PANEL DATA ANALYSIS OF THE IMPACT OF AGRICULTURAL INDICATORS ON ECONOMIC DEVELOPMENT ASPECTS: THE EXPERIENCE FROM THE BRICS COUNTRIES

Lidija Madžar[1], *Ivan Đekić*[2], *Zorica Đurić*[3]

**Corresponding author E-mail: lidi.madzar@gmail.com*

A R T I C L E I N F O

Original Article

Received: *20 August 2025*

Accepted: *20 October 2025*

doi:10.59267/ekoPolj25041279M

UDC 338.435:339.923 BRICS

Keywords:

BRICS, GDP growth rate, Average income, Random Effects Models, agricultural productivity, agricultural indicators

JEL: C23, O13, Q16

A B S T R A C T

The aim of this paper is to empirically assess the influence of the most significant agricultural measures on basic economic indicators in original BRICS countries (Brazil, Russia, India, China and South Africa), as well as to offer reasonable explanations for the nature of the established relations. For this purpose, two models were built: a) The Period Random Effects Model that traces their influence on GDP growth rate, and b) Two-way Random Effects Model that assesses their influence on Average income in BRICS nations. The paper determined mostly negative and statistically significant relations between mere agricultural measures and economic indicators, pointing to the conclusion that these countries are burdened by problems of law agricultural productivity, poor technological progress and low value added in their agriculture, as well as to the need for the implementation of more serious institutional, land, production, education, infrastructural and other fields of reforms in BRICS.

Introduction

Agriculture is one of the key factors of economic development that significantly contributes to the GDP growth rate, income generation, employment, export incomes, human feed, production of industrial raw materials, improvement of infrastructure and related industries' development. It is one of the essential economic branches of exceptional importance for the national economy itself since it highly influences

1 Lidija Madžar, Associate Professor, Alfa BK University, 8 Bulevar maršala Tolbuhina, 11070 New Belgrade, Serbia, E-mail: lidi.madzar@gmail.com, ORCID ID (https://orcid.org/0000-0002-1708-5683)

2 Ivan Đekić, Assistant Professor, Alfa BK University, 8 Bulevar maršala Tolbuhina, 11070 New Belgrade, Serbia, E-mail: ivan.djekic@alfa.edu.rs, ORCID ID (https://orcid.org/0000-0002-0369-1455)

3 Zorica Đurić, Assistant Professor, Alfa BK University, 8 Bulevar maršala Tolbuhina, 11070 New Belgrade, Serbia, E-mail: zorica.djuric@alfa.edu.rs, ORCID ID (https://orcid.org/0000-0002-6851-0635)

macroeconomic indicators and development trends (Grujić Vučkovski et al., 2022). Developed countries have long since confirmed the role of agriculture, which determines their overall growth and development. On the other hand, developing countries still face numerous limitations in this area, and especially the need for greater agricultural investments and more balanced rural development (Ilić et al., 2017). Agriculture has a special importance for developing countries since it provides them with nutrients, income and employment in rural areas (Prasanth & Sivanantha, 2021). It serves as a major source of poverty reduction, food security and livelihood, especially for poor rural households in developing farmland. However, the contemporary agricultural systems of these countries are increasingly threatened by changing climatic circumstances, their general vulnerability and inadaptability, which threaten their productivity and resistance to climate change (Trentinaglia et al., 2023).

Agriculture is also of key importance in the BRICS countries (Brazil, Russia, India, China and South Africa) since they make a large share in the global population, world agricultural land, food production and global exports of agricultural products. They are key actors in global food production, playing a pivotal role in boosting agricultural productivity, sustainability and ensuring global food security. The original BRICS countries account for 59% of the global population, 33% of the world's agricultural land, 42% of the world's agricultural production and 35.4% of the global economy (BRICS Agriculture Working Group, 2025). These nations belong to the group of major players in the agri-food products' international markets, especially when it comes to the trade of primary foodstuffs with other members of the Global South that face food shortages, poverty and malnutrition (Glauben & Duric, 2024). However, the BRICS members also face their own numerous challenges such as global warming, climate change, land devastation, scarcity of water resources and reduction of biodiversity, limited arable land, agricultural pollution, and lowering of yields (Magazzino et al., 2024). In addition, their agricultural activities indirectly, through their impact on the emissions of carbon dioxide (CO_2) and environmental degradation, can represent a significant obstacle to their sustainable economic growth (Balsalobre-Lorente et al., 2019).

