UDC: 63

ISSN 1450-8109

JOURNAL OF AGRICULTURAL SCIENCES BELGRADE

Vol. 71, No. 1, 2026

Published by University of Belgrade
Faculty of Agriculture
Republic of Serbia

UDC: 63 ISSN 1450-8109

JOURNAL OF AGRICULTURAL SCIENCES BELGRADE

Vol. 71, No. 1, 2026

Published by University of Belgrade
Faculty of Agriculture
Republic of Serbia

PUBLISHED BY

University of Belgrade-Faculty of Agriculture
11081 Belgrade-Zemun, Nemanjina 6, PO Box 14, Serbia
Tel: + 381 11 4413-555/467; Fax: + 381 11 2193-659; E-mail: redakcija@agrif.bg.ac.rs
URL: https://agrif.bg.ac.rs/en/faculty/publishing/journal-of-agricultural-sciences-belgrade

DTP Service: Snežana Spirić

Printed by the Faculty of Agriculture, Belgrade
Circulation: 100

Publishing is supported by the Ministry of Education, Science and
Technological Development of the Republic of Serbia, Belgrade

According to the opinion of the Ministry of Science of the Republic of Serbia
No. 413-00-1928/2001-01 dated November 6, 2001
this Journal is exempt from general tax liability

Frequency: Four times per year

Abstracting and Indexing
SCIndeks, CAB Abstracts, AGRICOLA, Scopus, EBSCO, DOAJ

Number of institutions the Journal is exchanged with: 80

JOURNAL OF AGRICULTURAL SCIENCES (BELGRADE)
Vol. 71, No. 1, 2026

C O N T E N T S

JOURNAL OF AGRICULTURAL SCIENCES (BELGRADE)
Vol. 71, No. 1, 2026

S A D R Ž A J

Journal of Agricultural Sciences (Belgrade) https://doi.org/10.2298/JAS2601001M
Vol. 71, No. 1, 2026 UDC: 633.11:631.85
Pages 1-13 Original scientific paper

INFLUENCE OF PHOSPHORUS CONTENT OF SEEDS ON THE PLANT GROWTH OF 11 VARIETIES OF DURUM WHEAT (*TRITICUM DURUM* DESF.)

Lakhdar T. Mazouz[1,2] and Salim A. Lebbal[3*]

[1]Agro-veterinary Institute, Batna 1 University, Batna, Algeria
[2]Biotechnology, Water, Environment and Health Laboratory, Abbes Laghrour University, Khenchela, Algeria
[3]Laboratory of Management, Conservation and Valorization of Agricultural and Natural Resources (LMCVANR), Abbes Laghrour University, Khenchela, Algeria

Abstract: The phosphorus has an important role in the plant growth. Furthermore, the use of alternative methods, such as the cultivation of appropriate cultivars to satisfy the plant nutrient requirements and to reduce the negative effect of chemical fertilisers, is highly recommended. Thus, the aim of the present study was to screen the influence of the seed phosphorus content on the plant growth of 11 durum wheat (*Triticum durum* Desf.) varieties from numerous origins. Different morphological traits and their relation with the phosphorus quantities were investigated. These traits include root and aerial length, number of leaves, number of herbaceous tillers and number of ears. The obtained results revealed significant differences in the studied morphological characters among the examined wheat varieties. In addition, a positive correlation was recorded between the phosphorus levels in seeds and some morphological characters, particularly the aerial length, the number of leaves and tillers and the root length. It is concluded that higher phosphorus content in seeds has helped some varieties to achieve a good start. This suggests the necessity to consider this property when choosing durum wheat varieties for regions where P is scarce at sowing. It also fits into a broader global vision of sustainability by lowering the need for phosphate fertilisers.

Key words: durum wheat, sustainability, morphological parameters, correlation, genotype.

Introduction

Phosphorus (P) is an essential nutrient for plants that affects the productivity of crops (Karandashov and Bucher, 2005; Lin et al., 2020). P is the second most limiting nutrient for crop production after nitrogen (N) (Bernardino et al., 2019).

*Corresponding author: e-mail: salim-leb@hotmail.com

Worldwide, 67% of the total farmed land is considered P deficient (Cakmak, 2002). P exhibits poor mobility and availability to plants in soil. Low soil phosphorus availability is a primary constraint for plant growth in many terrestrial ecosystems, as P is involved in several energy transformation and biochemical reactions essential for plant growth and development (Liao et al., 2008). Thus, plants have various adaptive strategies to boost P absorption and mobilisation to cope with reduced P availability in soil (Guo et al., 2022). Besides, the P reserve in the seed can have a positive impact on crop establishment in P-deficient environments.

In durum wheat, the development of the root system is one of the traits associated with P-efficient genotypes (Liu et al., 1998). At harvest, most phosphorus is found in the grain, while the content in the straw is generally low (Johnson, 1993). Growing plants store few simple phosphate ions, generally PO_4^{-3} (orthophosphate), unlike seeds. This storage ensures a good start to growth and the development of germinating seeds before the root system is established (Johnston and Steen, 2000). The embryo in plant seeds needs phosphorus to grow and develop. Before the embryo develops a root system, its only source of phosphorus is the seed, so phosphorus from the seed has the greatest direct effect on plant yield during the very early stages of plant growth (Bolland and Paynter, 1990). The importance of phosphorus during the early stages of development is illustrated by the impossibility of compensating for its temporary absence with later additions (Gervy, 1970). Phosphorus is mainly stored in the form of polyphosphates such as phytates, which represents around 50% of the total phosphorus contained in legume seeds and around 60–70% in cereal seeds. In germinating seeds, phosphorus is released by the phytase enzyme and incorporated into other molecules (Azeke et al., 2011). The effect of the initial P reserve on plant performance is mainly significant under specific conditions such as low P environments (Ros et al., 1997) or drought (Burnett et al., 1997).

Thus, the aim of the present study is to screen the influence of the P content in seeds on the development of wheat varieties in a semi-arid region characterised by low to medium phosphorus levels and drought.

Material and Methods

Plant material

The plant material consisted of 11 durum wheat varieties, cultivated in Algeria (local, introduced and improved): Waha, GTA dur, Semito, Boussellam, Vitron, Cirta, Wahbi, Beliouni, Mohamed Ben Bachir, Djennah Khetifa, and Guemgoum R'khem. The main characteristics of these varieties are shown in Table 1.

