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THE EFFECT OF INVESTMENTS, MECHANIZATION AND FERTILIZER USE ON AGRICULTURAL GROWTH IN TÜRKİYE'S AGRICULTURAL SECTOR: AN ECONOMETRIC ANALYSIS

Gülferah ERTÜRKMEN[1*]

[1]*Kahramanmaraş Sütçü İmam University, Göksun School of Applied Sciences, Department of Finance and Banking, 46000, Kahramanmaraş, Türkiye*

Abstract: This research comprehensively examines the economic factors affecting agricultural growth in Türkiye between 1998 and 2022. The agricultural sector has a strategic importance for economic growth and rural development. In the study, variables affecting agricultural growth such as fixed capital investments, use of agricultural machinery and fertilization are considered and the effects of these factors are analyzed by econometric methods. The data set used in the study is based on annual data covering the years 1998-2022. The stationarity levels of the data are analyzed by Augmented Dickey-Fuller (ADF), Phillips-Perron (PP) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) unit root tests. VAR model is used to analyze the dynamic relationships of time series, Toda-Yamamoto causality test is used to determine the direction of the effects, impulse-response functions and period decomposition methods are used to evaluate the magnitude and duration of the effects. Diagnostic tests such as normality, autocorrelation and variance tests were used to test the validity of the model. The results of the research show that the impact of fixed capital investments on agricultural growth is significant and that private sector investments have become more determinant in recent years, although public investments were effective in the early years. Modern agricultural practices such as the use of agricultural machinery and nitrogen fertilizers have been found to increase productivity in the short run, but have limited effects in the long run. Despite the declining share of agriculture in GDP, the sector remains critical for economic growth, rural employment and food security.

Keywords: Economic growth, Agricultural growth, Economic determinants

***Corresponding author:** Kahramanmaraş Sütçü İmam University, Göksun School of Applied Sciences, Department of Finance and Banking, 46000, Kahramanmaraş, Türkiye
E mail: gbozkaya@ksu.edu.tr (G. ERTÜRKMEN)
Gülferah ERTÜRKMEN https://orcid.org/0000-0003-2239-0241

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1. Introduction

The agricultural sector is strategically important for economic development and growth as well as meeting humanity's basic nutritional needs. Factors such as the growing world population, climate change, rapid resource depletion and global political tensions have further increased the importance of agriculture both locally and globally (Bağcı, 2022). In this context, the agricultural sector not only provides food security, but also makes significant contributions to macroeconomic objectives such as economic growth, job creation and poverty reduction. Especially in developing countries, agriculture is often one of the largest sources of employment and the livelihood of rural populations (Benfica et al., 2019).

Technological advances make it possible to produce more with fewer resources by optimizing agricultural production processes. All agricultural activities such as irrigation, fertilization, harvesting and storage benefit from advanced technology (Kılıçarslan and Dinç, 2007). However, in developing countries such as Türkiye, the inadequacy of agricultural equipment and the lack of technological infrastructure prevent the production level from reaching the desired level (Taban and Kar, 2016). Therefore, the integration of technological innovations in the agricultural sector is of great importance. Technology not only increases production efficiency, but also helps to raise the welfare level and living standards of countries.

Investments in the agricultural sector directly affect not only agricultural production but also economic growth. Fixed capital investments contribute to economic growth by increasing agricultural productivity (Roy and Pal, 2002). Today, fertilizers, which constitute approximately 15-20% of agricultural production costs, are considered as an indispensable element in terms of increasing agricultural productivity. Correct and conscious fertilization can increase yields in crop production by 50-75%, and this increase can be up to 100% in some crops. Various studies on ways to increase productivity in agricultural production have shown that fertilizer use has a significant impact on agricultural yield. However, fertilization is not the only way to increase agricultural productivity (Tıraş, 2024). Mechanization in agriculture is also one of the important factors affecting productivity. Mechanization means the replacement of human and animal power by mechanical energy in agricultural activities. The most important symbol of this process is the tractor. Since the 1930s, there has been a great increase in the use of tractors worldwide. Especially between 1930 and 1953, the number of tractors in the world quintupled (Anker, 1956). This development was an important step that increased productivity in the agricultural sector.

The agricultural sector in Türkiye has a great potential thanks to its geographical location and climate diversity. However, problems such as the fragmented structure of agricultural lands, lack of technological equipment and ineffective use of agricultural supports prevent the sector from reaching its full potential (Tan et al., 2015). Moreover, the downward trend in employment due to mechanization and industrialization in agriculture negatively affects the sector's capacity to attract labor force. Despite this, the agricultural sector in Türkiye still maintains its importance and provides about 20% of employment (Gülçubuk, 2005). Considering the contributions of the agricultural sector to nutrition, employment, industry, national income and ecological balance, it stands out as a sector that cannot be ignored (Yıldız and Oğuzhan, 2007).

Considering the impact of agricultural growth on economic growth, it is of great importance to reveal the relationship between agricultural subsidies, the share of agriculture in GDP, public and private fixed capital investments in the sector and the number of agricultural employment. In the literature, there are many studies in which the positive effect of fixed capital investments on agricultural growth is determined (Roy and Pal, 2002; Fan et al., 2008). In addition, agricultural loans and subsidies are also reported to stimulate agricultural growth (Şaşmaz and Özel, 2019). However, the decline in the population employed in agriculture is seen as a consequence of technological advances, which has a negative impact on agricultural growth (Terin et al. 2013).

The aim of this research is to identify the economic factors affecting agricultural growth in Türkiye between 1998 and 2022 and to analyze the effects of these factors using econometric methods. In the study, the effects of variables such as fixed capital investments, agricultural machinery use and fertilization on agricultural growth are examined in detail. In the analysis process, time series methods are used to test the relationships between variables, Toda-Yamamoto causality analysis, impulse-response functions and period decomposition methods are applied. One of the most important features that distinguishes this research from similar studies in the literature is that it comparatively analyzes the changes in public and private investments in the agricultural sector over time and reveals the short and long term effects of these investments on agricultural growth. Moreover, in order to ensure the reliability of the model, various diagnostic tests were applied to test the validity of the analysis.

