squalene content in the oil is 6-8%. The protein content in seeds is 18.6%. Seed yield is up to 30 dt/ha.

Aztec. Entered in the Register of Plant Varieties of Ukraine in 1998. Feeding Institute of the National Academy of Agrarian Sciences of Ukraine. The cultivar is grain, feeding, mid-season. The vegetation to full ripeness of seeds is 120 days. The plant reaches 150 centimetres. The length of the panicle with light brown seeds is 45-50 cm. The panicle is red, and the stem is the same colour. The leaves of the plant of this species have a red-green colour. It is characterised by a high level of grain yield and green mass. The seed yield is 30-40 dt/ha. The content of crude protein in dry matter is 17.8%. Grain is used for making oil and for producing flour, which, in turn, is used for baking products. Suitable for combine harvesting.

Ultra. Entered in the Register of Plant Varieties

of Ukraine in 1998. *A. hybridus*. Early season – 90-95 days. Plants up to 180 cm tall. The leaves are green, downiness is absent. Inflorescence – semi-dense compact panicle, light green, yellow when ripe. The seeds are light yellow. The cultivar is resistant to shedding. The seed yield is 14 dt/ha. The oil content in seeds is up to 5%. The oil contains 11.25% of squalene, tocopherols – 0.28%.

Polishchuk. Entered in the Register of Plant Varieties of Ukraine in 1999, mid-season. Originator Polissia Institute of Agriculture. The plant reaches 150 centimetres. The length of the panicle with dark brown seeds is 45-50 cm. The panicle is red, and the stem is the same colour. The leaves of this species are green with red veins. Grain yield up to 3 t/ha. It is characterised by low resistance to shedding and high resistance to drought.

The Ultra cultivar, selected by KNAU, was used as a standard.

RESULTS AND DISCUSSION

Due to global climate change, it is important to establish the response of amaranth to new growing conditions. The dependence of the level of genetic potential fulfilment of amaranth cultivars on weather conditions is quite high. Therewith, the conditions of moisture and temperature regime that develop during the vegetation and especially in the first half of vegetation have the greatest influence on crop productivity in all soil and climatic zones.

In the studies conducted by the authors, the yield of amaranth grain varied depending on the hydrothermal conditions of the year. In 2019, the yield was lower compared to 2021 and varied depending on the cultivar in the range of 2.08-4.11 t/ha (Table 1). The difference between the lowest yield in the Ultra cultivar and the highest in the Kharkivskiyi 1 cultivar was 2.03 t/ha.

Table 1. Yield of amaranth seeds depending on the cultivar

Cultivars	Years			Average for three years	Crop gain	
	2019	2020	2021		Yield, t/ha	%
Studentskyi	2.51	2.22	2.62	2.45	0.48	24.4
Kharkivskiyi 1	4.11	3.67	4.35	4.03	2.06	104.6
Lera	3.32	3.08	3.44	3.28	1.31	66.5
Ultra (standard)	2.08	1.37	2.46	1.97	–	–
Aztec	2.33	1.68	2.56	2.19	0.22	11.2
Sam	2.93	2.31	2.98	2.74	0.77	39.1
Polishchuk	2.39	1.71	2.53	2.21	0.24	12.2

Notes: HIP_{05} 2019 – 0.15 t/ha; 2020 – 0.16 t/ha; 2021 – 0.19 t/ha

The decrease in amaranth yield in 2019 is explained by specific hydrothermal conditions. In general, vegetation was characterised by higher temperatures and precipitation compared to the average long-term

data. However, in May, at an average annual rate of 69 mm, 161 mm of precipitation fell, which is 92 mm higher than normal (Fig. 1). Due to the constant rains, it was difficult to effectively control the level of contamination

of amaranth crops. In addition, due to overwatering, air was displaced from the soil and there was not enough oxygen in the soil for the normal development of the root system. This limited the assimilation of nutrients, slowed down the growth processes in amaranth, inhibited the development of the root system, the increase in biomass, which ultimately led to a decrease in yield.

The works of T.I. Hoptsii note that when establishing the interaction and effect on the sowing-germination period of climatic conditions of the year, sowing methods and plant density on the yield of green mass, the conditions of the research year had a more pronounced effect for species *A. hypochondriacus* and *A. hybridus* – 4.7 and 4.9% than for the species *A. cruentus* – 2.4% [18].

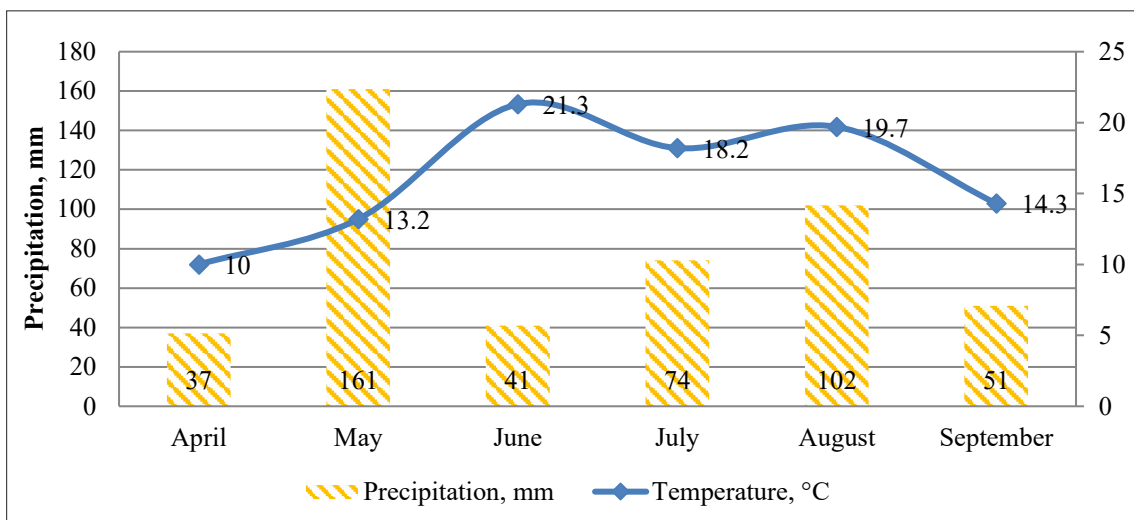


Figure 1. Hydrothermal conditions in 2019

The lowest grain yield in all the studied cultivars was in 2020 and ranged from 1.37-3.67 t/ha (Table 1). The difference between the lowest yield in the amaranth Ultra cultivar and the highest in the Kharkivskiyi 1 cultivar is 2.30 t/ha. The reason for the decline in yields in 2020, as in 2019, was excessive precipitation. However, unlike in 2019, when soil overwatering was observed in May, in 2020 it was very wet for a longer period of two months – May and June. Thus, in May, 138 mm of precipitation fell, which is twice as much as normal, by 69 mm (Fig. 2).

June was also rainy, with 140 mm falling, or 56 mm higher than the long-term average. Notably, in addition to overwatering, May 2020 was cold. The average monthly temperature this month was only 10.9°C, which is 3.1°C less than normal. Excessive rainfall combined with low temperatures in May caused a significant reduction in yields in 2020 compared to 2019 and 2021. Amaranth is of tropical origin and is characterised by heat-loving and drought resistance.

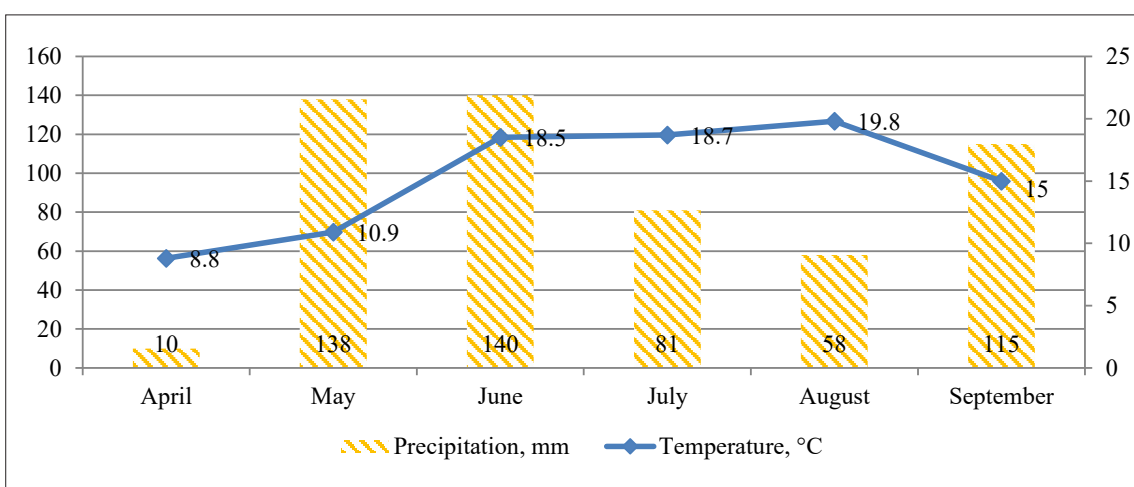


Figure 2. Hydrothermal conditions in 2020

Similar results of studies on the negative impact of overwatering in May-June 2014 on amaranth yield

in the Polissia zone were also obtained by other researchers [24]. Correlation and regression analysis has

shown that the amount of precipitation during the vegetation affects the grain yield of all the studied amaranth cultivars. A strong relationship was identified for: Kharkivskiyi 1, Ultra and Lera cultivars, the correlation coefficient was $r=-0.82$, $r=-0.82$ and $r=-0.83$, and for the Studentskiy, Aztec, Polishchuk, and Sam cultivars it was $r=-0.86$, $r=-0.87$, $r=-0.91$, and $r=-0.95$, respectively.

This dependence for the Kharkivskiyi 1 cultivar can be described by the regression equation:

$$Y=0.12X+3.803 \quad (1)$$

where Y – yield, t/ha;

This equation describes the process of forming the yield of amaranth, which is confirmed by the multiple correlation coefficient ($r=-0.82$), the relationship between the effective feature and the argument is quite close. The coefficient of determination is $R^2=0.121$.

The hydrothermal conditions of 2021 were the most favourable for the development of amaranth grain yields. The yield, depending on the cultivar, varied in the

range of 2.46-4.35 t/ha. The difference between the lowest yield of the Ultra cultivar and the highest yield of the Kharkivskiyi 1 cultivar is 1.89 t/ha. In the third year of research, the amount of precipitation in the first half of the vegetation was within the normal range, as a result of which there was no soil overwatering. Higher than normal precipitation in August (144 mm) and September (108 mm) did not have a negative impact on the development of amaranth yield (Fig. 3). The sum of temperatures also corresponded to the long-term average, and what is important, in July it was the highest in three years of research – 21.7°C, which is 3.1°C higher than normal. Influence of hydrothermal conditions during studies on the productivity of paniculate amaranth (*Amaranthus paniculatus*) of the American cultivar sample R-158 was observed in studies in the conditions of the northern steppe of Ukraine. In particular, the most favourable growing conditions of amaranth with a hydrothermal coefficient of 1.06 were noted [9].

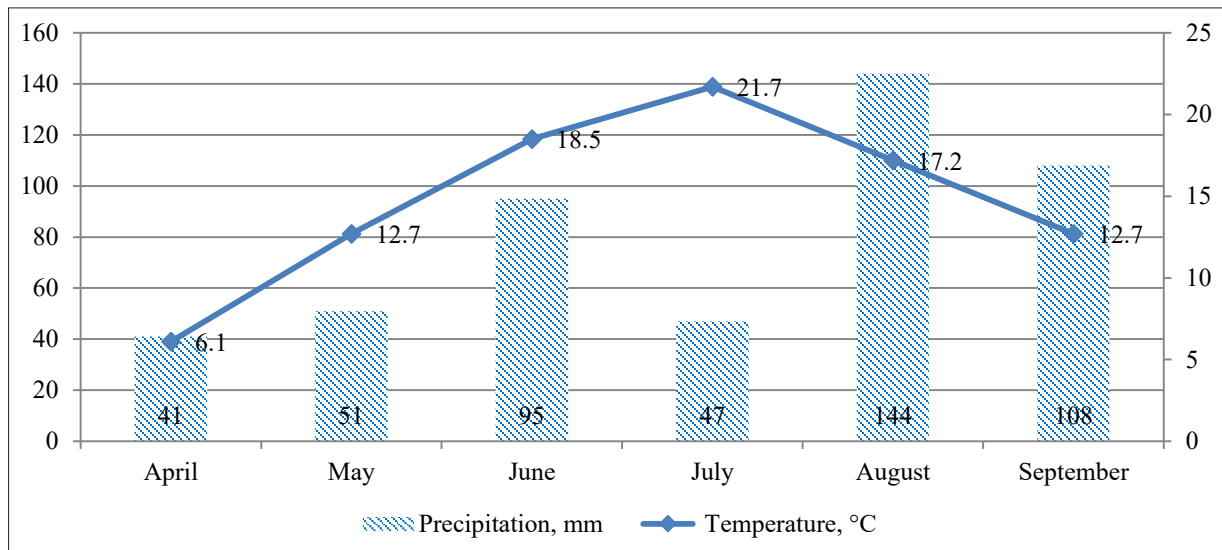


Figure 3. Hydrothermal conditions in 2021

On average, for three years among amaranth cultivars, the lowest grain yield was obtained in the Ultra cultivar – 1.97 t/ha (Table 1). The Aztec cultivar also had a low yield of 2.19 t/ha, which is 0.22 t/ha higher than the Ultra cultivar (11.2%). The grain yield of the Polishchuk cultivar was formed almost at the same level – 2.21 t/ha, or more than the Ultra cultivar by 0.24 t/ha (12.2%). The Studentskiy cultivar had a yield of 2.45 t/ha, which is 0.48 t/ha higher than the Ultra cultivar (24.4%). The Sam cultivar with a yield of 2.74 t/ha exceeded the Ultra cultivar by 0.77 t/ha (39.1%). Fluctuations in the yield of Ultra (1.8-4.9 t/ha) and Studentskiy cultivars (1.6-5.1 t/ha) depending on weather conditions during the study years were noted in studies conducted in the left-bank forest-steppe of Ukraine during 2014-2016 [20]. Seed yield of species *A. hypochondriacus* and *A. hybridus*

ranged from 51.8-203.3 g/m² and 104.7-142.2 g/m² accordingly [17].

As a result of research, it was established that the highest yield on average for three years was formed by the cultivars Kharkivskiyi 1 and Lera. The Lera cultivar had a yield of 3.28 t/ha, which is 1.31 t/ha (66.5%) more than the Ultra cultivar. The highest yield was obtained in the Kharkivskiyi 1 cultivar, which was 4.03 t/ha, or higher than in the Ultra cultivar by 2.06 t/ha (104.6%). Compared to the Lera cultivar, the yield increase in the Kharkivskiyi 1 cultivar is 0.75 t/ha or 22.9%.

Analysis of the structural elements shows that sufficient precipitation provided good vegetative growth. The biggest plant height was in the Sam cultivar (207.4 cm). The most productive cultivars were also distinguished by good growth: in Kharkivskiyi 1, the plant height was

193.6 cm, in the Lera cultivar – 195.3 cm (Table 2). As a result of the correlation and regression analysis, a direct strong influence of precipitation on the height of the stem of amaranth plants was identified, namely, for the cultivars Kharkivskiyi 1, Polishchuk, and Aztec, the correlation coefficient was $r=0.84$, $r=0.83$, $r=0.79$, and for the cultivars Sam, Ultra, Lera, Studentskiyi – $r=0.77$, $r=0.74$,

$r=0.72$, $r=0.70$, respectively. The relationship between the height of plants and the temperature regime in the years of research was also established: the correlation coefficient for the Studentskiyi, Lera, Ultra cultivars was $r=0.39$, $r=0.37$, $r=0.34$, which indicates an average direct and weak direct relationship – for Polishchuk ($r=0.20$), Sam ($r=0.30$), Aztec ($r=0.27$), and Kharkiv 1 ($r=0.17$) cultivars.

Table 2. Elements of the crop structure of amaranth cultivars

Cultivar	Plant height, cm	Panicle length, cm	Seed weight per plant, g	Weight of 1000 seeds	Number of plants per m ² at the time of harvesting
Studentskiyi	192.0	49.2	12.4	0.76	20
Kharkivskiyi 1	193.6	54.5	19.2	0.88	21
Lera	195.3	61.0	16.4	0.76	20
Ultra	131.5	69.4	11.0	0.78	18
Aztec	171.2	55.2	11.5	0.74	19
Sam	207.4	60.3	15.2	0.75	18
Polishchuk	170.0	64.7	11.6	0.85	19

The length of the panicle was the highest in Ultra cultivar, but this cultivar was the least productive, while in the Kharkivskiyi 1 cultivar, the panicle length was one of the shortest and the yield was the highest, which is conditioned upon botanical and morphological features and the yield potential of the cultivars. An average inverse correlation was identified between the panicle length and the yield of the studied cultivars – $r=-0.36$. It was also established that the amount of precipitation had a direct strong effect on the development of panicle length in Aztec ($r=0.76$), Ultra ($r=0.75$), Polishchuk ($r=0.77$), and Lera ($r=0.71$) cultivars, and correlation coefficient in the Sam, Kharkivskiyi 1 and Studentskiyi cultivars was $r=0.63$, $r=0.54$ and $r=0.58$, respectively, which indicates a direct relationship of average strength. There is a positive average correlation between the temperature regime and the development of the panicle length – from $r=0.30$ to $r=0.57$.

The weight of 1000 seeds ranged from 0.74-0.88 g. The largest grain was in the Kharkivskiyi 1 cultivar, which provided this one with the highest yield. A direct average relationship was established between the weight of 1000 seeds and the yield of amaranth grain – $r=0.47$. According to the results of studies in the conditions of the left-bank forest-steppe of Ukraine, the mass of 1000 seeds fluctuated depending on the conditions of the year, and amounted to 0.51-0.68 g in the Ultra cultivar and 0.57-0.71 g in the Studentskiyi cultivar [6].

Number of plants per m² at the time of harvesting varied in a narrow range, from 18 to 21 plants. With such a relatively small number of plants, a pattern was observed: the higher the density of plants, the higher the yield. Correlation and regression analysis has shown that

an increase in the number of plants at the time of harvesting provides an increase in the yield of amaranth grain. The correlation coefficient was $r=0.76$, which indicates a direct strong connection.

The greatest direct impact on the level of grain yield in amaranth cultivars is the low mass of seeds per plant, which is confirmed by the correlation coefficient $r=0.99$. In the Kharkivskiyi 1 cultivar, the grain weight per plant was 19.2 g, which is 0.14 g higher with the Aztec cultivar. A high inverse relationship was established between the amount of precipitation during the vegetation and the weight of seeds from 1 plant: $r=-0.84$ for the Aztec cultivar, $r=-0.92$ for Ultra and Polishchuk cultivars, $r=-0.83$ for the Lera cultivar, $r=-0.90$ for the Studentskiyi, Kharkivskiyi 1, and Sam cultivars. A strong direct relationship was also established between the temperature regime and the weight of grain from 1 plant: $r=0.72$ for Polishchuk and Ultra cultivars, $r=0.75$ for Studentskiyi, Kharkivskiyi 1, Sam cultivars, $r=0.82$ for the Aztec cultivar, and $r=0.84$ for the Lera cultivar. Thus, the highest yield of the Lera cultivar (3.28 t/ha) was obtained with a plant density of 20 pcs/m² and the mass of grain in the panicle was 16.4 g, and in the Kharkivskiyi 1 cultivar with the highest yield (4.03 t/ha), these structural elements were higher: 21 plants/m² and the weight of grain in the panicle was 19.2 g.

CONCLUSIONS

The yield of amaranth, as a drought-resistant crop, decreased (in 2019 and 2020) with excessive precipitation in the first half of vegetation. The highest yield (2.46-4.35 t/ha) was formed in 2021 when the amount of precipitation in May, June and July was within the

normal range. A strong inverse correlation was established ($r=-0.82$ – $r=-0.95$) between the yield of amaranth cultivars and the amount of precipitation. In the conditions of the western forest-steppe, with sufficient and excessive moisture supply on dark grey podzolised light loamy soil, the highest grain yield (4.03 t/ha) among the seven studied amaranth cultivars was obtained in Kharkivskiyi 1. The lowest yield was formed in the Ultra cultivars (1.97 t/ha), which is less than in the Kharkivskiyi 1 by 2.06 t/ha.

Plant height and panicle length did not directly affect the level of amaranth grain yield. The study of

elements of the crop structure showed that the height of the plant had a positive effect ($r=0.63$) on the level of amaranth grain yield, while average relationship was observed between panicle length and yield ($r=-0.36$). The weight of 1000 seeds in the cultivars ranged from 0.74-0.88 g. The low mass of seeds per plant had the greatest impact on yield (correlation coefficient $r=0.99$). The highest yield of amaranth in the Kharkivskiyi 1 cultivar was formed with the following ratio of the main elements of the crop structure: the number of plants is 21 p/m² and the mass of seeds from the plant is 19.2 g.

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Урожайність амаранту (*Amaranthus*) залежно від сорту в умовах Лісостепу Західної України

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Анотація. Амарант називають культурою майбутнього завдяки його унікальним харчовим, кормовим і лікарським властивостям. Посівні площі амаранту в Україні є дуже малі, що можна пояснити відсутністю адаптивних технологій вирощування, особливо для вирощування цієї культури на зерно. Метою досліджень було встановити найбільш урожайні сорти для вирощування в умовах надмірного і достатнього зволоження в умовах західного Лісостепу на темно-сірому ґрунті. Для цього проводили польові дослідження на дослідному полі Львівського національного аграрного університету. Загальна площа ділянки становила 30 м², облікова – 20 м². Дослідження проводились у трьох повтореннях. Автори вивчали сім найбільш поширених в Україні сортів амаранту: Харківський 1, Лера, Сем, Студентський, Поліщук, Ацтек, Ультра. Встановлено, що врожайність амаранту значно залежала від гідротермічних умов року. Вона була меншою уроки з надмірною кількістю опадів у першій половині вегетації (2019 та 2020 рр.). Найвища врожайність зерна (2,46–4,35 т/га) формувалась у 2021 році, в якому сума опадів у травні, червні і липні була в межах норми. Встановлено сильний зворотній кореляційний зв'язок ($r=-0,82$ – $r=-0,95$) між урожайністю сортів амаранту та кількістю опадів. Найвищу врожайність зерна (4,03 т/га) серед досліджуваних сортів амаранту одержано в сорту Харківський 1. Найменша урожайність формувалась у сорту Ультра (1,97 т/га), що менше порівняно з сортом Харківський 1 на 2,06 т/га. Вивчення елементів структури урожаю показало, що висота рослини мала позитивний вплив ($r=0,63$) на рівень урожайності зерна амаранту, тоді як між довжиною волоті та урожайністю спостерігався зворотній зв'язок середньої сили ($r=-0,36$). Маса 1000 насінин у сортів коливалась в межах 0,74–0,88 г. Найбільший вплив на врожайність мала маса насіння з рослини ($r=0,99$). Найвища врожайність амаранту сорту Харківський 1 формувалась за такого співвідношення основних елементів структури урожаю: кількість рослин – 21 р/м² та маса насіння з рослини – 19,2 г. Для одержання високого стабільного урожаю зерна амаранту необхідні додаткові дослідження з уточнення основних елементів технології вирощування для даних ґрунтово-кліматичних умов

Ключові слова: амарант, сорти, приріст урожаю, маса 1000 насінин, гідротермічні умови, елементи структури



UDC 632.11

DOI: 10.48077/scihor.24(10).2021.52-57

Study of Plant Adaptation to the Arid Zone of Uzbekistan based on System Analysis

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Article's History:

Received: 24.09.2021

Revised: 22.10.2021

Accepted: 25.11.2021

Suggested Citation:

Allaberdiev, R., Rakhimova, T., Komilova, N., Kamalova, M., & Kuchkarov, N. (2021). Study of plant adaptation to the arid zone of Uzbekistan based on system analysis. *Scientific Horizons*, 24(10), 52-57.

Abstract. Studying the ecological and biological features and water regime of plants of the mountainous semidesert of Uzbekistan to determine their stability in these conditions, we concluded to use an integrated approach to solve the problem of adaptation. Functional, structural or other biological features can equally determine the resistance of a species to extreme factors, such as, for example, the rhythm of development. The purpose of the work is to identify a complex of elements of plant adaptation to arid zone to xerothermic conditions and to characterize ecological groups by the generality of adaptation systems. Based on the system analysis, the biological and structural-functional adaptive features of plants were analyzed, and the studied species were classified into ecological groups as adaptive systems and according to the generality of adaptations to the experience of the dry period. The original data obtained, which relate to the characteristics of the elements of biomorphological adaptation and adaptation of the water regime, the remaining adaptive elements were identified based on the analysis of literary data. Along with structural and behavioral signs, we focus on those features of the water regime that ensure a positive water balance among representatives of various environmental groups. Each of the selected ecological groups of plants is characterized by a certain combination of adaptive features of a physiological and biomorphological plan. With a variety of adaptive features in different plant species to drought and the absence of an integral indicator of drought resistance, it is impossible to focus on any one of them, of course, it is necessary to take into account the whole complex of signs. The complex of features will allow determining more accurately the nature of a particular combination of biomorphological and functional features peculiar to a particular ecological group

Keywords: flora, biological features, hyperxerophyte, xerothermic conditions, leaves, ecological groups



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INTRODUCTION

Hyperxerophytes have a well-balanced water regime according to all the parameters studied. High water-holding capacity determines stable hydration and low water deficiency in plants. Very high heat resistance (59.5-62.8°C) characterizes Hyperxerophytes [1]. Roots of young taproot plants deepens into the soil faster than its desiccation occurs. That is of great adaptive importance for this group. Most hyperxerophytes of the arid zone of Uzbekistan (*Haloxylon aphyllum*, *Salsola orientalis*, *Halothamnus psammophilus*, *Anabasis eriopoda*, *Salsola paulsenii*, *Climacoptera lanata*, etc.) have reduced leaves, except for *Halimiphyllum atriplicoides*, *Halothamnus auriculus* and *Peganum harmala*, which have laminar ones. *Halimiphyllum atriplicoides* has two generations of leaves: spring leaves are large, mesophilic (falling in summer), summer leaves are small, more xerophilous, remaining green until the spring of the following year. Reducing the leaf surface is a common way to reduce the evaporation surface. In *Halothamnus auriculus* [2], as in species with reduced leaves [3; 4], a centric mesophyll type is observed, which an adaptation to arid conditions is. Some stomata are characteristic per 1 mm² of the leaf area. Assimilating organs have a cranial structure with signs of succulence. The retention of moisture in the leaves is facilitated by specialized water-bearing parenchyma, thin-walled, large-cell epidermis and hypoderm [5]. The walls of the epidermal cells of the leaves contain hemicellulose and pectin substances with high hygroscopicity [6].

Hyperxerophytes are characterized by a stable, relatively uniform daily and seasonal course of photosynthesis and the maximum degree of realization of its potential. The high resistance of the respiratory system to extreme temperatures has been revealed: the critical respiratory temperature is 51-57°C [7].

Vegetation continues until late autumn. In August, summer generation leaves are formed. In *Kochia prostrata*, the regrowth of wintering buds is observed in spring of favorable years. However, in summer, the depression of growth processes is clearly expressed, the shedding of part of the leaves. The reduction of the evaporating surface in these species is achieved in various ways: *Kochia prostrate* is a microphilic plant; *Geratoides eversmanniana* has laminar, relatively large leaves. In both species, compared with hyperxerophytes, the signs of scleromorphosis are more pronounced and less succulent [5].

As the intensity of transpiration, the photosynthetic activity is higher in *Kochia prostrate* and *Geratoides eversmanniana* than in plants from the hyperxerophyte group [8]. Phosphorus metabolism during drought is less stable in these species, a decrease in the content of nucleic acids due to RNA was noted [4; 9]. The critical respiration temperature is almost as high (50-55°C), as in hyperxerophytes.

The purpose of the study is to identify a complex of elements of plant adaptation to arid zone to xerothermic conditions and to characterize ecological groups by the generality of adaptation systems.

MATERIALS AND METHODS

The methodology of adaptation studies is based on system analysis [10]. We tried to display the ecological relationship. We have revealed that the most adapted to xerothermic conditions are representatives of hyperxerophytes: *Haloxylon aphyllum*, *Halothamnus psammophilus*, *Anabasis eriopoda*, *Salsola orientalis*, *Climacoptera lanata*, *S. sclerantha*, *Girgensohnia dintera*, etc. The given brief analysis of the biological, morphological and physiological data suggests that the considered representatives of the type of xerophytes, namely hyperxerophytes, euxerophytes, teroieromoxerophytes, hemixerophytes, are unequal in the complex of adaptive features that determine their stability in arid conditions. The growth in the same habitats and in the same type of vegetation of representatives of different drought-resistant ecological groups from the type of xerophytes indicates a wide range of plant adaptations to the conditions of the arid zone of Uzbekistan.