Considering all the above, the purpose of this article is to empirically examine the impact of the most important mere agricultural measures on the basic economic indicators of the BRICS countries in the period from 2002 to 2023, bridging the visible vacuum in the knowledge on these important issues. Its aim is also to provide reasonable explanations for the established negative relationships between their agriculture and basic economic indicators. The article starts from the assumption that agriculture significantly affects the economic activities of these countries measured by the GDP growth rate and the average income expressed in GDP per capita, representing a topic that was largely neglected in previously published studies. The next section gives the review of selected literature, while the third one is devoted to the description of the data used and the selected research methodology. The fourth and fifth sections present the findings and discuss the obtained results, while the last one concludes the paper.

Literature review

Agriculture is one of the most important sectors in any developing nation since it ensures the stability of economic structural changes by generating the necessary income, ensuring modernization and diversifying economic output (Alijonovna Inomjonova, 2024). Investments in agriculture and the agricultural sector development in many cases represent a prerequisite for economic growth, generating income and livelihoods, industrialization, food security and many other related activities (Chandrasekaran, 2024). The growth of its efficiency and agricultural investments are of great importance not only for the country's economic growth and agricultural GDP (Laurentiu & Ion, 2019), but also for wider social development since agriculture contributes to the rise of social well-being and the development of rural areas (Oluwabukade et al., 2024).

However, although it is traditionally considered a pillar of economic growth and development, agriculture can also have a negative impact on economic development, primarily due to low productivity and technological stagnation, weak production diversification, sensitivity to climatic conditions and world prices of agricultural products, ecological costs and environmental degradation, and accelerated industrialization accompanied by marked deagriculturalization. There is a significant negative relationship between deagriculturalization and economic growth, especially in the long term (Ullah et al., 2021), while the low total factor productivity in agriculture itself can have an unfavorable impact on economic growth (Tahamipour & Mahmoudi, 2018), hindering sustainable development.

Given the noticeable gap in the literature on these important issues, the authors of this article have found only a few studies that include the impact of some of the agricultural measures on the economic growth and development in the BRICS countries. Fakher et al. (2024) study the relation between financial development and environmental degradation in BRICS from 2005 to 2019 by constructing composite indicators of environmental quality (CEQP) and financial development (CFDP). The authors in this paper prove the indirect negative impact of agricultural activities measured by the agricultural share in GDP, through environmental degradation, on sustainable economic growth, given the established U-shaped relationship between the CEQP and economic growth.

Guo and Li (2024) examine the impact of industry and agriculture on the GDP of the BRICS countries in the period from 1970 to 2020 using static and dynamic methods. By constructing a multivariate nonlinear regression model, the authors conclude that the growth of agricultural value added as a percentage of GDP slows down their GDP growth, indicating that in these nations the share of agriculture in their economic structure can negatively affect their total GDP. Basu et al. (2013) considered the way in which changes in employment, especially those in industry, services and agriculture, affected the growth of GDP per capita in the BRICS countries in the period from 1991 to 2009. The authors concluded that the GDP per capita growth rate in the BRICS countries was largely determined by the faster growth of labor productivity in industry and the service sector, which was not the case with agriculture, where productivity was almost twice as low, indicating that economic growth in the BRICS is mainly conditioned by demographic, as well as sectorial factors. They also noted a visible sectorial shift in employment from the agricultural sector to industry and services.

However, there are also authors who have found a positive relation between agricultural production and economic growth in the BRICS countries. Tsaurai (2021) used a dynamic GMM model to study the joint effect of agricultural production, personal remittances, inflation, infrastructure development, trade openness, and financial development, as a transmission channel of agricultural activity, on the BRICS nations' economic growth from 1996 to 2018, concluding that agriculture had a significant positive impact. Similarly, Garidzirai (2020) used data for the period from 1995 to 2018 and applied the Pooled Mean Group model to find that agricultural production contributes to economic growth and the decrease of income inequality in BRICS, suggesting that short-term imbalances can be corrected in the long run. There are also articles such as Sergeevich Streltsov et al. (2021) that, by studying the BRICS countries individually, emphasize that agriculture and the vast mineral reserves have made a major contribution to the rapid development of the Russian economy. Nevertheless, so far there have been few published studies that take these perspectives into account in all BRICS members considered together.