1.2. Literature

The agricultural sector constitutes one of the basic building blocks of the economy in terms of production activities and the trade of the values obtained from this production. This sector, which has a wide scope, has an important place at the macroeconomic level. In this research, the factors affecting agricultural growth and the effects of these factors on agricultural growth are discussed. A review of the literature reveals that there are limited studies in which factors such as fixed capital investments, agricultural subsidies and agricultural employment, which have an impact on economic growth, are considered together. However, there are many co-integration studies examining the relationship between economic growth and agricultural subsidies or economic growth and capital investments. In this context, studies conducted both in Türkiye and in different countries have been included in the literature. Summaries of these studies are presented below:

The importance of agricultural credits on agricultural production has been emphasized in many academic studies. Das et al. (2009) evaluated the effects of agricultural loans on agricultural production, while Rahman (2011) and Ammani (2012) similarly addressed the critical role of these loans in agricultural production. More recently, Duramaz and Taş (2018) and Kadanalı and Kaya (2020) examined this relationship in detail and found that agricultural loans are an important tool to increase agricultural production. These studies clearly demonstrate the role of agricultural credits on the continuity and growth of agricultural activities.

The impact of agricultural credits on economic growth and the contribution of economic growth to agricultural credits have been analyzed from different perspectives. Yıldız and Oğuzhan (2007), Anthony (2010), Kaya et al. (2012), Ekwere and Edem (2014), Çevik and Zeren (2014) and Apaydın (2018) have shown the positive effects of agricultural credits on economic growth. In addition, Akram and Hussain (2008) argue that economic growth in Pakistan supports agricultural production by increasing the demand for agricultural loans. Olagunju and Adeyemo (2007) show that economic growth in Nigeria accelerates rural development by increasing agricultural sector loans. In Türkiye, Çetin and Ecevit (2015) find that economic growth facilitates access to agricultural loans, while Demir and Özcan (2019) find that economic growth has long-term positive effects on agricultural loans. Moreover, Önder (2023) argues that the relationship between agricultural loans and economic growth is long-run and positive, but these loans are not the cause of economic growth.

Studies examining the effects of agricultural credits on agricultural growth reveal important results in this field. Iganiga and Unemhilin (2011) and Akmal et al., (2012) emphasized the positive effects of these credits on agricultural growth, and Cömertler Şimşir (2012) reached similar findings. In more recent studies, Yalçınkaya (2018), Koç et al. (2019) and Tuan et al.,

(2020) have analyzed the contribution of agricultural loans to agricultural growth in detail. However, the increase in agricultural credit encourages the use of agricultural inputs but has a weak impact on agricultural GDP. In the Turkish context, there is a positive long-term relationship between agricultural credit and agricultural growth using data from 2005-2021.

The effects of agricultural R&D expenditures have attracted attention in Türkiye-specific studies. Subaşı and Ören (2013) found that total factor productivity increased by 0.51% annually due to technical efficiency and technological change. Özaydın and Çelik (2019) emphasized the positive impact of R&D expenditures on agricultural growth worldwide and predicted that this increase will continue until 2023. Özen et al. (2024) examined the relationship between carbon emissions (CO_2) and human development (HDI), urbanization (PU), industrialization (SAN) and agricultural development (AGR) in Türkiye between 1990-2020. According to the results of Toda-Yamamoto causality test, CO_2 emissions are affected by HDI and AGR indicators, but not by PU and SAN indicators. Ülger (2025) analyzed the impact of agriculture, industry and economic growth on carbon emissions in E-7 countries in the period 1992-2020. As a result of the analysis with the panel ARDL method, it is determined that agricultural activities reduce carbon emissions in the long run, while industry and economic growth increase emissions. In the short run, economic growth increases emissions, while the effect of agriculture and industry is not significant.

Some studies have focused on the effects of public investments and incentives. Public fixed capital investments do not have a significant effect on economic growth. Şaşmaz and Özel (2019) find that fiscal incentives provided to the agricultural sector are ineffective in the long run, but economic growth has a positive effect on the agricultural sector. Köse and Meral (2021), on the other hand, find no link between economic growth and agricultural subsidies.

The effects of economic growth on the agricultural sector have also been analyzed with cross-sectoral comparisons. Kopuk and Meçik (2020) found that there is a unidirectional causality relationship from the agricultural sector to economic growth in Türkiye. Canbay and Kırca (2020) found that agriculture has a positive effect on growth, while growth has a negative effect on agriculture. Okine and Özel (2018)'s research on Ghana, found that an increase in agricultural production increases GDP growth. Finally, Merdan (2023) analyzed the economic factors affecting agricultural growth in the 2000-2022 period and emphasized the positive effects of agricultural subsidies and fixed capital investments and the negative effects of agricultural employment. In general, it is understood that investments in the agricultural sector and agricultural R&D activities stimulate economic growth, but this effect is sometimes limited or depends on sector-specific dynamics.

2. Materials and Methods

In this section of the study, the variables used in the research, the data set, econometric methods and the results of the analysis are presented.

2.1. Data Set Used in the Study

This research utilizes annual data for the period 1998-2022 in Türkiye. In all variables used in the analysis, year intervals that ensure data integrity are used. In line with the objective of the study, in order to investigate the factors affecting agricultural growth, agricultural GDP was used as the dependent variable and investment in agriculture sector (public and private) within fixed capital investments, share of agriculture in GDP, agricultural machinery per agricultural land and nitrogen fertilizer use were used as independent variables. Before starting the data analysis and modeling process, logarithmic transformation was applied to the data to normalize the data, minimize the effect of extreme outliers and linearize exponential relationships. Table 1 presents the variables and data sources.