Our scientific research continued in the zone of the global ecological crisis of the Southern Aral Sea region of the Muynak district of the Republic of Karakalpakstan, a fibrous high-performance technical culture of kenaf is the object of the study (*Hibiscus cannabinus*). The site is located in Muynak district of Karakalpakstan 20 km from the former bank of the Aral Sea. The soil is slightly saline; groundwater is located 2.2 meters deep from the surface of the earth. Kenaf sowing was carried out on 04/12/2019. Sowing of seeds was carried out in the following way: the depth of seeding in the soil was 5 cm, between rows 60 cm, the distance between plants was 10 cm, the first shoots appeared on 04/24/2019, branching occurred in the second decade of May, budding was noted in mid-June, flowering at the end of June, fruiting was noted in July. During the growing season, watering of plants was carried out 2 times in July and August. The height of the plants at the end of the growing season reached 2-2.5 meters.

The reliability of the difference is significant between ecological groups in terms of maximum and minimum (average daily) values of transpiration, hydration and water scarcity [11]. Anatomical features play a significant role: submerged stomata of the anomocytic type, *mesophyll isopalysis*, sclerification of the main vein of the leaf, highly developed storage tissues [12]. Along with forage plants of the arid zone, the biological and ecological features of the introduced kenaf (*Hibiscus cannabinus*) representative of the Malvaceae family were studied.

RESULTS AND DISCUSSION

The water regime of representatives of the xerophyte group is more labile than that of hyperxerophytes. The intensity of transpiration in them is much higher, and the hydration of assimilation shoots is lower. From spring to summer, the hydration of shoots decreases sharply, and osmotic pressure increases. The water retention capacity

is lower than that of hyperxerophytes, and the water deficit is higher. Less economical water consumption in the mesothermic period is associated with their lower water retention capacity than that of hyperxerophytes (Table 1). There is an inverse relationship of transpiration intensity with osmotic pressure ($K=0.5-0.9$) and water-holding capacity ($K=-0.5-0.7$), as well as a positive

relationship between water retention capacity and osmotic pressure ($K=+0.4+0.8$). An increase in osmotic pressure determines the stability of plants during the xerothermic period. Heat resistance is lower (59°C) than in hyperxerophytes. Thus, the plants of this group are distinguished by a deep and versatile adaptation to living in conditions of lack of moisture and high temperatures.

Table 1. Water regime main indicators of plants from various ecological groups

Environmental group and type	Average daily evapotranspiration rate, m/g/h	Average daily moisture content, %	Water-retaining capacity, %	Maximum water deficiency, % of full saturation	Average daily osmotic pressure, atm.	Frequency of transpiration rate below 400 mg/g/h, %
Hyperxerophytes						
<i>Haloxyton aphyllum</i> (Minkv.) Iljin	123/630*	60.8/80.6	82.1	7/6	6/42	70.6
<i>Halimiphyllum atriplicoides</i> (Fesch et Mey.) Boriss.	276/518	64.8/85.5	81.8	19.7	6/22	09.9
<i>Halothamnus psammophilus</i> Botsch sp. nov.	240/349	72.6/83.8	94.2	11.4	7/17	97.5
<i>H. auriculus</i> (Moq.) Botsch	170/580	74.4/81.1	94.0	11.5	8/15	69.3
<i>Anabasis eriopoda</i> (Schrenk) Benth	127/344	68.3/74.4	–	7.6	8/23	01.0
<i>Peganum harmala</i> L.	225/412	71.2/79.5	–	21	24/34	64.6
<i>Salsola orientalis</i> S.G.Gmel.	169/660	52.2/86.2	83.8	12.2	5/43	82.7
<i>S. paulsenii</i> Lity.	161/625	69.7/78.5	88.4	25	10/32	66.3
<i>S. sclerantha</i> C.A.Mey	68/296	58.2/73.7	87.3	27.9	9/19	95.8
<i>Girgensohnia dintera</i> Bge.	133/401	54.4/63.7	89.1	26	9/44	66.2
<i>G. oppsitiflora</i> (Pall.) Pens.	95/644	51.0/73.3	87.8	27.8	9/28	–
<i>Climacoptera lanata</i> (Pall.)	65/186	75.0/86.2	95.2	17.0	6/19	–
Euxerophytes						
<i>Kochia prostrata</i> (L.) Schrad. subsp. <i>grisea</i> Prat.	114/762	34.9/76.4	–	45.9	6/22	65
<i>K. prostrata</i> (L.) Schrad. subsp. <i>virescens</i> .	180/900	36.1/79.9	71.7	24.0	6/65	65
<i>Geratoides eversmanniana</i> (Stschrq. ex Losinsk.) Botch. et Jkon.	175/170	37.2/78.5	72.6	49.0	7/67	56.0
<i>Ceratocarpus utriculosus</i> B.uk.	204/1017	34.1/75.2	62.4	34.0	9/50	40.2
Theroiremoxerophytes						
<i>Artemisia ferganensis</i> H. Krasch.	226/1704	42.3/77.5	56.0	58.0	5/56	63.8
<i>A. Sogdiana</i> Bge.	230/1676	46.0/80.6	56.0	63.3	4/56	52.8
<i>A. turonica</i> H.Krasch	226/1670	42.5/79.1	50.5	59.0	6/65	52.2
<i>F. tenuisecta</i> Nevski.	224/1645	35.4/76.1	52.7	57.2	6/65	55.2
Hemixerophytes						
<i>Alhagi pseudahalagi</i> (Bieb.) Desv.	414/1267	61.3/78.7	70.5	14	5/23	19.0
<i>Capparis spinosa</i> L.	519/900	63.1/72.0	–	19.0	5/37	19.0

As can be seen from the above data, the adaptation of euxerophytes was in the direction of increasing the ability to reduce the evaporating surface in summer, increase osmotic parameters, and change the generation of leaves from spring mesophilic to summer xerophilous. A smaller variety of adaptive features determined their lesser adaptability to xerothermic conditions [13].

Artemisia-wormwood species from the Seriphidium section are very widespread in the deserts and semi-deserts of Uzbekistan, which we refer to the group of theroiremoxerophytes, i.e. summer-resting xerophytes. Structurally and functionally, they are less adapted to xerothermic conditions than species from the hyper- and euxerophyte groups. The high viability of wormwood in arid conditions is mainly determined by the peculiarities of seasonal rhythmic and the specifics of the morphological structure of vegetative organs, to a lesser extent adaptation affected the more conservative anatomical and functional features.

The leaves of wormwood are small, dissected, pubescent, but anatomically less xeromorphic than those of the representatives of the above groups; the mesophyll is thin-walled, with an insignificant number of water-bearing cells located only around the veins [14].

The water regime of wormwood is even more labile than that of euxerophytes. The intensity of transpiration is very high in spring, and it decreases by six times in summer. The water content of assimilation shoots is halved in summer. Water retention capacity is significantly lower than that of representatives of hyper – and euxerophytes, water deficiency reaches high values. This causes a violation of the water balance and a forced period of semi-rest, when assimilation processes are minimized. The preservation of the water reserve in the summer is possible due to a sharp reduction in transpiration and an increase in osmotic parameters, as well as a decrease in the evaporating surface by dropping leaves (70-100% of leaves fall off). The development of shoots begins in autumn, and then continues in spring. In summer, there is a pronounced depression of growth processes. The maximum heat resistance is lower (52-56°C), than in hyper- and euxerophytes [1].

Photosynthetic activity in wormwood is active during the mesothermic period of the year, however, in summer, like water exchange, it slows down. The adaptability of photosynthesis to high temperatures and illumination is limited: light saturation is observed in the range of 40-50 thousand lux, and the temperature zone of the optimum of photosynthesis is in the range of 12-37°C. Critical breathing temperature – 47-50°C, which is somewhat lower than in all the plants described above [8]. So, the representatives of this group are characterized by a decrease in functional and biological activity during the xerothermic period, which is a kind of “escape” from unfavorable conditions.

Peculiar xerophytes are plants that have an extremely deep root system, up to 20-30 m, penetrating into

horizons with constant moisture, i.e., according to the method of water nutrition, they belong to phreatophytes. The most common representatives of phreatophytes in the arid zone are *Alhagi pseudalhagi*, *Capparis spinosa* and *Glycyrrhiza* species. We attributed them to hemixerophytes, as they are adapted to the transfer of air, but not soil drought. These species are characterized by high transpiration; its lower limit is on average 414 mg/g h per day. During the flight period, the intensity of transpiration increases, which is unusual for representatives of other ecological groups such as xerophytes. The water content of assimilation shoots decreases little during the growing season, osmotic pressure and water deficit increase slightly by summer. As can be seen, the plants of this group have a relatively stable water regime. Unlike hyperxerophytes, high transpiration, stable hydration and osmotic pressure are provided by the activity of a deep root system reaching the groundwater level. They vegetate from spring to late autumn, maintaining high vital activity throughout the summer period.

The aboveground organs are xerophilic in structure. According to L. Shamsuvalieva and M.N. Davletshina [12], *Alhagi pseudalhagi* is characterized by mesophyll isopalisade, sclerification of the main vein of the leaf, axial organs and thorns, strong development of water-retaining tissue with a large amount of starch.

The intensity of photosynthesis in representatives of hemixerophytes is higher than in the above-mentioned groups. According to S.F. Fazylova [15; 16], near Tashkent, *Alhagi sparsifolia* photosynthesis intensity was 57 mg CO₂ dm²/h, and *Alhagi pseudalhagi* was 40 mg CO₂ dm²/h. The maximum heat resistance was 60°C.

The functional adaptation of hyperxerophytes to the conditions of existence in the arid zone is manifested in the stability of the water balance and photosynthesis. Their water management is characterized by significant hydration of assimilating organs, economical water consumption, its insignificant deficit, high water retention capacity. The high heat tolerance of the assimilation apparatus determines the ability of plants of this group to tolerate overheating well.

Unlike hyperxerophytes, the lability of many biomorphological and functional features is of adaptive importance for euxerophytes. This is clearly manifested when comparing plants in sharply different meteorological conditions in years: in dry years, the rhythm of generative phases shifts, the assimilating surface decreases sharply in summer. During the growing season, in accordance with environmental conditions, the levels of the main indicators of the water balance (transpiration intensity, hydration, osmotic indicators, etc.) change dramatically.

In theroiremoxerophytes, the most important adaptation to experiencing an unfavorable xerothermic period is the ability to almost completely shed leaves in summer, which reduces water consumption for transpiration, and this does not interfere with the normal

development of reproductive organs. This feature (reduction of the evaporating surface) is very labile; its severity is determined by the degree of soil drought. Functional adaptation manifests itself in a sharp change in the activity of photosynthesis and the level of indicators of the water regime during the growing season: the most physiologically active period falls at the end of spring – beginning of summer, before the onset of soil drought [17].

In hemixerophytes, signs of functional adaptation are poorly expressed; high transpiration, low osmotic pressure, adaptability to living in xerothermic conditions are provided, first, by a deeply penetrating root system (up to 20-30 m), reaching constantly moistened soil horizons. In the conditions of the Southern Aral Sea region in Muynak, highly efficient, comprehensively used for various purposes (fiber, paper, cardboard, tarpaulin, etc.). The biological and ecological features of kenaf have not been fully studied by scientists [18; 19]. Kenaf has a biological feature, about 30-40 days after germination it grows very slowly (3-5 mm per day), and from budding to flowering its rapid growth begins (50-60 mm per day). The yield of green kenaf depends on the height of the plant and its development, which in turn is due to the density of standing. The yield of the aboveground mass of kenaf is 27.5 c/ha.

CONCLUSIONS

From the above material, it can be seen that according to the degree of adaptation to extreme xerothermic conditions, the studied species of the arid zone of Uzbekistan can be divided into a number of ecological groups. Representatives of each of them have similar adaptive traits, although their combination and severity in species belonging to the same group may be ambiguous, and this determines their different (within the group) degree of fitness. The analysis made it possible to deduce a complex of adaptive features inherent in environmental factors,

the physiological essence of the ways of adaptation. The ability to tolerate the xerothermic period normally is characteristic of a wide type of xerophytes. In hyperxerophytes and euxerophytes, this is achieved not only by structural adaptations of assimilation organs, but also as a result of the development of a powerful root system that provides water from the soil, economical consumption, increased water retention capacity, in teroieroxerophytes – as a result of a reduction in the evaporating surface during the xerothermic period, increased osmotic pressure, in hemixerophytes due to the strong development of the root system reaching groundwater.

Our research has revealed that kenaf adaptation to the conditions of the Southern Aral Sea region has the following ecological properties: kenaf is a therophyte (annual plant) in its life form in relation to photoheliophyte (photophilous) to mega temperatures (thermophilous). It is a hemixerophyte by the water factor and halomesophyte by the soil salinity. The root system is rapidly growing (more than 2 meters), it reaches the moistened horizon of the soil trichohydrophite. Based on our scientific research, it should be noted that kenaf is a promising highly profitable crop, ecologically adapted to the conditions of the Southern Aral Sea region. In addition, its role is great to optimize the environment as a sand protection.

The developed ecological classification of forage plants is the scientific basis of their zoning during phytomelioration. Representatives of ecological groups are unequal in the degree of adaptation to xerothermic factors. Plants with stable (hyperxerophytes) and medium-stable (euxerophytes) water regime, content with limited water supply, can be widely zoned in the arid zone. Culture phytocenoses are profitable only from teroieroxerophytes in areas where the annual precipitation exceeds 200 mm/year.

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Вивчення адаптації рослин до посушливої зони Узбекистану на основі системного аналізу

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Анотація. Вивчаючи еколого-біологічні особливості та водний режим рослин гірської напівпустелі Узбекистану для визначення їхньої стійкості в даних умовах, автори статті дійшли висновку про необхідність комплексного підходу до вирішення проблеми адаптації. Стійкість виду до екстремальних факторів може однаковою мірою визначатися функціональними, структурними або іншими біологічними особливостями, як, наприклад, ритміка розвитку. Мета роботи – виявлення комплексу елементів адаптації рослин до аридної зони до ксеротермічних умов і характеристика екологічних груп щодо спільності адаптаційних систем. На основі системного аналізу проаналізовано біологічні та структурно-функціональні пристосувальні особливості рослин, як адаптаційні системи та за спільністю пристосувань, до переживання посушливого періоду вивчені види класифіковані на екологічні групи. Отримані оригінальні дані, що належать до характеристики елементів біоморфологічної адаптації та адаптації водного режиму, інші адаптаційні елементи виявлено на підставі аналізу літературних даних. Поряд із структурними та поведінковими ознаками основну увагу приділено тим особливостям водного режиму, які забезпечують позитивний водний баланс у представників різних екологічних груп. Для кожної з виділених екологічних груп рослин характерне певне поєднання пристосувальних ознак фізіологічного та біоморфологічного плану. При різноманітності адаптаційних ознак у різних видів рослин до посухи та відсутності інтегрального показника посухостійкості не можна орієнтуватися на будь-який з них, безумовно, необхідно враховувати весь комплекс ознак. Комплекс ознак дозволить більш точно встановити характер того чи іншого поєднання біоморфологічних і функціональних особливостей, властивих тій чи іншій екологічній групі

Ключові слова: флора, біологічні особливості, гіперксерофіт, ксеротермічні умови, листя, екологічні групи

SCIENTIFIC HORIZONS

Journal homepage: <https://sciencehorizon.com.ua>

Scientific Horizons, 24(10), 58-71



UDC 336.1:332.1

DOI: 10.48077/scihor.24(10).2021.58-71

Infrastructural Support of Socio-Economic Development of Rural Territories of Ukraine

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Article's History:

Received: 16.10.2021

Revised: 14.11.2021

Accepted: 17.12.2021

Suggested Citation:

Kravchuk, N., Kilnitska, O., Lavrynenko, S., & Yaremova, M. (2021). Infrastructural support of socio-economic development of rural territories of Ukraine. *Scientific Horizons*, 24(10), 58-71.

Abstract. Rural territories of Ukraine are locked in a “circle of decline” by two mutually reinforcing trends: firstly, the lack of jobs and sustainable business activity, and secondly, the lack of positive changes in the service sector for the rural population. This is often conditioned upon the low development of infrastructural facilities. This causes the need to finance modern, efficient and environmentally friendly rural infrastructure, which will increase the comfort and quality of living, stop the outflow of the working-age population to cities, improve the demographic situation in rural areas, and contribute to the development of the rural economy. Therefore, the research is aimed at diagnosing the current state of infrastructure support for rural areas and finding effective tools to eliminate the causes of their socio-economic decline. The research methodology is based on the use of such general scientific research methods as economic analysis and synthesis in the interpretation of statistical data sets, comparison in determining dynamic changes in the socio-demographic characteristics of rural areas, logical method in making generalisations and conclusions, graphical and computational-constructive for constructing a Lorentz curve, etc. The essence, definition and types of infrastructure are established. The current level of socio-economic development of rural areas of Ukraine is clarified and its interdependence with infrastructure support is discovered. The level of transport, housing and communal services, medical, cultural and educational, trade, and business infrastructure development is described. The paper highlights the experience of stimulating rural development in the EU countries, in particular, outlines financial instruments and the scope of support and comprehensive assistance to rural businesses, environmental protection, competitiveness, and social integration. European investment funds and their role in the development of EU rural infrastructure are described

Keywords: infrastructure, rural communities, rural population, quality of life, demographic situation, financial instruments, European funds



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INTRODUCTION

Active processes of decentralisation in Ukraine have given new opportunities for the development of spatial organisation of economic systems, in particular rural areas. Rural communities can make their own decisions about their life support. Among the priorities are the restructuring of expensive inefficient services; the redistribution of available capital to the most problematic areas; focusing on a new type of partnership between the state, rural population, rural entrepreneurs, and other partners in rural development; the search for sources of financing for promising projects to reduce dependence on the state budget; the creation of decentralised funds for rural development, which communities manage independently; the development of diversified areas of rural entrepreneurship, etc. To set new mechanisms in motion and implement the best experience of such reforms, it is necessary to revive rural infrastructure, which would stop the negative processes of high mortality, depopulation, poverty, and migration of the working-age population to infrastructure-developed territories. In addition, the destroyed infrastructure of the village hinders investment processes and the development of new forms of rural entrepreneurship: organic production, green tourism, bio-energy, etc. The above makes it necessary to separately study the modern features of infrastructure support for rural areas.

A considerable part of scientific publications of Ukrainian and foreign scientists is devoted to the problems of infrastructure development in rural areas. Chinese researchers Q. Wu, X. Guan, J. Zhang, Y. Xu study the role of infrastructure in the development of agricultural production [1]. They focus on the impact of rural infrastructure on eco-friendly agriculture and reducing production costs of enterprises. In particular, the authors' reasoned relationships between irrigation infrastructure, poor-quality roads, and the cost of agricultural production deserve attention, which is proved by the quantile regression model [1]. I. Manggat, R. Zain and Z. Jamaluddin provide an in-depth analysis of literature sources on the impact of infrastructure and its relationship to the social well-being of rural communities [2]. The authors base their research on proving the importance of institutional support for rural development and the need for the functioning of social institutions. Among Russian scientists, of particular importance is the work of T.M. Yarkova, who studies the relationship between economic and social infrastructure and rural development [3]. Attention is focused on the considerable infrastructure impact on innovation and investment processes. In addition, as a result of the neglect of life-supporting infrastructure facilities, the demographic situation in Russian villages is deteriorating. Italian scientists E. Brovarone, G. Cotella study modern ways of reducing the distance between the socio-economic development of urban and rural settlements, prove the existence of the problem of social inequality and marginality [4]. They draw attention to the

problem of limited accessibility of remote rural communities to high-quality passenger transportation services and the need for effective institutional support for rural areas in Europe. It can also serve as an experience for Ukrainian transport infrastructure stakeholders.

The problem of infrastructure development is particularly acute in developing countries. Thus, an Indian researcher Nenavath Sreenu critically analyses the future challenges of developing India's rural health infrastructure, discussing the burden of disease, widespread financial shortages, vaccination policies, and poor access to health care [5].

This problem does not bypass Ukrainian scientists. Among the recent publications that have made a large contribution to the development of theoretical aspects and practical recommendations for infrastructure support in rural areas, it is advisable to highlight the works of D.S. Bohdanov, who raises the problem of the high capital intensity of infrastructure facilities and limited financial resources of rural communities for their development [6, p. 95]. He notes that important components of the implementation of rural areas infrastructure potential are improvement programmes (water supply, asphaltting, sewerage) with the support of public and private institutions; legislative regulation of the tax system simplification and the provision of benefits to business entities; improving the culture of peasants' living, and many others. O.V. Dovhal and L.S. Bezuhla identify barriers that hinder the effective functioning of the ecotourism infrastructure of the regions [7]. The authors propose a regional innovation model, the implementation of which will contribute to the growth of rural incomes, reduce unemployment, and develop small businesses in rural areas, which will be based on public-private partnership. M. Tymoshenko discloses scientific and theoretical foundations of the social infrastructure of a village and searches for the causes of its destruction in Ukraine [8, p. 134]. The researcher applies multifaceted correlation and regression models to determine the correlation between social factors that affect rural development. A rather exhaustive classification of rural social infrastructure facilities is appealing, depending on the impact on the professionalism and education of farmers, labour productivity, ensuring social and living conditions, living standards, and comfort of living. Attention should be paid to the results of research by O.M. Shubalyi, who carries out a deep comparative analysis of urban and rural housing infrastructure (housing stock, its accident rate, equipment with sewerage, heating, hot water supply, water supply, etc.) and transport [9].

After conducting a literary analysis of these and many other papers, the authors came to the conclusion that Ukrainian literature does not sufficiently cover current problems of infrastructure support of rural areas.

The purpose of the paper is to clarify theoretical and methodological approaches to the development of

infrastructure and evaluates the state, features of functioning and availability of infrastructure facilities in rural areas of Ukraine as an area of their socio-economic development.

MATERIALS AND METHODS

The methodology of the research is based on the identification, clarification and use of the framework of categories of research problems, in particular “infrastructure”, “rural territories”, “socio-economic development”, which allowed identifying their essential aspects and properties, find the main patterns of functioning, and establish the relationship between them. The course of the research consists of principles that also form its methodology: assumptions – the construction of a working hypothesis, its proof or refutation; the opposition of processes that contradict each other; objectivity and logic of judgments; quantity, which turns into quality and thus increases the standard of living of the population in a certain territory; continuity of development and variability of socio-economic processes, etc.

The working hypothesis consists in suggesting that the proper development of rural infrastructure will contribute to the socio-economic growth of the rural population. To test the hypothesis, an economic analysis of the results was applied.

In addition to categories and principles, the methodology of the research is formed by a system of certain research methods. The dialectical method of cognition in combination with logical and comparative methods allowed establishing the truth in the scientific discussion about the concept and significance of infrastructure in the socio-economic development of a particular community. The paper uses general scientific methods: induction and deduction in reasoning about the cause-and-effect ties between modern trends in infrastructure support and the development of entrepreneurship in rural areas; scientific abstraction and concretisation in identifying the most important problems of infrastructure support in rural areas, system analysis in establishing structural links between various elements of infrastructure support in rural areas and establishing the sequence of research process, reductionism and wholism in explaining the regularity of functioning of the socio-economic system “rural territory – community” and demographic processes and characteristics that arise in it, etc. Statistical methods of comparison in determining dynamic changes in the demographic characteristics of the rural population of Ukraine for 1990-2020, the average monthly salary by type of economic activity, differentiation of the standard of living of the population, providing social and commercial infrastructure of the rural population with objects are of great importance in establishing individual facts and proving their impact on rural development. The reception of mean values is applied in the calculation of

indicators of infrastructure support for rural territories of Ukraine in general and on the example of the Zhytomyr region in particular. Graphic methods are used to visually represent the results of the study: diagrams, figures, tables.

The main data sources are materials from the state statistics service of Ukraine and the Main Department of Statistics in Zhytomyr region. In particular, the sections of demographic and social statistics [10] are of interest, such as: “Population and migration”, which highlights arrays of initial data on demographic processes and phenomena; “Labour market” contains information about employment, unemployment and earnings of the population of Ukraine in various industries and territories; “Income and living conditions” provides an opportunity for in-depth research of the causes of deterioration in the socio-economic development of the rural population. Materials of a sample survey of Ukrainian households on living conditions and the level of their material support, conducted by the department of household surveys of the State Statistics Service through a survey in January 2021 became significant in clarifying the arguments of negative dynamic processes in rural areas [11]. In addition, to evaluate the degree of satisfaction of the rural population with the level of development of individual social infrastructure facilities in the context of the COVID-19 pandemic, statistical materials such as “Access of Ukrainian households to the Internet” [12], “Self-assessment of the population’s health status and availability of certain types of medical care” [13], and others were used.

RESULTS AND DISCUSSION

Identification of the infrastructure entity as an economic category

The provision of rural infrastructure usually consists of relatively small investments over a geographically large area. Having appropriate management tools and considerable resource potential (large land areas, free labour resources, entrepreneurial initiatives), local authorities have the opportunity to plan and control the functioning of rural infrastructure [14]. In general, rural development is considered necessary to reduce differentiation at the social, economic and cultural levels between regions. The developed infrastructure is designed to improve the quality of life, thereby solving the problem of migration to the city in search of a comfortable life [15]; create the necessary auxiliary production for agriculture, ensure equal involvement of rural entrepreneurship in market relations. Investing in rural infrastructure will provide long-term competitive advantages and a reliable basis for community development [16].

The origin of the term “infrastructure” itself is well known from the Latin words “infra” – below and “structura” – structure [17], but its practical application is found primarily in construction as the basis, the foundation of a building. In addition, it is associated with

“...military sphere as a complex of structures, communications that ensured the success of military operations (training grounds, sites, airfields, radar posts, etc.), and supported the defence capability of the state in peacetime” [18]. Modern interpretations and the scope of the term have changed and expanded. It has penetrated all spheres of society. Referring to the Cambridge Dictionary, infrastructure is interpreted as a system of transport and energy supply services that a country or organisation uses for efficient operation [19]. A similar definition is given in the Oxford Dictionary – “basic physical and organisational structures (for example, buildings, roads, power supply) necessary for the functioning of a society or enterprise” [20]. In the Dutch dictionary, infrastructure is defined as a system of roads,

railways, waterways, ports, airports, electrical equipment, cables, etc. [21], but in fact, it provides the same function – traffic. When studying infrastructure, most often scientists use objects of the transport system, which are certainly the elements of infrastructure support, but such a list is far from complete. A broader interpretation of this category is provided by World Bank experts, who vary it from railway lines and electricity consumption to internet subscribers and daily newspapers [22]. The contradictions of previous visions of the essence of infrastructure consist in an incomplete list of its objects that limit its functional purpose. Thus, for example, infrastructure as a category, should perform social, organisational and economic functions in addition to the function of movement (Fig. 1).

