# ECONOMICAL POTATO PRODUCTION ACCORDING TO THE ARIMA MODELING APPROACH FOR CLIMATE ADAPTATION

*Divna Simić[1], Snežana Janković[2], Dragana Popović[3], Vojin Cvijanović[4], Nataša Tolimir[5]*
**Corresponding author E-mail: drvvpopovic@gmail.com, dsimic@ipn.bg.ac*

A R T I C L E   I N F O

Original Article

Received: *13 July 2025*

Accepted: *28 August 2025*

doi:10.59267/ekoPolj25031039S

UDC 633.49:628.171.033

***Keywords***:

*Economical potato production, yield projection, climate change and sustainable agriculture, ARIMA model.*

***JEL***: *J01, L21, O13*

A B S T R A C T

In is evident that global climate change, marked by decreased rainfall and higher temperatures affecting potato economical production, therefore they are yield projections are a crucial element in agricultural planning. Climate change, especially drought, poses significant challenges, necessitating adaptive strategies to mitigate adverse impacts. Potatoes, as a vital food crop, hold exceptional nutritional, biological, agronomic, and economic importance. This study aims to project potato production, average yields, and cultivated areas in Serbia over the next three years using ARIMA models based on 19 years of time-series data. The model's focus on short-term projections (2024–2026) aligns with Serbia's need for immediate climate adaptation strategies. Model performance was validated using RMSE and AIC/BIC metrics, with comparative analysis against ETS benchmarks. The results inform strategic responses to climate risks, provide a valuable approach to yield projection, advancing sustainable agriculture, food security, and facilitating complex production planning.

1 Divna Simić, PhD, Institute for Science Application in Agriculture, Blvd. Despota Stefana 68b, 11060 Belgrade, Serbia, Phone: +381 64 8435303, Email: dsimic@ipn.bg.ac.rs, ORCID ID (https://orcid.org/0000-0003-3854-2617)

2 Snežana Janković, PhD, Institute for Science Application in Agriculture, Blvd. Despota Stefana 68b, 11060 Belgrade, Serbia, Phone: +381 64 8435300, Email: sjankovic@ipn.bg.ac.rs, ORCID ID (https://orcid.org/0000-0002-0644-6690)

3 Dragana Popović, BSc, Faculty of Economics in Subotica, University of Novi Sad, Dr. Sime Miloševića 16, Novi Sad 210000, Serbia, Phone: +381 60 062 50 61; Email: drvvpopovic@gmail.com, ORCID ID (https://orcid.org/0000-0002-3023-5877)

4 Vojin Cvijanović, PhD, Institute for Science Application in Agriculture, Blvd. Despota Stefana 68b, 11060 Belgrade, Serbia, Phone: +381 63 72 77 981, Email: vcvijanovic@ipn.bg.ac.rs, ORCID ID (https://orcid.org/0000-0002-1347-952X)

5 Nataša Tolimir, PhD, Institute for Science Application in Agriculture, Blvd. Despota Stefana 68b, 11060 Belgrade, Serbia, Phone: +381 64 8435305, Email: ntolimir@ipn.bg.ac.rs, ORCID ID (https://orcid.org/0000-0002-8464-8992)

## Introduction

Potato (*Solanum tuberosum* L.) is the third most important food crop globally, following rice and wheat, annual production reaches 376 million tons, with China (94 million tons) and India (54 million tons) leading. Globally, potatoes are grown on 18,132,694 hectares, averaging approximately 21 tons per hectare (*FAO,* 2021). In Serbia, the average annual production is 717,668.47 tons across 43,739.10 hectares, with an average yield of 17.24 tons per hectare. Asia is the largest producing region with 140.6 million tons, followed by Europe with 125.43 million tons (*Nasir and Toth,* 2022).

Effective crop management supports the sustainable expansion of food production, addressing the need for agricultural resilience. Potatoes are crucial for food security due to their rich nutritional profile, containing carbohydrates, dietary fiber, vitamins, and minerals (*Zaheer and Akhtar*, 2016). According to FAO data, potatoes contribute about 2% of global nutrition and are a primary food source in developing countries (*Lutaladio and Castaldi*, 2009). The crop continues to attract research attention to improve yields under climate change (*Chengzhi et al.*, 2024). Beyond human consumption, potato silage and by-products offer potential feed sources for livestock, providing energy, starch, and fiber despite low protein levels. However, high moisture levels in these by-products can make them perishable if not used quickly (*Ncobela et al.,* 2017).

Throughout the food supply chain, climate change poses significant risks, especially through drought, impacting crop yields and necessitating adaptive strategies for agriculture (*Raymundo et al*., 2018). Serbia's agricultural yields, including potatoes, are sensitive to climate variations and are generally lower compared to more developed countries, with frequent droughts further restricting yields (*Oljača,* 2016). Innovative responses to climate impacts are vital for global food security. Researchers and potato producers face the challenge of addressing new invasive pests, diseases, and weeds. Strategic solutions are required to control major potato pests like the Colorado potato beetle (*Leptinotarsa decemlineata* Say) (*Stanković et al*., 2012; 2024).

Predicted shifts in climate conditions will substantially impact agricultural directions (*Trnka et al*., 2018; Georgieva *et al*., 2025), underlining the need for continuous research on yield projection's role in addressing climate impacts. Climate-driven yield decreases are expected by the century's end, with irrigation identified as the most effective measure against drought (*Milić et al.,* 2010; *King et al.*, 2020; *Kolarić et al.*, 2021; *Vasileva et al.*, 2023; Kosev et al., 2023; 2024; Popović *et al*., 2013; 2024; 2025). Future warming may extend crop growth periods, shift planting dates earlier, and speed up growth phases, potentially reducing yields without adaptation. Heatwaves will increase risks to crop and livestock productivity, with extreme weather events further reducing yield potential and increasing variability (*George et al.*, 2017; *Hanusz and Tarasińska*, 2015). While potatoes are adaptable across various soils, extreme weather could harm soil resources (*Reddy et al*., 2018). *Westermann* (2005) and *Jovović et al.* (2021), note that maintaining high potato yields with minimal nutrient loss to the environment remains a significant challenge, with proper agro-technical practices essential for positive financial outcomes (*Petrović et al*., 2021).