Data and research methods

The paper examines the impact of agricultural indicators on the economic growth rate and average income in BRICS countries measured by GDP per capita from 2002 to 2023 within the framework of two compalementary models, both of which belong to the group of Random Effects (RE) models: a) the first one is the Period RE Model that traces the influence of agricultural indicators on the GDP growth rate, while b) the other one is the Two-way RE Model that monitors the influence of agricultural predictors on the GDP per capita. The advantage of RE models is that they include time-invariant variables, generate more efficient regression coefficients' estimates, and are characterized by less loss of information compared to Fixed Effects (FE) models that can be expensive in terms of degrees of freedom (Gujarati, 2003). Data for analysis are derived from the World Bank Group, FAOSTAT and U.S. Department of Agriculture (USDA) databases, as evidenced by the following Table 1. These models can be represented by the following system of equations (Fitrianto et al., 2016):

Model 1:

$$GROWTH_{it} = \alpha + \beta_1 AGRITFP_{it} + \beta_2 PUBEXP_{it} + \beta_3 AVA_{it} + \lambda_t + v_{it}$$

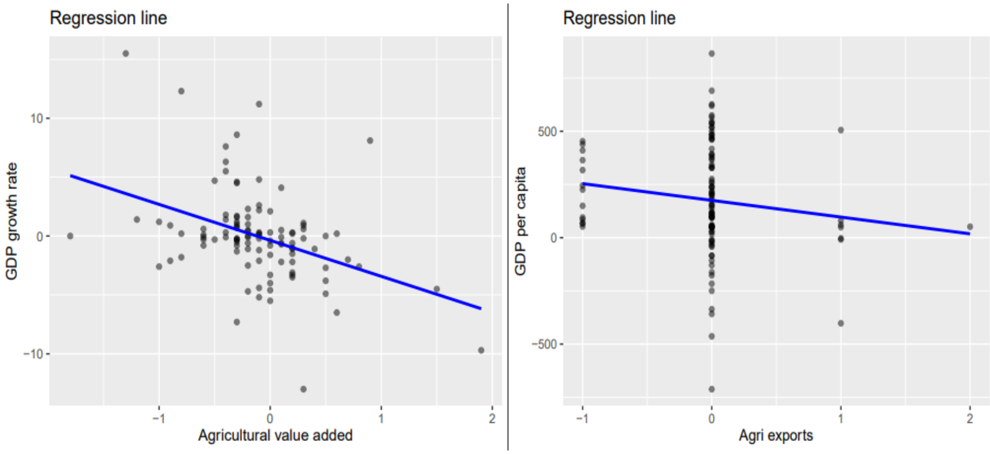
Model 2:

$$INC_{it} = \alpha + \beta_1 AGRITFP_{it} + \beta_2 AGRIEXP_{it} + \beta_3 RURPOP_{it} + u_i + \lambda_t + v_{it}$$

where β are model coefficients, $GROWTH_{it}$ and INC_{it} are dependent variables, x_{it} are predictors, v_{it} is zero mean random disturbance with variance σ_v^2, u_i are unobserved individual specific effects and λ_t are unobserved time specific effects.

Below is a fitted graph of scatter plots (Figure 1) of the observed independent variables (GDP growth rate and GDP per capita) with the predictors that most affect them in both constructed models (Agricultural value added and Agri exports), indicating a clear negative relationship between the considered variables.

Figure 1. Negative fitted relationships between observed variables in the considered models



Source: Authors' contribution

The following Table 1 provides a detailed overview, description and sources of data used in the study.

Table 1. Overview and description of the data used in the analysis

Variables	Description	Label	Data sources
Growth rate	Annual GDP growth rate (in %)	GROWTH	World Bank Data
Average income	Real GDP per capita (in constant 2015 US$)	INC	World Bank Data
Agri TFP index	Agricultural total factor production index (100=2015)	AGRITFP	U.S. Department of Agriculture (USDA)
Total agri expenditures	Total government expenditure on agriculture, forestry and fisheries (in millions of constant 2015 US$)	PUBEXP	FAOSTAT
Agricultural value added	Agriculture, forestry, forestry and fishing value added (as a % of GDP)	AVA	World Bank Data
Agricultural exports	Agricultural raw materials exports (in % of merchandise exports)	AGRIEXP	World Bank Data
Rural population	Rural population (as a % of total population)	RURPOP	World Bank Data

Source: Authors' analysis

Research findings

The following Table 2 presents the results of descriptive statistics of the variables used in the constructed models.