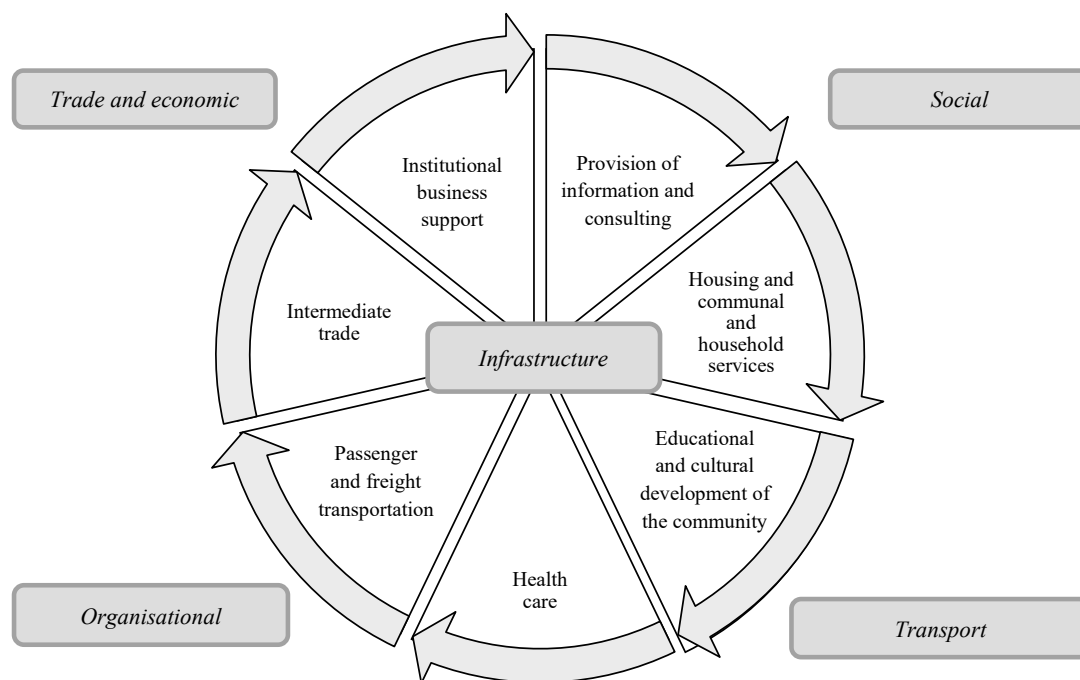


Figure 1. Infrastructure functions depending on the scope of operation

Source: developed by the author

In particular, infrastructure should include objects that perform social functions, such as hospitals, schools, cultural and artistic institutions, public buildings. It is also advisable to include objects that perform market functions and serve the development of entrepreneurship (exchanges, service cooperatives, fairs, exhibitions). In addition, if the infrastructure has the function of an auxiliary basis of society, this should include objects of financial and credit services (banks, insurance companies, credit unions) and information and advisory centres that help with entrepreneurship, financing, employment, education, advanced training, retraining, etc. This list is not complete and depends on the object of research. Gustav Nemes divides the concept of infrastructure into three categories: physical, economic and

political [23]. Physical infrastructure consists of buildings and structures for residential, transport, commercial, and social purposes. The infrastructure that mediates the movement of money, information and labour is considered economic. Finally, the political infrastructure serves the functioning of state and public institutions, as well as contributes to the development of effective partnerships between all participants of economic activity: society, investors, state and local self-government bodies. Thus, infrastructure is a whole system of physical objects and organisational and economic processes, consisting of subsystems designed to ensure the life of business, comfortable life of the population, its way of life, cultural development, health and amenity (Fig. 2).

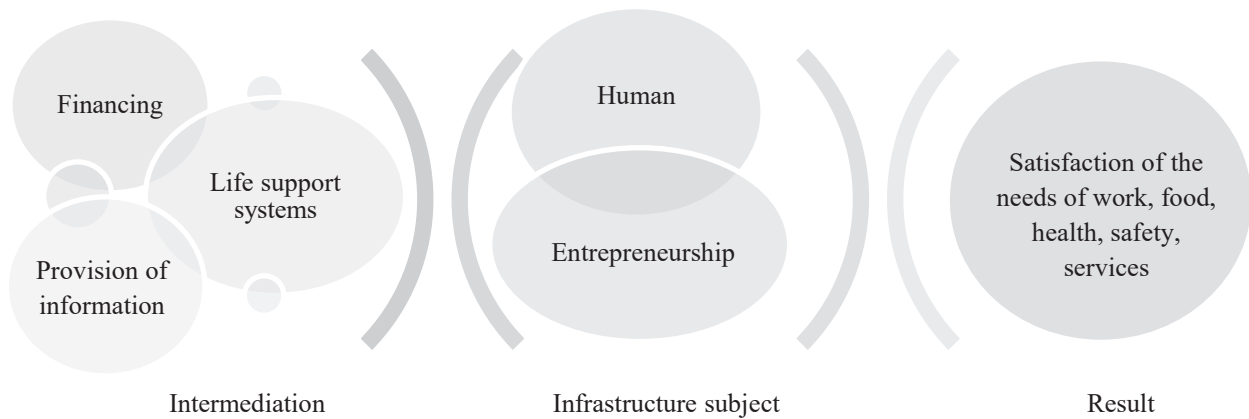


Figure 2. Infrastructure functioning process

Source: developed by the author

Infrastructure can include a fairly wide list of objects that are difficult to limit: road and railway systems, tunnels and bridges; ports, airports, waterways, and channels; public transport systems (buses, trolleybuses, metro); energy facilities (wind, hydroelectric, power plants, etc.); national power grid (power lines and connections); communication (telephone cables, mobile communication

towers, Internet); water supply (reservoirs, dams, pumping stations); medical services, hospitals, clinics, and emergency response systems; education (kindergartens, schools, colleges, universities, and other educational institutions for adults); police and prisons; waste removal and disposal, sanitary conditions. Therewith, all infrastructural facilities can be systematised in the following way (Fig. 3).

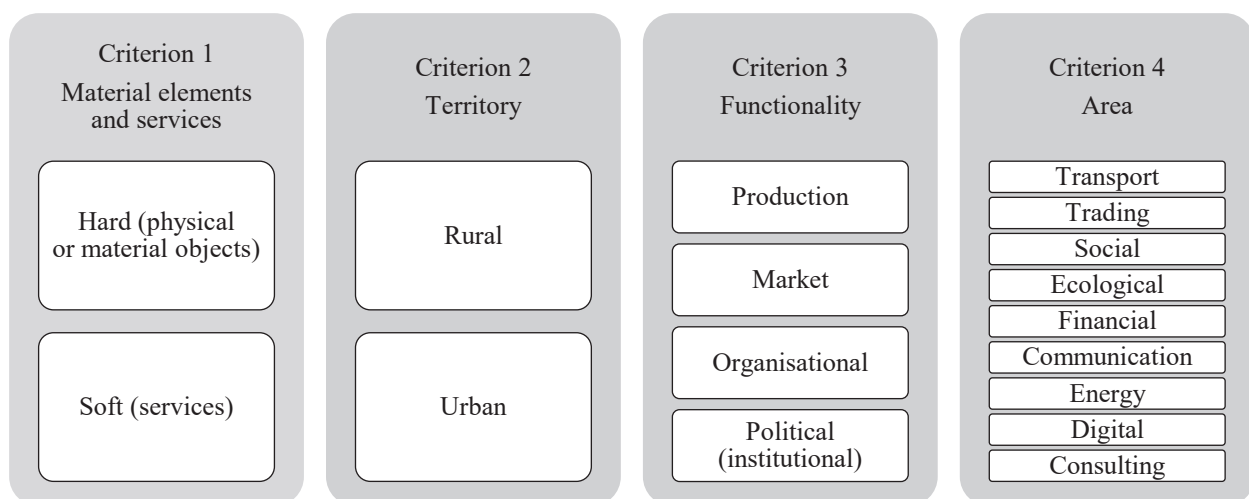


Figure 3. Classification of the main types of infrastructure by criteria

Source: compiled by the author

There are many types of infrastructure, but for the most part, it is divided into two classes: hard and soft [24]. The first one is defined as the physical (material) vector of auxiliary production necessary for the functioning of the economy. The second one applies to all institutions that provide cultural, social, medical, environmental, and economic services in the country and consists of educational institutions, law enforcement agencies, emergency services, parks, recreation centres, etc. From a functional standpoint, the production infrastructure creates conditions for the implementation of the production process (workshops, warehouses); the market promotes the distribution and sale of goods and services; the political

infrastructure provides institutional support for the comprehensive development of the rural community (development of strategies, plans, financial measures); the organisational infrastructure helps to combine all the necessary processes and provide them with systemic unity. Urban and rural infrastructure are distinguished by territorial features.

Current level of socio-economic development of rural areas of Ukraine

In Ukraine, after the shocks of the global financial crisis, economic reforms, political instability, and social tension, there is a destabilisation of territorial development. The

situation is complicated by the military conflict in the east of the country, the annexation of Crimea, and the global COVID-19 pandemic. For many years, rural areas have experienced depopulation, population ageing, migration of mostly young people to cities and abroad, lack of jobs and investment. The rural settlement network and the revival of rural infrastructure need to be considered and refined.

Infrastructure development of rural areas has not been given due attention since the development of independence, which, along with other factors, has led to a demographic crisis (a decrease in birth rates, an increase in morbidity and mortality of the population) (Table 1), low standard of living, labour migration of capable rural residents to European countries (Poland, Italy, Germany, etc.).

Table 1. Main demographic characteristics of the rural population of Ukraine

Indicator	1990	1995	2000	2005	2010	2015	2020	2020 to 1990, +, -, %
Rural population, million people	17.0	16.6	16.1	15.3	14.4	13.3	12.8	-4.2
Share of the rural population in the total population, %	32.7	32.1	32.6	32.3	31.4	30.1	30.5	-2.2
Birth rate, %	12.6	11.1	9.2	9.4	11.9	11.3	8.5	-4.1
Mortality rate, %	17.2	19.1	18.8	20.5	18.6	18.0	17.2	0
including children under 1 year old	13.9	14.7	11.9	10.0	9.1	7.8	7.0	-6.9
Natural growth rate (reduction)	-4.6	-8.0	-9.6	-11.1	-6.7	-6.7	-8.7	-4.1
Average life expectancy at birth, years	68.5	66.8	67.4	66.9	69.0	69.9	70.7	2.2
Migration growth (reduction), thousand people	1.5	-2.6	-2.7	-5.1	-5.2	+11.9	-21.2	-19.7
Demographic burden per 1 thousand population aged 15-64 years.	507	517	465	445	425	443	480	-27

Source: developed according to the state statistics service of Ukraine [10; 25]

The most urbanised regions in Ukraine are the eastern regions, where at the beginning of 2021 the share of the urban population was [25]: Donetsk region – 91%, Luhansk – 87%, Dnipropetrovsk – 84%, Zaporizhzhia – 77%. A large share of the rural population is observed in the western part of Ukraine. Thus, the share of people living in cities is: Transcarpathian – 63%, Chernivtsi – 59%, Ivano-Frankivsk – 56%, Rivne – 52%. In 2020, the worst situation in terms of natural population decline was observed in rural areas of Chernihiv region – -19.7%, as well as Sumy – -14.5%, Cherkasy and Khmelnytsky regions – -13.6% each. The highest mortality rate of the rural population was recorded from diseases of the circulatory system – 70.4%, in second place – from malignant neoplasms – 11%. Compared to European countries, Ukraine has a low life expectancy.

For example, this figure for men in Ukraine is 66.7 years, while in the EU countries it is about 80 years.

The assessment of interstate migration [25] shows that the largest number of rural residents who left for Europe is 46%, in particular to Russia – 27%, to Germany – 19%. A considerable part goes to Belarus, Poland and Lithuania (8% on average). Asian countries are in second place – 30%. 17% of the population of Ukraine left for the United States. The main reason for population migration is the search for work, higher wages, and the desire for better conditions and quality of life. Official data of the statistical service indicate a low level of income of the population in all sectors of economic activity (Table 2). In 2020, the average monthly salary of 1 full-time employee was 430.50 US dollars.

Table 2. Average monthly salary in Ukraine by type of economic activity, USD per 1 full-time employee

Type of economic activity	2015	2016	2017	2018	2019	2020	2020 in % to 2015
On average in the economy	192.0	202.46	267.07	325.92	406.86	430.5	335.1
Agriculture and forestry	151.51	163.87	227.71	277.83	343.26	362.7	239.4
Production	219.28	230.55	286.88	354.15	456.90	474.3	162.4
Construction	162.59	184.80	235.00	288.42	362.64	365.5	224.7
Trading	214.84	226.88	286.88	345.74	418.41	419.5	195.3
Transport activities	208.61	225.63	296.35	368.01	455.58	444.2	219.9
Information and telecommunications	325.60	372.27	451.80	524.85	679.96	739.3	227.0
Financial and insurance activities	393.91	399.49	483.65	594.15	741.55	757.5	192.3
Education	143.41	147.23	220.19	258.86	315.31	344.6	240.3
Healthcare	129.53	132.81	187.11	215.18	272.09	328.9	253.9
Art, sports, recreation, entertainment	189.29	189.22	248.42	279.85	337.02	357.7	188.9

Source: developed by the authors according to the NBU [26] and the state statistics service of Ukraine [27]

According to the Ministry of Finance of Ukraine, in 2020, the average European received 2,073 dollars for a month [26], while a Ukrainian received 430 dollars, which is 4.8 times less. The lowest level of average monthly wages is conventionally recorded in the healthcare sector – 3 328.9 dollars/month; education – 344.6 dollars/month;

culture, sports, entertainment and recreation – 357.7 dollars/month; agriculture – 362.7 dollars/month, which indicates the lack of an effective social policy in the country. The Lorenz curve illustrates the differentiation of the well-being level of the population (Fig. 4).

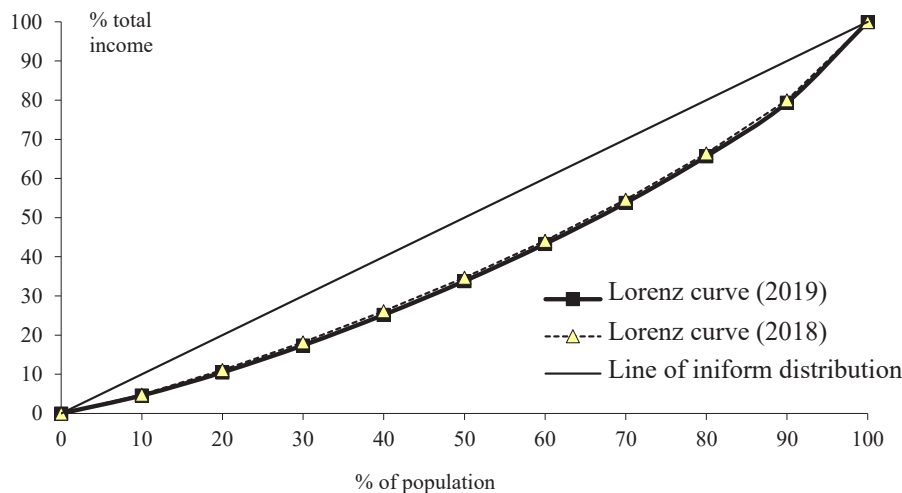


Figure 4. Inequality of distribution of total income by decile (10%) groups of the population of Ukraine in 2018-2019
Source: developed according to the state statistics service of Ukraine [28]

Since the line of the actual income distribution of decile groups deviates considerably from the line of uniform distribution, a large gap in the highest incomes of the 10% of the poorest population and the lowest incomes of the 10% of the richest population can be noted.

Negative trends can be traced in the structure of total household expenditures in rural areas, where the largest share belongs to food expenditures – 50.7% in 2019 and 41.6% in 2021; housing, water, electricity, and fuel costs account for 12%; another 12.6% – clothing, medicines and transport services. Spending on recreation and cultural development is quite low and continues to decrease from 2.6% in 2019 to 0.7% in 2021 [29]. In addition, food insecurity is observed in the most vulnerable population of the 1st decile group with the lowest incomes. In 2021, one person accounted for 3.7 kg of meat and meat products consumed, 1.1 kg of fish, 2.5 kg of fruit, which is half the recommended medical standards [29]. Although Ukraine almost completely provides itself with food, there is an under-consumption of animal food by its inhabitants. A Ukrainian is forced to

compensate for the lack of animal proteins with potatoes, vegetables, bread, butter, which violates a healthy diet.

According to calculations made by M.V. Ptoukha Institute of Demography and Social Research of the National Academy of Sciences of Ukraine, the level of relative poverty is growing due to the coronavirus crisis and amounts to 51% in 2020. The poverty line reached the level of 3017 UAH on average per person per month and increased by 15% [30]. At the same time, data from the State Statistics Committee's report on a sociological study conducted on household self-assessment of their income level in 2020 shows that 67.1% of the population consider themselves poor [11].

The share of poor people among rural households was 31%, compared with urban households – 16%, among households with children – 29% (including 60% of poor large households). In 2020, the population with an average equivalent total income per capita per month below the actual subsistence level was 8.8 million people (Table 3).

Table 3. Differentiation of the standard of living of the population of Ukraine

Indicator	2014	2015	2020	2020 to 2010, +/-
Population with average equivalent total income per capita per month below the legally established subsistence minimum, million people	3.6	2.5	0.6	-3.0
% of the total population	8.6	6.4	1.6	-7.0
Population with average equivalent total income per capita per month below the actual subsistence level, million people	-	20.2	8.8	-
% of the total population	-	51.9	23.2	-
Average annual amount of the legally established subsistence minimum (on average per person per month), UAH	843.2	1227.3	2078.4	1235.2
Average annual amount of the actual subsistence minimum (on average per person per month, UAH)	-	2257.0	3847.2	-
Quintile coefficient of differentiation of total incomes of the population, times	1.9	1.9	2.0	0.1
Quintile ratio of funds (by total income), times	3.5	3.2	3.5	-

Source: developed according to the data [31]

Almost every fourth person in Ukrainian society has an income below the actual subsistence level. Such indicators show a low level of social and economic development of Ukraine, cultural degradation of Ukrainian peasants, and the need to survive in difficult conditions.

Infrastructure support for rural areas of Ukraine

The deterioration of demographic characteristics associated with the low level of socio-economic development of rural areas is aggravated by the unsatisfactory situation of social and industrial infrastructure. This is indicated by argumentative factors. Firstly, rural transport infrastructure ensures the mobility of labour resources and promotes access of the population to services that are not available in rural areas, and farmers to the necessary material and technical resources, logistics of raw materials and finished products. By improving transport links (the presence of paved roads and transport itself), rural areas become investment attractive. A sample survey conducted in January 2020 established that 23% of rural areas do not have regular daily transport links with infrastructure-developed localities [11]. According to a sample survey [11], a significant proportion of households are not provided with housing. The living area of 29% of rural households is below the sanitary norm (13.65 m² per person). Every second person lived in overcrowded housing. 20% of households have poor living conditions: 10.8% of rural homes have leaking roofs, wet walls, rotting window frames or floors; 30.5% have low residential temperatures during the heating period, which leads to an increase in colds, especially among children, and increases the cost of treatment. For comparison, in the EU countries in 2020, the same indicator was 7.3%.

A positive trend is observed in the prevalence, availability and free use of mobile communication and internet services, which is especially important in the context of informatisation, digitalisation and distance learning. In rural areas, the share of people with internet access increased from 40% to 66% during the coronavirus crisis, mainly due to households with children (79% of people used the Internet) [12]. 34% of the rural population does not have internet services, the main reasons are no need, lack of knowledge, poor health, and high cost of services.

The rural water supply system affects the provision of drinking water to the population and water-intensive types of production, in particular agriculture and private

farming. Despite the dense network of rivers in Ukraine, not all localities have a centralised water supply, which forces farmers to independently build wells, pumping stations, and irrigation systems, which creates additional pressure on the expenditure side of the limited budget. According to the state statistics service, 27.6% of the rural population suffers from the lack of water supply in housing, and therefore 32.7% do not have a bathroom or shower room inside the housing [32].

Medical infrastructure serves to prevent and treat diseases. Ukraine has an extremely low level of medical support. There are not enough outpatient clinics, beds, pharmacies, and qualified medical personnel. According to a survey conducted in October 2020 [13], the level of availability of healthcare services and the purchase of pharmaceutical products has improved compared to 2019. Among the households surveyed, almost one in five reported that it was impossible to receive medical care if necessary, which is 1.3 times less than in 2019, and to purchase the necessary medicines. Therewith, there is a problem of provision of medical personnel in rural areas: 35% of households did not receive medical care if necessary; 42% of sick rural families did not have the opportunity to visit a doctor, 30% of them explained this by the lack of a medical specialist of the necessary profile [13]. In addition, 39% of rural areas are not provided with emergency medical care.

In rural areas in Ukraine, the sphere of public utilities remains problematic, in particular, the high cost of electricity and gas and the lack of autonomous thermal power plants from alternative sources lead to high dependence on intermediary structures and an increase in the energy intensity of production. In the structure of expenditures of the rural population, payment for housing, utilities and services increased by 1% over two years and amounted to 9% or 797 UAH per month. Therewith, the cost of services is growing annually: water supply – by 18.4%, sewerage – by 20%, supply and consumption of natural gas – by 2.6%, heating – by 18.3%, compared to 2019 [33]. As a result of such processes, 18.3% of rural households are unable to pay their gas, water and supply bills on time and in full. The presence of household communications as a source of comfortable living is indicated by the data in Table 4. In particular, the differentiation between urban and rural areas in providing water supply, sewerage, and centralised gas supply is illustrated.

Table 4. Comfort of housing for Ukrainian households and the degree of its satisfaction in 2020

Indicator	All households		Including residents					
	2019	2020	Of cities			Of villages		
			Large	Small	Total		2019	2020
					2020			
Number of households, thousand units	14881.7	14784.3	5852.0	4150.2	10037.5	10002.2	4844.2	4782.1

Table 4, Continued

Indicator	All households		Including residents					
	2019	2020	Of cities			Of villages		
			Large	Small	Total	2019	2020	
	2020			2019	2020			
Distribution of households by availability in their housing, %:								
Central heating system	36.4	35.6	73.7	22.9	53.7	52.6	0.5	0.1
Individual heating system	45.2	48.0	24.5	65.1	39.1	41.3	58.0	61.8
Water supply system	82.9	85.6	98.9	90.9	94.2	95.6	59.5	64.9
Sewers	82.3	85.2	98.8	90.3	93.7	95.3	58.8	64.2
Hot water supply	46.9	52.6	78.6	44.3	59.4	64.4	21.0	27.9
Electric boiler	1.3	1.4	0.9	2.0	1.3	1.4	1.4	1.3
Double-circuit gas boiler	19.6	23.9	15.4	34.6	19.4	23.4	19.9	25.0
Solid fuel boiler	7.8	8.4	1.1	8.6	4.6	4.2	14.5	17.0
Electric water heater	32.7	36.8	36.5	39.2	32.8	37.7	32.6	34.9
Gas-fired water heater	11.7	10.3	10.8	13.4	14.2	11.9	6.4	7.1
Centralised gas supply	78.8	80.5	90.1	85.2	87.6	88.1	60.6	64.6
Bottled gas	11.2	10.3	0.4	6.3	2.8	2.8	28.6	25.9
Electric stove	5.4	5.6	8.9	4.3	6.9	7.0	2.4	2.7
Bath or shower	79.1	82.3	98.0	85.9	91.3	93.0	54.0	59.8
Telephone	14.4	8.3	12.3	7.2	17.7	10.2	7.5	4.3
Garbage chute	12.3	13.3	29.9	5.2	18.3	19.6	0.0	0.2
Distribution of households by a degree of satisfaction with their housing conditions, %:								
Very dissatisfied	2.9	2.9	1.9	2.9	2.1	2.3	4.6	4.1
Dissatisfied	11.7	10.5	7.6	9.6	9.9	8.5	15.3	14.8
Not much satisfied	30.4	26.9	23.3	28.1	28.3	25.3	34.6	30.2
Satisfied	52.9	57.6	64.5	58.1	57.3	61.8	43.8	48.9
Very satisfied	2.1	2.1	2.7	1.3	2.4	2.1	1.7	2.0

Source: developed by the author based on data [32]

The lack of infrastructure for centralised processes of collection, sorting and disposal of economic waste, as well as sewage systems, considerably worsens the quality of life of the rural population. Thus, 38% of the surveyed population in 2020 did not have a toilet inside their home (for example, 45.7% in 2017) [32]. Therefore, it is necessary to invest in environmental infrastructure facilities: sewers, drains, specialised transport, sorting stations and waste processing plants, etc. In addition, part of the organic waste of agriculture, forestry and public utilities is the potential of bioenergy, which in developed countries of the world is a strategic area of energy conservation. This problem sets Ukraine apart from the prospects of a civilised European country for many decades.

Negative demographic processes in rural areas have exacerbated the problems of preschool and school education. Rural schools and kindergartens are being closed and the staff of such infrastructure facilities is being reduced due to the extremely small amount of children in classes and groups. In the village, there is often a 1st graduating class where up to 10 children study. There are often cases when a family that has children moves to a city where there are necessary educational infrastructure facilities. The net rate of pre-school coverage of children in rural areas is 29.3%. For comparison, this indicator was 24.0% in 2010 [34]. 7.6% of the surveyed population do not have money to pay for any professional education (Table 5).

Table 5. Dynamics of infrastructure provision of preschool education in Ukraine

Indicator	2014	2015	2020	2020 to 2010, %
A number of pre-school educational institutions, thousand units	8.5	9.1	9.2	108.2
Places in total	315	333	343	108.9
Kindergartens	124	135	135	108.9
Nurseries-kindergartens	152	128	127	83.6
Others	38	70	80	210.5
Number of children in institutions, thousand people	247	310	266	107.7
The level of pre-school education institutions' coverage of children of different age groups, %	33	40	39	118.2
Number of children in pre-school institutions per 100 places	82	87	73	89.0

Source: developed according to the data [34; 35]

Due to the optimisation of general secondary educational institutions, the number of kindergartens in rural areas is also decreasing. The primary reasons for closing preschool institutions are the lack of a sufficient number of preschool-age children and, most importantly, the lack of funding. In addition, starting from 2027, a three-year senior specialised school will start operating, which provides for the creation of specialised lyceums. This will require appropriate transport infrastructure to ensure access to education for children from remote rural areas with a small population to educational institutions (gymnasiums, lyceums) of other communities. In 2020, the fleet of buses that transport students consists

of 276 units, of which 186 buses meet the technical requirements of DSTU 7013:2009, and the additional need for them is 40 new ones [36].

The full value of life in rural areas is provided by such less important but necessary service facilities as hairdressers, dry cleaners, workshops for tailoring clothes and shoes and repairing household appliances. According to the results of the study, these infrastructure facilities are not available at all in 50% of localities. Considerable potential for economic growth in rural areas now lies in the trade infrastructure as the most profitable area (Table 6).

Table 6. Profitability of operating activities of infrastructure entities in Ukraine in 2020, %

Type of economic activity	Ukraine	Zhytomyr region
Total	3.9	7.2
Construction	2.0	3.7
Wholesale and retail trade; repair of motor vehicles	16.2	11.8
Transport, warehousing, postal and courier services	-0.4	-6.1
Temporary accommodation and catering services	-12.7	-4.5
Information and telecommunications	24.2	4.6
Financial and insurance activities	5.8	2.6
Real estate transactions	-7.7	-14.7
Professional, scientific and technical activities	-7.8	6.1
Administrative and support services activities	2.5	-5.1
Education	-7.5	3.1
Health and social assistance	7.6	15.7
Arts, sports, entertainment and recreation	-40.6	-6.3
Provision of other types of services	-8.2	-2.2

Source: developed according to the state statistics service of Ukraine and the Main Department of Statistics in Zhytomyr region [37; 38]

Enterprises of wholesale and retail trade, information and telecommunications, financial and insurance activities, healthcare are profitable in 2020. Therewith, social infrastructure entities are the most vulnerable to negative processes in the country, whose operating

profitability was -40.6%. These include art, sports, entertainment and recreation. Transport and warehouse facilities, postal and courier activities, as well as public catering remain unprofitable. The availability of a network of retail enterprises in rural areas is shown in Table 7.

Table 7. Network of retail enterprises in rural areas of Ukraine, as of 01.01.2020

Indicator	Value
Retail items in total, units	7429
Including stores	6168
Stands	101
Gas stations	1160
Retail area of retail stores, thousand m ²	7030.8
Including in urban-type settlements	6436.0
In rural areas	594.8
Availability of retail space, per 10000 people, m ²	1659
Including in urban-type settlements	2191
In rural areas	457
Network of pharmacies and pharmacy points, units	1385
Including pharmacies	901
Pharmacy points	484
Retail area of pharmacies and pharmacy points, thousand m ²	619.2
Provision of the population with retail space of pharmacies and pharmacy points, per 10000 people, m ²	338

Source: developed according to the data [39]

The programme “Development of rural territories and territories around the cities of the region” [40] also provides for the creation of regional wholesale markets, which will contribute to the development of the entrepreneurial potential of rural territories. The development of information and advisory infrastructure in rural areas is of great importance in creating a favourable environment for ensuring entrepreneurial potential in the context of digitalisation. Public associations designed to promote and comprehensively support entrepreneurship are the most common in Zhytomyr region, in particular in rural areas. In total, according to the Ministry of Economic Development, Trade and Agriculture of Ukraine, as of 1.01.2020, Zhytomyr region has 2 business centres, 1 business incubator, 2 technoparks, 4 leasing centres, 2 entrepreneurship support funds, 7 investment funds and companies, 8 innovation funds and companies, 257 information and advisory institutions, 112 public associations of entrepreneurs, 29 coordination councils [41]. Analytical studies show that in 2019, the region hosted 338 training seminars and trainings on entrepreneurship, 50 forums, round tables and conferences, which were attended by approximately 4200 people. As a result of this work, 41324 regional orders were made, 13 business projects were financed [40; 41].