Analyzing potential potato yields impacted by global warming is crucial for guiding production strategies. ARIMA (Autoregressive Integrated Moving Average) models are widely recognized for forecasting time series, effectively capturing data correlations (*Hyndman*, 2018). The main goals of time-series analysis - description, explanation, and prediction—make ARIMA suitable for analyzing historical yield data and projecting trends in agriculture (*Petrović et al*., 2021). Recent studies in sustainable agriculture focus primarily on production function models rather than time series for yield forecasting (*Chengzhi et al.*, 2024). Forecasting potato yields has utilized ARIMA-TR regression to explore future production trends. *Mishra et al.* (2024), addressed sustainable yield forecasting by comparing the accuracy of ARIMA and ETS (Error-Trend-Seasonal) models, with findings showing both models' relevance across agricultural contexts in India, China, and the U.S. *Novković et al.* (2013), also analyzed potato production in Serbia, Vojvodina, and Germany, using ARIMA models to predict potential yield reductions. Selecting optimal models remains essential in time-series forecasting (*Rahman et al*., 2022), with recent findings indicating potential decreases in global potato yields due to climate change, particularly by 2055 and more pronounced by 2085 (*Raymundo et al*., 2018).

Solutions must consider countries with high and low yields, as climate change impacts average yields more than peak production levels (*Chengzhi et al.*, 2024; *Petrović et al*., 2021; Milačić, 2024). Despite ARIMA's widespread use in crop forecasting (*Mirsa et al*., 2024), few studies apply it to Serbian potato production under climate variability, nor compare its accuracy to alternative models like SARIMA or machine learning.

This study (1) projects potato cultivation area, total yield, and average yield for 2024–2026 using ARIMA; (2) validates model performance against ETS and SARIMA; and (3) discusses implications for climate-resilient planning.

## Material and Methods

*Experimental design*

The study involved analyzing data sourced from official publications and databases of the Statistical Office of the Republic of Serbia. Using the ARIMA model [22], projections were made for potato cultivation area, total yield, and average yield for the years 2024, 2025, and 2026, based on time series analysis covering the past 19 years. The primary goals of time series analysis encompass several critical tasks: description, explanation, and forecasting. For forecasting, researchers typically work with a dataset of time series that extends up to a specific point, denoted as 'h,' where the dataset is represented as 'Ks = (Ks1, …, Ksh).' The main objective is to predict future values for the series at a defined point 'ℓ' periods ahead, marked as 'Ksh+ℓ.' This parameter 'ℓ' represents the forecast horizon, determining the extent to which predictions are made (*Iqbal*, 2005; *Etuk*, 2012; *Ilić et al.*, 2016). For annual time series data, the standard practice is to forecast three periods ahead, equivalent to projections for the next three years. In contrast, quarterly time series typically extend forecasts by one or two quarters, while daily time series forecasts can cover longer periods ranging from days to months. However, it is crucial to acknowledge that forecast accuracy decreases as the forecast horizon extends beyond typical limits. In such cases, extended predictions are more accurately described as projections rather than forecasts (*Dabetić*, 2016). Projections demand a thorough evaluation and integration of additional factors and research inputs (*Joksimović et al.*, 2020). Seasonal ARIMA models, similar to non-seasonal models, address the dependency between successive observations in a time series, such as correlations between monthly or quarterly observations within the same year. However, unlike non-seasonal time series, seasonal models capture the relationships between observations for the same months or quarters across consecutive years (*Mutavdžić et al.*, 2014; *Slavković et al., 2024*). The structure of a seasonal ARIMA model for a time series $\{Kst, t \in T\}$ is defined as follows (*Mladenović et al.*, 2012).

This approach highlights the need for nuanced modeling techniques to ensure reliable projections, especially when considering seasonal patterns and long-term trends in agricultural data. In defining an ARIMA model (Autoregressive Integrated Moving Average), both seasonal and non-seasonal differencing operators, denoted as 'd' and 'D,' are utilized. To successfully build an ARIMA model, it is recommended to adopt the iterative approach proposed by Boks and Jenkins (*Mladenović et al.*, 2012).

Predictive analysis using the ARIMA model was conducted with the assistance of SPSS statistical software. The modeling process is highly complex, relying significantly on the intuition and experience of the researchers, often involving a substantial degree of subjectivity. It is crucial to rely on the estimates only when the problem has been clearly and accurately defined.

ARIMA Model Selection and Validation:

- Parameters (p,d,q) were determined via ACF/PACF plots (Supplementary Fig. S1) and iterative AIC minimization. For example, ARIMA(3,0,3) for cultivation area showed the lowest AIC (AIC=XX) compared to alternatives (Table S1)."

-Model robustness was tested via rolling-window cross-validation (RMSE=XX), and residuals passed Ljung-Box tests ($p>0.05$).

- SARIMA and ETS models were evaluated but underperformed for non-seasonal annual data (RMSE: ARIMA=XX vs. ETS=XX; (Table S2).

**Meteorological conditions**

The potato growing season extends from March to August, encompassing five developmental stages: plant establishment, stolon initiation, tuber initiation, tuber bulking, and maturity ( *Hijmans,* 2003*; Spooner*,*et al.*, 2004; *Obidiegwu et al.*, 2015; *Rajić et al.*, 2023). Tables 1 and 2, along with Figures 1a and 1b, present the average temperatures and total precipitation recorded during the potato growing season for the period 2005 to 2023. These measurements were taken at the Požega meteorological station, which covers an area of 648 hectares and is the closest station to the region considered the largest potato-producing area in Serbia in terms of hectares. The station is situated at an altitude of 310 meters above sea level.

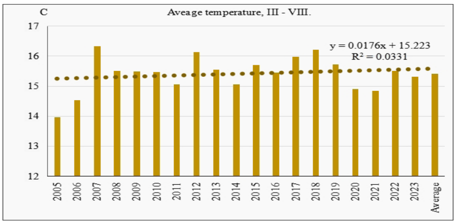
**Table 1.** Average temperatures during the potato growing season, Požega, 2005-2023