Table 1. Variables and Data Sources

Variables	Data Sources
Agricultural GDP (%) (AGDP)	Türkiye Strategy and Budget Presidency
Investment in the Agricultural Sector within Fixed Capital Investments (Public) (IACP)	Türkiye Strategy and Budget Presidency
Investment in the Agricultural Sector within Fixed Capital Investments (Private) (IACPR)	Türkiye Strategy and Budget Presidency
Agriculture Share in GDP (ASG)	Türkiye Strategy and Budget Presidency
Agricultural Machinery Per Agricultural Land (AML)	Türkiye Strategy and Budget Presidency
Nitrogen Fertilizer Use (NFU)	Türkiye Strategy and Budget Presidency

To measure the stationarity level of the data, Augmented Dickey-Fuller (ADF), Phillips-Perron (PP) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests were used to determine whether the statistical properties of the time series changed over time. Various diagnostic tests were applied to ensure the reliability and accuracy of the model. In this context, the inverse roots of the AR characteristic polynomial are used to examine whether the characteristic roots are within the unit circle, the Jarque-Bera Normality test is applied to determine the normality assumption of the model, the Autocorrelation LM test is applied to determine the presence of autocorrelation, and the White Homogeneity/Heterogeneity of Variance test is applied to examine the heteroskedasticity problem.

2.2. Unit Root Test

Series with unit roots are non-stationary series and are affected by exogenous shocks. Series without unit roots are stationary and insensitive to exogenous shocks. This implies that the main logic of unit root tests is to test whether incoming shocks have a temporary or permanent effect on the series (Nelson and Plosser, 1982; Glynn, et al., 2007).

Three methods are generally used to determine whether a time series is stationary or not. These methods are time path graph method, correlagram method and unit root test method (Gujarati, 2011). Before conducting the unit root test, the variables were examined whether they contain a trend or not, and the variables containing a trend were identified and de-trended. These variables are; TBDM, TGS, AGK and TGSP. Table 2 presents the results of ADF, PP and KPSS unit root tests.

Table 2. ADF and PP unit root test results

Level	Variables	ADF	PP
		Intercept (Fixed)	Intercept (Fixed)
I(0)	DEAGDPF	-1.580332 [0.4768]	-1.830806 [0.3574]
	DEASGF	-4.101375*** [0.0043]	-4.109657*** [0.0043]
	DEAMLF	0.307267 [0.9737]	-0.453837 [0.8841]
	DENFUF	-3.081500** [0.0429]	-4.661064*** [0.0015]
	IACP	-0.946346 [0.7551]	-0.973965 [0.7456]
	IACPR	-0.387671 [0.8964]	-0.407460 [0.8929]
I(1)	ΔDEAGDPF	-1.829248 [0.3578]	-1.648278 [0.4430]
	ΔDEAMLF	-2.986493 [0.0512]	-2.924642 [0.0579]
	ΔIACP	-3.369588** [0.0243]	-2.539329 [0.1198]
	ΔIACPR	-4.495746*** [0.0018]	-4.491122*** [0.0019]
I(2)	ΔΔDEAGDPF	-5.445986* [0.0002]	-5.445986* [0.0002]
	ΔΔDEAMLF	-9.027249*** [0.0001]	-9.131013*** [0.0001]
	ΔΔIACP	-5.294303” [0.0003]	-5.323201*** [0.0003]

Note= ***, ** and * denote significance at 1%, 5% and 10% significance levels, respectively. Δ= represents taking the difference.

Before applying the unit root tests, it is checked whether the variables are trended or not. Since all variables included in the analysis are trended except for the AGDP variable, the stationarity of the variables was evaluated based on the fixed and trended column in the unit root test. In Table 2, it is seen that the variables except NFU and AGDP are non-stationary according to ADF, PP and KPSS test results (P<0.05). When the first differences of the variables are taken as I(1), it is found that only the SCCT variable is stationary. The variables IACP, AML and AGDP are I(2) stationary at the second difference (P<0.05).

3.3. Diagnostic Test Results

The diagnostic tests in the analyses are used to check whether the VAR (1) model, which is estimated after determining the lag length of the series, is stationary and whether there is autocorrelation and heteroscedasticity problem in the model. In this context, the diagnostic test results obtained in the analyses are reported and given below, respectively.

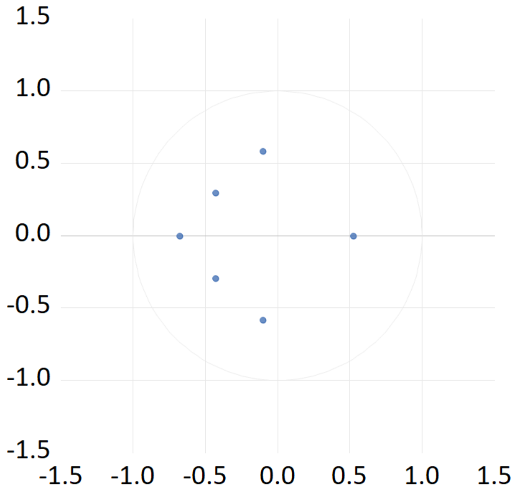

Figure 1. Inverse roots of the ar characteristic polynomial.

The circle graph in Figure 1 shows that the characteristic roots are within the unit circle, hence they are smaller than 1 in absolute degree and as a result, the stability condition is satisfied. The fact that all of the characteristic roots are within the unit circle indicates that the estimated VAR (1) model is stationary. This means that the stability condition is met in the VAR (1) model. Table 3 presents the results of normality, autocorrelation lm and white variance test.