Methodology

Seeds of the chosen 11 contrasting varieties of durum wheat (*Triticum durum*) were sown in trays filled with a phosphorus-free peat substrate, to germinate and obtain rooted seedlings. Sowing was carried out on 12 May 2021. The trial was set up in the greenhouse located at the Khenchela Agricultural Vocational Training Institute in Algeria.

Table 1. Properties of the studied durum wheat varieties.

Code	Variety	Origin	Type	Registration year
V1	Waha	Syria	Pure line	1997
V2	GTA dur	Mexico	Pure line	2001
V3	Simeto	Italy	Pure line	2001
V4	Boussellam	ICARDA-CIMMYT	Pure line	2000
V5	Vitron	Spain	Pure line	1997
V6	Cirta	Algeria	Pure line	1999
V7	Wahbi	Algeria	Pure line	1986
V8	Beliouni	Algeria	Local variety	/
V9	Mohamed Ben Bachir	Algeria	Local population	2001
V10	Djenah Khetifa	Algeria/Tunisia	Local population	/
V11	Guemgoum R'khem	Algeria	Local population	2008

Source: Authors' systematisation based on published literature.

Once they had emerged and reached a stage of growth at which they could be transplanted, the seedlings were grown hydroponically. This method was chosen because it allows: better control and homogenisation of the mineral input, and the production of healthy roots free from any disturbance that could interfere with the plants' own responses (Dubos, 2001). Furthermore, it avoids soil stresses, allowing rapid growth and good plant development under totally controlled conditions, as well as making it easier to monitor and measure the root development at each stage.

The plants were transplanted into the hydroponics tank as follows:

1. At the beginning, the cups intended to hold the seedlings were perforated, and then holes were made in the polyester plate to accommodate the number of the tested varieties and their repetitions (Figure 1a) (Mahlangu et al., 2016);
2. Once the seedlings were placed in the cups, they were surrounded by pieces of sponge (Figure 1b). The sponge serves as a support to help the plant to maintain its balance;
3. Next, the seedlings surrounded by the sponge were placed inside the cups so that both the aerial part and the root system were outside the cup (Figure 1c);

4. The seedlings transplanted into the hydroponic system were labelled (V1, V2, V3, etc.) to distinguish them and make it easier to monitor and record their progress (Figure 1d);

5. A nutritive solution was then prepared and poured into the hydroponic tank to feed the seedlings. This preparation was made in two separate compositions: the first (A) consisted of 850g of NPK, 350 g of KNO_3, 400 g of magnesium sulphate and 10 L of water. The second solution (B) consisted of 100 g of calcium nitrate, 35 g of iron chelate and 10 L of water. For the A+B solution to be used, 1 L of the mixed solution was diluted in 100 L of water (Figure 1e);

6. The polyester plate containing the cups with the seedlings was placed on top of the water film in the tank, so that the root system was immersed in the water in the tank (Figure 1f), according to the experimental protocol described by Mahlanagu et al. (2016), with three repetitions.

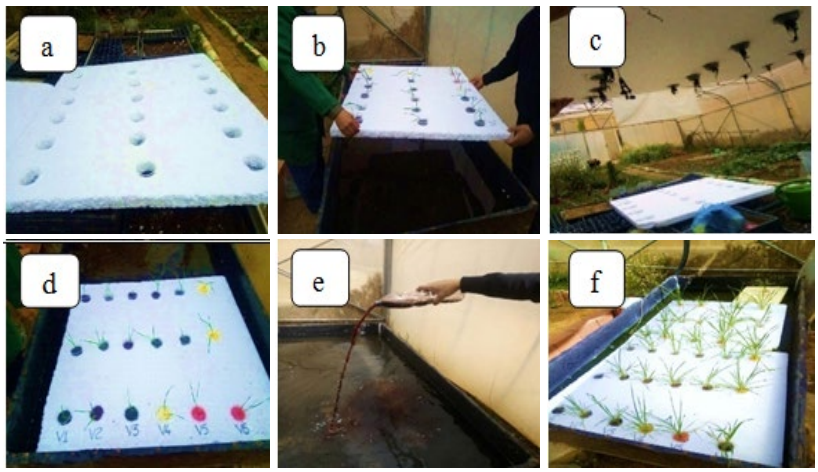


Figure 1. Steps followed when transplanting plants into the hydroponic tank.
Source: Authors' own data.

The phosphorus content of the seeds: the phosphorus dosage is carried out on the extract obtained by mineralisation according to the general procedure. Phosphorus is present in the extract as orthophosphate. In the presence of vanadate and molybdate ions, phosphorus forms a yellow phospho-vanado-molybdate complex that can be measured by a molecular absorption spectrophotometer at 430 nm.

According to the Misson method (ref. NF U42-246), phosphorus was measured using molecular absorption spectrophotometry as a yellow phosphovanadomolybdate complex. A nitro-vanadate-molybdate reagent was used with the mineralised extract. Vanadomolybdophosphoric acid, which is stable and yellow, is created when orthophosphate combines with vanadate and molybdate ions in an acidic medium. A

spectrophotometer was used to measure the absorbance at a wavelength of 430 nm following a 15-minute incubation period at room temperature to allow the colour to develop. The phosphorus content of the samples was determined using a monopotassium phosphate (KH_2PO_4) calibration range of 0 to 20 mg/L P (Vogel and Mendham, 1989).

Morphological parameters: The first period occurs during the installation of seedlings in the trays (before transplanting into the hydroponic tank) (12 May 2021). At this stage, we measured the following parameters: the seedling length (before transplanting) and the leaf number before transplanting.

During the second period, which is the transplantation day in the hydroponic tank (15 May 2021), the root length (during transplanting) was measured.

In the final period, after transplanting (19 May, 27 May, 03 June, 09 June, and 24 June 2021), the plant was removed from its polyester cup and the following parameters were measured:

- Number of leaves (Leaf 19, Leaf 27);
- Aerial length (Aerial 19, Aerial 27, Aerial 3, and Aerial 9);
- Number of herbaceous tillers (from the fourth leaf stage to the early swelling stage);
- Number of ears;
- Root length on different dates (Root 19, Root 27, Root 3, Root 9, and Root 24).