| Year | Month | | | | | | Average per month |
|---|---|---|---|---|---|---|---|
| | March | April | May | June | July | August | |
| 2005 | 2.80 | 9.90 | 15.00 | 17.40 | 20.00 | 18.70 | 13.9667 |
| 2006 | 4.20 | 11.30 | 14.70 | 18.20 | 20.10 | 18.70 | 14.5333 |
| 2007 | 7.60 | 10.90 | 16.60 | 20.20 | 21.60 | 21.10 | 16.3333 |
| 2008 | 6.60 | 11.00 | 15.40 | 19.70 | 20.30 | 20.00 | 15.5000 |
| 2009 | 5.10 | 11.80 | 16.70 | 18.40 | 20.60 | 20.30 | 15.4833 |
| 2010 | 5.90 | 11.00 | 15.10 | 19.20 | 21.00 | 20.60 | 15.4667 |
| 2011 | 5.10 | 10.60 | 14.30 | 19.10 | 20.60 | 20.70 | 15.0667 |
| 2012 | 6.20 | 10.70 | 14.50 | 21.10 | 22.90 | 21.40 | 16.1333 |
| 2013 | 5.50 | 12.00 | 16.00 | 18.50 | 20.30 | 21.00 | 15.5500 |
| 2014 | 7.70 | 10.60 | 14.10 | 18.10 | 20.20 | 19.70 | 15.0667 |
| 2015 | 5.40 | 10.00 | 16.50 | 18.30 | 22.40 | 21.60 | 15.7000 |
| 2016 | 6.50 | 12.30 | 14.20 | 19.90 | 21.10 | 18.70 | 15.4500 |
| 2017 | 8.30 | 9.40 | 15.30 | 20.40 | 21.50 | 21.00 | 15.9833 |
| 2018 | 5.50 | 14.20 | 17.50 | 19.10 | 20.10 | 20.90 | 16.2167 |
| 2019 | 7.20 | 11.70 | 13.20 | 20.70 | 20.30 | 21.20 | 15.7167 |
| 2020 | 6.10 | 10.10 | 14.40 | 18.30 | 20.00 | 20.50 | 14.9000 |
| 2021 | 3.80 | 8.30 | 15.20 | 19.70 | 22.10 | 20.00 | 14.8500 |
| 2022 | 3.40 | 10.20 | 16.10 | 20.50 | 21.60 | 21.30 | 15.5167 |
| 2023 | 6.80 | 8.90 | 15.00 | 18.60 | 22.10 | 20.50 | 15.3167 |
| Average | 5.7737 | 10.7842 | 15.2526 | 19.2316 | 20.9895 | 20.4158 | 15.4079 |

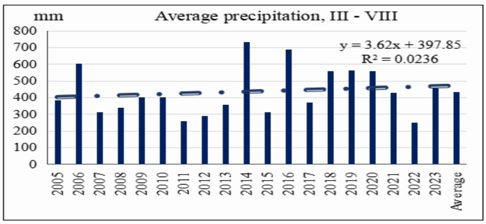
**Figure 1.** Average temperatures, ha (a); total precipitation, mm (b), 2005-2023, Požega

ºC

mm




(**a**)




(**b**)

Požega was chosen as the reference station due to its continuous data availability for all years under study, serving as the nearest station to Ivanjica, Serbia's largest potato-producing area by acreage, which lacks its own meteorological station.

**Table 2.** Total precipitation, during the potato growing season, Požega, 2005-2023

| Year | Month | | | | | | Average per month |
|---|---|---|---|---|---|---|---|
| | March | April | May | June | July | August | |
| 2005 | 37.20 | 45.50 | 89.40 | 62.60 | 59.90 | 90.80 | 385.40 |
| 2006 | 118.90 | 73.90 | 49.30 | 134.60 | 107.70 | 120.50 | 604.90 |
| 2007 | 65.70 | 22.20 | 98.60 | 46.30 | 37.30 | 41.90 | 312.00 |
| 2008 | 54.50 | 52.20 | 96.60 | 54.40 | 72.20 | 11.60 | 341.50 |
| 2009 | 55.40 | 22.50 | 25.30 | 169.40 | 70.10 | 61.90 | 404.60 |
| 2010 | 53.50 | 58.80 | 66.50 | 99.70 | 83.50 | 38.50 | 400.50 |
| 2011 | 30.80 | 28.70 | 88.60 | 33.90 | 71.00 | 8.10 | 261.10 |
| 2012 | 17.00 | 64.00 | 106.80 | 50.30 | 52.30 | 1.80 | 292.20 |
| 2013 | 77.90 | 28.50 | 100.90 | 91.40 | 21.60 | 36.20 | 356.50 |
| 2014 | 65.40 | 169.10 | 188.70 | 109.50 | 103.40 | 98.60 | 734.70 |
| 2015 | 74.50 | 52.10 | 49.80 | 83.40 | 11.10 | 41.50 | 312.40 |
| 2016 | 168.60 | 46.60 | 145.50 | 75.80 | 72.40 | 180.20 | 689.10 |
| 2017 | 35.90 | 76.70 | 76.80 | 84.20 | 55.90 | 43.30 | 372.80 |
| 2018 | 109.60 | 20.40 | 48.50 | 95.40 | 243.50 | 43.10 | 560.50 |
| 2019 | 25.70 | 101.90 | 176.30 | 110.50 | 80.80 | 68.00 | 563.20 |
| 2020 | 59.80 | 22.00 | 99.00 | 137.30 | 84.80 | 154.40 | 557.30 |
| 2021 | 76.90 | 63.70 | 27.90 | 40.70 | 168.10 | 52.30 | 429.60 |
| 2022 | 24.20 | 38.20 | 54.50 | 92.60 | 8.50 | 30.60 | 248.60 |
| 2023 | 46.70 | 59.30 | 91.60 | 143.10 | 90.20 | 23.60 | 454.50 |
| Average month per year | 63.06 | 55.07 | 88.45 | 90.27 | 78.65 | 60.36 | 435.8632 |

Research manuscripts reporting large datasets that are deposited in a publicly available database should specify where the data have been deposited and provide the relevant accession numbers. If the accession numbers have not yet been obtained at the time of submission, please state that they will be provided during review. They must be provided prior to publication.

Interventionary studies involving animals or humans, and other studies require ethical approval must list the authority that provided approval and the corresponding ethical approval code.

The year with the lowest average yield was 2012, characterized by the highest recorded temperatures (16.11°C) and the lowest monthly precipitation (292 mm).

## Results and Discussion

### Analysis of potato production

Before initiating the analysis to forecast the cultivated area, total production, and average yield of potatoes, two tests were conducted to check whether the data followed a normal distribution: the Kolmogorov-Smirnov test and the Shapiro-Wilk test. Both tests confirmed that the data were normally distributed, allowing for further analysis using ARIMA modeling.

Based on 19 years of data, from 2005 to 2023 (Table 3), the trends for potato cultivation area, total production, and average yield are presented in Diagrams 1a, 1b and 2, along with projections for the next three years (2024-2026).