European experience of rural infrastructure growth

Infrastructure support of rural areas is the main vector of rural development not only in Ukraine but also worldwide. The implementation of positive experience of the national policy on the development of rural communities of the European community on the territory of Ukraine is of considerable importance. The main financial instrument for the development of the European economy is the European Structural and Investment Funds (ESIF) [42]: the European Regional Development Fund (ERDF), the Cohesion Fund (CF), the European Social Fund Plus (ESF+), the European Agricultural Fund for Rural Development (EAFRD), and the European Maritime Fisheries and Aquaculture Fund (EMFAF) (Fig. 5). The European Commission allocates the budget of the five funds to EU member states, which, for their part, use ESIF resources through operational programmes managed at the national and/or regional level by designated governing bodies. Thus, the European Agricultural Fund for Rural Development (EAFRD) for 2017-2020 has developed a system of programmes, financing, monitoring, and audit aimed at achieving the main vectors of rural development [43]: competitiveness of rural business, environmental protection, economic diversification, which is a powerful foundation for the growth of the quality and standard of living of the rural population.

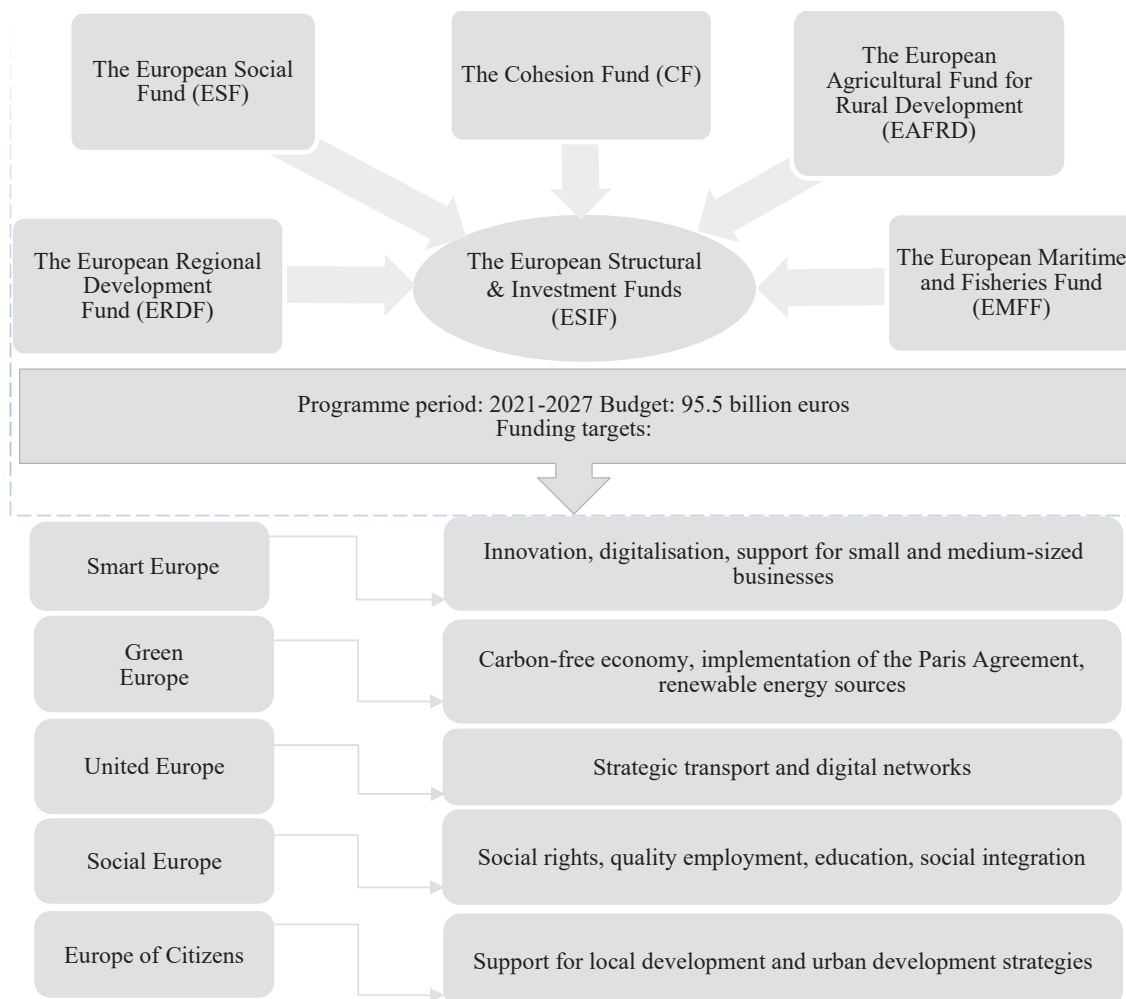


Figure 5. EU rural infrastructure development funds

Source: developed by the authors according to the data [42]

CONCLUSIONS

The priority areas or so-called “areas of attention” of financing in the rural development programmes of European countries were: restoration and preservation of ecosystems – 44%, competitiveness of agriculture – 20%, social integration, economic development and poverty eradication – 15%. The next programme period started in 2021 and will end in 2027 and has the following priority funding vectors: Smart Europe, Green Europe, United Europe, Social Europe, Citizens' Europe. The amount of funding for rural development projects for 2021-2027 is 95.5 billion euros [44].

CEF is a key EU financing tool designed specifically for direct investment in European transport, energy and digital infrastructure to address weaknesses and bottlenecks. Financial support is provided to priority projects. The instrument's budget is 30.4 billion euros (22.4 billion euros for transport, 4.7 billion euros for energy, and 0.3 billion euros for telecommunications) [45]. EFSI was created to encourage investment in the EU-28, which contribute to economic growth in rural areas and employment, in particular in infrastructure and innovation, in the amount of 16 billion euros from the EU budget and 5 billion euros from small and medium-sized enterprises.

The European Commission aims to support rural initiatives not only in EU member states. Much attention is also paid to developing countries. On 28.01.2020, an agreement was signed between the Government of Ukraine and the European Commission on financing the event “EU support for the development of agriculture and small farms in Ukraine” [46], with a total estimated cost of 26 million euros with an implementation period of 108 months. The main purpose of the event was to promote the development of an inclusive, competitive agricultural sector and fight against the impoverishment and depopulation of rural areas of Ukraine.

Therefore, the attention is being paid to rural development and it has the potential for revival, in particular due to financing from European funds. The only condition for such assistance should be transparency and targeted use of funds, as well as the absence of corruption schemes.

1. Infrastructure is a set of enterprises, institutions, organisations, and individuals that provide favourable and comfortable living conditions for people both in the sphere of economic activity and in everyday life. Infrastructure support for rural areas of Ukraine is marked by negative dynamic changes due to the structural crisis of the economy, anti-terrorist operations of the Luhansk and Donetsk regions, the complication of doing business, changes in living conditions, and the implementation of work activities of people in the context of a pandemic.

2. The establishment, development and self-fulfilment of people in rural areas is influenced by a number of factors: the specific features of the organisation of a rural family's life, the features of small educational institutions, the settlement network, limited access to institutions of high-quality education, health, communal-housing, sanitary-hygienic, sports, cultural, household, transport, trade services.

3. Problematic areas of infrastructure support for rural areas are: poor quality of roads and transport links; lack of central communications and sanitary facilities, abandoned educational infrastructure; underdeveloped health infrastructure.

4. To achieve socio-economic growth and reduce poverty in the country, it is advisable to implement positive European experience. The main financial instruments for supporting and stimulating rural development of the European Union are 5 investment funds of the European Commission, in particular: the European Regional Development Fund, the Cohesion Fund, the European Social Fund Plus, the European Agricultural Fund for Rural Development, and the European Maritime, Fisheries and Aquaculture Fund. Financing is provided in the amounts that correspond to the priority of the development programme. The amount of funding for rural development projects in the EU member states for 2021-2027 is 95.5 billion euros.

5. Positive effects of rural infrastructure development will include: rural business development; reduction of regional inequality, increase in investment in the region, creation of jobs, diversification of the rural economy, and increase in the level of citizens' mobility.

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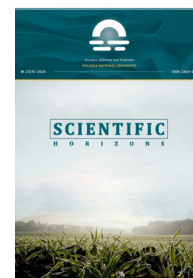
Інфраструктурне забезпечення соціально-економічного розвитку сільських територій України

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Анотація. Сільські території України замкнені в «коло занепаду» двома взаємопідсилюючими тенденціями: по-перше, нестачею робочих місць і стійкої ділової активності, по-друге, відсутністю позитивних змін у сфері послуг для сільського населення. Часто це відбувається через низький розвиток об'єктів інфраструктури. Означене викликає потребу фінансування сучасної, ефективної та екологічно чистої сільської інфраструктури, що підвищить комфортність та якість проживання, зупинить відтік працездатного населення до міст, поліпшить демографічну ситуацію в селі, сприятиме розвитку сільської економіки. Відтак проведені дослідження направлені на діагностування сучасного стану інфраструктурного забезпечення сільських територій і пошук ефективних інструментів усунення причин їхнього соціально-економічного занепаду. Методика дослідження ґрунтується на застосуванні загальнонаукових методів дослідження, таких як економічний аналіз і синтез в інтерпретуванні статистичних масивів даних, порівняння у визначенні динамічних змін соціально-демографічних характеристик сільських територій, логічний у здійсненні узагальнень і висновків, графічний і розрахунково-конструктивний для побудови кривої Лоренца тощо. Встановлено сутність, значення, типи інфраструктури. З'ясовано сучасний рівень соціально-економічного розвитку сільських територій України та виявлено його взаємозалежність з інфраструктурним забезпеченням. Охарактеризовано рівень розвитку транспортної, житлово-комунальної, медичної, культурно-освітньої, торгівельної, підприємницької інфраструктури. Висвітлено досвід стимулювання розвитку сільських територій у країнах ЄС, зокрема окреслено фінансові інструменти та обсяг підтримки й всебічного сприяння сільському бізнесу, охороні навколишнього середовища, конкурентоспроможності та соціальній інтеграції. Удокладнено європейські інвестиційні фонди та їхню роль у розвитку інфраструктури сільських територій ЄС.

Ключові слова: інфраструктура, сільські громади, сільське населення, якість життя, демографічна ситуація, фінансові інструменти, європейські фонди



UDC 338.3/.12:69.003

DOI: 10.48077/scihor.24(10).2021.72-82

Assessment of the Influence of Adaptability Factors on the Effectiveness of Managing Changes in Enterprises by Fuzzy Logic

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Article's History:

Received: 10.11.2021

Revised: 09.12.2021

Accepted: 12.01.2022

Suggested Citation:

Shpakov, A., Stetsenko, S., Shpakova, H., Sorokina, L., & Akselrod, R. (2021). Assessment of the influence of adaptability factors on the effectiveness of managing changes in enterprises by fuzzy logic. *Scientific Horizons*, 24(10), 72-82.

Abstract. The article is devoted to solving the urgent issue of identifying factors to stimulate staff that will best provide flexibility and the ability to manage changes in the operating system of the enterprise. The purpose of the study is to identify the correlation between the transformation ability of enterprises and the adaptive capabilities of the main driver of change management – personnel, and to identify internal factors that are the drivers of change. The study was conducted on the example of data from Ukrainian construction companies. The McKinsey “7S” model is used as a conceptual framework to identify such factors. According to the model, all factors are grouped by the following components: strategy, skills, shared values (corporate culture), structure, staff, systems, and style. Since the purpose of the study is to identify the impact that adaptive capabilities of staff have on the flexibility and ability to transform the company, the paper describes a model of the impact of factors of the group “staff” on the flexibility and effectiveness of change. The simulation was performed using tools of fuzzy logic. As a result, it was determined that the effectiveness of transformations is influenced by the following indicators: productivity (output), the administrative burden on wages (the ratio of administrative expenses to wages in operating expenses), the availability of employees with higher education among management staff, the experience of management staff, the ratio of labor costs to wage costs. The proposed evaluation system allowed to identify key factors for the transformational ability of enterprises, which will, if necessary, purposefully influence them, achieving the desired level of flexibility and providing adaptive capabilities of the enterprise system. Prospects for further research should be the creation of models based on fuzzy logic, which take into account the influence of factors in the formation of strategy, skills, corporate culture, structure, systems, and style on the transformation ability of enterprises in construction

Keywords: change management, tools of fuzzy logic, staff, construction company, efficiency



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INTRODUCTION

Ukrainian enterprises, during the implementation of operational, financial, and investment activities, are constantly faced with the variability of the environment due to transformational processes that are constantly taking place at the level of the world economy, the Ukrainian financial and economic system, sectoral markets, etc. In the long run, the tendencies of changes for Ukrainian enterprises are [1]: “Ukraine’s accession to the European Economic Space; implementation of projects to harmonise the Ukrainian national standardisation system with the requirements and rules, according to which the systems of national standardisation of the European Union members are functioning; implementation of energy and resource-saving programs as a priority direction of the country economic security development; the digital transformation of the country economic system; transition to the digital basis of many organisational, structural, and financial-economic relations between economic entities; deregulation and institutional changes of the economy; the influence of economic cycles, structural transformations caused by events in the east of the country”. Changes constantly affect all spheres of enterprises activity. They influence all factors of future development, and also have different directions. That is, changes can influence enterprises in a positive aspect (transformation of the institutional environment [2], changing the regulatory framework due to the transition to European product quality requirements [3]), and in a negative aspect (COVID-19 epidemic, etc.). To develop effectively, to use favorable trends, and confront negative challenges, enterprises need to change, transforming the operational system in response to external environment impacts, even ahead of them. That will help to ensure their own survival and sustainable development in the long term. But the uncontrolled changes can threaten the existence of the enterprise even more than external influences, so the actual direction of economic science development today is change management.

For successful implementation of changes in the system of strategic management, business entities need to change the approach to management, involve personnel support, form an effective organisational structure, promote changes in corporate culture, and establish links between all management chains for effective communication. The paper [4] notes: “the implementation of changes is a complex process, which is not always successful due to different reasons. Failures in most change processes can be caused by poor communications and connections, underestimation of the amount of necessary preparation for change, and the main goal of the study is to identify key steps that can improve change management”. It is also important to emphasise the importance of change management not only at the level of individual enterprises but also for the implementation of projects in different sectors of the economy. Thus, in the article [5] it is noted that “change management plays an important

role in improving the success of projects. Flexible project management provides new management opportunities based on the adoption of changes as an inevitable component of the project management process in the construction sector”. One can agree with the authors of the article that change management should be implemented at all levels of management and areas of activity of enterprises.

Change management is a relatively new direction of economic development and enterprise management, which along with the most pressing tasks of the present day, for example: ensuring sustainable development [6; 7], digital transformation of construction [8; 9], resource and energy saving [10], assuring long-term competitiveness [11-13], transition to industry 4.0 and 5.0 [14]. But the scientific studies, which are conducted in this direction, are trying to solve one of the most urgent tasks of economic science – providing opportunities for enterprises to implement adaptation to constant changes and transformations of the external environment. As a result of the change management process, enterprises should gain greater operational efficiency and/or productivity, while creating additional competitive advantages and gaining new perspectives and platforms for further development. The urgency of change management research is indisputable and has great prospects for development, therefore the *purpose of the study* is to build the dependence between the ability to transform enterprises and adaptive capabilities of enterprise personnel – the main driver of change management. In phase two, we have to identify internal factors that form the list of change factors (on the example of construction enterprises).

LITERATURE REVIEW

The issue of change management at enterprises is considered in numerous scientific works, which are focused on solving tasks on revealing changes and their consequences within the framework of construction projects [15], simulation modeling of changes [16], identification of factors of change management success at the level of realisation of construction mega-projects [17] and factors, which lead to changes in construction enterprises [18] the influence of organisational culture on the efficiency of construction enterprises [19-21], leadership [22-24] and support for changes by management staff [25; 26], a clear plan for implementation of changes [4] practical aspects of implementing changes [27], search for solutions that will provide the best flexibility and response to changes [5].

The article [12] analyses and groups the changes and their factors at the construction stage, which are grouped according to the degree of impact, the time of implementation, the person responsible for change management, the reason for changes, the renewable or non-renewable resources, the type of contract, the stakeholders’ interest, as well as shows the impact of changes on key

elements of the project and gives recommendations, which will minimise the consequences of unwanted changes for stakeholders. In the paper [16] it is stated that the processes of change management may fail due to dependence on the human factor, and also proposed the use of automation systems for change management in order to reduce the “human factor” influence. The authors of the work [17] identified eleven factors that ensure the efficiency of change management in construction projects. Namely: accumulation and application of technologies, innovations, application of specific management system, organisational regime and structure, support from management staff, implementing of project culture, social behavior, corporate reputation, and fulfillment of social obligations in five categories (project environment, construction opportunities, organisation, positive culture and behavior, as well as requirements for sustainable development). The study [18] presents a number of factors that lead to changes, among which authors distinguish the following: “increased competition, new laws and regulations, organisational growth, economic crises, support from top management, and clear planning of changes are factors of successful change management”.

The paper [19] examines the impact of organisational culture, learning, and knowledge management systems on the effectiveness of construction, and authors of [22; 25; 26] emphasise the importance of leadership, motivation, and support of transformations at the level of top management. The article [4] highlights critical importance for successful implementation of changes

in the following steps: clear planning of the program of changes, neutralisation of opposition, and formation of new organisational culture. Anthony Mento, Raymond Jones & Walter Dirndorfer [27] in their work consider practical aspects of the implementation of the three most famous change management models in the business, including Kotter’s strategic eight-step model for transforming organisations, Jick’s tactical ten-step model for implementing change, and General Electric (GE)’s seven-step change acceleration process model. In the work [5] it is stated that the most effective decisions of flexibility in change management are: permanent monitoring and improvement of resources, flexible working process, client participation, simplified communication, quick response to requirements, constant learning.

Since most of the analysed papers emphasise the importance of staff in change management, it is proposed to use the widely used McKinsey 7-S model created by the American authors’ team, T. Pithers and R. Waterman as the basis for assessing the company’s ability to transform [28]. This model gained wide popularity in the 1980-ies. The advantage of the model (compared to other models of the company’s microenvironment assessment) is that it emphasises the importance of the human factor in the company’s development and considers the structure of the company not only on the basis of available material values [29].

MATERIALS AND METHODS

The research is carried out in several stages (Fig. 1).

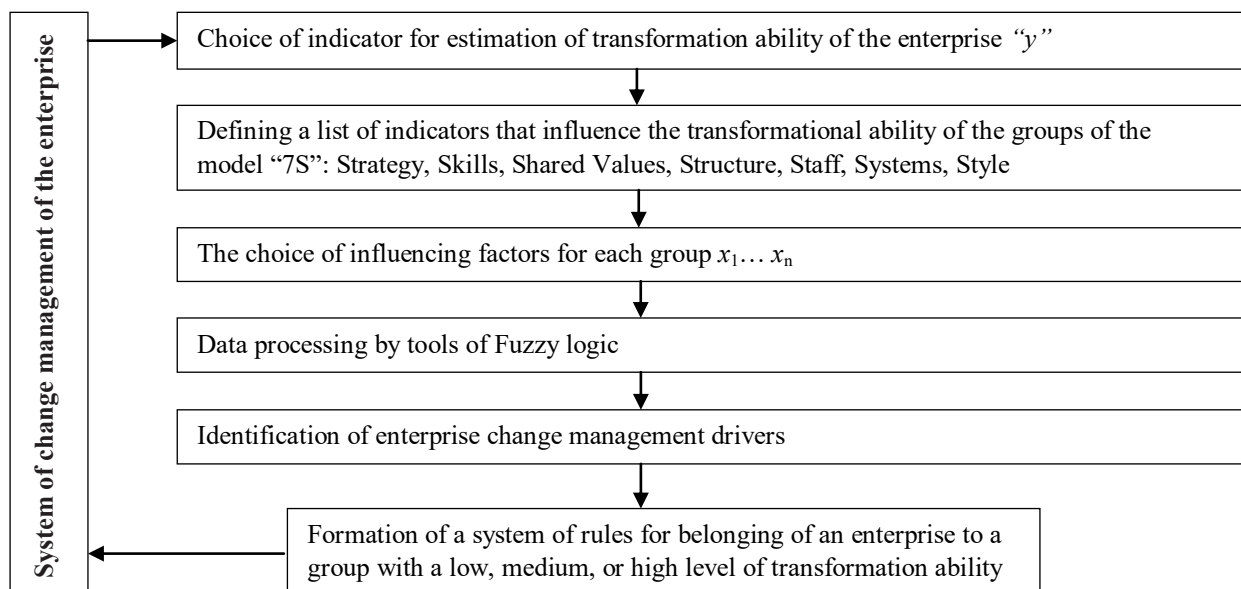


Figure 1. Conceptual model for determining the impact of staff adaptability on enterprise transformation

The first stage of the model is the assessment of the ability of the enterprise to change. Transformative ability is proposed to be defined as the ratio of the efficiency of the operational activities of the construction enterprise in the estimated period to the average efficiency

of the operational activities of the construction sector in the relevant period. This is due to a study hypothesis, which assumes that the higher the ability to change the enterprise is, the higher the effectiveness of its activity compared to other competitors.

The second stage of the research is to determine on the basis of the literature review the list of indicators to be combined in the group according to the model “7S” and to determine their influence on the transformation ability of the enterprise on the basis of Fuzzy logic. The system of fuzzy logical conclusion by means of the Matlab Fuzzy Logic Toolbox application package was created with the help of the system of fuzzy output of the Madami type. In this case, systems like Madami are the result of designing and learning a neurofuzzy hybrid model.

The third stage is the formation of a system of fuzzy rules to manage the transformation ability of enterprises and to identify change management drivers, due to which changes can be accelerated or slowed down.

As a sample, the authors used data on 26 construction enterprises collected from open sources. A sample of 151 observations was studied. All the enterprises chosen belong to section F of construction of buildings (section 41), construction of buildings (section 42) by the Classifier of economic activity types (KVED 2010). These enterprises

carry out general construction works and road construction. Data on the activity of companies from 2007 to 2020 are used. Among the indicators that characterise the development of enterprises are those that can describe the ability to change the personnel of the enterprise. It is assumed that the adaptation capacity of the construction enterprise “y” depends on the following factors:

P_1 – labor productivity in the investigated period (ratio of revenue from sales of products to the average annual number of employees of the building enterprise).

P_2 – the ratio of administrative expenses to wages in operating expenses.

P_3 – the share of employees with higher education in the total number of management staff.

P_4 – experience of management staff.

P_5 – the ratio of labor costs to wage costs.

For the hybrid network training, the authors used a “hibrid” method with error level 0 and number of cycles 40. For input factors x_1-x_5 and integral y the model “five inputs-one output” was obtained (Fig. 2).

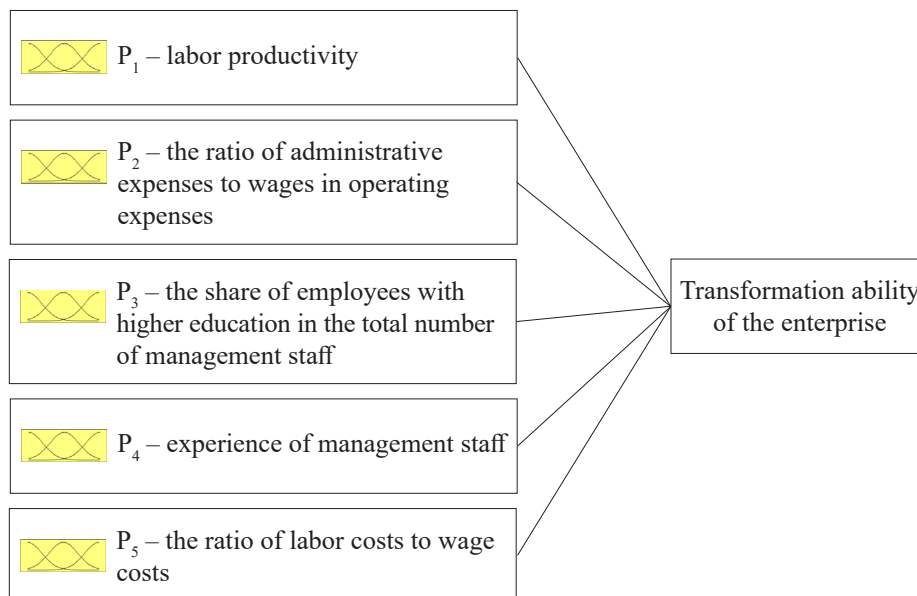


Figure 2. Model of influence of factors x_1-x_5 on the transformation ability of the enterprise

The fuzzification can be provided by means of the membership function of incoming variables, i.e., transition from numerical parameters of incoming variables to fuzzy values of linguistic variables. That is, the membership functions for variables $P_1 - P_5$, which allow for any value from a range of input data to determine its degree of membership to a fuzzy set. To both input variables, the authors set three membership functions of the “gaussmf” type (gaussian function), which sets the combination of membership functions in the form of gaussian curves and has the following appearance (1) [30; 31]:

$$\mu(P) = e^{-\frac{1}{2}\left(\frac{x-c}{\sigma}\right)^2} \quad (1)$$

where σ and c – numeric parameters, at the same time, c – is the coordinate of the maximum, which coincides

with the mathematical expectation of the value in the general assembly; σ – is the concentration or stretching coefficient that is determined based on the distribution of the characteristics in the general assembly. The concentration coefficient influences “the transition point”, a unique value for which the confidence measure is equal to 0.5, reflecting the maximum uncertainty of the investigated factor in some term. The Matlab environment does not explicitly state the formulas of the membership functions, but instead presents a compressed notation of the function’s parameters that are marked as an ordered array of two numbers of the “gaussmf” type: $[\sigma, c]$.

Add-on “Anfis-editor” of Matlab environment develop and test fuzzy conclusion algorithms with rules in which the combination of input variable terms represents

a complete set of all possible combinations of membership functions of the input variable in the design system, and not all of them may be used for further analysis. On the basis of the selected rules, it is proposed to assess the adaptive ability of the personnel, and also assess the impact of factors $P_1 - P_5$ on the transformation ability of the enterprise.

RESULTS AND DISCUSSION

The 7S model was developed by McKinsey employees to assess the effectiveness of the organisation by providing a thorough analysis of seven key elements of the firm: strategy, skills, common values (corporate culture), structure, employees, systems, and style. The model name "7S" is related to the fact that all of its components that are to be evaluated start with the English letter S: Strategy, Skills, Shared Values, Structure, Staff, Systems, Style (Fig. 3).

The key elements of the company, which are classified as "hard" and "soft", are mutually dependent on each

other and thus jointly participate in change management. The "hard" elements of the microenvironment of the company are three components: structure, strategy, and management system of the organisation. "Hard" elements are the easiest to describe, evaluate, and therefore easier to manage. The "soft" elements, which include all other components of the model, are more difficult to manage and evaluate, but they can often provide a long-term competitive advantage [33].

If the classic model is used to assess the effectiveness of company management, to identify the basic components of the effectiveness of any business, then the offered model is adapted to the conditions of dynamic changes, mainly focused on the ability of key elements of business to adapt to changes, avoidance, resistance, or confrontation to negative influences, taking into account the positive trends for the enterprise in the formation and implementation of development plans.

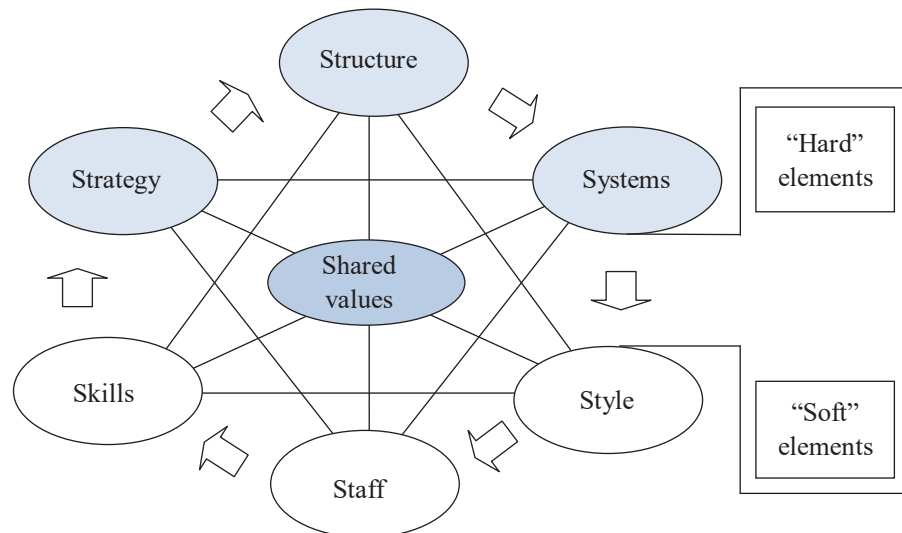


Figure 3. Graphic interpretation of McKinsey "7S" model

Source: [32]

Based on the developed model, the authors propose to expand the interpretation of its elements by incorporating a number of business indicators that define

the content of each component of the model and in general form a complex system of productivity changes in the construction enterprise (Table 1).