Table 3. Normality, autocorrelation LM and White variance test results

Component	Skewness χ^2 value	df (degrees of freedom)	P value
Unified	4.104	6	0.663
Component	Kurtosis χ^2 value	df (degrees of freedom)	P value
Unified	40.356	6	0.999
Component	Jarque-Bera	df (degrees of freedom)	P value
Unified	4.460	12	0.974
Lag	LRE* stat	df (degrees of freedom)	P value
1	51.881	(36,20.3)	0.102
Lag	χ^2 value	df (degrees of freedom)	P value
1	264.000	252	0.289

According to the results in Table 3, since the p-values of skewness, kurtosis and Jarque-Bera tests are greater than 0.05 significance level, it is seen that the normality assumption is met. According to the results of the Autocorrelation LM Test, since the p-value is greater than 0.05, it is determined that there is no autocorrelation, that is, there is no dependence relationship between the data. Finally, according to the results of the White Variance test, since the p-value is greater than 0.05, it is concluded that there is no varying variance problem. Overall, these results indicate that the model has a strong basis in terms of assumptions.

3.4. Impact-Response Functions

Impulse-response functions reveal the effects of a one standard deviation shock to a random error term on both the current and future values of endogenous variables. These functions play an important role in detecting dynamic and symmetric interactions between the variables analyzed by VAR method. While the variance decomposition method is used to determine which variable is the most influential variable on macroeconomic indicators, whether this variable can be used as a policy instrument is determined with the help of impulse-response functions (Sarı, 2008).

Shocks to economic variables in an economy are generally analyzed in two different categories. The first one is permanent and its effects persist in the long run. In other words, such shocks can significantly affect not only the period in which they occur but also future periods. One of the best examples of this situation is technology-based shocks. Transitory shocks, which fall into the second category, have a strong impact as of the moment of their emergence, but lose their permanent characteristics with the disappearance of this effect in a short time (Aktaş, 2010). Figure 2 shows the results of impulse-response functions applied to the VAR (1) estimation model.