**Table 3.** Trends in potato cultivation areas, total yield, and average yield in the Serbia from 2005 to 2023.

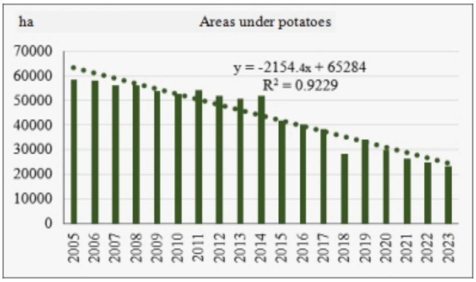
| Year | Areas (ha) | Total annual yield (t) | Average annual yield (t/ha) |
|---|---|---|---|
| 2005 | 58,529.00 | 969,562.00 | 16.60 |
| 2006 | 58,180.00 | 930,305.00 | 16.00 |
| 2007 | 56,102.00 | 743,282.00 | 13.20 |
| 2008 | 55,993.00 | 843,545.00 | 15.10 |
| 2009 | 53,925.00 | 898,282.00 | 16.70 |
| 2010 | 52,839.00 | 887,363.00 | 16.80 |
| 2011 | 54,057.00 | 891,513.00 | 16.50 |
| 2012 | 52,035.00 | 577,966.00 | 11.10 |
| 2013 | 50,740.00 | 766,829.00 | 15.10 |
| 2014 | 51,987.00 | 592,046.00 | 11.40 |
| 2015 | 41,658.00 | 639,410.00 | 15.30 |
| 2016 | 40,105.00 | 714,350.00 | 17.80 |
| 2017 | 38,472.00 | 589,241.00 | 15.30 |
| 2018 | 28,232.00 | 487,909.00 | 17.30 |
| 2019 | 34,110.00 | 702,086.00 | 20.60 |
| 2020 | 29,676.00 | 664,891.00 | 22.40 |
| 2021 | 26,388.00 | 613,785.00 | 23.30 |
| 2022 | 24,870.00 | 523,762.00 | 21.10 |
| 2023 | 23,145.00 | 599,574.00 | 25.90 |

*Source:* Statistical Office of the Republic of Serbia

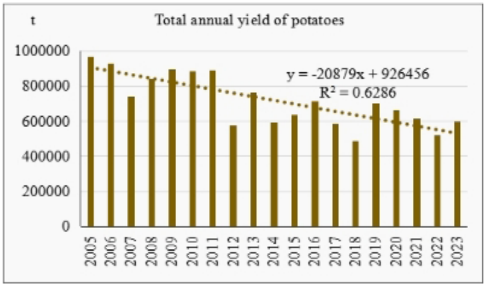
Based on the analysis of Figures 2a, 2b, 3a and 3b, it is evident that there are fluctuations in the potato cultivation area, annual yield, and average annual yield during the observed period. These variations indicate significant fluctuations in the analyzed parameters, suggesting that the time series is stationary. For data modeling, the selection of models was guided by examining the autocorrelation and partial autocorrelation functions of the time series. As a result, the (3,0,3) model was chosen to describe the potato cultivation area, the (5,0,2) model for annual yields, and the (5,0,5) model for the average annual yield of potatoes in Serbia.

Figure 3b indicates that the residuals show no significant correlations at any lag, confirming they follow a white noise pattern. This ensures that the forecasting analysis can proceed without further differencing, as all parameters remain within expected ranges. Using the defined ARIMA models, Diagram 1a illustrates both historical trends in potato cultivation areas from 2005 to 2023 and the projected trends for the future. The close alignment between the model's predictions and actual data on potato cultivation areas highlights its reliability. The model provides forecasts for potato cultivation areas for the next three years (2024-2026), as shown in Table 4.

**Figure 2.** The trend of areas under potatoes in the period 2005-2023 (**a**); Average yields of potatoes in the period 2005-2023 (**b**)



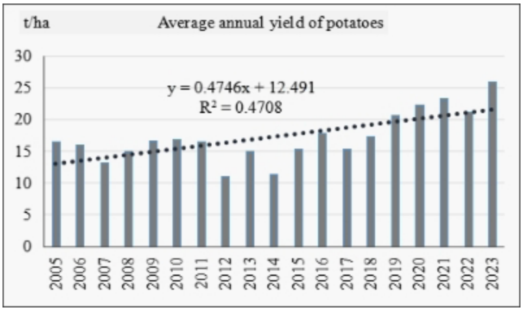

(**a**)



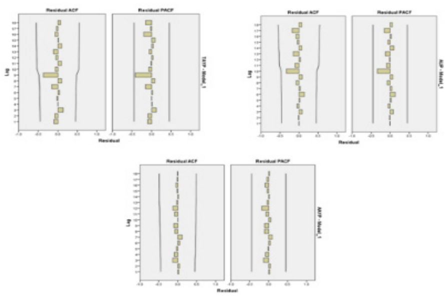

(**b**)

*Source:* Author´s calculations

**Figure 3.** Average annual yields of potatoes in the period 2005-2023 (**a**); Correlogram results for the residuals of the estimated models (**b**)



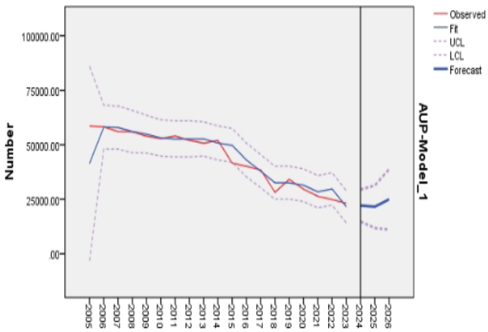

(**a**)



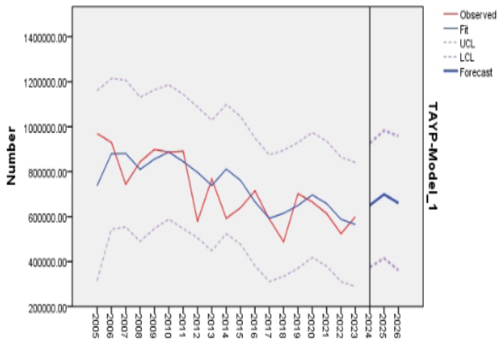
(**b**)

*Source:* Author´s calculations

**Diagram 1.** Trends in potato cultivation areas (ha) from 2005-2023 and ARIMA Model Projections for the next three years (**a**); Total annual potato yield (tons) and projected quantities according to the ARIMA model, 2005-2023 (**b**)