Table 2. Results of descriptive statistics

Variables	Mean	Median	Maximum	Minimum	Standard deviation	Skewness	Kurtosis
Growth rate	4.4464	4.6500	14.1000	-7.8000	3.9882	-0.4810	3.4247
Average income	6300.775	6270.700	12175.20	793.6000	3071.668	-0.4019	2.0230
Agri TFP index	94.0951	95.8102	120.6565	66.2095	12.5091	-0.2778	2.4564
Total agri expenditures	52897.71	8331.430	401182.2	1015.120	96631.00	2.2251	6.5959
Agricultural value added	7.4618	4.8000	19.6000	1.9000	5.4681	0.9354	2.3852
Agricultural exports	2.1909	2.0000	6.0000	0.0000	1.4992	0.4265	2.6468
Rural population	38.6636	36.0000	72.0000	12.0000	18.8292	0.3846	1.8967

Source: Authors' calculations

In the paper, a panel data regression analysis was carried out on the example of two selected models. The panel consisted of 5 countries (Brazil, Russia, India, China and South Africa) within which the influence of agricultural predictors was traced in the period from 2002 to 2023, making a total of 110 observations. Analyses were conducted in statistical packages Eviews and R programming language.

At the beginning of the analysis, a correlation analysis was conducted to determine whether the proposed models were subject to the risk of multicollinearity. The conducted correlation analysis indicated that there was no multicollinearity between the predictors, given that none of the correlation coefficients between the observed variables exceeded the value of 0.70 (Tabachnick & Fidell, 2019), which allowed the continuation of this analysis. The results of the conducted VIF test also indicated the safety of further analysis, given that their values were far lower than 5 (Siddamsetty et al., 2023). Due to the limitations in the length of this article, the results of these analyses are available upon reasonable request from the authors.

In the next step, the article proceeded to calculation of the Pesaran CD test with the aim of detecting cross-sectional dependence in individual variables (*Table 3*).

Table 3. Pesaran CD test results

Variables	Statistic	p-value
GDP growth rate	8.6328*	0.0000
Agri TFP index	12.6877*	0.0000
Total agri expenditures	2.9603*	0.0031
Agricultural value added	7.6281*	0.0000
GDP per capita	11.5384*	0.0000
Agricultural exports	0.0952	0.9241
Rural population	13.9073*	0.0000

Note: * indicates statistical significance at the level of α=0.01

Source: Authors' calculations

The results of the conducted Pesaran CD test indicated cross-sectional dependence in almost all observed variables with the exception of Agricultural exports, which is why the second generation of unit root tests was used embodied in the Pesaran CIPS test (*Table 4*). In addition, the advantage of this test is reflected in the fact that, unlike the first-generation tests, it corrects for the presence of common factors that cause interdependence among panel units, ensuring consistency even in the presence of a common factor with heterogeneous effects, while simultaneously taking into account cross-sectional dependence and correlation of serial residuals (Barbieri, 2009).

Table 4. Pesaran CIPS test results

	Variables at the level		Differentiated variables	
Variables	**t-statistics**	**p-value**	**t-statistics**	**p-value**
GDP growth rate	-3.2820*	<0.01	-5.6859*	<0.01
Agri TFP index	-1.4930	>=0.10	-3.4589*	<0.01
Total agri expenditures	-2.0952	>=0.10	-3.6006*	<0.01
Agricultural value added	-1.4442	>=0.10	-2.2767*	<0.01
GDP per capita	-1.5283	>=0.10	-3.4053*	<0.01
Agricultural exports	-3.2255*	<0.01	-4.6951*	<0.01
Rural population	-1.9947	>=0.10	-2.7742*	<0.01

Note: * indicates statistical significance at the level of α=0.01

Source: Authors' calculations

The results of the Pesaran CIPS test indicated the stationarity of all variables at their first differences, which is why the panel regression analysis in its further research steps was conducted on differentiated data, reducing the number of observations from 110 to 105. Table 5 represents the results of regression analysis for both models.