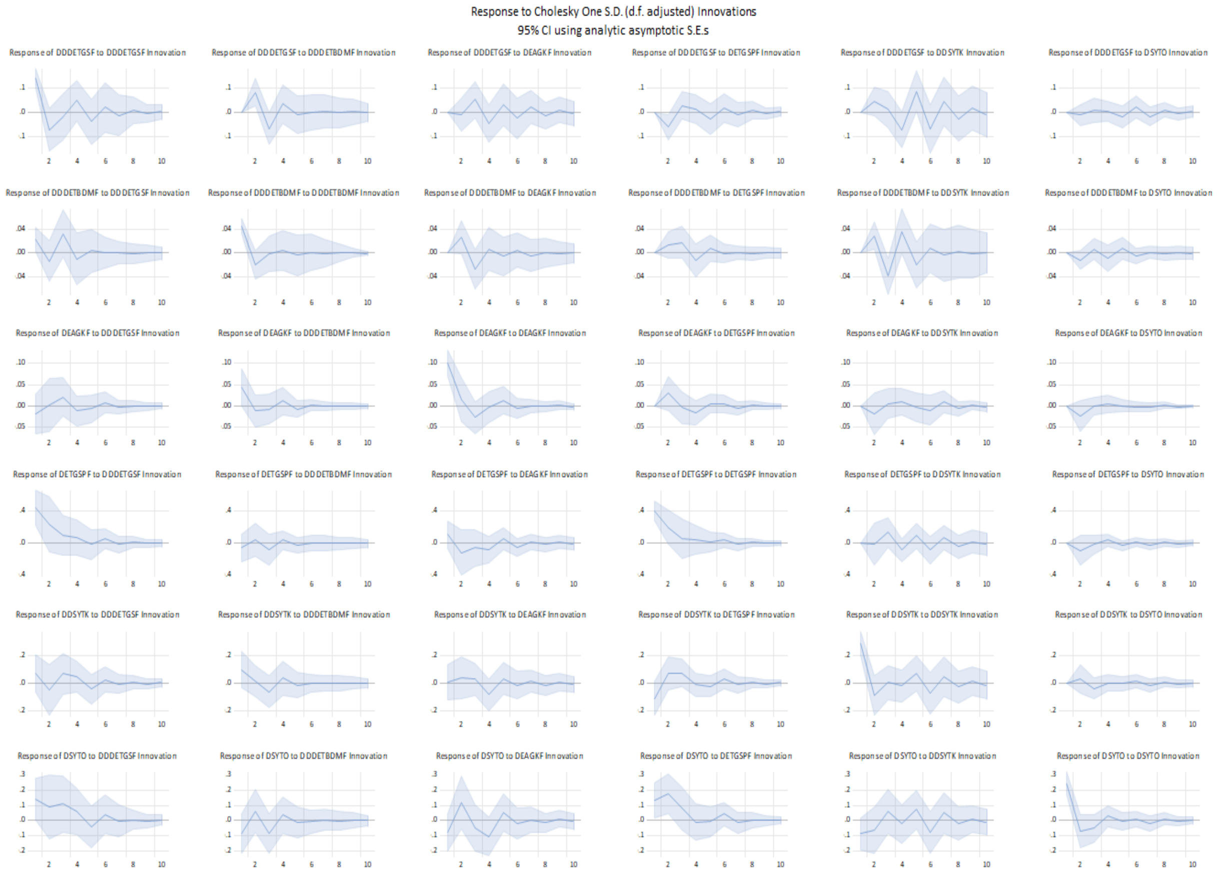

Figure 2. Impulse-response test results

The graphs in Figure 2 represent impulse-response functions showing the effects of Cholesky unit standard deviation shocks on variables and how these effects diminish over time. Some graphs show that the effect of agricultural machinery per agricultural land on other variables is short-lived and small-scale. The effect usually starts positive and rapidly approaches zero. For example, the effect of agricultural machinery per agricultural land on the agricultural GDP variable appears to be significant and positive in the first few periods. However, this effect weakens over time. The response of agricultural machinery per agricultural land to shocks from other variables is generally weak and short-term. This may indicate that agricultural machinery shows a rapid adaptation in the short run. Regarding the effect of agricultural GDP on other variables, the effect of the shock for nitrogen fertilizer use is generally weak in the short run and the confidence interval is wide. This implies that agricultural GDP does not have a significant impact on fertilizer use. The effects of private and public fixed capital investments on agricultural sector investment variables decline over time and approach zero. When the response of agricultural GDP is analyzed, it is found that the responses to shocks from other variables are more long-term. In particular, shocks from investments can have an impact on agricultural GDP for several periods. When the effect of nitrogen fertilizer use on other variables is examined, it is seen that its effect on agricultural machinery and investments is generally minimal and short-term. The response of nitrogen fertilizer use to shocks from other variables, on the other hand, is initially abrupt but soon stabilizes. The effect of agricultural GDP share on other variables is generally not significant. Since confidence intervals are wide around the zero line, the effects may not be statistically significant. The response of the share of agricultural GDP to shocks from other variables generally returns to zero in a short time. Finally, when the effects of private and public fixed capital investments on agricultural investment variables are analyzed, the effects of public and private investments on agricultural GDP and fertilizer use generally start positive but converge to zero over time. This suggests that the effects of investments on agriculture may be temporary. Regarding the response of investments, it is found that shocks, especially from variables such as agricultural GDP, can have short-term and sometimes volatile effects on investments. In general, short-term effects suggest that many variables respond quickly to shocks, and that the effects often weaken within a few periods. In terms of statistical significance, shock effects are not significant when blue confidence intervals are wide. Finally, policy implications suggest that the effects of variables such as investments and agricultural machinery on agricultural GDP should be examined in more detail and supported by long-term strategies.

3.5. Periodic Decomposition

In their study, Burbidge and Harrison (1985) transformed the residuals of the VAR model into structural residuals, and as a result of this transformation, each variable in the system was decomposed for each T time point by considering it as the sum of its own structural shocks as well as the structural shocks of other variables throughout the sample period.

While Impulse Response Analysis is used to understand the dynamic structure of the relationships between variables, the periodic decomposition test is used to understand the sources of past fluctuations. Figure 3 shows the periodic decomposition test results.

The periodic decomposition graphs in Figure 3 are evaluated in 3 periods: the first, middle and last year. The first year represents around 2000 (the period when the data starts), the middle year represents around 2010 (the middle years) and the last year represents 2020 (the period when the data ends). When the graphs are examined for the variable of agricultural machinery per agricultural land, the fluctuations in agricultural machinery in the first years are generally explained by shocks from public and private investments. In these years, the effect of investments significantly affected the fluctuation in the use of agricultural machinery. In the middle years, the effects from agricultural growth created a positive contribution to agricultural machinery. The effect of fertilizer use shocks becomes less pronounced in this period. In recent years, public investments have increased their effect and the blue bars have started to grow as seen in the graphs. This situation indicates the effect of public policies on agricultural machinery in recent years.

For the agricultural GDP variable, the change in agricultural GDP in the early years is explained mostly by shocks from public investments and agricultural machinery. The middle years indicate that the effect of private investments has increased and this situation has played a significant role on agricultural growth. In recent years, the effect of shocks from public investments and agricultural machinery has decreased, and private investments and fertilizer use have become more pronounced. For the nitrogen fertilizer use variable, the shocks from agricultural GDP and public investments in the early years have had dominant effects on fertilizer use. In the middle years, it has been determined that the source of changes in fertilizer use comes mostly from agricultural machinery and private investments. In recent years, the size of the blue bars has decreased and fluctuations in fertilizer use have become more limited. For the share in agricultural GDP variable, the early years have increased with effects from public investments and agricultural machinery. In the middle years, the effects from private investments have increased, but the overall contributions are limited. In recent years, the effect of public investments has weakened and the effects on agricultural share have become more balanced. If we look at the public investment variable, it had an impact on agricultural GDP and fertilizer use in the early years.

The effect of private investments is limited in this period. In the middle years, the effect of private investments increased and its role on agricultural growth became apparent. In recent years, public and private investments have created a balanced effect, especially the effects on agricultural machinery are remarkable. If the inferences on a yearly basis are evaluated in general terms, it is seen that the effects of public investments and agricultural machinery were dominant in the early years. In addition, agricultural growth was more affected by public policies. In the middle years, the effect of private investments began to become apparent. Agricultural machinery and fertilizer use contribute more to the fluctuations in agricultural GDP. In recent years, the effect between public and private investments has been balanced, especially the effects on agricultural machinery have increased. Fertilizer use has started to lose its effect on agricultural growth.