All measurements were repeated three times, and the lengths are given in cm.

Using SPSS software, version 10, two analyses were carried out: analysis of variance ANOVA (at a threshold of 5% followed by a Student-Newman-Keuls test) to compare the means of the various measured morphological parameters, in addition to a correlation test between the quantity of phosphorus contained in the seeds and the morphological parameters.

Results and Discussion

ANOVA analysis revealed a highly significant difference in the phosphorus content of seeds among the studied varieties (Table 2). The Waha and GTA dur varieties had the lowest quantities, whereas the Mohamed Ben Bachir, Vitron, Beliouni and Cirta varieties recorded the highest levels of P (Figure 2). Similarly, the examination of the measured morphological parameters shows highly significant differences between the varieties during all the growth phases (Table 2). In general, the Djenah Khetifa variety (V10) recorded the highest values after the transplanting stage, while the Waha variety (V1) had the lowest ones (Figure 3).

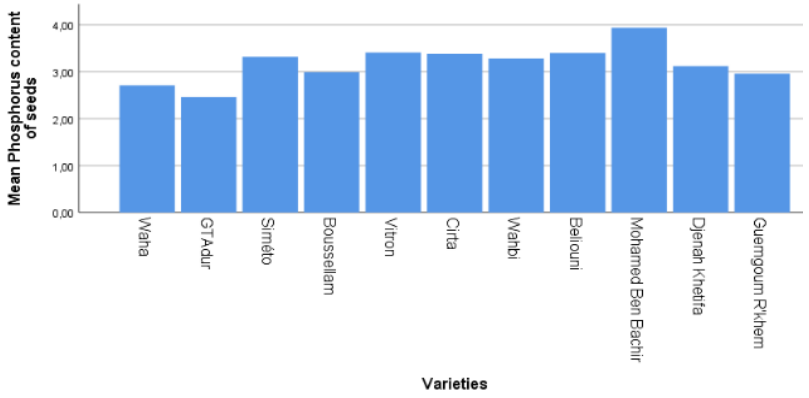


Figure 2. Phosphorus content (mg P/g dry matter) of seeds of varieties.
Source: Authors' own data.

Table 2. ANOVA results for measured parameters.

Measured parameters	Significance
Phosphorus content of the seeds	<0.001*
Plant length before transplanting	<0.001*
Leaf number before transplanting	0.473*
Root length during transplanting	0.022*
Aerial length 19/05/2021	<0.001*
Root length 19/05/2021	<0.001*
Number of leaves 19/05/2021	<0.001*
Aerial length 27/05/2021	<0.001*
Root length 27/05/2021	0.001*
Number of leaves 27/05/2021	<0.001*
Aerial length 03/06/2021	<0.001*
Root length 03/06/2021	0.002*
Number of tillers 03/06/2021	<0.001*
Aerial length 09/06/2021	<0.001*
Root length 09/06/2021	0.001*
Number of tillers 09/06/2021	0.000*
Number of ears 24/06/2021	0.000*
Root length 24/06/2021	0.000*

**Significant at P < 0.05.* Source: Authors' calculations.

On the other hand, the analysis of the relation between the phosphorus content of the seeds and some morphological characters revealed a positive correlation with the plant length before transplanting in addition to the aerial length, the number of leaves and tillers, and the root length during three measurements after transplanting (27/05, 03/06, and 09/06/2021) (Table 3).

Massle (1985) has confirmed that the number of tillers produced depends on the variety, the climate, and the plant's mineral and water supply. Moreover, Palta and Watt (2009) have mentioned that variations in root system depth are linked to genotypes.

The varieties Mohamed Ben Bachir, Cirta, Vitron, Beliouni, Djenah Khetifa and Guemgoum R'khem have a higher seed phosphorus content, which enables them to develop their root systems better and therefore achieve a good ear tillering capacity. The obtained results are similar to those of Hazmoune (1994), who carried out a study on the characterisation of the root system of a number of durum wheat varieties in relation to yield components.

Table 3. Correlations between phosphorus levels in seeds and morphological parameters in the studied wheat varieties.

Morphological parameters	Correlation with P content of seeds
Plant length before transplanting	0.540
Leaf number before transplanting	0.249
Root length during transplanting	-0.170
Aerial length 19/05/2021	0.186
Root length 19/05/2021	-0.025
Number of leaves 19/05/2021	-0.207
Aerial length 27/05/2021	0.407
Root length 27/05/2021	0.471
Number of leaves 27/05/2021	0.449
Aerial length 03/06/2021	0.375
Root length 03/06/2021	0.359
Number of tillers 03/06/2021	0.467
Aerial length 09/06/2021	0.487
Root length 09/06/2021	0.331
Number of tillers 09/06/2021	0.569
Number of ears 24/06/2021	-0.357
Root length 24/06/2021	0.3116

Source: Authors' calculations.

According to Zhang et al. (1990), root growth rate, root yield, and root height were lowest for seeds with low phosphorus content in barley21 days after planting. Besides, the highest root dry weight and the fastest spike emergence were observed in seedlings grown from seeds with higher phosphorus content (Thomson and Bolger, 1993). These findings are consistent with those of Derrick and Ryan (1998), who argue that seed P concentration and seed mass after three weeks, had a substantial beneficial impact on seedling shoot dry mass; in other words, shoot dry mass and seed P content had a positive correlation. After three weeks, the root dry mass and seed P content likewise showed a positive correlation.