Table 1. Matrix of business indicators of productivity of changes in the construction enterprise (based on McKinsey "7S" model)

Model element	Content of BP business indicator	Current situation	Business indicator
Shared values	Availability of the shared values of the enterprise	V_1	V
	Corporate culture level	V_2	
	Corporate social responsibility level	V_3	
Strategy	Flexibility of enterprise strategy	S_1	S
	Competitiveness	S_2	
	Activity effectiveness	S_3	
	The level of adaptability of the construction enterprise	S_4	

Table 1, Continued

Model element	Content of BP business indicator	Current situation	Business indicator
Structure	Type of organisational structure	T_1	T
	The effectiveness of communication between top management and employees of lower management level	T_2	
	Level of digitalisation	T_3	
System	Effectiveness of enterprise subsystem operation	M_1	M
	Sustainability of the financial system of the enterprise	M_2	
	Efficiency of human resources use	M_3	
	Availability of systems of control, monitoring, and evaluation of business processes	M_4	
Style	Availability of corporate style	Y_1	Y
	Management style	Y_2	
	Availability of competition/cooperation between subdivisions	Y_3	
	Involvement of employees in decision-making	Y_4	
Staff	Labor productivity	P_1	P
	Ratio of administrative expenses to wages in operating expenses	P_2	
	Share of employees with higher education among management staff	P_3	
	Experience of management staff	P_4	
	Ratio of labor costs to wage costs	P_5	
Skills	Ratio of number of employees who need new skills to the total number of employees	K_1	K
	Frequency of personnel training	K_2	
	Compliance of employees' qualification with their positions	K_3	
	Effectiveness of the advanced training system (ratio of number of employees who have increased qualification to the number of employees who need advanced training)	K_4	

Source: developed by the authors

Using the indicators defined by each integral indicator of the activity and development of the enterprise, the authors study the discrepancies and inconsistencies between the elements of the general system of operational management that is moving in the stream of constant changes of the internal and external environment.

Thus, using the developed system of business indicators of productivity changes in the operational activity of BP it is possible to find ways to improve internal business processes of the enterprise, optimise the organisational structure, forecast possible changes of each of the seven elements of the enterprise, correctly carry out reorganisation, increase the level of efficiency of resource use and optimise the staff and number of employees, and also to determine the best way and tools of realisation of the strategy of development of enterprises in construction sector.

Within the framework of the conceptual approach set out in the McKinsey model, it is proposed to determine the ability of enterprises to change to use artificial intelligence tools, which are used as an effective means of managing enterprises in the conditions of uncertainty and environmental variability.

Since the purpose of the article is to study the impact of staff adaptability on transformational opportunities of enterprises, only factors $P_1 - P_5$ are selected as factors of influence on the result index, as shown in Table 1. The system of fuzzy logical conclusion by means of the Matlab Fuzzy Logic Toolbox application package was created with the help of the system of the fuzzy output of the Madami type. For the training of a hybrid network, chosen method "hibrid" with error level 0 and number of cycles 40. As a result of the training of a network, the error 0.076 percentage points was obtained (Fig. 4).

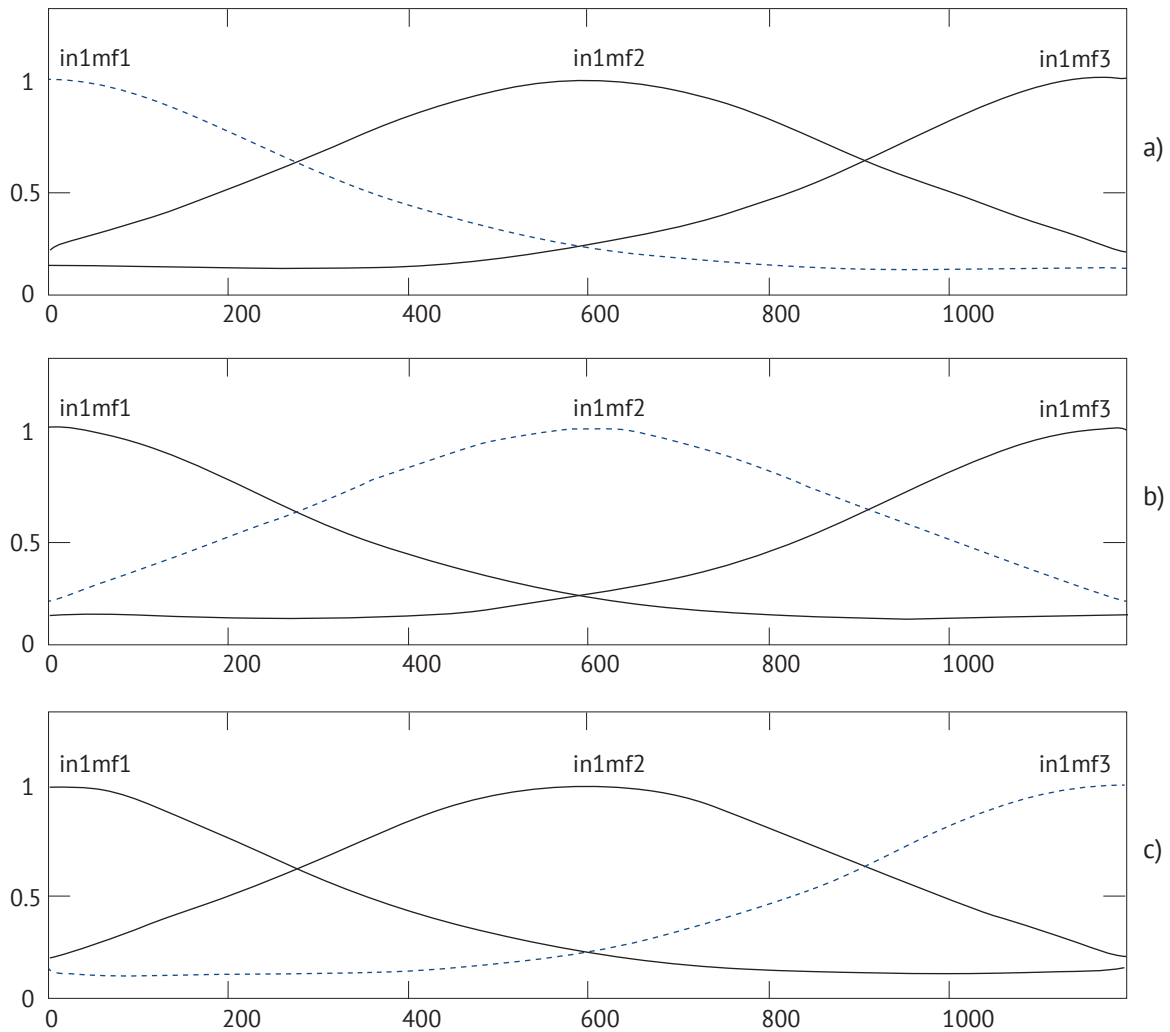


Figure 4. The gaussian membership functions for factor P_1 "labor productivity": a) "low labor productivity"; b) "average labor productivity"; c) "high labor productivity"

Source: calculated by authors

Graphs (Fig. 4 a-c) present the gaussian membership functions for terms "low labor productivity", "average labor productivity", "high labor productivity". As can be seen from Figure 4, the level of labor productivity among the analysed enterprises was ranging from 0 to 1,115.000 UAH/person per year.

According to the graphs in Figure 4, the maximum level of confidence regarding the high level of labor productivity is 1,115.000 UAH/person per year. The highest level of uncertainty about the high or average level of labor productivity in the enterprises studied, which corresponds to a probability of 0.5, with the value of index $P_1 = 882,900$ UAH/person per year. To achieve a high

level of staff adaptability to change, it is necessary to achieve labor productivity above the average level, and the membership function for this indicator goes like (2):

$$\mu_{nec}(P_1) = \begin{cases} e^{-\frac{1}{2} \left(\frac{P_1 - 557.4}{236.7} \right)^2}, & \text{if } P_1 < 557.4 \\ 1, & \text{if } P_1 \geq 557.4 \end{cases} \quad (2)$$

Similarly, the membership functions are calculated for the factors $P_2 - P_5$.

Finally, the membership functions for the other four indicators that characterise terms of type "enough to provide transformational abilities of enterprises" are systematised in Table 2.

Table 2. Membership functions for the other four indicators that characterise terms of type "enough to provide transformational abilities of enterprises"

Indicator	Membership function
P_2 – the ratio of administrative expenses to wages in operating expenses	$\mu_{nec}(P_2) = \begin{cases} e^{-\frac{1}{2} \left(\frac{P_2 - 0.676}{0.1822} \right)^2}, & \text{if } P_2 < 0.1822 \\ e^{-\frac{1}{2} \left(\frac{P_2 - 0.858}{0.1822} \right)^2}, & \text{if } P_2 > 0.676 \\ 1, & \text{if } P_2 \geq 0.1822 \\ 1, & \text{if } P_2 \leq 0.676 \end{cases}$

Table 2, Continued

Indicator	Membership function
P_3 – the share of employees with higher education in the total number of management staff	$\mu_{nec}(P_3) = \begin{cases} e^{-\frac{1}{2} \left(\frac{P_3 - 1}{0.4247} \right)^2}, & \text{if } P_3 < 0.4247 \\ 1, & \text{if } P_3 \geq 0.4247 \end{cases}$
P_4 – experience of management staff	$\mu_{nec}(P_4) = \begin{cases} 1, & \text{if } P_4 < 17.49 \\ e^{-\frac{1}{2} \left(\frac{P_4 - 42.2}{17.49} \right)^2}, & \text{if } P_4 \geq 17.49 \end{cases}$
P_5 – the ratio of labor costs to wage costs	$\mu_{nec}(P_5) = \begin{cases} 1, & \text{if } P_5 < 0.82 \\ e^{-\frac{1}{2} \left(\frac{P_5 - 0.82}{0.05} \right)^2}, & \text{if } P_5 \geq 0.82 \end{cases}$

Source: calculated by authors

By default, the “Anfis-editor” add-on of the Matlab environment develops and tests algorithms of fuzzy conclusion with rules, in which combination of terms of incoming variables represents a complete set of possible

combinations of membership functions of the incoming variable in the design system of Madami. Their substantiation is given in combination with the description of the rules' base of fuzzy logical conclusion (Fig. 5).

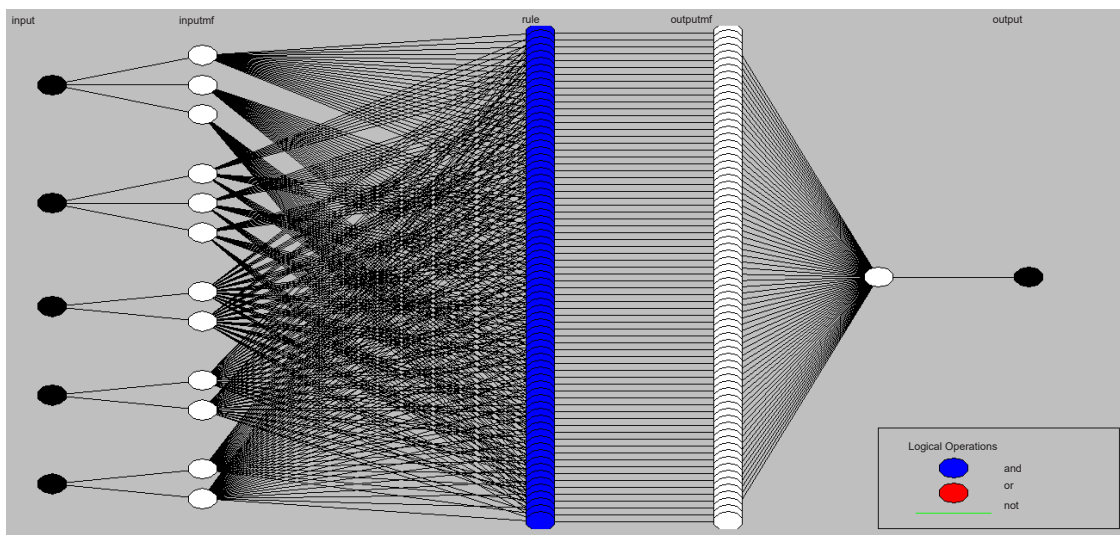


Figure 5. The rules' system of fuzzy conclusion

Source: calculated by authors

Since the system has three input variables, each of which has two terms and three variables have two terms, the maximum number of rules in the knowledge base to the formulation of all possible dependencies between factors and consequences should be $2^3 \cdot 3^2 = 72$. However, such a number of rules is superfluous because it makes management difficult. Besides, not all rules are necessary to adequately reflect the dependence between inputs and output y . In particular, in the works [30, p. 312; 31, p. 48] it is noted that the minimum number of rules can be within 2-3% of their total number.

According to the information provided in the “Rule Editor” dialog, the rules in the knowledge base are equal to 1. In the final version, ten rules were selected that reflect the main impact of the personnel on the transformation opportunities of the enterprise.

The rules are formulated as follows (fragment):

1. If the labor productivity of employees is insufficient AND the ratio of administrative expenses to wages in operating expenses is high AND the proportion of employees with higher education is less than 47% AND

the average experience of management personnel is more than 17.5 years AND the ratio of labor costs to wage costs is low (less than 0.82) THEN ability to manage changes of the enterprise can be determined by the formula: $mf15 = 0.03468 \cdot P_1 + 6.553 \cdot P_2 + 2.3988 \cdot P_3 + 11.33 \cdot P_4 + 4.855 \cdot P_5 + 0.3359$.

2. If the labor productivity of employees is insufficient AND the ratio of administrative expenses to wages in operating expenses is enough AND the proportion of employees with higher education is less than 47% AND the average experience of management personnel is more than 17.5 years AND the ratio of labor costs to wage costs is more than 0.82 THEN ability to manage changes of the enterprise can be determined by the formula: $mf20 = 0.0147 \cdot P_1 + 0.855 \cdot P_2 - 0.011 \cdot P_3 + 5.2 \cdot P_4 + 0.3289 \cdot P_5 + 0.1022$.

3. If the labor productivity of employees is insufficient AND the ratio of administrative expenses to wages in operating expenses is high AND the proportion of employees with higher education is less than 47% AND the average experience of management personnel is

more than 17.5 years AND the ratio of labor costs to wage costs is less than 0.82 THEN ability to manage changes of the enterprise can be determined by the formula: $mf23=0.00677 \cdot P_1 + 0.662 \cdot P_2 + 1.43 \cdot P_3 + 0.1466 \cdot P_4 + 0.6595 \cdot P_5 + 1.122$.

4. If the labor productivity of employees is insufficient AND the ratio of administrative expenses to wages in operating expenses is high AND the proportion of employees with higher education is more than 47% AND the average experience of management personnel is more than 17.5 years AND the ratio of labor costs to wage costs is more than 0.82 THEN ability to manage changes of the enterprise can be determined by the formula: $mf24=0.002328 \cdot P_1 + 0.4482 \cdot P_2 + 0.184 \cdot P_3 + 2.798 \cdot P_4 + 0.018 \cdot P_5 + 0.104$.

5. If the labor productivity of employees is average AND the ratio of administrative expenses to wages in operating expenses is high AND the proportion of employees with higher education is more than 47% AND the average experience of management personnel is more than 17.5 years AND the ratio of labor costs to wage costs is less than 0.82 THEN ability to manage changes of the enterprise can be determined by the formula: $mf34=0.00523 \cdot P_1 + 0.6147 \cdot P_2 + 1.26 \cdot P_3 + 0.68 \cdot P_4 - 2.42 \cdot P_5 + 1.139$.

6. If the labor productivity of employees is average AND the ratio of administrative expenses to wages in operating expenses is high AND the proportion of employees with higher education is more than 47% AND the average experience of management personnel is more than 17.5 years AND the ratio of labor costs to wage costs is more than 0.82 THEN ability to manage changes of the enterprise can be determined by the formula: $mf39=0.02935 \cdot P_1 + 4.147 \cdot P_2 + 1.601 \cdot P_3 + 0.1652 \cdot P_4 + 0.3506 \cdot P_5 + 2.127$.

7. If the labor productivity of employees is average AND the ratio of administrative expenses to wages in operating expenses is high AND the proportion of employees with higher education is less than 47% AND the average experience of management personnel

is more than 17.5 years AND the ratio of labor costs to wage costs is more than 0.82 THEN ability to manage changes of the enterprise can be determined by the formula: $mf44=0.002014 \cdot P_1 + 0.053 \cdot P_2 - 0.00069 \cdot P_3 + 0.3255 \cdot P_4 + 0.0205 \cdot P_5 + 0.0064$.

8. If the labor productivity of employees is average AND the ratio of administrative expenses to wages in operating expenses is high AND the proportion of employees with higher education is less than 47% AND the average experience of management personnel is less than 17.5 years AND the ratio of labor costs to wage costs is more than 0.82 THEN ability to manage changes of the enterprise can be determined by the formula: $mf45=0.0422 \cdot P_1 + 0.4164 \cdot P_2 + 0.09 \cdot P_3 + 0.9203 \cdot P_4 + 0.0418 \cdot P_5 + 0.07$.

9. If the labor productivity of employees is high AND the ratio of administrative expenses to wages in operating expenses is low AND the proportion of employees with higher education is less than 47% AND the average experience of management personnel is less than 17.5 years AND the ratio of labor costs to wage costs is low (less than 0.82) THEN ability to manage changes of the enterprise can be determined by the formula: $mf48=0.01499 \cdot P_1 + 0.0288 \cdot P_2 + 0.012 \cdot P_3 + 0.1763 \cdot P_4 + 0.0012 \cdot P_5 + 0.007$.

10. If the labor productivity of employees is high AND the ratio of administrative expenses to wages in operating expenses is low AND the proportion of employees with higher education is more than 47% AND the average experience of management personnel is less than 17.5 years AND the ratio of labor costs to wage costs is low (less than 0.82) THEN ability to manage changes of the enterprise can be determined by the formula: $mf53=-0.00198 \cdot P_1 + 0.6001 \cdot P_2 + 0.004 \cdot P_3 + 0.0004 \cdot P_4 + 0.00095 \cdot P_5 + 0.005$.

These ten rules reflect the basic provisions of the HR strategy by influencing the factors of staff's adaptive ability. In Figure 6 the influence of factors of labor productivity and administrative burden on wages on the ability of the enterprise to change is shown.

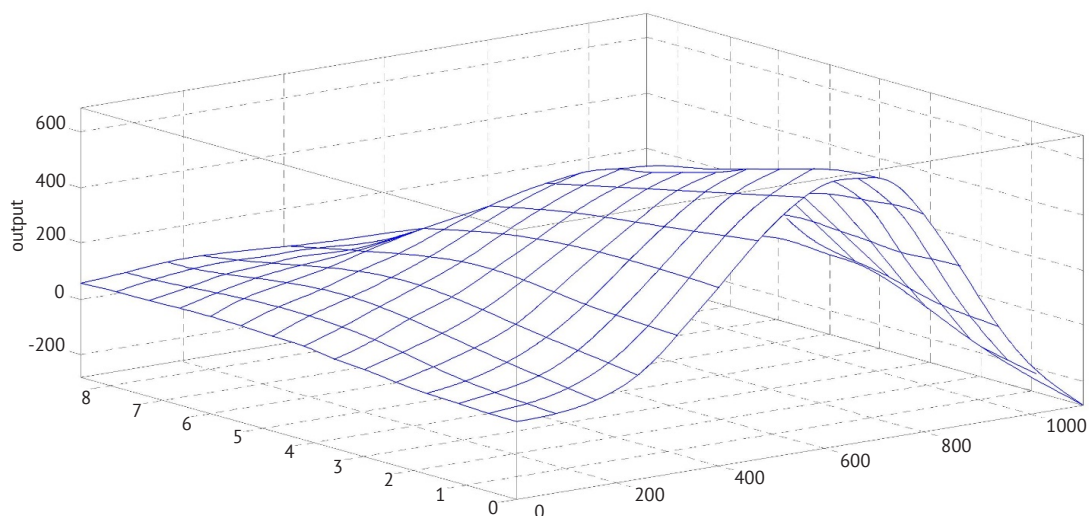


Figure 6. The influence of parameters P_1 and P_2 on the result indicator

Source: calculated by authors

Therefore, the largest level of adaptability to changes can be achieved by enterprises where labor productivity is higher than the average level, and administrative burden on wages is low. With an increased administrative burden, the ability to change at the enterprise is drastically reduced. It is possible to conclude that if it is necessary to change the strategy of the enterprise development, its adaptation to the influence of the surrounding influences in order to increase the adaptive ability of enterprises we should reduce administrative expenses.

Exceptions exist only for enterprises with high labor productivity, for which a low level of administrative burden, will likely reduce the efficiency of the management system, which should have a negative effect on adaptability to changes. For enterprises of this type, it is recommended to keep the average level of administrative load, which will allow to reaching a high level of adaptability, without losing control of the system.

CONCLUSIONS

The identified dependencies allow taking into account the impact of the company's personnel adaptability on the efficiency of changes, flexibility, and effectiveness of the response to changes in the company's external

internal environment. Among the factors of staff adaptability on the efficiency of transformations influence labor productivity, the administrative burden on wages, availability of employees with higher education among management personnel, the experience of management personnel, the ratio of labor costs to wage costs. The proposed system of assessment allowed to identify key factors for the transformation ability of enterprises, which will allow influencing them directly, when necessary, reaching the desired level of flexibility and providing adaptive capabilities of the enterprise system.

The approach proposed in the article for assessing the possibilities of managing changes in enterprises through the factors of the adaptive ability of staff can also be used for other factors of the McKinsey "7S" model. Defining the impact of changes due to fuzzy parameters of the system of indicators will allow to consider transformations through the prism of changes in strategy, skills, shared values (corporate culture), structure, staff, system, and style. This approach will help to model the efficiency of the enterprise development, its propensity to transformations, and the main thing, to identify factors that can prevent changes or vice versa, will reveal drivers of changes in each particular enterprise.

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Оцінювання впливу факторів адаптивності на результативність управління змінами підприємств засобами fuzzy logic

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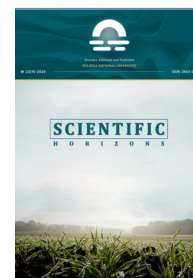
Анотація. Стаття присвячена вирішенню актуального завдання щодо виявлення чинників стимулювання персоналу, які найкращим чином забезпечать гнучкість і можливість управління змінами операційної системи підприємства. Метою дослідження є виявлення залежності здатності до трансформацій підприємств від адаптивних можливостей головного рушія управління змінами – персоналу, та виявлення внутрішніх чинників, які є драйверами змін. Дослідження проведено на прикладі даних українських будівельних підприємств. У якості концептуальної основи для виявлення таких чинників застосовано модель McKinsey «7S», відповідно із якою усі фактори згруповано за ознаками належності до таких складових: стратегії, навичок, спільних цінностей (корпоративної культури), структури, співробітників, систем і стилю. Оскільки метою дослідження є виявлення впливу адаптивних можливостей персоналу на гнучкість і здатність трансформуватись підприємства, то у роботі створено модель впливу чинників групи «персонал» на гнучкість і ефективність впровадження змін підприємства. Моделювання проводилось засобами fuzzy logic. У результаті визначено, що на ефективність трансформацій мають вплив такі показники: продуктивність праці (виробіток), адміністративне навантаження на заробітну плату (відношення адміністративних витрат до заробітної плати персоналу), наявність працівників із вищою освітою серед управлінського персоналу, стаж роботи управлінського персоналу, відношення зобов'язань із оплати праці до витрат на заробітну плату. Запропонована система оцінювання дозволила виявити ключові для трансформаційної здатності підприємств чинники, що дозволить у разі потреби цілеспрямовано впливати на них, досягаючи бажаного рівня гнучкості і забезпечуючи адаптивні можливості системи. Перспективами подальших досліджень мають стати створення моделей на базі нечіткої логіки, які урахують вплив чинників формування стратегії, навичок, корпоративної культури, структури, систем і стилю на здатність трансформації підприємств

Ключові слова: управління змінами, інструменти нечіткої логіки, персонал, будівельне підприємство, ефективність

SCIENTIFIC HORIZONS

Journal homepage: <https://sciencehorizon.com.ua>

Scientific Horizons, 24(10), 83-96



UDC 330.4:338.3:339.1:631.1/5

DOI: 10.48077/scihor.24(10).2021.83-96

Teff Production and Marketing Nexus: An Insight from Dera, North West Ethiopia

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Article's History:

Received: 20.10.2021

Revised: 22.11.2021

Accepted: 23.12.2021

Suggested Citation:

Amare, M.N. (2021). Teff production and marketing nexus: An insight from Dera, North West Ethiopia. *Scientific Horizons*, 24(10), 83-96.

Abstract. Although some production and marketing restrictions are barely defined, Dera area is a potential teff producer in Ethiopia's Southern Gondar zone. The study analysed teff production, focusing on factors that affect the volume of teff sold, based on data collected from household surveys, respondent interviews, and focus group discussions. Both descriptive and econometric analyses were used. The results show that teff grown in the study area is mixed, practised by 34.5% of households, followed by red teff (32.16%) with commonly used storage facilities such as Gota, Gotera, and Sack. In terms of marketing, the results show that 57.7% of teff produced in the 2019 sowing season was delivered to the market through rural retailers, wholesalers, and directly from producers to consumers. The result of the ordinary least squares estimates of the multiple linear regression model indicates the gender of the head of household, the experience of the head of household, the amount of teff produced, the lag in the market price of teff, on-farm income, in addition to payment outside the teff farm, positively affects the volume of teff sales. In contrast, livestock ownership and distance from the market have a negative and considerable impact. The paper also examines the main limitations and opportunities faced by farmers. The lack of an organised market and price setting is the most common limitation for farmers in the marketing system. Therewith, fraud and fluctuations in supply and demand, as well as insufficient working capital are considerable limitations for traders. However, the growth of urbanisation, continued price increases, and government investment in infrastructure development are great opportunities for both farmers and merchants. Thus, to have better results in the teff market, it is necessary to implement improved negotiation power, accurate market information, and infrastructure development. This study dictates a large number of further studies related to the impact of urbanisation on the consumption of processed teff products

Keywords: storage, price, revenue, ordinary least square, intensity



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INTRODUCTION

Agriculture remains the leading sector of the Ethiopian economy accounting for about 35.45% of gross domestic product (GDP) [1]. During 2010-2020, GDP grew by an annual average of 9.4% and the registered growth in GDP has been contributed by all sectors [2]. The smallholder agricultural sector: agriculture, manufacturing and service is the main source of employment, agricultural GDP, export earnings, supply of food and raw materials to urban areas and food industries. Crop production contributes more than 60% to agricultural GDP [3]. The most common agricultural crops grown in Ethiopia are grain crops (cereals, pulses and oil-seeds), fruits (banana, mango, avocado etc.) and vegetables (red pepper and Ethiopian cabbage), root crops (onion and garlic, potatoes, sweet potatoes) and stimulant crops (chat and coffee)[4]. Ethiopia is also the centre of origin and genetic diversity for many economically important crops including teff, niger seed, enset, coffee, khat, and Ethiopian mustard or gomenzer [5].

Teff is a small cereal grain indigenous to Ethiopia. The name was probably originated from the Amharic word "teffa" which means "lost" because of small seed size that is difficult to find once it is dropped. It takes the lion share of the total value of cereal production and it is because of its higher comparative price. It is the next most essential cash crop after coffee, whose commercial surplus equalled the combined commercial surplus of the other three main grains (wheat, maize and sorghum) in the country[4]. Teff grows mainly in Amhara and Oromia while Tigray and SNNP regions also produce lesser quantities in Ethiopia. Though, East Gojjam stands first (taking 10% of the national annual teff production). There are other potential teff production areas like Gondar, North Shewa, and West Gojjam in Amhara, as well as East, West, and South West Shewa zones in Oromia region, accounting five to ten percent of the national annual teff production [6].

Dera is one of the South Gondar woredas (the third level of administrative hierarchy in Ethiopia commonly known as district), where the livelihood system of its residents is based on both crop and livestock production. Agriculture in Dera is mainly dependent on rainfall while there are various surface and ground water resources that can be tapped into to maximise water utilisation for agriculture. Barely, finger millet and maize are the most consumed crops in the household while teff, oil seeds, and horticultural crops are marketed, making up an important source of cash income for farmers [7].