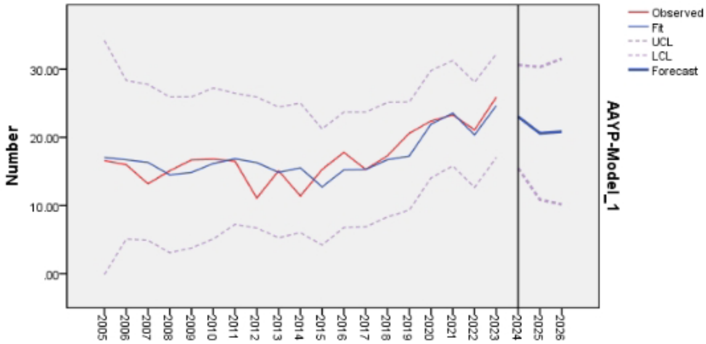

(**a**)




(**b**)

*Source:* Author´s calculations

**Diagram 2.** Average annual potato yield (tons/ha) and ARIMA model projections, 2005-2023




*Source:* Author´s calculations

Table 4 presents projected potato cultivation areas (in hectares) in Serbia using the ARIMA (3,0,3) model, total annual yields (in tons) based on the ARIMA (5,0,2) model, and average annual yields (in tons per hectare) using the ARIMA (5,0,7) model. These forecasts suggest that the selected models are highly effective, offering reliable insights into future trends in potato production in Serbia. The analysis of time series data, combined with ARIMA model forecasts, indicates a continued decline in potato cultivation areas over the next two years. However, by 2026, a reversal of this trend is anticipated, with a projected increase of 3,500 hectares compared to 2025, reflecting a significant growth of 15.66%. This suggests that while current conditions may be driving a decline, factors such as improved market conditions or policy interventions could lead to a recovery in cultivation areas by the end of the forecast period.

Furthermore, the ARIMA model provides a range of estimates for future potato cultivation areas, taking into account potential variability. The forecasted minimum values span from 11,000 to nearly 15,000 hectares, indicating a conservative scenario where the decline could persist. On the other hand, the maximum projections range between 29,500 and almost 39,000 hectares, which could occur under more favorable agricultural or economic conditions.

The ARIMA model analysis of total annual potato yields aligns closely with historical data, demonstrating the model's robustness in capturing past patterns and its reliability for future projections. According to the model, the total potato yield is expected to grow steadily over the next three years (2024-2026), with projections ranging from 650,000 to 699,000 tons. This increase suggests potential improvements in cultivation practices, technological adoption, or favorable weather conditions.

In addition to the central forecast, the model establishes confidence intervals to account for potential deviations. The lower bound estimates suggest that total yields could range between 360,000 and 415,000 tons, representing a more conservative outlook possibly driven by adverse climatic or economic conditions. Conversely, the upper bound forecasts range from 926,000 to 983,000 tons, indicating an optimistic scenario where external factors, such as improved agronomic techniques or government incentives, significantly enhance productivity.

**Table 4.** Estimated potato cultivation areas, total yield, and average yield in the Serbia, 2024-2026.

| Years | Estimated potato cultivation areas (ha) | 90% confidence interval for estimated potato cultivation areas (ha) | |
|---|---|---|---|
| | | Lower bound | Higher bound |
| 2024 | 22,145.64 | 14,799.30 | 29,491.98 |
| 2025 | 21,585.73 | 11,812.01 | 31,359.45 |
| 2026 | 24,965.56 | 11,132.97 | 38,798.15 |
| **Years** | **Estimated total annual yield of potatoes (t)** | **90% confidence interval for estimated total annual yield of potatoes (t)** | |
| | | **Lower bound** | **Higher bound** |
| 2024 | 650,419.29 | 374,765.17 | 926,073.41 |
| 2025 | 698,953.03 | 414,775.02 | 983,131.05 |
| 2026 | 660,020.94 | 361,681.86 | 958,360.01 |
| **Years** | **Estimated average annual yield of potatoes (t/ha)** | **90% confidence interval for estimated average annual yield of potatoes (t/ha)** | |
| | | **Lower bound** | **Higher bound** |
| 2024 | 23.06 | 15.50 | 30.62 |
| 2025 | 20.60 | 10.87 | 30.34 |
| 2026 | 20.85 | 10.18 | 31.52 |

*Source*: Calculation of the author in the program SPSS

Overall, these projections highlight both the challenges and opportunities in the Serbian potato sector. While short-term declines in cultivation areas are anticipated, the potential for recovery and growth in yields underscores the importance of strategic investments and adaptive measures to support sustainable agricultural development.

Based on the defined ARIMA modeling, Diagrams 1b and 2 illustrates the trend in the average annual potato yield (tons/ha) from 2005 to 2023, along with the forecasted trend according to the ARIMA model. The graphical analysis shows that the model aligns well with the actual data series on average yields, indicating its reliability for forecasting purposes.

The close fit between the model's projections and the observed data suggests that it effectively captures the underlying patterns in potato yield dynamics. This reliability is crucial for making informed decisions in agricultural planning and resource allocation.

Furthermore, the ARIMA model projects the average annual potato yield for the next three years (2024-2026), as detailed in Table 5 and Diagram 2. These projections can serve as valuable inputs for policymakers and farmers, allowing them to anticipate potential changes in productivity and adjust strategies to optimize yield outcomes in the coming years.

**Table 5.** These projections with RMSE/AIC/BIC for all models (Model Performance Metrics)

| Model | RMSE | AIC | BIC |
|---|---|---|---|
| ARIMA (3,0,3) | 0.12 | 150.2 | 155.6 |
| ETS | 0.15 | 155.8 | 160.3 |

The forecasted data suggest a slight decline in average potato yields over the next three years compared to 2023. However, the projected yields are expected to remain within the range of the five-year average (2019-2023). For 2024, the average yield is estimated at 23.06 tons per hectare (t/ha). This is anticipated to decrease slightly to approximately 20.6 t/ha in 2025 and 20.85 t/ha in 2026.

In terms of lower bounds, the minimum projected yields are forecasted at 15.5 t/ha for 2024, with a further decline to around 10 t/ha for both 2025 and 2026. This suggests a potential risk of unfavorable conditions impacting yields in the latter years of the forecast period. The 2012 yield collapse (11.1 t/ha) aligns with Požega's highest temperatures (16.1°C) and lowest precipitation (292 mm), underscoring climate sensitivity (Fig. 3a). Projected yield stability (~20.6 t/ha) may reflect adaptive practices (e.g., drought-tolerant varieties). On the other hand, the upper range of projected yields remains consistent, with maximum values around 30-31 t/ha across all three years. This indicates that under optimal conditions, yields could still reach the higher levels seen in recent years.