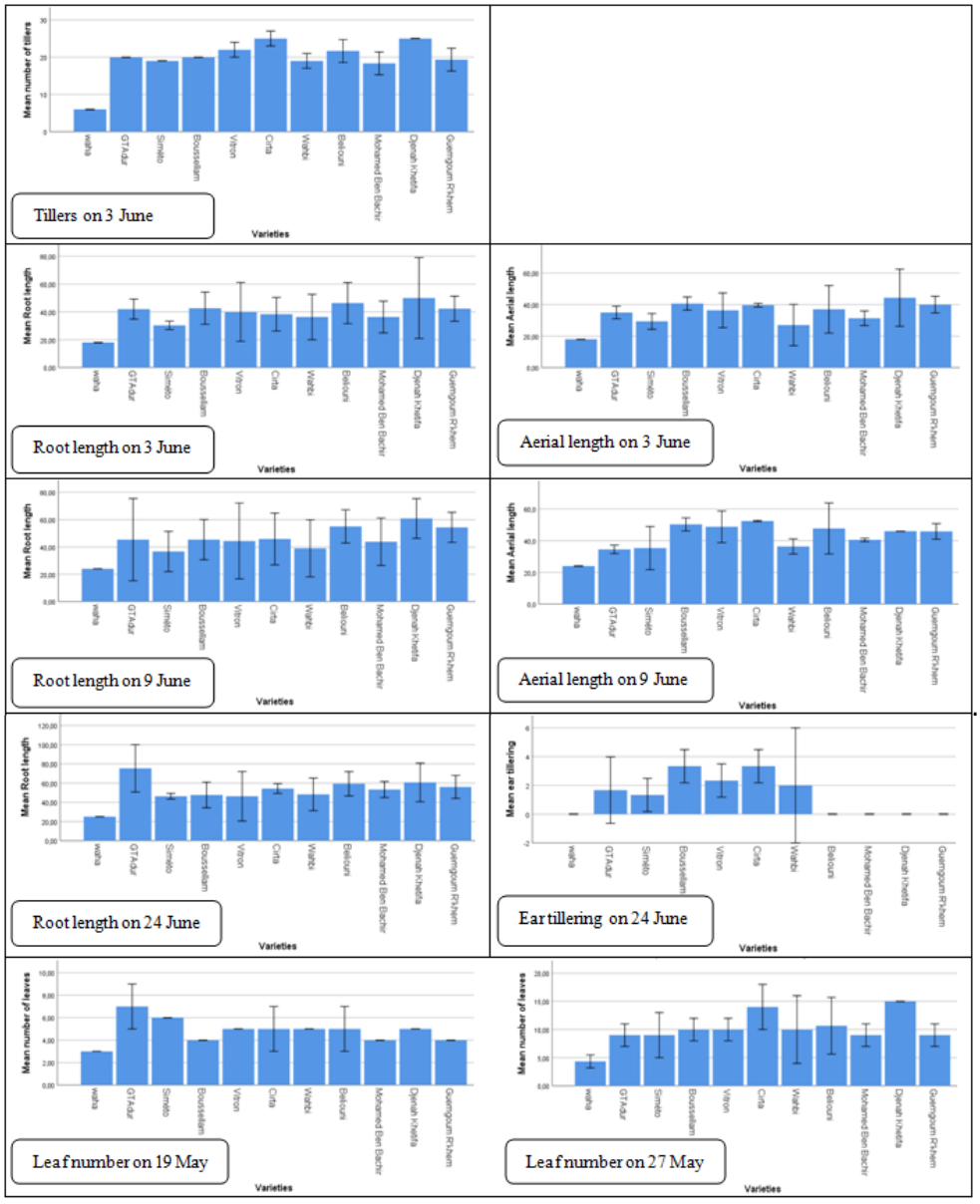


Figure 3. Agro-morphological parameters of the studied varieties. The values represent means ± standard deviation. Lengths are indicated in 'cm'.
Source: Authors' own data.

The results of the present study, which are supported by the results of previous studies, showed that seed phosphorus content had a significant effect on different organs, and that this effect was independent of external P supply. For instance, in the study on subterranean clover seed (*Trifolium subterraneum* cv. Dalkeith) with phosphorus concentrations of 0.75% (high P seed) and 0.48% (low P seed) and of uniform size, Thomson and Bolger (1993) found that seedling emergence numbers were 35% greater for the high P seed, and this effect was independent of external P supply. They also found that leaf emergence was faster and shoot dry weight was greater for seedlings grown from high seed P compared with seedlings grown from low seed P, but only when external P supply was deficient for plant growth.

White and Veneeklas (2012) have suggested that this relation between phosphorus seed content and root length is likely due to faster initial root growth, which provides seedlings with earlier access to growth-limiting resources, such as water and mineral elements. Furthermore, a previous study has indicated that the genotype developing a greater root length is the most efficient at using phosphorus, and one aspect of this efficiency is that root development performance was correlated with the initial phosphorus reserve of the grain (Schweiger et al., 1995). The seed P reserves can sustain maximal growth of cereal seedlings for several weeks after germination, until the plant has three or more leaves and an extensive root system (White and Veneeklas, 2012). Seed P is the only phosphorus source available to sustain the initial growth of seedlings and, upon germination, seed P reserves are rapidly mobilised and translocated to emerging root and shoot tissues (Schweiger et al., 1995). This P source is subsequently supplemented by P uptake by the developing root system. Thus, greater seed P reserves allow seedlings to establish faster and ultimately produce plants with higher yields (Zhu and Smith, 2001). Indeed, according to Marco and De (1990), three batches of uniform-weight wheat seeds with phosphate (P) contents of 0.14, 0.17, and 0.19% were seeded in soil treated with various P treatments. The faster the seedlings emerged, the greater the seed P content. All plants cultivated at the maximum applied P concentration were comparable in size by 25 days after planting, however plants from seeds with higher P concentrations had an advantage with lower applied P. Besides, in a study to determine the relative contribution of seed P reserves and exogenous P to maize nutrition during the early stages of growth, Nadeem et al. (2011) stated that, although the two P supply processes overlapped in time, seed P was the main source of P during the early stages of growth. Of the total P in the seed, 60% and 92% were transferred to the growing seedlings by the 7^{th} and 17^{th} days after sowing, respectively, after which seed P ceased to be a significant source of P for growth.

Conclusion

The first result worth mentioning is the variability observed in the different studied morphological characters, including the root system growth, among the 11 durum wheat varieties studied. In general, this variability is characterised by its proportional relationship with grain phosphorus content. This suggests that higher seed phosphorus content has contributed to the better initial growth of certain varieties, which may prompt consideration of this parameter when selecting durum wheat varieties for areas with low phosphorus availability at sowing. Additionally, this approach aligns with a broader vision of sustainability by reducing the use of phosphate fertilisers.

The Cirta, GTA dur, Beliouni, Djennah Khetifa and Guemgoum R'khem varieties have high phosphorus levels and are characterised by a long root system and a large number of spikes. As a result, these varieties produce good yields when improved, as is the case for Cirta and GTA dur, and show better adaptation to difficult conditions when they are local varieties, such as Beliouni, Djennah Khetifa, or Guemgoum R'khem.