Table 5. Results of the regression analysis

Variables	Model 1	Variables	Model 2
C	0.0333 (0.9601)	C	155.1669 (0.0889)
Agri TFP	-0.1933* (0.0067)	Agri TFP	-7.4073 (0.0743)
Total agri expenditure	6.42e-06 (0.6770)	Agricultural exports	-76.7055* (0.0005)
Agri value added	-2.3358* (0.0001)	Rural population	-63.5432** (0.0162)
R-squared	0.1999	R-squared	0.0916
Adjusted R-squared	0.1761	Adjusted R-squared	0.0646
S.E. of regerssion	2.2773	S.E. of regerssion	162.9916
Total sum of squares	654.69	Total sum of squares	2953700
Residual sum of squares	523.82	Residual sum of squares	2683200
F-statistic	8.4111*	F-statistic	3.3946**
Prob.(F-statistic)	0.0000	Prob.(F-statistic)	0.0208
Durbin-Watson stat.	2.6106	Durbin-Watson stat.	1.4537*
Prob.(DW stat.)	0.9993	Prob.(DW stat.)	0.0032

Note: * indicates statistical significance at the level of α=0.01, while ** indicates statistical significance at the level of α=0.05

Source: Authors' calculations

Model 1: Tests conducted with the aim to select the appropriate panel data model favoured the selection of the Period RE model (*Table 6*). From the results, it was clearly concluded that the proposed Model 1 explained 17.61% of the variability of the dependent variable (GDP growth rate), as well as that all predictors taken together affected the dependent variable. Also, the effect of the considered agricultural indicators (Agri TFP and Agri value added) on the growth rate of BRICS countries was predominantly negative and statistically significant at the level of α=0.01. Conducted post hoc tests also suggested the absence of cross-sectional dependence, serial correlation in residuals and heteroskedasticity in error variances.

Model 2: In this case, tests conducted in order to select the appropriate panel data model were also in favour of choosing the RE model (*Table 6*). From the obtained results, it followed that the selected Model 2 explained 6.46% of the variation of the dependent variable (GDP per capita), that all predictors taken together influenced the dependent variable, and that the proposed model also did not suffer from significant serial correlations in the residuals. The impact of the considered agricultural indicators (Agri TFP, Agricultural exports and Rural population) on the standard of living in the BRICS countries measured by GDP per capita was negative, with a statistically significant effect of the second and third predictor at the level of α=0.05. Conducted post hoc tests indicated the absence of heteroscedasticity and serial correlation in the residuals, but also the presence of cross-sectional dependence, which is why the correction of the standard error was performed using the Driscoll-Kraay method, thus ensuring the consistency and robustness of the estimated standard errors.

The following Table 6 provides an overview of the conducted tests for selecting the appropriate panel data model and the post hoc tests for both generated models.

Table 6. Results of panel model selection tests and post hoc tests

	Model 1			Model 2		
Test type	**Statistic**	**d.f.**	**Prob.**	**Statistic**	**d.f.**	**Prob.**
Redundant Fixed Effects	8.2849*	(20,81)	0.0000	5.7952*	(20,77)	0.0000
Hausman	3.8584	3	0.2772	0.9368	3	0.8165
Breusch-Pagan LM	66.1764*	1	0.0000	33.0597*	1	0.0000
Pesaran CD test	0.0092		0.9927	7.0353*		0.0000
Breusch-Godfrey/Wooldridge	31.632	21	0.0638	28.197	21	0.1346
Studentized Breusch-Pagan	4.273	3	0.2335	1.2184	3	0.7486

Note: * indicates statistical significance at the level of α=0.01

Source: Authors' calculations

Discussions of the results

The results of published studies on the relation between agriculture and economic growth are very mixed, as can be seen from the Literature review section. The findings of this study on the negative link between agriculture and economic indicators in BRICS countries fit well with the reviewed articles such as Basu et al. (2013), Ullah et al. (2021), Fakher et al. (2024) and Guo and Li (2024) that confirm an indirect or direct negative effect of agricultural production on economic growth in these countries. However, compared to some other studies that combined agricultural with other types of predominantly economic indicators, this study did not provide consistent results. More specifically, these are the studies by Garidzirai (2020) and Tsaurai (2021) that indicate a positive contribution of agricultural production to economic development, although they use multiple economic, financial, and trade control variables in their built models.

As can be seen from the constructed models, most of the considered agricultural indicators generally have a negative and significant impact on economic growth and living standards in the BRICS countries. The explanation of this phenomenon can be found in their developmental, economic, structural and institutional problems. Although BRICS members are among the leading top agricultural producers in the world, they are still characterized by lower agricultural productivity and pronounced environmental vulnerability compared to the rest of the developed world. Most of the countries of the Group, and especially India, lag significantly behind and have lower productivity compared to the global average. Farmers from these countries are still not ready to adopt modern technologies and imported seeds, as well as to use foreign funds to improve their agricultural productivity. The BRICS countries also suffer from outdated production techniques, accelerated urbanization and inefficient use of resources, which collectively threaten their agricultural productivity, while leaving their agricultural sector in a critical position, as evidenced by researches of many authors such as Shah et al. (2023), Patel and Joshi (2023) and Inkaya and Masca (2025).