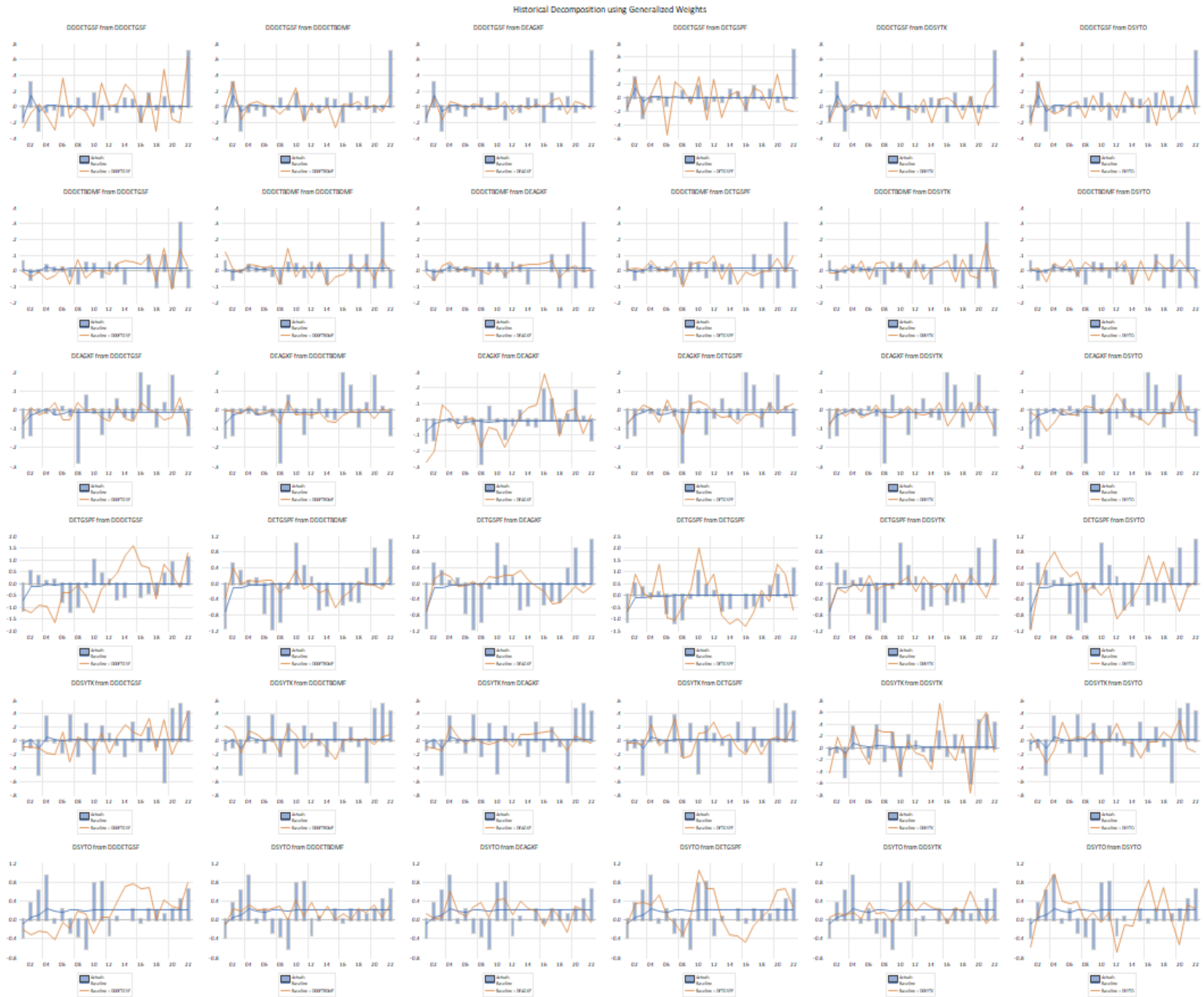

Figure 3. Periodic decomposition test results

3.6. Toda-Yamamoto Causality Test

The Toda-Yamamoto causality test was developed by Toda and Yamamoto in 1995 to investigate the existence and direction of the causality relationship between variables. This method is applied to variables through a VAR model with increased lag. The Toda-Yamamoto causality test has two important advantages over other causality tests. Firstly, only the stationarity test is used to determine the maximum lag length. Second, this test does not require a precondition such as the presence of a cointegration relationship between variables. In the first step of the test, the level at which the variables are stationary is determined and this value is called "dmax". After dmax is determined, the appropriate lag length for the variables is determined and this value is indicated by "k". In the third step, the VAR model with increased lag is estimated by combining the determined dmax and k values. In the last step, the Toda-Yamamoto causality test is applied to the variables through this model (Mert and Çağlar, 2019; Toda and Yamamoto, 1995). The Toda-Yamamoto causality models for the variables used in the study are shown in the equations (1-6) below. Table 4 shows the results of the Toda-Yamamoto causality test.

$$dddeagdpf_t = \mu + \sum_{i=1}^{k+d_{max}} \alpha_1 dddeagdpf_{t-i} + \sum_{i=1}^{k+d_{max}} \alpha_2 dddeamlf_{t-i} + \sum_{i=1}^{k+d_{max}} \alpha_3 denfuf_{t-i} + \sum_{i=1}^{k+d_{max}} \alpha_4 deasgf_{t-i} + \sum_{i=1}^{k+d_{max}} \alpha_5 ddiacp_{t-i} + \sum_{i=1}^{k+d_{max}} \alpha_6 diacpr_{t-i} + \varepsilon_t \quad (1)$$

$$dddeamlf_t = \mu + \sum_{i=1}^{k+d_{max}} \beta_1 dddeamlf_{t-i} + \sum_{i=1}^{k+d_{max}} \beta_2 dddeagdpf_{t-i} + \sum_{i=1}^{k+d_{max}} \beta_3 denfuf_{t-i} + \sum_{i=1}^{k+d_{max}} \beta_4 deasgf_{t-i} + \sum_{i=1}^{k+d_{max}} \beta_5 ddiacp_{t-i} + \sum_{i=1}^{k+d_{max}} \beta_6 diacpr_{t-i} + \varepsilon_t \quad (2)$$

$$denfuf_t = \mu + \sum_{i=1}^{k+d_{max}} \lambda_1 denfuf_{t-i} + \sum_{i=1}^{k+d_{max}} \lambda_2 dddeagdpf_{t-i} + \sum_{i=1}^{k+d_{max}} \lambda_3 dddeamlf_{t-i} + \sum_{i=1}^{k+d_{max}} \lambda_4 deasgf_{t-i} + \sum_{i=1}^{k+d_{max}} \lambda_5 ddiacp_{t-i} + \sum_{i=1}^{k+d_{max}} \lambda_6 diacpr_{t-i} + \varepsilon_t \quad (3)$$

$$deasgf_t = \mu + \sum_{i=1}^{k+d_{max}} \Pi_1 deasgf_{t-i} + \sum_{i=1}^{k+d_{max}} \Pi_2 dddeagdpf_{t-i} + \sum_{i=1}^{k+d_{max}} \Pi_3 dddeamlf_{t-i} + \sum_{i=1}^{k+d_{max}} \Pi_4 denfuf_{t-i} + \sum_{i=1}^{k+d_{max}} \Pi_5 ddiacp_{t-i} + \sum_{i=1}^{k+d_{max}} \Pi_6 diacpr_{t-i} + \varepsilon_t \quad (4)$$