Dera woreda stands 1st in teff production from south Gondar zone [8]. Almost all of the 29 rural kebeles (the last administrative unit in Ethiopian administrative hierarchy) are potential teff producers. However, there are major constraints regarding agricultural problems in the study area. These include high fertiliser price (use of sufficient fertiliser has become difficult for most farmers and it lowers productivity), loss of soil fertility

(declining crop production and application of high dose of fertiliser to have reasonable yield has become essential), land shortage, use of low yielding local cultivars, and crop pest (because of continuous sole cropping of the same land repeatedly). Besides, there are marketing problems of teff which are price fixing by wholesaler (selling agricultural products at low prices), selling farm outputs in harvest time for loan repayment, lack of government intervention, and weakness of cooperatives [9].

According to the information obtained from office of agriculture, pre- and post- harvest losses harm farmers' agricultural yield particularly in teff. Shattering brings huge yield loss. Threshing is also performed on the ground that leads to the mixing of grains with the soil, sand, and/or other foreign matter which plays its own role in loss of teff quality that ultimately affects its market. These problems in general deteriorate surplus of teff to be value added and supplied to the market, which would improve farmers' lives and profitability of each teff market chain actor [10].

Teff production is a potential engagement [8] and it is the livelihood of many farmers, despite the crop not giving due policy attention. Sufficient information concerning the factors determining the volume of teff marketing in the study area is still missing. Even though farmers produce the teff grain well, they do not bother about quality, standard, the use of improved variety[11]. T.M. Challa et al. [12], T.M. Abate et al. [13], T. Beyene [14], A. Feyso Ergetew [15], E. Oyka [16], and A. Workye et al. [17] made an attempt to investigate the predominant factors affecting farmers' supply of teff, honey, cotton, sesame, red pepper, and rice respectively. However, their study lacks details of teff production, storage, volume marketed, and determining factors precisely.

Hence, this paper aims to understand the extent of agricultural product marketing in Ethiopia regarding teff production and marketing status in the study area. It identifies the volume of teff marketed and its determinant factors, opportunities, and challenges of production and marketing in the study areas to understand better and set possible improvement strategies to upgrade teff productivity and marketability for the benefit of smallholder farmers.

The overall objective of this study was to analyse the factors that determine the volume of teff marketed and associated challenges and opportunities in Dera woreda while the particular purposes addressed were: to investigate the production storage and marketing of teff; to analyse the factors that determine the volume of teff marketed; to identify the opportunities and challenges of teff production and marketing.

MATERIALS AND METHODS

Description of the study area

Dera is one of the woredas in the south Gondar zone of the Amhara regional state, Ethiopia. It is bordered by

Abay River in the south separating from east Gojjam, Lake Tana in the west, Fogera in the north, east Estie in the northeast, and west Estie in the east. The woreda covers 158 948 ha, of which 35% is plain, 20% is mountainous, 18% is gorges, and 27% is undulating. The altitude of the woreda ranges from 1 560 m to 2 600 m above sea level, while the annual average rainfall is 1,250 millimetre. Regarding agro-ecology, 85% is *Woinadega* while 15% is *Dega*. There are 32 kebeles in the woreda, of which 29 are rural, and 3 are town kebeles. The total population of the woreda is 279 845, of which 142 851 are male, and 136 994 are female. The number of households in the woreda is 69 961, 58 767 are male-headed, and 11 194 are female-headed [10].

The woreda experiences annual rainfall ranging from 1 000-1 500 mm, which one of the most humid woredas in the country. It has one long rainy season, “Kiremt”, from June to September. The main crops cultivated by farmers in the woreda are teff, finger millet, maize, sorghum, and rice in *Woinadega* (midland) areas.

In Dega (highland) areas of the woreda, wheat and teff are grown. Households also grow crops and fruits like Irish potato, onions, tomato, sugarcane, mango, orange, spice, and chili pepper. Oil seeds, such as oats, flax, and niger seed are also cultivated using irrigation during the dry season. While finger millet and maize are used primarily for household consumption, teff, oilseeds, and horticulture crops are marketed, making up an essential source of cash income for farmers [7]. The geographical illustration of the studied area is pictured in Figure 1.

In the woreda, the land is used for annual crops, perennial crops, grazing, forest, and construction of roads and settlements, while water bodies and other uses cover the rest. As the livelihood of individuals in the study area is farming, a large share of land is used to produce crops, followed by bushes and shrubs. However, the proportion of land covered by road is very small which confirms that infrastructure is not well developed. The fundamental insight of the balance of land use and its coverage is illustrated in Table 1.

Table 1. Land use in Dera woreda

Land Use	Area coverage (ha)	Percentage
Annual crops	68 071	42.83
Perennial crops	7 283	4.58
Grazing land	9 764	6.14
Forest land	13 221	8.32
Bushes and shrubs	15 372	9.67
Road	2 254	1.42
Westland	15 105	9.50
Covered by water	7 201	4.53
Construction and settlement	11 513	7.24
Others	9 164	5.77
Total	158 948	100

Source: [10]

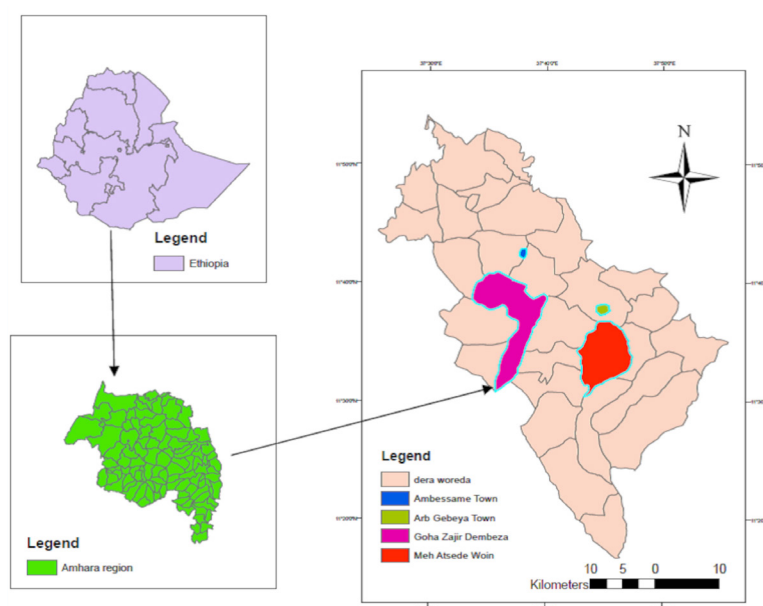


Figure 1. Map of the study area

Source: [10]

Types, sources, and method of data collection

The authors collected both primary and secondary data for the study. Household surveys, key informants, focused group discussions, and personal observations were the primary data collection. Besides, secondary data collected from different sources, including the Office of Agriculture, Trade and Industry, CSA, and Amhara regional agricultural research institute.

Before the data collection, the authors checked the content using a pilot survey by interviewing five households to limit the duration of the schedule and the validity of the semi-structured questionnaire content. After that, the semi-structured questionnaire constituting the preliminary insights was reorganised, the interview schedule was adjusted, and enumerators were trained about the questionnaire's range and system of gathering information and way of approaching respondents. Finally, the authors did the formal survey with randomly selected farmers. To check the validity of the collected data and complement the questionnaire survey, focus group discussions, key informant interviews, and field observation were applied.

This research was conducted according to the declaration of Helsinki and the legal requirements of the Ethiopian National Health Research Ethics Review Guideline. The ethical research committee approved this study at Debre Tabor University. Study participants were informed that clients have a full right to discontinue or refuse to take part in the study. Hence, all participants throughout the research, including survey households, enumerators, the supervisors, and key informants were fully informed of the objectives of the study. They were asked consent to do this research.

Focus Group Discussion (FGD): Focused group discussions were used to validate the information given by an individual farmer and to receive essential points that respondent farmers did not raise. Focus group discussion was conducted with community representatives, including elders, women, model farmers, and youth who have experience in teff production. The participants were selected to discuss issues related to the purpose of the study and members shared their background, opinion, and experience in the matters under research. A total of two focus group discussions were performed in sampled kebeles. Each group had seven members. The purpose of this discussion was to understand the bottlenecks farmers faced in commercial teff production, identify the existing marketing practice commonly presented in the study area, and what type of information farmers need in participating in teff market.

Key Informant Interview: Key informant interviews were carried out with individuals who had lived in the community for a long time and have sound knowledge about the area's existing teff production and marketing situation. For this discussion, a checklist developed for this purpose was prepared and used.

The purpose of the critical informant interview was to obtain the views, opinions, and suggestions of the key informants about teff production and marketing to better understand the pattern of production and marketing in the study area. For this purpose, key informants were selected from each peasant association (Pas) through kebele leaders, and enumerators and a personal dialog was conducted. Besides, experts at the woreda level, development associations (Das), and Kebele administration were included in the critical informant interview, and a total of 14 key informants' interviews were conducted.

Household survey: A household survey was undertaken by developing a structured questionnaire with closed and open-ended questions to generate information at a household level, managed through face-to-face contact and interviewing the head of the sample households. The pilot was oriented by the kebele administrator about the purpose of the survey. The information collected from the household questionnaire included demographic characteristics, economic factors, institutional activities, information source of farmers, and constraints of effective farming practices of this study area.

Field observation: In addition to data collected through structured questionnaires, an essential part of the survey was the practical observation on the production and marketing of teff with an informal survey. As a result, the field observation was applied to clearly understand the natural environmental setting and socio-economic activities, financial institutions (rural credit services), infrastructural facilities like communication services, road and transport facilities, production and marketing situations of the study area.

Sample size and sampling procedure

The selection of sample respondents for the study engaged a three-stage sampling. In the first stage, Dera woreda was selected among 13 woredas of the south Gondar zone. The underlying principle for the choice was woreda-level crop production rankings. Dera woreda stands first in teff production compared with the rest of woreda. In consultation with the Agriculture and Natural Resources Development Office in the second stage, two kebeles were selected from Dera woreda purposively based on their teff production and marketing potential. In the third stage, using probability proportional to size (PPS), the number of respondents was selected from each kebele using a simple random sampling technique. Accordingly, 171 teff producers were chosen randomly. The maximum number of respondents (farmers) determined by using a formula developed by [18] was:

$$n = \frac{N}{1 + N(e)^2} \quad (1)$$

where n – the sample size for the research; N – the population size (total number of households in the selected kebeles); e – the level of accuracy.

To determine the required sample size at a 95% confidence level, with a 0.5 degree of variability and a 7.5% level of precision, 2136 household heads from Meha-Atsedeweyine and 2797 households and Goha kebeles were employed. The number of male and female-headed families was 1867, 269, 2462, and 335 in Meha-Atsedeweyine and Goha kebeles. Respondent farmers:

$$n = \frac{4933}{1 + 4933(0.075)^2} = 171$$

Methods of data analysis

Descriptive statistics and econometric analysis were actively employed for data analysis. This analysis was performed using Microsoft Office Excel 2013, SPSS 20, and STATA (Statistical & Qualitative Data Analysis Software), 15 statistical software packages.

Descriptive Statistics. The descriptive analysis is essential in providing better understanding of specific features of sample units. It allows comparing different categories of the sample unit for the desired characteristics by using tables, minimum, maximum, frequency, percentages, means, ratios, and standard deviations. It explains and interprets the data obtained from sampled households' socioeconomic characteristics. Appropriate statistical tests such as t-test (for continuous variables) and (Chi-square test) for discrete variables were applied to compare and verify the mean or proportion difference between selected characteristics.

Econometric Analysis. This method of data analysis refers to the use of different economic and statistical tools or models for testing hypotheses related to the study's objective. Hence, a multiple regression model was used to identify the marketing volume factors. The model consists of a dependent variable, also called the left-hand side variable, independent variable(s), also called explanatory or right-hand side variable(s), and error terms (stochastic disturbance term) that stand for unobservable random variables not explicitly included in the model.

To address the determinants of the volume of teff marketed, a multiple regression model was used in the study. The underlying reason for selecting the model is its practical applicability, simplicity, and compatibility with the data [19]. Hence, the Ordinary Least Squares (OLS) method was used to estimate the approximate parameters when the dependent variable is continuous. The specification of the multiple linear regression model looks as follows:

$$Y = \alpha + \beta_i X_i + U_i \quad (2)$$

where Y – quantity of teff supplied to market; α – intercept; β_i – vector of parameters to be estimated; X_i – vector of explanatory variables; U_i – disturbance term.

Before taking the selected variables into the model, the necessary diagnostic tests for the existence

of multicollinearity (among the continuous variables) problem and the degree of association (among discrete variables) were employed by using Variance Inflation Factors (VIF) and Contingency Coefficient (CC), respectively. The larger the value of VIF , the more troublesome or collinear is the variable X_i and those explanatory variables with $VIF > 10$ would be excluded from the regression analysis [20]. The variance inflation factor is specified as:

$$VIF(X_j) = (1 - R_j^2)^{-1} \quad (3)$$

R_j^2 denotes multiple correlation coefficients. A higher value of R_j^2 shows the higher value of $VIF(X_j)$, indicating higher collinearity among continuous explanatory variables (X_j).

Similarly, there might also be an interaction between two discrete variables, which would lead to the problem of high association. The contingency coefficients were computed from the survey data to detect the problem, and a contingency coefficient greater than 0.75 indicates multicollinearity among qualitative variables.

$$CC = \sqrt{\frac{X^2}{N + X^2}} \quad (4)$$

CC is the contingency coefficient, χ^2 chi-square test, and N is the total sample size [20].

RESULTS AND DISCUSSION

Socioeconomic characteristics of teff producers

Table 2 shows the results of the descriptive statistics of the continuous variables investigated in this study. Accordingly, the age structure of the sample households shows that the average age of the sample household was 51.3 years. These families include people of 28-84 years old which falls in the productive age category. Regarding the family size, the survey result indicates that the average family size of sample households was 5.37, which ranges 1 to 10 members with a standard deviation of 1.63. It confirms that sample households in the study area have a medium-size family [10].

Education is essential in improving producer attitude towards modern technology in production. It allows farmers getting innovative ideas on improved productivity, post-harvest handling, and marketing strategies related to different options. The highest level of education followed by households reaches up to grade ten. Based on categorisation, about 25.1% of the respondents did not get formal education, while 60% got formal education up to grade four and can read and write. Only less than 16% of sample producers had a full-cycle primary education in the study area.

The result shows that the households in the study area have an average teff growing experience of 26.27 years, implying that respondent farmers have enough knowledge and competence in teff production and marketing and

make informed farm management practices. The survey results also show that farming is the primary source of household income in the study area. The sample household's average annual farming other than teff farm income for 2019 was Birr 15585.72 per household with a standard deviation of 6851.50. The off-farm yearly income of farmers ranges from 1200 to 15000 birr, at off-season farmers engaged in both off-farm and no-farm activities like handicraft, trade and production, sale of firewood and charcoal raised their level of income.

Resource ownership is characterised in terms of livestock and landholding size. Livestock is an essential asset that farmers heavily depend on to support their families in any crisis. Livestock is considered a measure of wealth in the rural area, and it is kept as generating additional income and traction power for farmers. The livestock species found in the study area are oxen, cows,

goats, sheep, donkeys, and poultry. The total number of livestock owned by the sample households was converted into Tropical Livestock Unit (TLU) to determine household livestock ownership. The average livestock holding size of farmers was between 2.7 and 28.64.

Land ownership is an indispensable factor for the production of crops, rearing livestock, and other ancillary agricultural activities. The proper utilisation of landholdings under different components contributes to the farmer's agricultural teff production increment. The livelihood of the farmers in the study area is highly attached to the land and land-related resources. The mean landholding size of the household was 1.77 ha, whereas the area used for teff production ranges from 0.13 to 1.75 hectares. The average national and regional teff farm size was (0.24 and 0.15) ha per household [4].

Table 2. Descriptive statistics of continuous variables

Variables	N	Minimum	Maximum	Mean	Std. Dev.
Age of the household head (years)	171	28	84	51.32	9.65
Family size (number)	171	1	10	5.37	1.63
Education of the household head	171	0	10	2.35	2.96
Number of livestock owned (TLU)	171	2.70	28.64	8.29	2.61
Experience in teff production (years)	171	1	52	26.27	9.36
Total Landholding Size (Hectare)	171	0.50	3.00	1.77	0.56
Total farm size (hectares)	171	0.13	1.75	0.88	0.33
Amount of teff produced (Kg)	171	250	1900	1035.09	358.34
Amount of teff marketed (kg)	171	50	1200	597.66	243.72
Distance to the nearest market (km)	171	2.50	15.00	8.12	3.41
Lagged market price of teff (birr/kg)	171	7.50	12.00	9.0000	0.88
On-farm income (birr)	171	1900.00	32150.0	15585.7	6851.50
Off-farm income (birr)	42	1200	15000	6364.29	3316.76

Note: items in the brackets are measurement units

Source: survey result, 2019

Concerning the gender of the respondents, the result shows that out of the total respondents of the two kebele, 87.7% were male-headed; a considerable proportion like other parts of Ethiopia. Since the majority of the households belong to married categories, males automatically assume the headship. Credit access plays a vital role in developing livelihood by building the farmers' capacity to purchase improved agricultural inputs and technologies in time, which maximises productivity and commercialisation. Farmers in rural areas of Dera woreda get most of their financial requirements from the Government/woreda office and Amhara Credit and Saving Institution (ACSI). About 64.3% of the sample respondents replied that they had access to credit for

improving agricultural production and marketing, including teff. Key informants also affirmed that most of these farmers take credit and pay back in cash.

Large numbers of sampled households have access to extension services in the study area. The survey result shows that only 2.3% of the sample households have no access to agricultural extension services. The frequency of extension contact was not much different among the families, as discussions with focus groups indicated. An efficient market information system needs to address information flows smoothly between consumers and producers. According to the study results, 69.1% of sample households got accurate market information as shown in Table 3.

Table 3. Descriptive statistics of dummy variables

Variables	Categories	Frequency	Percent
Gender of household head	Male	150	87.7
	Female	21	12.3
Marital status	Married	150	87.7
	Divorced	8	4.7
	Widowed	13	7.6
Extension service	No	4	2.3
	Yes	167	97.7
Credit access	No	61	35.7
	Yes	110	64.3
Market information	No	51	30.9
	Yes	114	69.1

Source: survey result, 2019

Respondents were asked about where they obtain the market information, 28.5%, 20% and 2.4% of the total sample households pointed out that they obtain market information from neighbour, traders, and

mass media respectively. More producers (49%) got information from trader and neighbour in combination in which 32% of them get the information in a week as depicted in Figure 2.

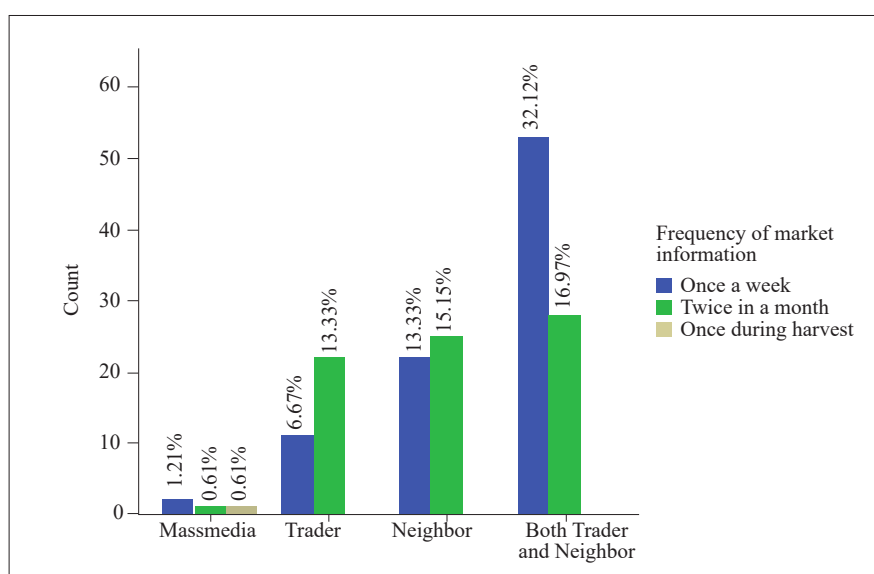


Figure 2. Source of teff producers market information

Source: survey result, 2019

Farm inputs utilisation. Utilisations of improved variety come first in the adoption of innovated technology. It strengthens the productivity in intensive farming as farm size goes fragmented from time to time. However, the number of farmers that use improved seed is limited in the study area. The result shows that a small proportion of sample households used improved sources (30.4%).

Due to a supply shortage from farmers' cooperatives, most farmers bought them from the market. However, Table 4 suggests that more Goha farmers (45.4%) used improved seed than Meha-Atsedeweyine farmers (10.8%). There was a difference at less than 1% significance level on various teff used.

Table 4. Farm inputs used for teff production

Variable	Kebele (N=97)						T-test/ χ^2 Value	
	Goha		Meha-Atsedeweyine		Total (N=74)			
	N	%	N	%	N	%		
Variety of teff crops	Local	53	54.6	66	89.2	119	69.6	23.678***
	Improved	54	45.4	8	10.8	52	30.4	
Type of teff grown	White	9	9.28	1	1.35	10	5.85	8.985**
	Red	24	24.74	31	41.89	55	32.16	
	Seregegna	35	36.0	24	32.43	59	34.50	
	White and red	29	29.9	18	24.32	47	27.49	
DAP used for teff (kg)		129.28 (60.264)		132.703 (52.96)		130.760 (57.08)		29.956***
Urea used for teff (kg)		24.33 (23.38)		34.93 (19.646)		28.92 (22.41)		16.874***

Note: (***) and (**) are significant at less than 1% and 5% significance level respectively, parenthesis indicate standard deviation

Source: survey result, 2019

The main types of teff grown in the area are locally mixed teff (Seregegna) (34.5%) followed by Red (32.16%), though significant variation exists at less than 5% precision level. According to the survey, all of the total sample farmers used diammonium phosphate (DAP) for teff production. Moreover, sample households in Goha used about 24.33 kg of urea and 129.28 kg of DAP. The survey shows that Meha-Atsedeweyine farmers used higher urea and DAP production than Goha farmers. The t-test indicates a difference at less than 1% significance level in the area used for teff production.

Production, storage, and marketing of teff

Production of teff is high, and it is an important crop in the study area. The average land cultivated for teff production in Meha-Atsedeweyine farmers (1.032 ha) was higher than Goha farmers (0.76 ha). The average quantity production of teff per sample household was 1035.93 kg. However, Meha-Atsedeweyine farmers produce 1154.05 kg more than Goha farmers, who make

only 942.23 kilograms per household. The study suggests a statistical difference between the two kebeles in average production quantity at a 1% significance level. Information from key informants and focus groups confirm that the reason for production difference was differences in soil fertility.

Table 5 also demonstrates that the average production per hectare in the total sample was 1317.50 kg. Data gathered from sample respondents show that 57.7% of teff produced in the cropping year is supplied to the market. According to the survey report, all sample respondents of the study area were potential market suppliers during the survey period. The average amount of teff marketed per household in Goha kebele was 527.32 kg, less than the amount sold in Meha-Atsedeweyine farmers (689.86 kg). The t-test statistics indicated a difference at less than 1% significance level concerning area allocated to teff, amount of teff produced and sold, and the productivity of teff between the two kebeles.

Table 5. Area cultivated, teff production and productivity

Variables	N=97 Goha	N=74 Meha-Atsedeweyine	N=171 Total	t-value
Total area allocated for teff (ha)	0.76 (0.2816)	1.032 (0.3304)	0.879 (0.3315)	34.627***
Quantity produced (kg)	944.33 (346.7)	1154.05 (340.1)	1035.93 (358.34)	37.773***
Productivity per ha	1351.72 (590.77)	1272.64 (676.58)	1317.50 (628.65)	27.406***
Amount of teff sold (kg)	527.32 (208.89)	689.86 (256.42)	597.66 (243.72)	32.067***

Note: (***) significant at less than 1% significance level, parenthesis indicates standard deviation

Source: survey result, 2019

Selecting a storage system is a considerable farming activity to avoid post-harvest losses. The survey shows that *Gota* and *gotera* (local store made up of mud and wood, respectively) were necessary storage facilities, but the farmers used sacks as temporary storage facilities when *Gota* and *gotera* were filled during harvesting. Farmers stated they use sacks as packaging material for teff to be transported from threshing field (locally called Awudima) to home and from home to either market or mill-houses. The advantage of this storage facility is that it is locally made and less costly. However, these facilities are susceptible to rats, floods, dampness, and fire damages.

The data shows that the storage system in the study areas was not identical. As summarised in Table 6, 75.3%

of the sample households in Meha-Atsedeweyine and 24.7% of Goha store their teff using *Gotera*. It also confirms the motive for storage where 49.1% of the participant households store their products expecting a high price in the future, 26.3% store for saving purposes, and 7.6% remain in the absence of market demand. The chi-square test indicates a significant difference in the storage system and underlying reason for storing teff between the two areas at less than 1% significance level. The study results show that almost all sample farmers avoided sales immediately after the harvest in both regions and stored for 11.38 months. Farmers in Goha kebele kept their teff production until 10.65 months which is smaller than Meha-Atsedeweyine (12.34).

Table 6. Type of storage facility, purpose and duration of teff storing

	N=97% Goha		N=74% Meha-Atsedeweyine		N=171% Total		t/ χ^2 Value
Ways of teff storage Store/ <i>Gotera</i>	24	24.7	21	75.3	45	26.3	0.286
<i>Gota</i>	73	28.4	53	71.6	126	73.7	
Storage time (months)	10.65 (4.648)		12.34 (4.516)		11.38 (4.654)		31.975***
Reasons for storing Expecting high price	40	41.2	44	59.4	84	49.1	30.02***
Lack of market demand	8	8.2	5	6.8	13	7.6	
Saving purpose	28	28.9	17	23.0	45	26.3	
Expecting high price & saving	21	21.6	0	0.0	21	12.3	

Note: (***) significant at less than 1% significance level, parenthesis indicates standard deviation

Source: survey result, 2019

Constraints and opportunities of teff producers

As depicted in Table 7, several factors constrain teff marketing in the study area. These include lack of organised market, pricing, shortage of land, high input price, and infrastructural challenges. Lack of organised demand and cost setup is the most dominating constraint in the teff marketing system, accounting for 26.3% and 22.8% of sample households, respectively. The time-to-time price increments of agricultural inputs affect the level of production in terms of the purchase of improved varieties and fertiliser, which indirectly affects marketing. Hence, the survey result indicates that 18.1% of sample farmers faced a high agricultural input price. The other infrastructural problem is that village markets are connected with the woreda town markets by poorly paved roads.

Human portages and pack animals are the most frequently used transport mechanism to transport larger loads. Many of the streets to the market are unreliable, especially during the rainy season. The results show that 15% of the sample households had infrastructural problem. The study area has other problems associated not only with marketing. Diversified opportunities also need to be exploited to improve marketing and effectiveness. Among the different options that prevailed, the major ones are increased urban consumption, high price, and availability of choice. The continuously growing urbanisation with urban residents' favour to teff *Injera* is an eye-catching situation while the cost of teff is also going high time to time.

Table 7. Marketing constraints and opportunities of producers

Constraints of teff marketing	Frequency	Percent
Price setting	39	22.8
High fertiliser and new teff variety price	31	18.1
Lack of organised market	45	26.3
Shortage of land	30	17.5
Infrastructural challenges	26	15.2
Total	171	100

Table 7, Continued

Constraints of teff marketing	Frequency	Percent
	Opportunities of teff marketing	
High price	54	31.6
Increase in urban teff consumption	65	38.0
Availability of productive teff variety	52	30.4
Total	171	100

Source: survey result, 2019

Discussions on important factors affecting intensity of teff marketed

In Table 8, the primary determinant factors of the volume of teff sold resulted from OLS. More than 50% of the hypothesised explanatory variables significantly affect the amount of teff supplied. The test of goodness of fit (F-test) shows how the model is significantly fit to the

data used. The coefficient of determination (R^2) has also clarified that the hypothesised independent variables explain 88.67% of the model (volume of teff marketed). The diagnostic test has confirmed the absence of multicollinearity problem among independent variables, as found in the Table 9-11.