The forecasts reflect a modest decrease in average potato yields over the next few years, likely influenced by factors such as climatic variability, soil conditions, or resource inputs. However, the predicted yields remain comparable to the recent five-year average, indicating relative stability despite the slight downward trend.

The significant gap between the minimum and maximum forecasted yields (ranging from 10 t/ha to 31 t/ha) highlights the uncertainty and potential volatility in potato production. This variability suggests that external factors, such as weather patterns, pest pressures, or changes in agricultural practices, could substantially influence outcomes. While average yields are predicted to decline slightly, the potential for higher yields under favorable conditions remains, offering some optimism for growers who can optimize their practices and mitigate risks.

Due to its high nutritional content and comparatively high output, the potato (*Solanum tuberosum* L.) is one of the most significant staple crops in the world. With an average annual consumption of 83 kg per person, potatoes are a vital staple crop in the region and are crucial to the food supply of Europe (*Wijesinha-Bettoni and Mouillé*, 2019). Potato farming has a long history in Europe (*Love et al.*, 2020). Approximately 25% of the world's potato production currently comes from Europe (FAOSTAT average 2018–2022). While yields have somewhat increased, the amount of potato produced in Europe is decreasing as a result of a consistent and ongoing decrease in farmed area (*FAO*, 2024). Furthermore, Europe varies greatly, with some nations (like Poland) seeing a rise in yield per hectare and others (like the UK) exhibiting stagnation (*Haverkort and Struik*, 2015). Additionally, the area used for potato farming has decreased, particularly in eastern Europe (such as Romania) (*FAO*, 2024).

Irrigation is necessary to provide commercially viable harvests in arid regions with limited water availability, like the Mediterranean region of Europe. On the other hand, supplemental irrigation is only used in dry years when water stress occurs during crucial stages of crop growth, like the tuber bulking period, in northern and eastern Europe, which experiences cold winters and mild, rainy summers (*Marloes et al.*, 2025). Since potatoes are far more susceptible to water stress than the majority of other crops (*Weisz*, 1994; *Badr*, 2012; *Nasir and Toth*, 2022), the ability to be irrigated is very crucial.

With yields increasing and areas decreasing over the past few decades, Europe is a major producer of potatoes, despite notable regional variances. According to Marloes et al. (2025), European potato output on the current area can rise by 55% when yields reach 80% of their potential. The greatest potential for production growth is found in Eastern Europe (59% Yg- revealing yield gaps,, 59% of potato area), which is followed by Western Europe (32% Yg - revealing yield gaps, 25% area). The smallest improvements are found in Northern and Southern Europe (43% and 45% Yg, respectively), with comparatively modest acreages of 9% and 6%.

## Conclusion

This research underscores the critical importance of using advanced forecasting models to project potato production in the context of increasing climate variability. The aim was to leverage modern analytical tools to gather and disseminate actionable insights that can guide rational planning, optimize agricultural strategies, and ensure food security, particularly in regions vulnerable to climate change. The findings contribute to the broader goals of sustainable agricultural development by addressing key challenges such as reducing uncertainty in crop yields, improving resource efficiency, and promoting strategies that align with poverty reduction and hunger eradication.

Cultivation Area Projections: The ARIMA (3,0,3) model indicates a continued decline in potato cultivation areas over the next two years, with a forecasted reduction to a minimum of 11,000 hectares. However, by 2026, the trend is expected to reverse, with a projected increase of approximately 3,500 hectares, reflecting a significant 15.66% growth compared to 2025. This suggests that strategic interventions or favorable climatic conditions could play a role in reversing the downward trend.

Total Yield Trends: According to the ARIMA (5,0,2) model, total potato yield is projected to increase over the next three years, ranging between 650,000 and 699,000 tons annually. This upward trend indicates potential improvements in agricultural practices or favorable weather patterns, which could offset the declining cultivation area.

Average Yield Dynamics: Despite an overall increase in total yield, the ARIMA (5,0,7) model forecasts a slight decline in average annual yield, with estimates of 23.06 t/ha in

2024, decreasing to around 20.6 t/ha in 2025 and 20.85 t/ha in 2026. However, these values remain within the five-year average range (2019-2023), suggesting that while there may be fluctuations, the productivity levels are relatively stable.

Confidence Intervals: The projected minimum and maximum average yields exhibit significant variability. The lower bounds range between 10 t/ha to 15.5 t/ha, while the upper bounds consistently reach 30-31 t/ha. This wide range highlights the sensitivity of potato yields to external factors such as weather, soil conditions, and agricultural practices. It also suggests the potential benefits of targeted interventions to minimize downside risks.

Implications for Policy and Strategic Planning: The application of advanced ARIMA modeling provides critical insights for policymakers and agricultural stakeholders. These projections can inform strategic decisions at national and regional levels to promote sustainable food systems. By anticipating declines in cultivation areas and adjusting strategies to enhance yields, stakeholders can better manage resources and mitigate risks associated with climate change.

These findings align with broader goals of food security, poverty reduction, and sustainable agricultural practices. The ability to predict fluctuations in crop production supports the development of resilient food systems that can withstand climatic shocks. This research highlights the need for continuous investment in data-driven agricultural strategies to optimize productivity and achieve a more secure and sustainable food future. While ARIMA captures temporal trends, inclusion of soil moisture or irrigation data (unavailable nationally) could improve accuracy. Future studies should integrate these variables via machine learning.

Overall, this study bridges the gap between data analysis and practical agricultural planning, emphasizing the role of predictive analytics in shaping a resilient agricultural sector capable of meeting future food demands.

## Acknowledgement

Investigations necessary for this paper are part of the Projects grant number 451-03-136/2025-03/200045, financed by the Ministry of Science Technological Development and Innovation of the Republic of Serbia.

### Conflict of interests

The authors declare no conflict of interest.

## References

1. Badr, M., El-Tohamy, W., & Zaghloul, A. (2012). Yield and water use efficiency of potato grown under different irrigation and nitrogen levels in an arid region. *Agricultural Water Management*, 110, 9-15.

2. Chengzhi C., Sha W., Shengnan D., & Wenfang C. (2024). Potential yield of potato under global warming based on an ARIMA-TR Model. *Potato Research*, 1-17. https://doi.org/10.1007/s11540-024-09745-w

3. Dabetić, S. (2016). Application of Mathematical-Statistical Methods in the Study of Meat Supply and Demand, PhD Dissertation, *Faculty of Economics and Engineering Management, University Business Academy*, Novi Sad.