As recommendations and future directions, raising awareness among cereal farmers about the use of varieties with high phosphorus content should be part of a broader approach to improve productivity and sustainability, enabling individual fields to yield better and farms to become more resilient.

References

Azeke, M. A., Egielewa, S. J., Eigbogbo, M. U., & Ihimire, I. G. (2011). Effect of germination on the phytase activity, phytate and total phosphorus contents of rice (*Oryza sativa*), maize (*Zea mays*), millet (*Panicum miliaceum*), sorghum (*Sorghum bicolor*) and wheat (*Triticum aestivum*). *Journal of Food Science and Technology*, *48*(6), 724–729. https://doi.org/10.1007/s13197-010-0186-y

Bernardino, K. C., Pastina, M. M., Menezes, C. B., De Sousa, S. M., Maciel, L. S., Carvalho Jr, G., Guimarães, C. T., Barros, B. A., Luciano da Costa e Silva., Carneiro, P. C. S., Schaffert, R. E., Kochian, L. V., & Magalhaes, J. V. (2019). The genetic architecture of phosphorus efficiency in sorghum involves pleiotropic QTL for root morphology and grain yield under low phosphorus availability in the soil. *BMC Plant Biology*, *19*, 1–15. https://doi.org/10.1186/s12870-019-1689-y

Bolland, M. D., & Paynter, B. H. (1990). Increasing phosphorus concentration in seed of annual pasture legume species increases herbage and seed yields. *Plant and Soil, 125*, 197–205. https://doi.org/10.1007/BF00010657

Burnett, V. F., Newton, P. J., & Coventry, D. R. (1997). Effect of seed source and seed phosphorus content on the growth and yield of wheat in north-eastern Victoria. *Australian Journal of Experimental Agriculture, 37*(2), 191–197. https://doi.org/10.1007/BF00010657

Cakmak, I. (2002). Plant nutrition research: Priorities to meet human needs for food in sustainable ways. *Plant and Soil*, *247*, 3–24. https://doi.org/10.1023/A:1021194511492

Derrick, J. W., & Ryan, M. H. (1998). Influence of seed phosphorus content on seedling growth in wheat: Implications for organic and conventional farm management in South East Australia.

Biological Agriculture & Horticulture, 16(3), 223–237. https://doi.org/10.1080/01448765.1998.10823197

Dubos, C. (2001). *Réponse moléculaire de jeunes plants de pin maritime soumis à un stress hydrique en milieu hydroponique.* Doctoral dissertation, Université Henri Poincaré, Nancy.

Gervy, R. (1970). *Les phosphates et l'agriculture.* Paris: DUNOD.

Guo, L., Yu, Z., Li, Y., Xie, Z., Wang, G., Liu, X., Liu, J.,Liu, J., & Jin, J. (2022). Plant phosphorus acquisition links to phosphorus transformation in the rhizospheres of soybean and rice grown under CO2 and temperature co-elevation. *Science of the Total Environment*, *823*, 153558. https://doi.org/10.1016/j.scitotenv.2022.153558

Hazmoune, T. (1994). Contribution à la caractérisation de l'appareil racinaire de quelques variétés de blé dur (*Triticum durum* Desf.) en relation avec les composants de rendement. Magister dissertation. University of Batna.

Johnson, B. (1993). Effect of various sources of nitrogen and phosphorus on growth and yield of two wheat genotypes. University of Agriculture.

Johnston, A., & Steen, I. (2000). Understanding Phosphorus and its use in agriculture. EFMA.

Karandashov, V., & Bucher, M. (2005). Symbiotic phosphate transport in arbuscular mycorrhizas. *Trends in Plant Science*, *10*(1), 22–29. https://doi.org/10.1016/j.tplants.2004.12.003

Liao, M., Hocking, P. J., Dong, B., Delhaize, E., Richardson, A. E., & Ryan, P. R. (2008).Variation in early phosphorus-uptake efficiency among wheat genotypes grown on two contrasting Australian soils. *Australian Journal of Agricultural Research*, *59*(2), 157–166. https://doi.org/10.1071/AR06311

Lin, C., Wang, Y., Liu, M., Li, Q., Xiao, W., & Song, X. (2020). Effects of nitrogen deposition and phosphorus addition on arbuscular mycorrhizal fungi of Chinese fir (*Cunninghamia lanceolata*). *Scientific Reports*, *10*(1), 12260. https://doi.org/10.1038/s41598-020-69213-6

Liu, G., Li, J., & Li, Z. (1998). Effect from horizontally dividing the root system of wheat plants having different phosphorus efficiencies. *Journal of Plant Nutrition*, *21*(12), 2535–2544. https://doi.org/10.1080/01904169809365585

Mahlangu, R. I. S., Maboko, M. M., Sivakumar, D., Soundy, P., & Jifon, J. (2016). Lettuce (*Lactuca sativa* L.) growth, yield and quality response to nitrogen fertilization in a non-circulating hydroponic system. *Journal of Plant Nutrition, 39*(12), 1766–1775. https://doi.org/10.1080/01904167.2016.1187739

Marco, D., & De, M.D. (1990). Effect of seed weight, and seed phosphorus and nitrogen concentrations on the early growth of wheat seedlings. *Australian Journal of Experimental Agriculture, 30*, 545–549. https://doi.org/10.1071/EA9900545

Massle, J. (1985). Competition among tillers in winter wheat: consequences for growth and development of the crop. In: *Wheat growth and modelling* (pp. 33–54). Boston, MA: Springer US. https://doi.org/10.1007/978-1-4899-3665-3_4

Nadeem, M., Mollier, A., Morel, C., Vives, A., Prud'homme, L., & Pellerin, S. (2011). Relative contribution of seed phosphorus reserves and exogenous phosphorus uptake to maize (*Zea mays* L.) nutrition during early growth stages. *Plant and Soil*, *346*(1), 231–244. https://doi.org/10.1007/s11104-011-0814-y

Palta, J., & Watt, M. (2009). Vigorous crop root systems: form and function for improving the capture of water and nutrients. *Applied crop physiology: boundaries between genetic improvement and agronomy. Academic, San Diego*, 309–325.