$$diacp_t = \mu + \sum_{i=1}^{k+d_{max}} \phi_1 diacp_{t-i} + \sum_{i=1}^{k+d_{max}} \phi_2 dddeagdpf_{t-i} + \sum_{i=1}^{k+d_{max}} \phi_3 dddeamlf_{t-i} + \sum_{i=1}^{k+d_{max}} \phi_4 denfuf_{t-i} + \sum_{i=1}^{k+d_{max}} \phi_5 deasgf_{t-i} + \sum_{i=1}^{k+d_{max}} \phi_6 diacpr_{t-i} + \varepsilon_t \quad (5)$$

$$diacpr_t = \mu + \sum_{i=1}^{k+d_{max}} £_1 diacpr_{t-i} + \sum_{i=1}^{k+d_{max}} £_2 dddeagdpf_{t-i} + \sum_{i=1}^{k+d_{max}} £_3 dddeamlf_{t-i} + \sum_{i=1}^{k+d_{max}} £_4 denfuf_{t-i} + \sum_{i=1}^{k+d_{max}} £_5 deasgf_{t-i} + \sum_{i=1}^{k+d_{max}} £_6 ddiacp_{t-i} + \varepsilon_t \quad (6)$$

Table 4. Toda-Yamamoto causality test results

Model 1	Dependent Variable: dddeagdpf				
Independent Variables	$k+d_{max}$	χ^2 value	*P* value	Hypotheses	Result
dddeamlf	2	1.648	0.199	H_0: Accept	dddetbdmf $\nRightarrow$ dddetgsf
denfuf	2	0.076	0.783	H_0: Accept	deagkf $\nRightarrow$ dddetgsf
deasgf	2	0.030	0.862	H_0: Accept	detgspf $\nRightarrow$ dddetgsf
ddiacp	2	1.775	0.183	H_0: Accept	ddsytk $\nRightarrow$ dddetgsf
diacpr	2	0.384	0.535	H_0: Accept	dsyto $\nRightarrow$ dddetgsf
All	2	7.933	0.160	H_0: Accept	All $\nRightarrow$ dddetgsf
Model 2	Dependent Variable: dddeamlf				
Independent Variables	$k+d_{max}$	χ^2 value	*P* value	Hypotheses	Result
dddeagdpf	2	3.476	0.062	H_0: Accept	dddetgsf $\nRightarrow$ dddetbdmf
denfuf	2	0.137	0.711	H_0:Accept	deagkf $\nRightarrow$ dddetbdmf
deasgf	2	9.231	0.002	H_0: Rejection	detgspf $\Rightarrow$ dddetbdmf
ddiacp	2	6.083	0.014	H_0: Rejection	ddsytk $\Rightarrow$ dddetbdmf
diacpr	2	2.660	0.103	H_0: Accept	dsyto $\nRightarrow$ dddetbdmf
All	2	23.603	0.001	H_0: Rejection	All $\Rightarrow$ dddetbdmf
Model 3	Dependent Variable: denfuf				
Independent Variables	$k+d_{max}$	χ^2 value	*P* value	Hypotheses	Result
dddeagdpf	2	2.336	0.126	H_0: Accept	dddetgsf $\nRightarrow$ deagkf
dddeamlf	2	4.001	0.046	H_0: Rejection	dddetbdmf $\Rightarrow$ deagkf
deasgf	2	0.506	0.477	H_0: Accept	detgspf $\nRightarrow$ deagkf
ddiacp	2	0.013	0.910	H_0: Accept	ddsytk $\nRightarrow$ deagkf
diacpr	2	0.562	0.454	H_0: Accept	dsyto $\nRightarrow$ deagkf
All	2	8.308	0.140	H_0: Accept	All $\nRightarrow$ deagkf
Model 4	Dependent Variable: deasgf				
Independent Variables	$k+d_{max}$	χ^2 value	*P* value	Hypotheses	Result
dddeagdpf	2	0.874	0.350	H_0: Accept	dddetgsf $\nRightarrow$ detgspf
dddeamlf	2	2.746	0.098	H_0: Accept	dddetbdmf $\nRightarrow$ detgspf
denfuf	2	2.165	0.141	H_0: Accept	deagkf $\nRightarrow$ detgspf
ddiacp	2	0.003	0.955	H_0: Accept	ddsytk $\nRightarrow$ detgspf
diacpr	2	0.123	0.726	H_0: Accept	dsyto $\nRightarrow$ detgspf
All	2	4.022	0.546	H_0: Accept	All $\nRightarrow$ detgspf
Model 5	Dependent Variable: diacp				
Independent Variables	$k+d_{max}$	χ^2 value	*P* value	Hypotheses	Result
dddeagdpf	2	0.056	0.813	H_0: Accept	dddetgsf $\nRightarrow$ dsytk
dddeamlf	2	4.508	0.034	H_0: Rejection	dddetbdmf $\Rightarrow$ dsytk
denfuf	2	0.111	0.739	H_0: Accept	deagkf $\nRightarrow$ dsytk
deasgf	2	0.480	0.488	H_0: Accept	detgspf $\nRightarrow$ dsytk
diacpr	2	1.815	0.178	H_0: Accept	dsyto $\nRightarrow$ dsytk
All	2	6.265	0.281	H_0: Accept	All $\nRightarrow$ dsytk
Model 6	Dependent Variable: diacpr				
Independent Variables	$k+d_{max}$	χ^2 value	*P* value	Hipotezler	Result
dddeagdpf	2	2.784	0.095	H_0: Accept	dddetgsf $\nRightarrow$ dsyto
dddeamlf	2	4.649	0.031	H_0: Rejection	deagkf $\nRightarrow$ dsyto
denfuf	2	0.001	0.976	H_0: Accept	detgspf $\Rightarrow$ dsyto
deasgf	2	5.899	0.015	H_0: Rejection	ddsytk $\Rightarrow$ dsyto
ddiacp	2	0.037	0.846	H_0: Accept	dsyto $\nRightarrow$ dsyto
All	2	17.315	0.004	H_0: Rejection	All $\Rightarrow$ dsyto