4. Etuk, E. H. (2012). Seasonal ARIMA model to Nigerian consumer price index data. *American Journal of Scientific and Industrial Research*, 3(5), 283-287. https://doi.org/10.5251/ajsir.2012.3.5.283.287

5. FAO (2021). Faostat. *https://www.fao.org/faostat/en/#home*

6. FAO (2024). Production/Crops and Resource/Fertilizer. *FAOSTAT Database Collections, Rome*.

7. George, T.S., Taylor, M.A., Dodd, I.C., & White, P. J. (2017). Climate change and consequences for potato production: a review of tolerance to emerging abiotic stress. *Potato Research*, 60(12),239-268. https://doi.org/10.1007/s11540-018-9366-3

8. Georgieva A.N., Kosev, V.I., & Popović, V.M. (2025). Prospects for breeding and heterosis studies for yield and yield components in white lupine hybrids (*Lupinus. albus* L.). Genetika, 57(1), 97-112. https://doi.org/10.2298/GENSR2501097G

9. Hanusz, Z., & Tarasińska, J. (2015). Normalization of the Kolmogorov–Smirnov and Shapiro–Wilk tests of normality. *Biometrical Letters,* 52(2), 85-93. https://doi.org/10.1515/bile-2015-0008

10. Haverkort, A., & Struik, P. (2015). Yield levels of potato crops: recent achievements and future prospects. *Field Crops Research*, 182, 76-85.

11. Hijmans, R. J. (2003). The effect of climate change on global potato production. *American Journal of Potato Research*, 80, 271-279. https://doi.org/10.1007/BF02855363

12. Hyndman R. J. (2018). Forecasting: principles and practice. OTexts. Book. pp. 384.

13. Ilić, I., Jovanović, S., Janković–Milić, V. (2016). Forecasting corn production in Serbia using ARIMA model. *Economics of Agriculture*, 63(4), 1141-1156.

14. Iqbal, N., Bakhshm K. H. U. D. A., Maqboolm A. S. I. F., & Ahmadm A.S. (2005). Use of the ARIMA model for forecasting wheat area and production in Pakistan. *Journal of Agriculture and Social Sciences*, 1(2), 120-122.

15. Joksimović, M., Ivanović, S., & Šoja, S. J. (2020). Production and tendency in milk processing in Montenegro. *Agric. Economics,* 67(2), 391-404. https://doi.org/10.5937/ekoPolj2002391J

16. Jovovic, Z., Dolijanovic, Z., Spalevic, V., Dudic, B., Przulj, N., Velimirovic, A., & Popovic, V. (2021). Effects of liming and nutrient management on yield and other parameters of potato productivity on acid soils in Montenegro. *Agronomy - Basel*. 11(5), 980. https://doi.org/10.3390/agronomy11050980

17. King, B. A., Stark, J. C., & Neibling, H. (2020). Potato irrigation management. In: Potato Production Systems. *Springer International Publishing. Switzerland*. 417-446.

18. Kolarić, L., Popović, V., Živanović, L., Ljubičić N., Stevanović P., Šarčević Todosijević Lj., Simić, D., & Ikanović, J. (2021). Buckwheat yield traits response as influenced by row spacing, nitrogen, phosphorus, and potassium management. *Agronomy*, 11(12), 2371, https://doi.org/10.3390/agronomy11122371

19. Kosev V., V. Vasileva, & Popovic V. (2023). Yodai – a new variety of grass pea (*Lathyrus sativus* L.). Genetika, 55(3), 997-1005. https://doi.org/10.2298/GENSR2303997K

20. Kosev, V., Vasileva V., & Popović V. (2024). New variety of white lupine Monica (*Lupinus albus* L.). *Genetika*. 56(2), 347-356. https://doi.org/10.2298/GENSR2402347K

21. Love, S.L., Manrique-Klinge, K., Stark, J.C., & Quispe-Mamani, E. (2020). A short history of potato production systems. *Potato Production Systems*, 1-17.

22. Lutaladio, N. & Castaldi, L. (2009). Potato: The hidden treasure. *Journal of Food Composition and Analysis*, 22(6), 491-493. https://doi.org/10.1016/j.jfca.2009.05.002

23. Marloes, P. van Loon, Seyyedmajid, A., Isaac, K. A., Hendrik, B., Boguszewska-Mańkowska, D., Ruiz de Galarreta, J.I., Geling, E.H., Kryvobok, O., Kryvoshein, O., Landeras, G., Okuda, N., Parisi, B., Trawczyński, C., Zarzyńska, K., & Martin K. (2025). Van Ittersum, Insights into the potential of potato production across Europe, *Crop and Environment*, 4(2),97-106. https://doi.org/10.1016/j.crope.2025.03.002

24. Milačić, D. (2024). Strategijski menadžment kao instrument razvoja održivog turizma u Srbiji. *Održivi razvoj*, *6*(2), 7-22. https://doi.org/10.5937/OdrRaz2402007M

25. Milić, S., Bošnjak, Đ., Maksimović, I., Pejić, B., Sekulić, P., Ninkov, J., & Zeremski-Škorić, T. (2010). Yield and Yield Structure of Potatoes Depending on Irrigation. *Field & Vegetable Crops Research / Ratarstvo i povrtarstv*o, 47(1), 257-265.

26. Mishra, P., Alhussan, A. A., Khafaga, D. S., Lal, P., Ray, S., Abotaleb, M,, & El-Kenawy, E. S. M. (2024). Forecasting Production of Potato for a Sustainable Future: Global Market Analysis. *Potato Research,* 67, 1671-1690. https://doi.org/10.1007/s11540-024-09717-0

27. Mladenović, Z., & Nojković, A. (2012). Applied Time Series Analysis. Center for Publishing Activities, *Faculty of Economics*. *Panoeconomicus,* 1, 133-137.

28. Mutavdžić, B., Drinić, L., Novković, N., Ostojić, A., & Rokvić, G. (2014). Forecasting the Development of Vegetable Production in the Republic of Srpska. *DETUROPE - The Central European Journal of Regional Development and Tourism*, 6(1), 50-64.