Although the developing BRICS nations are experiencing visible technological improvements in many spheres of their economic activities, they have not yet sufficiently introduced technological innovations in their agricultural sector, pointing to the fact that their transition to high-tech agriculture is still ongoing. Thus, for example, China lags behind developed countries in the use of precision agriculture, primarily because of its agricultural system that relies on small family farms, which show resistance to change. Moreover, small farmers consider it unnecessary for the development of their family farms. The exception in this sense is only Brazil, which since the 1990s has made great progress in the production and export of agricultural products, focusing on the abundant use of information technologies and the computerization of fundamental research in its agro-industrial sector. Brazil has widely adopted Agriculture 4.0 practices, cloud computing and big data analytics, as well as artificial neural networks to estimate crop harvests and determine the ideal size of planting area, paving the way for the successful digitization of its agricultural production. However, insufficient availability of technological innovations in other BRICS nations directly threatens productivity, income generation, sustainable food production and food security, leading to low returns per worker and affecting the relatively small contribution of a large part of the workforce to GDP creation. These findings have been confirmed by numerous published studies such as Kendall et al. (2017), Salnikova and Rozhakova (2021) and Inkaya and Masca (2025).

The BRICS countries are also facing key structural changes in their economies, primarily with intensive urbanization and industrialization that relativized the role and importance of agriculture itself in generating their GDP. Although constant technological improvements in their many economic sectors have fuelled their economic rise, it is still largely based on extensive agricultural activities. These countries, especially Brazil and Russia, have a dominant role in the export of low and medium-low technological goods, remaining at the lower levels of global value chains. In contrast to the industrial and service sectors as drivers of economic development, the agriculture of BRICS countries still produces raw agricultural products with low added value, endangering its very contribution to their economic growth and development. They witness a decrease in the share of agriculture in their GDP, which is in line with the structural transformation of their economies, by anchoring the levers of their future growth and development towards an economy based on services and knowledge. Unlike Brazil and Russia where the share of the primary sector remained relatively stable, China and India experienced a dramatic decline in the share of agriculture in their GDP, while industry and services grew consistently (Magacho et al., 2018; Jiaduo et al., 2023; de Sousa Filho et al., 2024). Finally, as evidenced by the data used in this research, in addition to accelerated industrialization, BRICS members also face a constant decline in their rural population that moves to cities and other industries, naturally causing a negative impact of agriculture on the considered economic indicators.

Conclusions

The purpose of this article was to examine the impact of the most important mere agricultural indicators on the economic growth rate and the average income of the BRICS nations from 2002 to 2023 through the construction of two panel data models. For this purpose, two complementary models were constructed, namely: a) Model 1 which examined the effect of Total Factor Productivity, Total Agricultural Expenditure and Agricultural Added Value on GDP growth rate, and b) Model 2 which considered the effect of Total Factor Productivity, Agricultural Export and Rural Population on GDP per capita of these countries. Both generated models belonged to the group of RE panel data models, the first of which was the Period RE Model, while the second one was the Two-way RE Model. The results of the analysis unequivocally indicated a predominantly negative and statistically significant effect of most of the considered variables on the growth rate and average income in BRICS, confirming the initial hypotheses of this analysis.

These countries are primarily characterized by low agricultural productivity, insufficiently developed agricultural innovations and limited access to modern technologies, all of which result in a limited contribution of agriculture to GDP growth. In addition, the BRICS countries are also burdened by the export of large quantities of primary products to world markets, as well as their low added value, all of which limit their further growth and lead these countries into the trap of an economy based on raw materials. In addition to the structural changes in their economies, in which rapid industrialization, the service sector and the knowledge economy are taking precedence, their certain infrastructural weaknesses can also be observed, which all point to the need for the conduction of more effective land policies, better subsidy policies, as well as for strengthening the protection of the small farmers' rights. The agricultural base of most BRICS countries is still technologically back warded and inefficiently organized, pointing to the urgent need for its further modernization and technological development, diversification of agricultural products, implementation of appropriate institutional and land reforms, development of rural infrastructure, but also for conducting a better investment policy in education and training of farmers.

Acknowledgements

The article presents findings of a study developed as a part of the Alfa BK University research project *U Sustainable development and environmental protection in the economy*.

Conflict of interests

The authors declare no conflict of interest.

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