According to the results in Table 4, agricultural GDP was considered as the dependent variable in the equation created for model 1, and since the p-values 0.05 of the independent variables are greater than the 0.05 significance level, it is concluded that they have no effect on the dependent variable. In other words, the null hypothesis H0, which expresses the absence of the relationship, was accepted. Agricultural machinery per agricultural land was considered as the dependent variable in the equation created for model 2, and since the p-values 0.05 of the variables of the share of agriculture in GDP and the investment in the agricultural sector (public) within fixed capital investments are less than the 0.05 significance level, it is concluded that there is a significant causal relationship from these variables to the dependent variable. No causal relationship was determined for the other independent variables. In the equation of model 3, where nitrogenous fertilizer use is the dependent variable, a significant causal relationship was determined between the variable of agricultural machinery per agricultural land and nitrogenous fertilizer use in the dependent variable direction ($p=0.046$). There is no significant relationship between the other variables and the dependent variable for this model. In Model 4, no significant causal effect of the independent variables on the dependent variable, agriculture's share in GDP, was detected ($P>0.05$). In the equation created for Model 5, the dependent variable was selected as investments in the agricultural sector (public) within fixed capital investments and a significant causality relationship was found between agricultural machinery per agricultural land towards the dependent variable ($P<0.05$). There is no significant relationship for the other variables. Finally, in Model 6, where the variable investment in the agricultural sector (private) within fixed capital investments is the dependent variable, it is observed that there is a significant causal relationship between the variables agricultural machinery per agricultural land and agriculture's share in GDP towards the dependent variable ($P<0.05$). No causal relationship was found between the other independent variables and the dependent variable for this model. In general, it is observed that the variables agricultural machinery per agricultural land and agriculture's share in GDP have a causal relationship towards the dependent variable in many models. This indicates that these variables are important independent variables in the analysis. Other variables do not generally show significant causality.

4. Conclusion

In this research, the economic factors affecting agricultural growth in Türkiye between 1998 and 2022 are analyzed comprehensively. The agricultural sector, as one of the cornerstones of the Turkish economy, makes significant contributions to both economic growth and rural development. In this research, the effects of variables such as fixed capital investments, use of agricultural machinery and fertilization on agricultural growth are analyzed and it is revealed how important roles these variables play in agricultural growth.

The findings of the study show that the impact of fixed capital investments on agricultural growth is significant. While public investments had a decisive role in agricultural growth, especially in the early years of the period under consideration, the impact of private sector investments has become more prominent in recent years. However, the impact of these investments is generally short-term, while more comprehensive and long-term strategic investments are necessary for the sustainability of agricultural growth in the long run. Studies by Roy and Pal (2002) and Fan et al. (2008) also show that fixed capital investments have positive effects on agricultural growth, but private sector investments provide more sustainable growth in the long run.

These findings suggest that public and private sector cooperation should be developed in a balanced manner to support growth in the agricultural sector. In particular, policies such as strengthening agricultural infrastructure, promoting modern agricultural techniques and facilitating access to agricultural finance stand out as critical elements to support the growth of the sector.

The short-term positive impact of agricultural machinery on agricultural growth is noteworthy. Agricultural machinery such as tractors, which are part of mechanized production, increase productivity in production processes and reduce the need for manpower. However, it is determined that the long-term impact of agricultural machinery has diminished and technological innovations need to be integrated into the sector more effectively.

This finding is in line with studies by Anker (1956) and Terin et al. (2013). These studies show that agricultural machinery increases productivity, but for the long-term sustainable growth of the sector, smart agricultural practices and digital technologies need to be widespread in addition to mechanization. In the future, innovative solutions such as AI-powered irrigation systems, sensor-based soil analysis, and agricultural monitoring systems with unmanned aerial vehicles (UAVs) can make agricultural growth more sustainable and efficient. Therefore, smart agricultural technologies and advanced mechanization methods should be further promoted.

Research results show that the use of nitrogen fertilizers has a positive impact on agricultural growth, but this impact is limited compared to other variables. Although fertilization increases yields in the short term, it is not sufficient on its own to support agricultural growth in the long term. Studies by Tıraş (2024) also show that fertilizer use increases productivity, but it needs to be considered together with other factors for sustainable agricultural growth in the long run.

This suggests that fertilizer use should be made more efficient and farmers should be trained on conscious fertilization methods. Furthermore, organic and biological fertilization techniques should be promoted to ensure environmental sustainability.

Another important finding of the study is that the share of agriculture in GDP has tended to decline over time. Despite this, the agricultural sector continues to play a vital role in areas such as job creation, rural development and food security.

In particular, Kopuk and Meçik (2020) find a unidirectional causality from agriculture to economic growth in Türkiye. Similarly, Canbay and Kırca (2020) found that agriculture contributes positively to economic growth, but economic growth can negatively affect the agricultural sector.

Therefore, in order to increase the contribution of agricultural growth to economic growth, incentives and investments in the sector should be planned more effectively and policies targeting rural development should be implemented.

In conclusion, Türkiye needs a comprehensive transformation to support and sustain agricultural growth. Further integration of fixed capital investments, mechanization and technological advances into agricultural production is critical for the sector's long-term growth.

However, promoting environmentally friendly and sustainable agricultural practices, increasing support for organic agriculture and strengthening the integration of agriculture and the food industry will enhance the competitiveness of the sector. Considering the contribution of agriculture not only to economic growth but also to rural development and social welfare, the sector needs to be supported more strongly.

This provides a roadmap for strengthening the Turkish agricultural sector's place in economic growth. The integration of long-term investment strategies, technology-driven transformation and rural development policies will make the agricultural sector more competitive and sustainable in the future. Agriculture is an indispensable sector for both meeting today's economic needs and securing future food security.

Author Contributions

The percentages of the author' contributions are presented below. The author reviewed and approved the final version of the manuscript.

	G.E.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study, as it did not involve any research on humans or animals.

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