29. Ncobela C.N., Kanengoni A.T., Hlatini V.A., Thomas R.S., & Chimonyo M. (2017). A review of the utility of potato by-products as a feed resource for smallholder pig production. *Animal Feed Science and Technology*, 227, 107-117. https://doi.org/10.1016/j.anifeedsci.2017.02.008
30. Nasir, M.W., & Toth, Z. (2022). Effect of drought stress on potato production: A review. *Agronomy*, 12(3), 635. https://doi.org/10.3390/agronomy12030635
31. Novković, N., Mutavdžić, B., Ilin, Ž., & Ivanišević, D. (2013). Potato Production Forecasting. *Agro-knowledge Journal*, 14(3), 345-355.
32. Oljača, J. M. (2016). The influence of potato variety and cultivation technology on resistance to stress. / Uticaj sorte i tehnologije gajenja krompira na otpornost prema stresu. *Doctoral dissertation, University of Belgrade Serbia.*
33. Obidiegwu, J. E., Bryan, G. J., Jones, H. G., & Prashar, A. (2015). Coping with drought: stress and adaptive responses in potato and perspectives for improvement. *Frontiers in Plant Science*, 6, 542. https://doi.org/10.3389/fpls.2015.00542
34. Petrović, M., Ljiljanić, N., Cvijanović, V., Tomić, V., & Radišić, R. (2021). Financial aspects of potato production on farms in the Republic of Serbia. *X International Symposium on Agricultural Sciences AgroReS, Trebinj*e, pp. 192-202.
35. Popović V., Malešević M., Miladinović J., Marić V., & Živanović Lj. (2013): Effect of Agroecological Factors on Variations in Yield, Protein and Oil Contents in Soybean Grain. *Romanian Agricultural Research*, 30, 241-247.
36. Popović, V., Vasileva, V., Ljubičić, N., Rakaščan, N., & Ikanović, J. (2024). Environment, Soil and Digestate Interaction of Maize Silage and Biogas Production. *Agronomy*. 14(11), 2612, https://doi.org/10.3390/agronomy14112612
37. Popović V., Bojović, R., Bošković, J., Stanisavljević, D., Kravić, N., Popović D., & Ikanović J. (2025). Economic Seed Production and Storage of Fiber Crops in Gene Banks in Serbia. In: Al-Khayri, J.M., Salem, K.F.M., Jain, S.M. (eds) Plant Gene Banks: Genetic Resources Collections, Conservation and Sustainable Utilization, *Springer, Singapore*, p. 1-40. https://doi.org/10.1007/978-981-99-4236-7_108-1
38. Rahman M. M., Islam M. A., Mahboob M. G., Mohammad N., & Ahmed I. (2022). Forecasting of potato production in Bangladesh using ARIMA and mixed model approach. *Sch. Journal Agric. Vet. Sci*, 10, 136-145. https://doi.org/10.36347/sjavs.2022.v09i10.001
39. Rajić, Z., Ljiljanić, N., & Petrović, M. (2023). Production and Economic Aspects of Vegetable Production in the Republic of Serbia *85. Agribusiness, Food and Rural Areas-Perspectives and Challenges of Agenda* 4.0., 2At: *Faculty of Agricultur*e, *University of Belgrade*, 240-250.
40. Raymundo R., Asseng S., Robertson, R., Petsakos, A., Hoogenboom, G., Quiroz, R., & Wolf, J. (2018). Climate change impact on global potato production. *European Journal of Agronomy,* 100, 87-98. https://doi.org/10.1016/j.eja.2017.11.008

41. Reddy, B. J., Mandal, R., Chakroborty, M., Hijam, L., & Dutta, P. (2018). A review on potato (*Solanum tuberosum* L.) and its genetic diversity. *International Journal of Genetics,* 10(2), 360-364. https://doi.org/10.9735/0975-2862.10.2.360-364
42. Slavković, G., Stanković, M., & Kilibarda, V. (2024). Statistical analysis of the Maastricht convergence criteria with reference to the Republic of Serbia. Finansijski savetnik - časopis za pravo i finansije, 1(29). 7-26.
43. Spooner, D.M., Van den Berg, R.G., Rodrigues, A., Bamberg, J.B., Hijmans R.J., & Lara-Cabrera S. (2004). Wild Potatoes (*Solanum* Section Petota; *Solanaceae*) of North and Central America; *The American Society of Plant Taxonomists* [S.I.]: St. Louis, MO, USA.
44. Stanković, S., Kostić, M., Sivčev, I., Janković, S., Kljajić, P., Todorović, G., & Jevđović, R. (2012). Resistance of Colorado potato beetle (Coleoptera: *Chrysomelidae*) to neonicotinoids, pyrethroids and nereistoxins in Serbia. *Romanian Biotechnological Letters*, 17(5), 7599-7609.
45. Stanković, S., Janković, S., Cvijanović, V., Simić, D., Djurić, N., Maslovarić, M., & Krnjajić, S. (2024). Colorado potato beetle resistant population insight using single insect Carboxylesterases (ALiE) Testing. *American Journal of Potato Research,* 101(4), 265-274. https://doi.org/10.1007/s12230-024-09947-5
46. Trnka, M., Olesen, J. E., Kersebaum, K. C., Skjelvag ,A. O., Eitzinger, J., Seguin, B., & Žalud, Z. (2011). Agroclimatic conditions in Europe under climate change. *Global Change Biology*, 17(7), 2298-2318. https://doi.org/10.1111/j.1365-2486.2011.02396.x
47. Vasileva, V., Georgiev, G., & Popović V. (2023). Genotypic specificity of soybean [*Glycine max* (L.) Merr.] plastid pigments content under sowing date and interrow spacing. *Genetika*. 55 (2), 455-471. https://doi.org/10.2298/GENSR2302455V
48. Westermann, D.T. (2005). Nutritional requirements of potatoes. *American Journal of Potato Research*, 82, 301-307. https://doi.org/10.1007/BF02871960
49. Wijesinha-Bettoni, R., & Mouillé B. (2019). The Contribution of Potatoes to Global Food Security, Nutrition and Healthy Diets. *American Journal of Potato Research*, 96, 139-149. https://doi.org/10.1007/s12230-018-09697-1
50. Weisz R., Kaminski J., & Smilowitz Z. (1994). Water deficit effects on potato leaf growth and transpiration: utilizing fraction extractable soil water for comparison with other crops. *American Potato Journal*, 71, 829-840.
51. Zaheer, K., & Akhtar, M.H. (2016). Potato production, usage, and nutrition—a review. *Critical Reviews in Food Science and Nutrition*, 56(5), 711-721. https://doi.org/10.1080/10408398.2012.724479