Ros, C., Bell, R. W., & White, P. F. (1997). Effect of seed phosphorus and soil phosphorus applications on early growth of rice (*Oryza sativa* L.) cv. IR66. *Soil Science and Plant Nutrition, 43*(3), 499–509. https://doi.org/10.1080/00380768.1997.10414777

Schweiger, P. F., Robson, A. D., & Barrow, N. J. (1995). Root hair length determines beneficial effect of a Glomus species on shoot growth of some pasture species. *New Phytologist*, *131*(2), 247–254. https://doi.org/10.1111/j.1469-8137.1995.tb05726.x

Thomson, C. J., & Bolger, T. P. (1993). Effects of seed phosphorus concentration on the emergence and growth of subterranean clover (*Trifolium subterraneum*). In: *Plant Nutrition—from Genetic Engineering to Field Practice: Proceedings of the Twelfth International Plant Nutrition Colloquium, 21–26 September 1993, Perth, Western Australia* (pp. 353-356). Springer Netherlands. https://doi.org/10.1007/BF00025038

Vogel, A. I., & Mendham, J. (1989). Vogel's textbook of quantitative chemical analysis.

White, P., & Veneklaas, E. (2012). Nature and nurture: the importance of seed phosphorus content. *Plant and Soil, 357*, 1–8. https://doi.org/10.1007/s11104-012-1128-4

Zhang, M., Nyborg, M., & McGill, W. B. (1990). Phosphorus concentration in barley (*Hordeumvulgare* L.) seed: Influence on seedling growth and dry matter production. *Plant and Soil*, *122*, 79–83. https://doi.org/10.1007/BF02851912

Zhu, Y. G., & Smith, S. E. (2001). Seed phosphorus (P) content affects growth, and P uptake of wheat plants and their association with arbuscular mycorrhizal (AM) fungi. *Plant and Soil*, *231*, 105–112. https://doi.org/10.1023/A:1010320903592

Received: 13 September 2024
Accepted: 14 March 2026

UTICAJ SADRŽAJA FOSFORA U SEMENU NA RAST BILJAKA 11 SORTI TVRDE PŠENICE (*TRITICUM DURUM* DESF.)

Lakhdar T. Mazouz[1,2] i Salim A. Lebbal[3*]

[1]Agro-veterinary Institute, Batna 1 University, Batna, Algeria
[2]Biotechnology, Water, Environment and Health Laboratory, Abbes Laghrour University, Khenchela, Algeria
[3]Laboratory of Management, Conservation and Valorization of Agricultural and Natural Resources (LMCVANR), Abbes Laghrour University, Khenchela, Algeria

R e z i m e

Fosfor ima važnu ulogu u rastu biljaka. U tom kontekstu, preporučuje se primena alternativnih metoda, kao što je gajenje odgovarajućih sorti radi zadovoljenja potreba biljaka za hranljivim materijama i smanjenja negativnih uticaja hemijskih đubriva. Stoga je cilj ovog istraživanja bio da se ispita uticaj sadržaja fosfora u semenu na rast biljaka 11 sorti tvrde pšenice (*Triticum durum* Desf.) različitog porekla. Ispitivane su različite morfološke osobine i njihov odnos sa količinama fosfora. Ove osobine obuhvataju dužinu korena i stabla, broj listova, broj bočnih izdanaka (bokora) i broj klasića. Dobijeni rezultati su pokazali značajne razlike u ispitivanim morfološkim osobinama među proučavanim sortama pšenice. Pored toga, utvrđena je pozitivna korelacija između nivoa fosfora u semenu i pojedinih morfoloških osobina, naročito dužine stabla, broja listova i izdanaka, kao i dužine korena. Zaključuje se da je veći sadržaj fosfora u semenu pomogao pojedinim sortama da ostvare dobar početni rast. Ovo ukazuje na potrebu da se ovo svojstvo uzme u obzir prilikom izbora sorti tvrde pšenice za područja u kojima je oskudan sadržaj fosfora u zemljištu u vreme setve. Takođe, ovo se uklapa u širu globalnu viziju o poboljšanju održivosti poljoprivredne proizvodnje, kroz smanjenu upotrebu fosfatnih đubriva.

Ključne reči: tvrda pšenica, održivost, morfološki parametri, korelacija, genotip.

Primljeno: 13. septembra 2024.
Odobreno: 14. marta 2026.

[*]Autor za kontakt: e-mail: salim-leb@hotmail.com

Journal of Agricultural Sciences (Belgrade) https://doi.org/10.2298/JAS2601015R
Vol. 71, No. 1, 2026 UDC: 634.23-154.74
Pages 15-26 Original scientific paper

RESPONSE OF POLLEN GERMINATION AND POLLEN TUBE GROWTH OF SOUR CHERRY GENOTYPES TO TEMPERATURE

Vera S. Rakonjac[1], Slavica D. Čolić[2*], Slađana A. Marić[3], Milena R. Đorđević[3], Ivana S. Glišić[3] and Sanja M. Radičević[3]

[1]University of Belgrade, Faculty of Agriculture, Belgrade, Serbia
[2]Institute for Science Application in Agriculture, Belgrade, Serbia
[3]Fruit Research Institute, Čačak, Serbia

Abstract: The aim of this study was to determine the influence of genotype, environmental factors across three consecutive years (2022–2024), and incubation temperature (17°C and 20°C) on *in vitro* pollen germination and pollen tube length in sour cherry, as well as to monitor flowering phenology during the same period. Six cherry genotypes were used: two cultivars created in the Republic of Serbia ("Sofija" and "Šumadinka"), one introduced cultivar ("Érdi Bötermö"), one autochthonous cultivar ("Feketićka") and two promising genotypes ("GV-6" and "GV-10"). The flowering phenophase was recorded as the beginning, full and end of flowering. To determine germination and pollen tube length, pollen was collected and sown in Petri dishes on an agarose-sucrose nutrient medium and incubated at the two temperatures for 24 h. The obtained results demonstrated that flowering time varied between years in terms of date and duration. *In vitro* pollen germination ranged from 3.16% to 53.75%, while pollen tube length ranged from 225.6 μm to 960.2 μm. Significant differences were recorded between most sour cherry genotypes for both pollen germination and tube length. Differences between years were also significant, while incubation temperatures did not significantly affect the evaluated traits. The significant influence of many interactions, as established by analysis of variance, indicates that the response of genotypes to environmental conditions was different, which could be explained by differences in their stability. Knowledge of pollen germination and pollen tube growth plays a crucial role in understanding the value of a cultivar as a pollinator, both for commercial cultivation and breeding.