Table 8. OLS estimates of factors affecting volume of teff marketed

Variables	Coefficients	Standard error	T-ratio	P-value
Constant	-1.5125	1.0516	-1.44	0.152
Gender of household head	0.4688	0.2125	2.21	0.029**
Age of household head	-0.0130	0.0107	-1.21	0.229
Family size	0.0362	0.0437	0.83	0.408
Education of the household head	-0.0849	0.0689	-1.23	0.219
Number of livestock owned	-0.0587	0.0294	-1.99	0.048**
Experience in teff production	0.0345	0.0113	3.06	0.003***
Teff farm size	0.1116	0.2584	0.43	0.666
Amount of teff produced	0.5569	0.0239	23.25	0.000***
Credit access	0.0218	0.1444	0.15	0.880
Extension service	-0.1269	0.4802	-0.26	0.792
Lagged market price of teff	0.2183	0.0879	2.48	0.014**
On-farm income	0.00003	0.00001	2.08	0.039**
Off-farm income	0.00005	0.00002	2.10	0.038**
Market information	-0.3893	0.3812	-1.02	0.309
Distance to the nearest market	-0.0902	0.0212	-4.26	0.000***

Note: dependent variable – amount of teff marketed, number observations – 171, $F(15, 155)=80.85$, (Probability > F value=0.000) R -square=0.8867 and adjusted R -square=0.8757. (*, ** and*** denote significance levels at less than 10, 5 and 1% respectively)

Source: survey result, 2019

Table 9. Multicollinearity test result for continuous variables

Variable	Variance Inflation Factor (VIF)	1/VIF
Experience of household head	2.50	0.399887
Age of household head	2.42	0.413218
On-farm income	1.91	0.5202618
Amount of teff produced	1.59	0.628315
Teff farm size	1.55	0.644964
Off-farm income	1.37	0.729623
Number of livestock owned	1.35	0.742319
Lagged market price of teff	1.32	0.758900
Distance to the nearest market	1.18	0.848645
Family size	1.11	0.902822
Education of household	1.06	0.941370
Mean Variance Inflation Factor	1.58	

Source: survey result, 2019

Table 10. Contingency coefficients of dummy variables

Variables	Gender of household head	Credit access	Extension service	Market information
Gender of household head	1			
Credit access	0.0040	1		
Extension service	0.1752	0.1296	1	
Market information	0.0070	0.0331	0.1818	1

Source: survey result, 2019

Table 11. Conversion factors used to compute tropical livestock units

Livestock category	Tropical livestock unit
Oxen/Cow	1
Sheep/Goat	0.13
Horse/Mule	1.1.
Donkey	0.7
Chicken	0.013
Heifer/Bull	0.75
Calf	0.25

Source: [31]

Gender of the household head. Gender plays an indispensable role in the marketing intensity. The gender of the household head affects the amount of teff supply considerably (less than 5%) and positively. The results show that other things being constant, being a male-headed household increases the volume of teff marketed by 0.4688Qt. Male household heads have enhanced labour capacity and mobility (better exposure for improved farm practice demonstrations) over a female household, enabling them better access to innovative agricultural practices and market information. On the other hand, males spend more money than females in different study areas. More volume of teff is supplied to the market by male-headed households to cover these costs. This result is supported by prior studies of A. Getahun [3], T.M. Challa et al. [11], and A. Elias et al. [21].

The number of livestock owned. This variable was expected to negatively affect the volume of teff marketed, which is in line with the actual result. The number of animals owned negatively affects the amount of teff supplied to the market at less than 5% significance. *Ceteris paribus*, a unit increase in tropical livestock reduces the amount of teff marketed by 0.0587Qt. It implies that farmers with more livestock keep their land for grazing/fodder or need to produce crops generating more straw for feed than teff like finger millet and wheat. On the other hand, though mixed farming is practiced in the study area, farmers sell livestock beyond their need for farming practices. E.G. Tura et al. [6] and W. Gobie [22] had found the same result on determinants of intensity of marketed surplus of teff and pepper, respectively, increase in the number of livestock had negative relation to market supply.

Experience in teff production. Experiences of HH head in producing and selling teff is found to affect the market supply of teff positively and significantly. As hypothesised, the experience of household heads in producing and selling affected the intensity of teff marketed thoroughly and intensely at less than 1%. Keeping other variables constant, a year increase in farmers' experience of teff production increases the volume of teff supplied to the market by 0.0345Qt. It can be since when farmers produce and sell teff for many years, the probability of establishing market contacts and building up 'credit worthiness' will be high. Hence, farmers are going to supply more quantity to the market. Farmers with more vast experience are supposed to have better competence in assessing the characteristics and potential benefits of teff than farmers with shorter experience. Besides, farmers with more extended experience were expected to be more knowledgeable and skillful. Studies by T.K. Amentae et al. [23] were exploring value chain and post-harvest losses of teff.

Amount of teff produced. As shown in Table 8, the amount of teff paid affects the quantity of teff supplied to the market positively at less than 1% significance. It affirms that increasing teff production by one quintal will enable farmers to increase the volume of teff marketed by 0.5569Qt, *ceteris paribus*. The better the level of production the farmers have, the increased amount of teff they are ready to supply to the market (that is, high teff yield is important for a large amount of marketing). The result is similar to studies of A.A. Fikadu et al. [24], S. Hassen et al. [25], and Z.O. Mohammed [26].

Lagged market price of teff: As expected before, the lagged market price regression coefficient has a

positive and significant relation to the volume of teff marketed at less than 5% significance level. It indicates that keeping other variables constant, a one-birr increase in teff price before a production season causes a 0.2183Qt rise in the amount of teff marketed by farmers this year. It showed a positive and significant relationship since the costs of 2018 can stimulate farmers to produce more teff, which was supplied more in 2019. This study aligns with [6] and [27].

On-farm income. The result shows that income from farming activities other than teff farming affects the volume of teff marketed positively at less than 5% significance level. It means that a one-birr increase in the income from farming activities brings farmers' volume of teff supplied to the market to increase by 0.00003Qt, *ceteris paribus*. Revenues from other crops or livestock could help farmers buy teff production inputs and enable them to produce more teff and supply more to the market. It means that farmers were active in providing other crops (mustard, niger seed, and linseed), livestock and livestock products (sheep, goat, cow, oxen, chicken, and egg, etc.) to the market to get money to purchase production inputs and other household costs. E.G. Tura et al. [6] and A. Elias et al. [21] also found a similar result.

Off-farm income. Off-farm income earned by farmers affects the volume of teff marketed positively and significantly at less than 5% precision level. A one-birr increase in off-farm revenue, *ceteris paribus*, is associated with a 0.00005Qt rise in the quantity of teff sold in the market. It implies that farmers may engage in off-farm activities such as daily labour, petty trading, handicraft, etc., which helps them to earn additional income. This extra income increases farmers' financial capacity in investing in teff production and thereby supply to the market. This result is supported by E.G. Tura et al. [6] and R.M. Berem [28].

Distance to the nearest market. The closest product market has a strong and highly negative effect on participation and the amount of product marketed. As depicted in Table 8, it adversely affects the volume of teff supplied to the nearest market at less than 1% significance. This means that each kilometre to the closest product market lowers the quantity of teff to be supplied by 0.0902Qt, *ceteris paribus*. It is directly related to means of transportation (human portage and animal backs) used in the study area as it is challenging to load large quantities by humans. It can also result from high transportation costs due to the distant dwelling of the household from the nearest market centre. The results of this study are similar to the findings of E.G. Tura et al. [6], T.K. Ametae [29], and M. Sharma [30].

CONCLUSIONS

This study was aimed to investigate teff production, marketing supply, and main factors affecting the volume of teff marketed in Dera woreda, one of the potential

teff producing areas in North West Ethiopia. The study established that teff is one of the major cereal crops produced for consumption. The type of teff grown in the study area is locally mixed teff (*Seregegna*) followed by red teff.

The study results show that most producer farmers get market information but their data is often skewed to traders. It calls for introducing a system that provides timely and accurate information. It can be possible by introducing an automatic daily or weekly market price board and creating awareness in the automatic weekly market price board. The study showed that the kebele with a high volume of teff produced is the one in which a low volume of teff is supplied to the market and vice versa since the producers have better access to the market as the distance from producers is closed. The implication is that road networks and transport infrastructure need to be developed in the area. Furthermore, it calls for new market centres near the farmers.

The OLS estimate of the MLR model indicated the gender of the household head, the experience of the household head, amount of teff produced, lagged market teff price, on-farm income other than teff farm and off-farm income positively influenced the volume of teff sold. In contrast, livestock ownership and distance to the market affect negatively and significantly. Furthermore, lack of organised market and price is the most frequently mentioned constraint by farmers in the teff marketing system. Therewith, adulteration, supply and demand fluctuation, and insufficient working capital are the traders' problems in the teff marketing system. However, the rising urbanisation and infrastructural developments are good opportunities for farmers and traders. Farmers who use improved seeds produce more. It implies introducing a vital extension service on improved crop variety and other inputs.

It suggests the need for improving farmers' knowledge and performance by addressing essential training, incentives, and advice to use new crop varieties and inputs that increase productivity, thereby maximising the quantity of teff supplied to the market. The amount of off-farm income earned by the household head is directly related to the amount marketed. Thus, engaging in off-farm activities rather than teff farming has a vital role in generating cash to cover production expenses. However, the more livestock ownership, the lower the volume of teff marketed. It implies that farmers with large amounts of TLU can specialise in livestock farming rather than teff though mixed farming in the livelihood of the study area.

ACKNOWLEDGMENTS

The researcher acknowledges respondents' consent for a personal interview in the data collection process. The researcher also expresses gratitude to the advisor and reviewers for providing constructive comments to improve this paper. It is the author's view and does not necessarily regard the institution's official position.

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Взаємозв'язок виробництва та маркетингу теф на прикладі району Дера, Північно-Західна Ефіопія

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Анотація. Незважаючи на те, що деякі виробничі та маркетингові обмеження ледве визначені, район Дера є потенційним виробником тефу в зоні Південного Гондара Ефіопії. У дослідженні проаналізовано виробництво тефу, зосереджено увагу на факторах, які впливають на обсяг проданого тефу, на основі даних, зібраних з опитувань домогосподарств, інтерв'ю респондентів та обговорень у фокус-групах. Для аналізу даних використовувалися як описовий, так і економетричний аналізи. Результати показують, що теф, вирощений на досліджуваній території, є змішаним, який практикується в 34,5 % домогосподарств, за ним слідує червоний теф (32,16 %) із загальноновживаними сховищами, такими як Гота, Готера та Сак. З точки зору маркетингу, результати показують, що 57,7 % тефу, виробленого в посівний сезон 2019 року, постачалося на ринок через сільських роздрібних торговців, оптових торговців і безпосередньо від виробників до споживачів. Результат оцінок за методом найменших квадратів моделі множинної лінійної регресії вказує на стать і досвід голови домогосподарства, кількість виробленого тефу, відставання ринкової ціни на теф, внутрішньогосподарський дохід, крім оплати за межами ферми тефу, позитивно впливає на обсяги реалізації тефу. Навпаки, володіння худобою та віддаленість від ринку мають негативний і значний вплив. У статті також розглядаються основні обмеження та можливості, з якими стикаються фермери. Відсутність організованого ринку та встановлення цін є найбільш поширеним обмеженням для фермерів у системі маркетингу. Водночас шахрайство, коливання попиту та пропозиції, а також недостатній оборотний капітал є значними обмеженнями для трейдерів. Однак зростання урбанізації, постійне підвищення цін та державні інвестиції в розвиток інфраструктури є великими можливостями як для фермерів, так і для торговців. Отже, щоб досягти кращих результатів на ринку тефу, необхідно впровадити окращені можливості переговорів, точну інформацію про ринок і розвиток інфраструктури. Це дослідження диктує велику кількість подальших досліджень, пов'язаних з впливом урбанізації на споживання перероблених продуктів тефу

Ключові слова: зберігання, ціна, дохід, звичайний найменший квадрат, інтенсивність

SCIENTIFIC HORIZONS

Journal homepage: <https://sciencehorizon.com.ua>

Scientific Horizons, 24(10), 97-108



UDC 336

DOI: 10.48077/scihor.24(10).2021.97-108

The Genesis of Financial Market Institutionalisation in Ukraine: An International Perspective

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Article's History:

Received: 13.10.2021

Revised: 12.11.2021

Accepted: 15.12.2021

Suggested Citation:

Sirenko, N., Baryshevska, I., & Melnyk, O. (2021). The genesis of financial market institutionalisation in Ukraine: An international perspective. *Scientific Horizons*, 24(10), 97-108.

Abstract. The relevance of the article is due to the need for a comprehensive analysis of the latest processes in the global financial system, as well as a complex development of a methodological approach to its study. With the transition to digital technologies in the global financial market, in particular, when processing and storing data in electronic format, there is a change in the form of financial circulation, which can lead to a number of problems and risks. In this context, special attention should be paid to the international credit market and the international bond market, which are, in fact, circulating in cyberspace and are evolving through info-communication technologies. The purpose of this research is an in-depth analysis of the main globalisation processes of the world economy and their impact on the development of competition between exchange and over-the-counter trade. The study used general scientific methods of analysis, theoretical generalisation, and synthesis, as well as methods of mathematical, statistical, and economic analysis. According to the study of the dynamics of capitalisation of the global stock market, the authors of this article identified a trend towards dynamic growth in the use of alternative trading systems, which is a factor in the development of exchange and over-the-counter securities trading. The article provides a comprehensive analysis of the directions of impacts of digitalisation on the global monetary and financial system, among which the positive and negative effects are considered in detail and substantiated. The negative effects of virtualisation of the global monetary and financial system are identified, as well as perspective directions of modification of the economic system and finance with the introduction of digital technologies are formulated. The information presented in this paper can be used to further consider the dynamics of stock market capitalisation in the world, as well as to develop methods to improve the efficiency of digitalisation of operating processes for individual enterprises and the global economy as a whole

Keywords: stock market, development, structure, institution, provision



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INTRODUCTION

In the context of virtualisation, the theoretical and methodological foundations of the global monetary and financial system need to be reconsidered. To comprehensively analyse the latest processes in the global financial system and develop a methodological approach to its study, let us first clarify the specifics of the current understanding of the term “financial system” [1]. The term finance comes from the Latin word “finantia”, which means the obligatory payment of money. Finances originated with the emergence of the first state entities, but the term “finance” in its modern sense first began to be used in Italy in the 18th century, when it began to mean the accumulation of monetary funds by the state to ensure the performance of state functions. To date, academic economists have developed a number of definitions for the term “finance” [2]. Given the characteristics of information and telecommunications development and its impact on the financial sector, a new definition of finance should be added. Finance in the context of virtualisation takes the form of the alienated intrinsic value of goods embodied in electronic units of payment circulating in the information economy to mediate exchange. With regard to the financial system as a whole, the paper first explores the classical definitions and then augments them, taking into account the information aspect of development and the virtualisation of the global financial market.

A financial system is a set of markets and other institutions necessary for financial transactions to exchange assets and risks. The system includes securities markets, financial intermediaries (banks, insurance companies, etc.), and the institutions that regulate all these institutions [3]. A virtualised global financial system is an interconnected and interdependent integrated set of financial markets, institutions developed based on server virtualisation (information and communication networks) that serve as its infrastructure support. In the modern stage, finance is taking the form of electronic money. Electronic money (e-money) – monetary assets presented electronically, placed on an electronic medium, held by the user. This medium could be a micro-SD, a computer, a settlement system server where users' electronic money is stored centrally [4]. E-money makes it possible to quickly build up payment reserves by issuing money on smart cards, e-wallets, etc. and receive funds from businesses or individuals for services or goods sold.

Economic theory distinguishes five functions of money, namely: measure of value, means of circulation, means of capital accumulation, means of payment, world money when it is used for its intended purpose of covering costs and generating income (losses). Redistribution is a secondary distribution through centralised funds (budget, extra-budgetary funds and the like), ensuring that resources are channelled to the non-productive sphere. The controlling function consists in exercising control over the real cash flow and the formation of cash

funds. The main functions of money in the virtualisation of the global financial system have two aspects [5]:

1) if we consider fiduciary money in its primary form of virtualisation, i.e., in the context of the use of ICT in finance, in which case all five functions of money remain, and virtualisation has a positive effect on finance by speeding up its circularity;

2) if we view virtual currencies as a secondary form of virtualisation of the global financial market, then cryptocurrencies' performance of the basic functions of money remains in question.

The functions of measure of value, means of circulation, means of payment and world money will only exist as long as they are used and accepted by other entities. Regarding the function of capital accumulation, in today's environment, given the volatility of the cryptocurrency market, virtual money can become a means of capital accumulation rather than a means of capital loss.

World money is a means of payment that serves the movement of value in international economic circulation and ensures social and economic relations between countries. E-money fulfils this function to the full. The use of electronic money issued by one state is also possible outside its borders. However, this use of money on the territory of another state must be based on common technology. For example, the payment systems Web-money, Yandex.Money are based on the joint Pay Cash technology [6].

Based on the above, the function of money is fully performed by electronic fiduciary money [7]. However, with the development of the information economy, not only are the existing functions of money modified, but new ones are emerging, reflecting the general dialectic of the development of monetary relations and the principle of historicism [8]. E-money fully retains all the functions of money. They fall into two large groups: plastic card-based and global network-based, most commonly the Internet [9].

It is well-known that the financial system is based on monetary funds, which are defined as certain amounts of money or other securities with corresponding, clearly defined areas of formation and use. The existence of finance is characterised by certain financial categories, such as public revenues and expenditures [10]. Public revenue is the part of monetary relations that relates to the distribution of the value of gross domestic product (GDP) and national income (NI), which results in the creation of centralised monetary funds. But public expenditure is a monetary relationship that allows the use of centralised monetary funds. These include the expenditure of the state itself, the expenditure of state-owned enterprises [11]. The financial system is defined as the totality of different types of funds of financial resources concentrated at the disposal of the state, the business sector, households and financial institutions

for the purpose of meeting economic and social needs and ensuring the performance of proper functions.

MATERIALS AND METHODS

Financial systems have certain characteristics:

- each part of the financial system possesses its own specific methods of raising funds for the creation of the financial funds and the direction of their implementation;
- all parts of the financial system have their own specific scope and are relatively independent;
- all parts of the financial system are closely interlinked and will function effectively when the system is perfect;
- the legal basis for each component of the financial system helps to achieve the greatest efficiency;
- each part of the financial systems can be divided into smaller units, depending on the factors affecting the formation and use of the funds of financial resources.

There is not yet a single universally accepted classification of this system; four structural elements are distinguished: the debt market, the derivatives market, the foreign exchange market and the title market. However, with the emergence of cryptocurrencies, one must also consider their potential impact if they develop and spread rapidly. The features and key differences between virtual, fiduciary and digital currencies will be discussed below. All the structural elements are interconnected and function in an integrated way. The constant circulation of capital in the financial environment removes clear boundaries between markets [12].

Virtualisation and globalisation are two mutually interdependent, interconnected processes. The global financial market falls under the simultaneous influence of these factors, manifested in synergies [13]. Virtualisation primarily modifies the shape of the global financial market's operational processes, eventually leading to further specifications in its building blocks [14]. The results of the virtualisation of the global financial market are defined as follows: in the stock market – consolidation of exchanges, rapid development of over the counter (OTC) trading, competition between exchanges and information agencies; in the international derivatives market – deepening of the market and use of conditionally virtual derivatives for speculative transactions in the international currency market – emergence and spread of extra-institutional monetary units (cryptocurrencies); in the global banking sector – international interbank digital payment systems, cloud services and non-bank payment systems [15]. The virtualisation of the financial system manifests itself in the digitalisation of operational processes, the development of digital payment systems (both banking and non-banking), the introduction of cloud services in the financial sector, and institutional consolidation based on server virtualisation [16].

The challenge today is to determine the place of the international derivatives market in the global financial market. The global derivatives market has the

characteristics of both a money market and a capital market. In addition, derivatives have the characteristics of long-term debt capital market instruments. Financial institutions accumulate significant amounts of financial resources around the world. Monetary resources are then reallocated between countries through credit and investment vehicles, further ensuring capital concentration and growth. Through the institutional mechanism of the global financial market, international financial flows are competitively channelled to areas and regions with the highest demand, which will subsequently generate higher profits [17]. International currency markets are global network centres where foreign currencies are bought and sold [18]. Foreign exchange markets guarantee timely international settlements, diversify foreign exchange reserves and provide insurance against currency and credit risks. Significant market fluctuations turn the global currency market into a speculative market.

RESULTS AND DISCUSSION

The modern global foreign exchange market has evolved from the interconnectedness and development of national foreign exchange markets. In terms of the way the market space for buying and selling foreign currencies is organised, the global foreign exchange market is a worldwide telecommunication network that connects banks and brokerage firms in different countries. Thanks to telecommunication technologies, information on the demand for foreign currencies, exchange rates, bank conditions and the like is quickly transmitted [19].

It should be emphasised that the integration of virtual currencies into the global financial market occurs precisely through the foreign exchange market, due to the convertibility of virtual currencies into a national currency (if that virtual currency is convertible).

The world foreign exchange market is several times larger than the scale of other components of the world financial market. For example, the daily volume of transactions is around \$1.5 trillion, increasing by 10% annually. Dollar transactions take the main place here. Transactions are carried out both within states and by partners who are located in other countries. London, New York, Tokyo are the world's centres of international monetary transactions. Currency trading is mediated by major banking institutions. In the world's financial centres, where 3/4 of transactions take place, 10-11% of banking institutions trade.

The international debt market is the place where debt instruments are traded, giving the creditor the right to collect the debt. The debt market is made up of two components: the international credit market (the market for bank loans) and the international debt securities market (the international bond market). These markets are developed based on innovative technologies using telecommunication systems, which predetermines their virtualisation, i.e., they actually circulate in cyberspace. International banking is another important

element of global finance. The transnationalisation of the world economy is reflected in the rapid growth of international banking operations, the emergence of networks of foreign branches, and the promotion of an expansion strategy by the world's leading banking institutions. Since the 1950s and 1960s, banks in Western Europe, the United States, Japan and some other countries have shifted their activities abroad by establishing branches or joint branches with local financial institutions in the host country.

The internationalisation of the credit and financial infrastructure has led to the emergence of transnational banks, which are among the main actors in the global financial system. Although the primary motive of their international activities was to serve the export and import operations of their foreign affiliates, multinational companies (MNCs) used their presence in the recipient country to explore new ways of operating and mainly to expand their fields of operations (innovation, the Eurocurrency market and the like). The virtualisation of the global financial space is the most effective and powerful component of globalisation of the world economy. The global economy is highly internationalised and integrated, characterised by qualitatively new interdependencies, the reasons for which are the rapid development of information and communication technologies. The internationalisation of capital flows is the result of an increased interconnection and cohesion of national capital flows with international capital flows, manifested in the emergence of international forms of capital linkages between different states. The current financial and economic environment states a paradoxical financial globalisation that precedes financial integration. The reason for this paradox is precisely the virtualisation of the global financial market based on the development of innovative infrastructures.

International financial relations have evolved and are influenced, as already noted, by changes in finance itself. The share of financial services in global foreign trade has increased significantly due to the rapid development of server virtualisation, database virtualisation. Financial ties between states are growing stronger. Today, the main global financial flows include international direct investment, international bonds, international loans, international equity capital, and the interwoven stock markets of nations. The mobility of capital flows is therefore increasing. The catalyst for accelerating mobility and spinning up speed is ICT. In addition, greater mobility and diversification of capital flows are structuring the global financial environment more clearly. The re-orientation of capital flows leads to a diversification of risks. Increasing returns on assets accelerate economic growth and the integration of financial markets improves overall well-being. The global changes in the world economy caused by the informatisation of socio-economic realities require the latest revision of the theoretical and methodological foundations for defining the

main provisions of the transformation of the monetary and financial system.

The use of precious metals, first as a means of payment (in the form of coins) and later as a store of value, guaranteed the stability of the financial system. The emergence of the gold standard was necessitated by the need to regulate financial relations between countries, establishing a single equivalent in international payments. Gold was legally recognised as the only form of world money from the Paris Conference in 1867. Since the Bretton Woods Agreement in 1945, the US dollar, with a gold content of 35 dollars per troy ounce, has taken on the role of world money along with gold, and all other currencies are pegged to it. The system of fixed exchange rates ensured the stability of the international monetary and financial system as long as the US monetary unit could serve as the world's reserve currency and exchange dollars for gold. But after Charles de Gaulle's demands to honour his commitments, the US unilaterally stopped the exchange. Fixed exchange rates were replaced by a system of floating exchange rates, legally enshrined by the 1976 Jamaica Conference. Credit forms of money, such as banknotes, cheques and the like, began to serve as the universal equivalent. The modern credit money is devoid of intrinsic value, because its presence at this stage of social-historical development began to inhibit production and commodity-exchange relations.

The modern economy uses fiduciary money. The fiduciary money is superficially similar to intrinsic value money, but conceptually significantly different. The main driving forces in changing the forms of money are the dematerialisation of the economy from energy to information resources and intellectual technology. This process can also be observed in the financial sector. When production and commodity-exchange relations begin to be limited to the value of monetary goods or transaction costs, the measure of monetary value is replaced and given a qualitatively new status, which at each stage of development is objectively limited by the information and technological level of society.

The phenomenon of the "virtual economy" manifests itself in the contradictions arising from the introduction into the financial sphere of the latest information technology. On the one hand, independence from place, time and volume of transmitted information increases the freedom of action of market actors and facilitates the emergence of new financial instruments. On the other hand, advanced information technology allows the creation of gigantic financial pyramids, almost instantaneous transactions in securities, particularly derivatives, and the creation of "bubbles" that hinder productive development and lead to global crises. Transactions with shares, bonds and other securities, in particular derivatives, can in certain cases be classified as speculative virtualisation. The focus on generating ad hoc income from price fluctuations in the value of financial assets is usually refers to financial speculation.

Securities trading is used by businesses to raise capital. But when securities become an instrument of “quick money”, when there is a gap between their real value and their stock market value, then one can speak of a speculative virtualisation of the stock market. Exchange speculation gradually leads to an overvaluation of securities and a substantial excess of stock market capitalisation over the real annual income of the company.

We note that the era of informatisation is integrating the components of the global financial market and globalising the world economy as a whole. This direction of development forms both the obvious advantages of the information society, highlighting the virtual component of the financial system, and serves as a basis for financial abuse and a tool for its implementation. The quintessence of the global monetary and financial system is to fulfil its primary function as an exchange equivalent. The intrinsic value of the means of payment is not required, as this is one of the factors leading to the transformation of money into a commodity. The convergence of information and telecommunications systems with the financial sector is a factor in the changing financial paradigm of the world. A transformation is taking place under the influence of virtualisation, which consists, firstly, in a change in the nature of means of payment, highlighting the information content of monetary units with the simultaneous elimination of intrinsic value, secondly, the transformation of monetary relations into network flows of information and financial resources, thirdly, the emergence of private payment systems and the spread of virtual currencies. Revolutionary developments in information and communications technology (ICT) communications systems and tools have made it possible to synchronise exchange markets across continents into a single global market. The development of the Internet as a global medium for the distribution of financial transactions and investments has led to the movement of financial markets online. The development of network technologies has outpaced existing theoretical and methodological concepts of the stock market, leading to its transformation and the revi-

sion of the very foundations of stock trading. The stock market (securities market), as defined by the Securities and Stock Market Commission (NSSMC), is the part of the capital market where securities are issued, bought and sold. The stock market is an abstract notion that is needed to refer to the actions and mechanisms that allow securities to be traded. The stock market differs from a stock exchange in that a stock exchange is an organisation that brings together buyers and sellers of securities. The main functions of the stock market include:

- 1) capital procurement
- 2) ensuring capital spillovers between sectors and areas of the economy;
- 3) distribution and redistribution of capital among corporations and control over their activities;
- 4) ensuring operational activities on individual capital movements.

The latest trend in the world’s stock markets is virtualisation. Stock market participants are the first to take advantage of the latest developments and opportunities in information technology. Advanced electronic technology and modern means of communication and informatisation have created the possibility of virtualisation of transactions on the global stock market. Today, therefore, the global stock market operates in a global virtual information space through virtual transactions, virtual trading and virtual financial flows. The developed virtual infrastructure of stock markets is embodied in the consolidation of exchanges. Exchange alliances are the next step in deepening virtualisation in stock markets. The following stages can be distinguished in the process of stock exchange consolidation (Fig. 1). The first period of exchange consolidation came at the end of the 1990s. It was then that the first unified stock exchange, Euronext, emerged – a union of the Paris, Amsterdam and Brussels exchanges that was characterised by the integration of the trading, clearing and settlement systems of the stock, futures and commodity markets of the three exchanges. Euronext is the first integrated international pan-European exchange.