Key words: *Prunus cerasus*, flowering phenophase, *in vitro* pollen germination, pollen tube length.

[*]Corresponding author: e-mail: slavicacol@yahoo.com

Introduction

Sour cherry (*Prunus cerasus* L.) is a unique fruit crop that is cultivated worldwide in many regions across the temperate zone due to its distinctive tart flavour and versatile uses. In the Republic of Serbia, sour cherry is one of the most important fruit species in terms of harvested area, production and economic value (Milošević et al., 2022), and together with raspberry, it represents one of the most important exporting fruits (Lukić et al., 2015). In this regard, several sour cherry breeding programmes are currently underway in Serbia to develop superior cultivars.

In fruit trees, successful pollination accompanied by effective fertilization is critical for optimising both the high quality and quantity of fruit yield. Nonfunctional or poor pollen production is a limiting factor for fertilisation (Uzun et al., 2018). Moreover, when growing self-incompatible or partially self-compatible genotypes, such as certain sour cherry cultivars, one of the most important factors for successful production is the appropriate varietal design of the orchard. In addition to compatibility with the main cultivar and overlapping flowering time, a pollinating cultivar should have good pollen quality (Nikolić et al., 2012). Therefore, knowledge of the viable pollen percentage and germination capacity is very important when choosing and selecting the appropriate polleniser (Nyéki et al., 2008). Understanding pollen functional ability is also important in breeding programmes, as it influences the prediction of hybrid formation (Davarynejad et al., 2008).

To be an effective pollen donor, a cultivar/genotype must have high-quality pollen. Pollen germination and tube growth rates are the most important characteristics related to pollen quality and effective pollination. Due to its allopolyploid nature and irregularities in microsporogenesis, sour cherry is characterised by lower pollen germination compared to other diploid species in the genus *Prunus* (Cerović, 1991; Fotirić Akšić et al., 2016). In order to determine the actual amount of viable pollen, germination tests are necessary (Bolat and Pirlak, 1999). Parfitt and Ganeshan (1989) examined the validity of seven pollen viability tests in *Prunus* species and found that the *in vitro* germination test on agarose–sucrose medium had the highest degree of validity and a high correlation for pollen viability assessment.

Pollen performance is clearly affected by genetic factors and represents one of the important criteria for determining the genotypes (Rakonjac et al., 2025). In addition to genetic factors, the percentage of pollen germination and tube growth are also influenced by environmental and management factors such as climate, mutagens, fertilisers, herbicides, and pesticides (Uzun et al., 2018; Corneanu et al., 2021). Temperature is one of the most important environmental factors that could affect pollen performance (Hedhly et al., 2005). Interest in the effect of

temperature on reproductive biology has increased due to the global rise in temperature, which impacts different stages of the reproductive process, such as the flowering phenophase (Osterman et al., 2024) and pollen germination and pollen tube growth (Fotirić Akšić et al., 2014; Irenaeus and Mitra, 2014; Feldmane et al., 2017; Beltrán et al., 2019).

Considering the importance of understanding the pollen functional ability from both commercial cultivation and breeding perspectives, the aim of this study was to evaluate the influence of environmental factors and incubation temperature on pollen germination and pollen tube length in six sour cherry genotypes under *in vitro* conditions.

Material and Methods

The study investigated the flowering phenophase and the functional ability of pollen in six sour cherry (*Prunus cerasus* L.) genotypes including two cultivars recognised in the Republic of Serbia ("Sofija" and "Šumadinka"), one introduced cultivar ("Érdi Bötermö"), one autochthonous cultivar ("Feketićka"), and two promising genotypes ("GV-6," and "GV-10"). The experiments were carried out at the experimental farm of the Faculty of Agriculture, Belgrade, "Radmilovac" ("Feketićka" and "Šumadinka") and at the experimental site of the Fruit Research Institute, Čačak, "Ljubić" ("Érdi Bötermö", "Sofija", "GV-6," and "GV-10"). Standard cultural practices (pruning, fertilisation, pest, and disease control) were applied in the orchards.

During the examination period (January–April, 2022–2024) the mean, minimum and maximum air temperatures were monitored at the nearest meteorological stations to evaluate the influence of the climate on the studied properties. Based on these data, mean, minimum, and maximum monthly temperatures, as well as the number of frosty days, were calculated. The blooming period was determined based on the beginning, full and end of flowering (growth stages 61, 65 and 69, respectively, according to the BBCH scale) (Meier, 2018). As indicators of the functional ability of pollen, *in vitro* germination (%) and tube growth (μm) were studied.

To collect pollen samples, flower buds of each genotype were taken from the branches at the late balloon stage and transferred to the laboratory. Anthers were removed from the flower buds, transferred to Petri dishes, and dried at room temperature (24–48 h) until pollen was released. Pollen from each genotype was placed in three Petri dishes (three replicates) on a nutrient medium containing 0.7% agar and 15% sucrose. The dishes were then transferred to "FOC 225I" incubators (Velp Scientifica, Usmate, Italy) and maintained at two temperatures (17°C and 20°C). After 24 hours of incubation, pollen germination and tube growth were stopped by adding formaldehyde. For each replication, at least 300 pollen grains

were counted to determine the germination percentage. Pollen was considered germinated when the pollen tube length exceeded the diameter of the pollen grain. For pollen tube growth assessment, 20 randomly selected pollen tubes per replicate were measured. Observations were made using a Leica DM2000 light microscope with a Leica DFC320 digital camera and a Leica IM 100 image processing software.

The experiment was set up as a three-factorial (genotype, temperature and year) design. For the *in vitro* pollen germination, as the values were expressed as percentages, an arcsine square-root transformation was applied prior to analysis. The data were statistically analysed by analysis of variance (ANOVA) at the 0.05 and 0.01 significance levels, and the Tukey's test for post hoc comparison at the 0.05 significance level, using the statistical software package STATISTICA, version 8 (StatSoft, Inc., Tulsa, OK, USA). Based on the expected mean squares from the three-factorial ANOVA, the variance components were calculated and expressed in % (Annicchiarico, 2002).