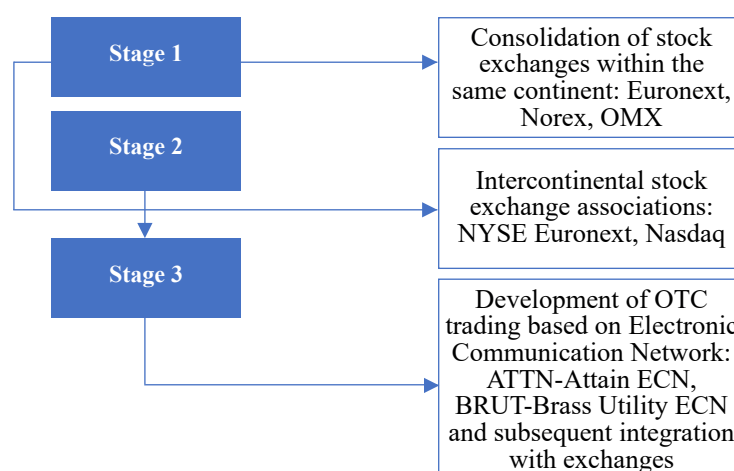


Figure 1. Stages of exchange consolidation

With the formation of Euronext, the integration of stock exchanges in Northern Europe intensified. The next was the alliance of the Copenhagen and Stockholm stock exchanges, NOREX, in 1998. Later, other Nordic and Baltic exchanges also joined the association. The consolidation process in northern Europe was organised through the creation of Aktiebolaget Optionsmdklarna / Helsinki Stock Exchange (OMX).

Intercontinental stock exchange unions began in 2006-2007. The premise was that the New York Stock Exchange (NYSE) and the National Association of Securities Dealers Automated Quotation would compete for entry to the European market. NYSE signed a merger agreement with Euronext in 2006. Consolidation of exchange and OTC trading is the latest unfinished business. Characterised by the use of electronic communication networks in operational activities. The features of the operation will be presented in more detail below. The integration of stock exchanges as a form of spreading the virtualisation of the global stock market has significant effects on the development of financial globalisation. The main motives for stock exchange alliances should be highlighted as the following:

- increasing capitalisation and trading volumes;
- an increase in competition between trading platforms;
- increase of operating time;
- gaining a competitive edge by entering new markets;
- economies of scale;
- increasing market liquidity;
- increasing competition from over-the-counter trading platforms;
- unification of market rules;
- an increase in the turnover of OTC trading;
- the intensification of world globalisation processes.

To assess the stock exchange alliances driven by the virtualisation of the global financial market, let us

analyse the results for one of the most important indicators for the stock market – capitalisation. The stock market capitalisation is a measure of the scale of stock market transactions. It is defined as the total market value of securities.

The virtualisation of the global stock market in the form of continental consolidation (Euronext, OMX) and then intercontinental consolidation (NYSE Euronext → NYSE:ICE, Nasdaq OMX → NasdaqNordic) has driven capitalisation growth on the world's major stock exchanges. In particular, the NYSE Euronext capitalisation dynamic prior to the consolidation agreement (total capitalisation of US \$ 15 trillion) and the year after (US \$ 20 trillion) shows a growth rate of 25% over two years. This trend can be seen both in the NYSE Euronext format (US \$ 24.67 trillion – the highest figure) (Fig. 2) and since the NYSE Euronext became a structural division of the Intercontinental Exchange. As of the end of 2019 NYSE: ICE remains the largest stock exchange in the world with a capitalization of US \$ 25.3 trillion, ahead of the closest competitor, the Nasdaq, by about US \$ 14 trillion.

In contrast to NYSE: ICE, Nasdaq Nordic (formerly Nasdaq OMX), after signing a consolidation agreement, initially showed a negative capitalisation trend of -30% (from US \$ 6 trillion total capitalisation prior to consolidation it fell to US \$ 4 trillion. In the year after the merger, Nasdaq Nordic (formerly Nasdaq OMX) showed a negative trend of -30% (US \$ 6 trillion in total capitalisation before consolidation). However, in the year following the merger, Nasdaq OMX saw its market capitalisation increase by 60% to US \$ 8.78 trillion in the period from the date of the drop to 2013. US \$ 8.78 trillion. The positive trend has continued in the future. As of the end of 2019, Nasdaq Nordic is the world's second largest securities trader with a total capitalisation of \$ 11.23 trillion. US \$ 11.23 trillion (Fig. 2).

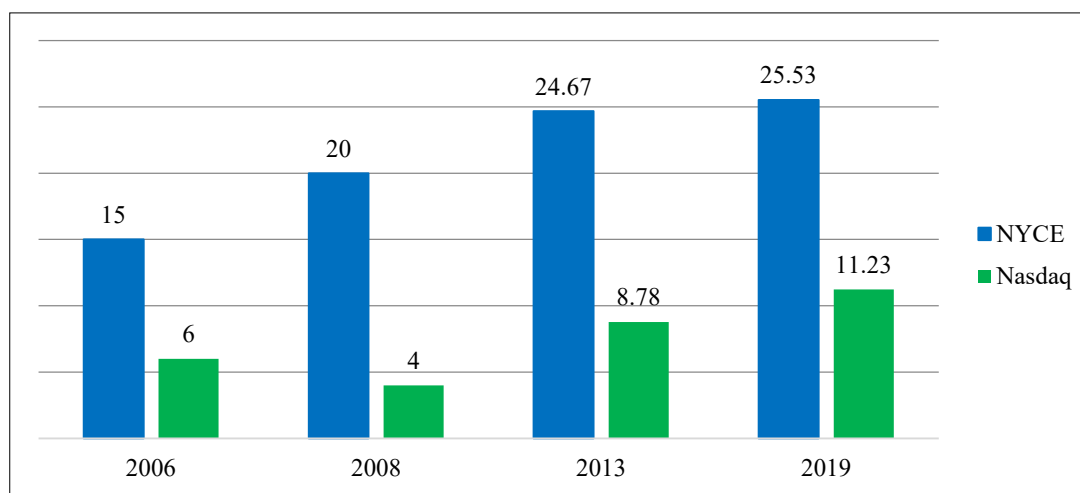


Figure 2. Capitalisation trends 2006-2020 NYSE: ICE and Nasdaq: Nordic (trillion USD)

By analysing the geographical structure of the global stock market's development, it was found that the USA is in first place (53.3% of the global stock market),

Japan is in second place (8.4%), and the UK is in third place (5.5%) (Fig. 3).

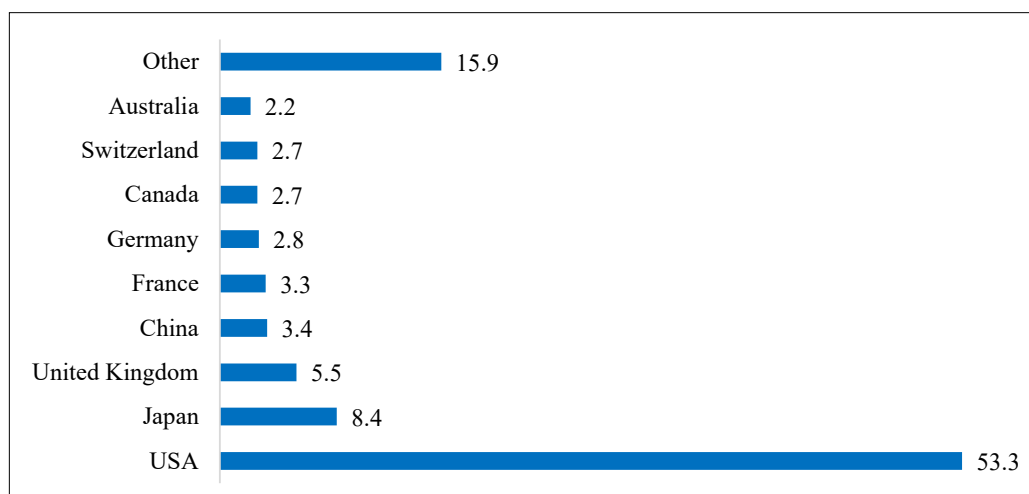


Figure 3. Share of countries in the global stock market, %

The digitalisation of exchange operations offers a number of benefits, namely: fast access to trading venues; accelerated processes for obtaining and distributing exchange price information; rapid settlement, control and accounting, increased stock market liquidity

and capitalisation. Figure 4 below shows the capitalisation levels of the world's largest stock exchanges as of March 2021, with top performers being the NYSE, NASDAQ and Japan Exchange Group.

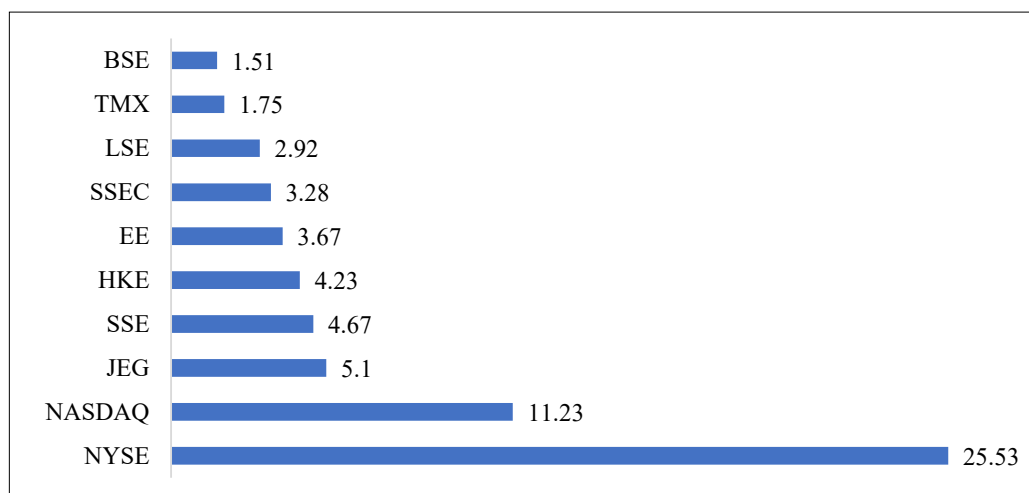


Figure 4. The capitalisation of major traders (trillions of dollars), March 2021

Based on a quantitative analysis of indicators characterising on- and off-exchange trading in securities, it has been established that over the past three years, off-exchange trading in the form of alternative trading systems based on electronic communication systems technology has shown an upward trend. In 2019, the global OTC trading market grew by 22% to 45.3 trillion dollars. In 2019, the volume of the global OTC trading market grew by 22% and reached 45.3 trillion dollars (2018 – 33.863 trillion dollars), while the global stock market saw a decrease in capitalization by 36% from

68.65 trillion dollars in 2018 to 43.27 trillion dollars in 2019 (Fig. 5).

Thus, the virtualisation of the global stock market is the transformation of the market based on the introduction of information and telecommunication technologies in operations, as well as the modernisation (digitalisation) of infrastructure, resulting in the consolidation of exchanges (and, consequently, increased capitalisation of the stock market) and the spread of OTC trading – alternative trading systems (ATS) based on electronic communication systems (ECN) technology.

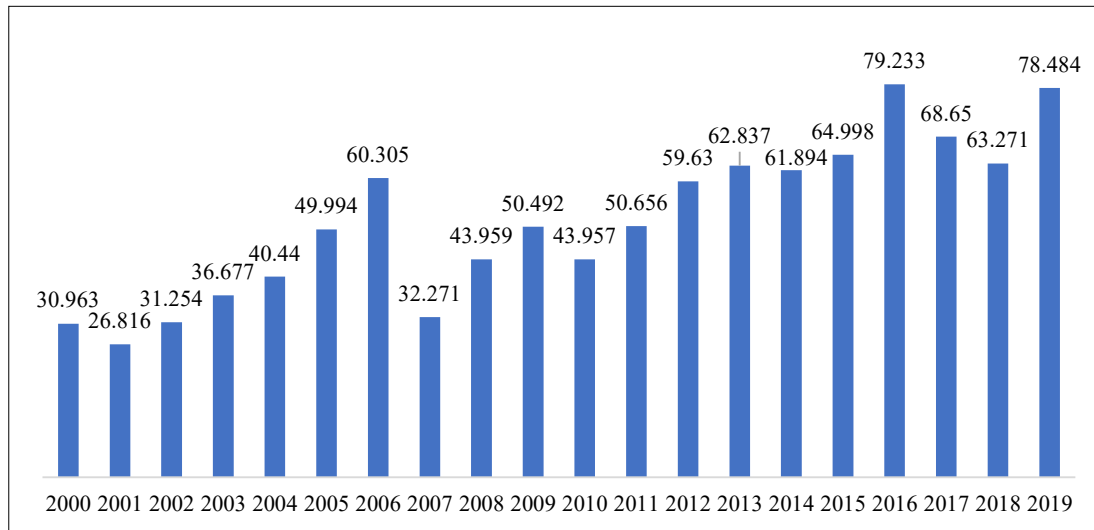


Figure 5. The growth of the securities trading market

A current trend in the virtualisation of the global stock market is the dynamic growth in the use of alternative trading systems as a factor in the development of OTC trading. In describing the current state of global stock market dynamics, it is necessary to note the main

indicators. According to Bloomberg news agency, in November 2015 capitalization amounted to 73 trillion dollars. At the end of 2017, capitalization reached USD 80 trillion dollars (Fig. 6).

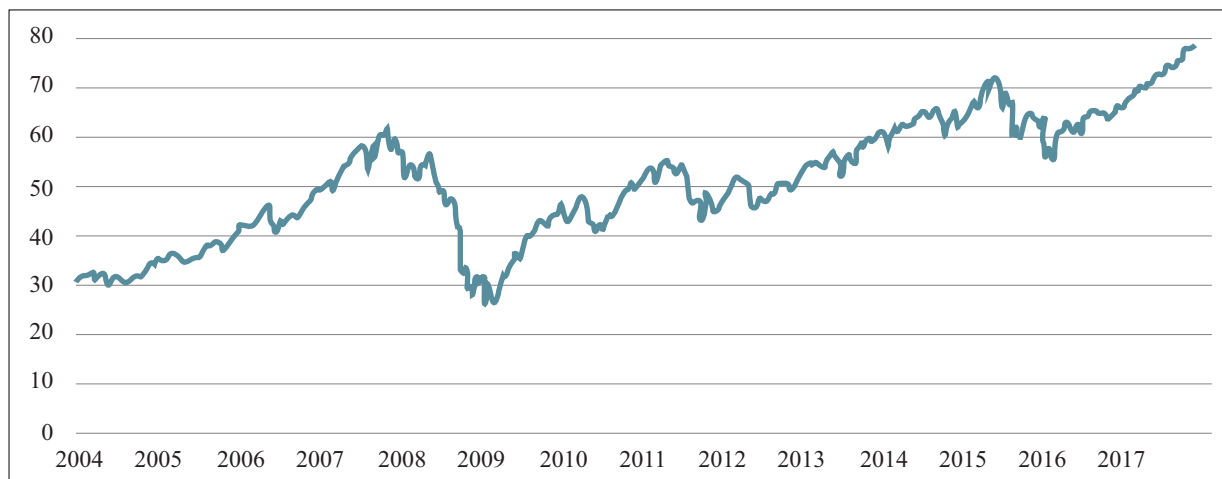


Figure 6. Global stock market capitalisation 2004-2017, trillion USD

The global stock market has been volatile in 2018. The maximum capitalization was in January – 87 trillion dollars, after which a significant recession – the market

fell by USD 7 trillion dollars. The global stock market capitalisation was at 72 trillion dollars at the end of December 2018 (Fig. 7).

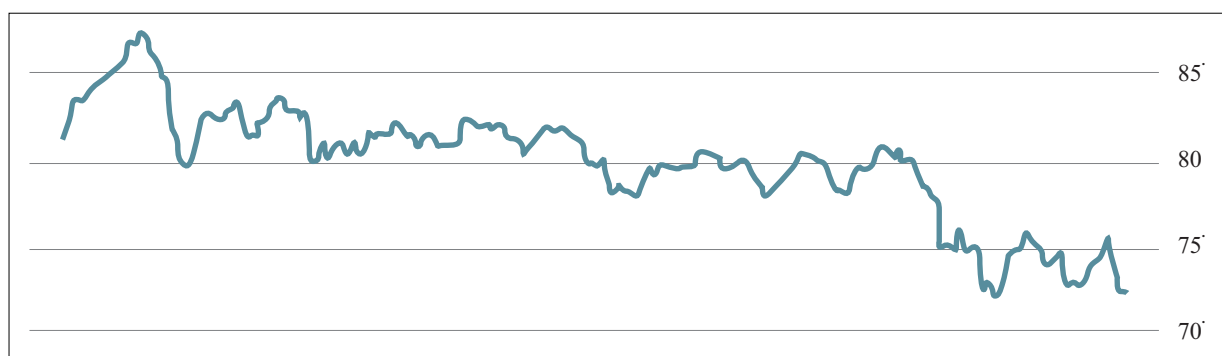


Figure 7. The global stock market capitalisation in 2018, trillion USD

Therefore, given the above indicators, the global trend in the development of stock exchanges is as follows:

- further consolidation and internationalisation of exchange activities based on ITC infrastructure. The need to compete is forcing stock exchanges to go global, using server-based communication networks and virtual environments;

- the universalisation of exchange activities, which is reflected in the organisational unity of financial instruments and clearing, a wide range of information services and the provision of custody and settlement services;

- integration of exchanges with OTC electronic trading systems;

- harmonisation of tendering and information exchange rules.

An analysis of recent trends in the development of the world's stock exchanges identifies the main consequences that could result from a wave of stock exchange consolidations. Here are the main consequences of these:

- the formation of the world's largest trading venues, which are grouped together based on specialisation. These exchanges are expected to have huge trading volumes and become the largest venues in their industry;

- encouraging new alliances. As a consequence, an accelerated process of consolidation and, eventually, the formation of monopolistic entities on the global stock market is possible;

- simplification of procedures, unification of document and listing standards, increased efficiency through the interconnection of systems;

- increasing the supply of securities to investors and reducing the cost of transactions.

Digital virtualisation in the form of the development of Electronic Communication Networks (ECM) is deepening the integration of the global stock market. The Electronic Communication Network (ECN) is an electronic system for executing trades in exchange-traded commodities that attempts to eliminate intermediaries. An ECN links leading brokers and individual traders together so that they can trade directly, bypassing intermediary exchange mechanisms. ECN technology is represented in the order matching system, which allows for the automatic execution of opposite (buy and sell) orders if certain parameters (assets, price, quantity) are matched. ECNs refer to direct-access electronic trading

systems, meaning that an order is submitted directly to the market on behalf of a client using this system. This is the main difference between an ECN and a broker who acts as an intermediary – processing the order in his internal system and placing it in the market on his own behalf. ECN globalises the market because it allows transactions to take place outside of the working hours of a particular locality. The obvious advantages of such electronic systems are:

- the possibility of daily and round-the-clock trading; bidders can be located in different time zones;

- an increase in the number of bidders offering quotes;

- providing participants with all necessary trade information as soon as possible;

- openness to participants who previously had no direct access to trading and could not compete with brokers. Orders even from individuals placed through ECNs appear on the market and can influence market dynamics;

- transparency, i.e., all orders are reflected in the system and information is available to all participants. The best order enters the market (on a particular trading floor) on behalf of the EUN, which has market maker status, meaning the EUN acts as an impersonal broker for its clients, who simply make a huge number of trades between themselves.

ECN technology provides increased security and confidentiality of information about participants and their trades. The ECN pays a lot of attention to this. Different technologies for user verification, separation of powers and access, and data encryption are used.

The proliferation of ECNs demonstrates the benefits of the network. Let's take the Currenex ECN platform model as an example. Currenex is a subsidiary of State Street Corp, a leading provider of financial services to institutional investors. State Street Corp has about 12 trillion dollars in assets + 1.7 trillion dollars in assets. The first independent and open ECN system, Currenex utilises an innovative and patented technology, which aggregates liquidity from the world's 60 largest banks. Currenex was established in 1999 in California. The company now has offices in London, New York, Chicago and Singapore. The system allows for spot, forward and swap transactions. The advantage of the system lies in the near absence of "slippage" – the difference between the real price of the order and the price of the placed order (Fig. 8).

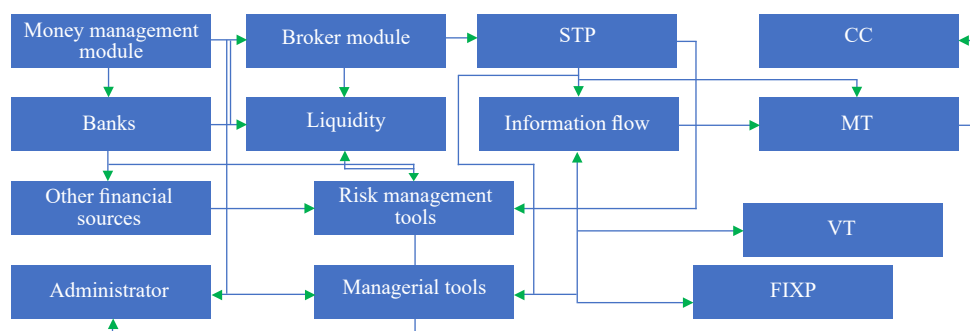


Figure 8. Schematic expression functioning of the electronic communication network Currenex

Figure 8 presents a comprehensive model for the operation of the Currenex electronic communication network, which consolidates liquidity flows, information flows into a single integrated virtual system, using both management tools and risk management. The main task of the communication network is to direct the flow of liquidity. This system is fully automated with no intermediaries. The “broker” module, the money management module, means software robots that help network members carry out the necessary transactions as requested. There are several options for trading platforms:

Currenex Classic is a trading platform aimed at large institutional traders providing fast access to a wide range of trading instruments with all possible order types. As a rule, to trade in the market, it is necessary to deposit a fairly substantial amount of money, which can be done via Currenex Classic. The Viking Trader platform is designed for retail traders with all the necessary features and capabilities, it supports multiple languages, technical analysis tools, online news and allows you to work comfortably on the Currenex network with acceptable requirements according to the size of your deposit. Mobile platforms for phones, smartphones and iPhones, designed to place orders and monitor open positions. FIX protocol – the ability to connect directly to the Currenex network using any application (including proprietary applications) using a special protocol – Financial Information eXchange (FIX) protocol. The biggest advantage of trading on the Currenex ECN platform is the lower trader's finance cost, which is 0.5-1.5 pips for the major currency pairs. Minimum commissions in ECN are achieved by providing quotes from dozens of market makers at the same time, and the system automatically selects the best price for each trade.

Features of risk management include:

- notifications on any margin changes;
- auto-liquidation of positions;
- account control and report on orders and positions;
- sorting accounts for effective risk management;
- providing extended reports, such as the auditors' conclusions.

Bidding through Currenex is restricted to registered persons exclusively. The members of Currenex can be banks, company treasury departments, central banks, international organisations, government agencies and corporate finance managers. Current Currenex members include Intel Corporation, Compaq, Autodesk, Ericsson and some 40 of the world's leading banks as market makers, including ABN Amro, Barclays Capital and Merrill Lynch.

Currenex does not carry out any payments between members, but only generates debit orders from their accounts. Currenex provides its members with foreign exchange market information, research and analytical information and news. The system works through applications. Several standard types of bids are available – limit bid, market bid, “as good as” bid and stop-loss bid.

The virtualisation of the global financial space also leads to another phenomenon – competition between organisations with different activities, competition between exchanges and information agencies in the provision of information services. The Reuters news agency, for example, makes it possible to obtain information on current prices and rates, economic and political news, to be virtually present at stock exchange trading, and to observe the execution of your own orders by stock exchange brokers. However, the information systems of Bloomberg, Reuters, Tenfore, Dow Jones do not allow real transactions of purchase and sale. E-trading brings exchange-traded and over-the-counter commodity and stock markets closer together. Trading in primary and secondary securities is shifting to the over-the-counter sector, as has already occurred with the commodity markets. Derivative futures are traded on commodity futures exchanges. These include commodity price risk markets, forward-looking markets that will allow hedging of real market transactions and particularly risky investments in rights and obligations on assets to preserve funds against inflation and generate additional income.

In the European, US and Asian stock markets, stock exchanges continue to be consolidated to deal in MNC securities, identified by industry rather than country of origin. The virtualisation leads to the exchange and OTC markets becoming part of a single system, as they redistribute financial risk between economic actors. The introduction of modern electronic trading systems stimulates the processes of merging stock exchanges. In the USA, for example, about 30% of transactions are conducted within these systems.

Thus, virtualisation has a powerful effect on the development of the global stock market. With innovative platforms, exchanges are being consolidated and virtualisation is also driving the spread of OTC trading, leading to competition between on-exchange and OTC trading. On the one hand, exchange alliances are formed to confront alternative trading systems; on the other hand, the integration process is a self-perpetuating factor in the virtualisation of the global financial market. Furthermore, there is a future trend towards a merger of the exchange and OTC sectors based on electronic communication networks.

CONCLUSIONS

The virtualisation of the global financial market operates in primary and secondary forms. The process of virtualisation of the global financial market has revealed itself *ex post facto*. The theoretical and methodological principles include: economic cycle theories, money theories, information society theories, and globalisation theories.

A virtualised financial system manifests itself as an interconnected and interdependent integrated set of financial markets, institutions developed based on server virtualisation (information and communication

networks) that serve as its infrastructure support. Given the impact of virtualisation on financial relations, we propose to treat finance as the alienated intrinsic value of goods expressed in the digital form of information and monetary flows circulating in the information economy to mediate exchange and settlement relations. The virtualised global financial system is defined as an interconnected and interdependent integrated set of financial markets, institutions developed based on server virtualisation (information and communication networks) that serve as its infrastructure support. The results of the

virtualisation of the global financial market are defined as follows: on the stock market – consolidation of exchanges, rapid development of over-the-counter trading, competition between exchanges and information agencies; on the international derivatives market – deepening of the market and use of virtual financial derivatives for speculative transactions on the international currency market – emergence and spread of extra-institutional monetary units (cryptocurrencies); in the global banking sector – international interbank digital payment systems, cloud services and non-bank payment systems.

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Генезис інституціонального забезпечення фінансового ринку в Україні: міжнародний аспект

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Анотація. Актуальність статті пов'язана з необхідністю всебічного аналізу новітніх процесів у глобальній фінансовій системі, а також комплексної розробки методологічного підходу до її вивчення. Із переходом на цифрові технології у світовому фінансовому ринку, зокрема при обробці та збереженні даних у електронному форматі, відбувається видозміна форми фінансового обігу, що може спричинити низку проблем і ризиків. У цьому контексті особливу увагу варто приділити міжнародному кредитному ринку та міжнародному ринку облігацій, що фактично циркулюють у кіберпросторі та розвиваються завдяки інформаційно-комунікаційним технологіям. Мета даної наукової роботи полягає у поглибленому аналізі основних глобалізаційних процесів світової економіки та їхній вплив на розвиток конкуренції між біржовою та позабіржовою торгівлями. У дослідженні використані загальнонаукові методи аналізу, теоретичне узагальнення та синтез, а також методи математичного, статистичного та економічного аналізів. За результатами дослідження динаміки капіталізації глобального фондового ринку авторами даної статті було виявлено тенденцію до динамічного зростання послуговування альтернативними торговельними системами, що є фактором розвитку біржової та позабіржової торгівлі цінними паперами. У статті надається всебічний аналіз напрямів впливу діджиталізації на глобальну валютно-фінансову систему, серед яких детально розглядається та обґрунтовується позитивний і негативний вплив. Виявлено негативні ефекти віртуалізації глобальної валютно-фінансової системи, а також сформульовано перспективні напрями модифікації економічної системи та фінансів за введення цифрових технологій. Викладена у цій роботі інформація може бути використана для подальшого розгляду динаміки капіталізації фондового ринку у світі, а також розробки методів з покращення ефективності впровадження цифровізації операційних процесів для окремих підприємств і світової економіки в цілому

Ключові слова: фондовий ринок, розвиток, структура, установа, забезпечення

**Журнал
«НАУКОВІ ГОРИЗОНТИ»**

**Том 24, № 10
2021**

(Англійською мовою)

Редагування англомовних текстів:

С. Воровський, А. Кравченко

Літературний редактор:

С. Пастух

Редагування бібліографічних списків:

С. Пастух, К. Сосєдко

Комп'ютерна верстка:

К. Сосєдко

Підписано до друку з оригінал-макета 26.01.2022 р.
Ум. друк. арк. 12,8

Видавництво Поліський національний університет
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**Journal
"SCIENTIFIC HORIZONS"**

**Volume 24, No. 10
2021**

Editing English-language texts:
S. Vorovsky, A. Kravchenko

Literary editor:
S. Pastukh

Editing bibliographic lists:
S. Pastukh, K. Sosiedko

Desktop publishing:
K. Sosiedko

Signed to the print with the original layout 26.01.2022.
Conventional Printed Sheet 12.8

Publisher: Polissia National University
10008, 7 Staryi Blvd., Zhytomyr, Polissia National University, Ukraine.
Tel. (0412) 22-04-17;
E-mail: info@sciencehorizon.com.ua
www: <https://sciencehorizon.com.ua/en>