Results and Discussion

A similar trend in the values of mean, minimum and maximum air temperatures, as well as the number of frosty days, was recorded at Radmilovac and Ljubić in all three years (Table 1), which confirms that both sites are within typical fruit-growing areas of the Republic of Serbia.

Table 1. Air temperatures for the period January–April at the Belgrade and Čačak sites (2022–2024).

Climatic parameter	Year	Belgrade				Čačak			
		January	February	March	April	January	February	March	April
Mean air temperature (°C)	2022	2.8	7.6	7.2	12.5	1.1	4.3	5.4	10.8
	2023	4.9	3.9	9.0	10.3	3.9	3.5	8.4	9.7
	2024	2.6	9.7	10.6	14.6	2.1	9.1	10.7	14.2
Minimum air temperature (°C)	2022	-8.8	-0.8	-5.4	0.8	-13.0	-3.4	-7.3	-1.2
	2023	-0.9	-9.2	-3.8	-0.6	-1.4	-8.7	-2.9	-1.2
	2024	-9.9	-4.8	-0.8	-1.2	-9.0	-3.4	-0.2	-0.3
Maximum air temperature (°C)	2022	6.1	18.5	23.0	25.5	14.5	15.2	23.0	25.8
	2023	16.9	19.0	24.1	23.0	16.0	21.6	23.6	23.6
	2024	18.6	20.6	28.6	30.4	19.4	20.9	28.9	30.4
Number of frosty days	2022	17	1	9	0	23	11	20	2
	2023	5	12	6	4	10	15	7	3
	2024	21	4	1	1	19	3	1	1

Source: Data from meteorological stations on "Radmilovac" experimental farm of the Faculty of Agriculture, Belgrade and experimental site "Ljubić" of the Fruit Research Institute, Čačak.

Flowering phenology is summarised in Figure 1. In 2022, flowering stages occurred later than in 2023 and 2024. In 2023, two distinct groups of genotypes were clearly separated based on the beginning of flowering. The first group included "Šumadinka", "Érdi Bötermö" and "Feketićka" (30 March, 31 March, and 2 April, respectively), while the second group comprised "GV 6", "GV 10" and "Sofija" (8, 9 and 12 April, respectively). Differences in the duration of this phenophase, which ranged from 11 days ("Sofija") to 22 days ("Feketićka"), were also observed. The smallest differences in both the beginning and duration of flowering were recorded in 2024.

In all three years, "Sofija" exhibited the latest beginning of flowering, which allows it to avoid damage from late frosts. In addition to the genetic factors, the flowering phenophase was also influenced by air temperatures. The large number of frost days in March 2022 delayed the start of flowering for all genotypes, while high average and maximum temperatures in March and April 2024 led to explosive flowering.

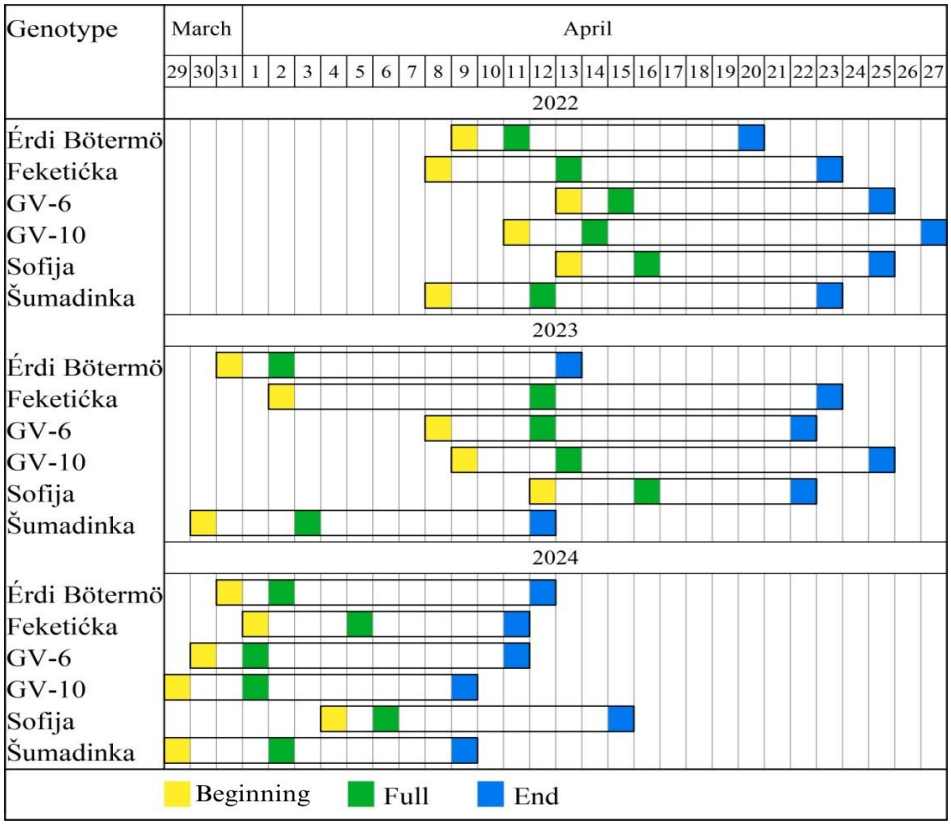


Figure 1. Flowering phenology of sour cherry genotypes (2022–2024).
Source: Authors observation.

In vitro pollen germination ranged from 2.42% in the "Érdi Bötermö" cultivar at 20°C in 2024 to 53.75% in the "GV 10" genotype at 17°C in 2023 (Table 2). "Šumadinka" exhibited the smallest variation in pollen germination across experimental variants (36.97%–44.53%), while "Sofija" showed the largest variation (6.57%–52.27%). This indicates that the response of these two cultivars to environmental conditions was different, which could be explained by differences in their stability.

Table 2. Pollen germination (%) of six sour cherry genotypes at 17°C and 20°C (2022–2024).

Genotype	17°C				20°C			
	2022	2023	2024	Average	2022	2023	2024	Average
Érdi Bötermö	18.76	22.69	3.16	14.87	21.45	22.71	2.42	15.52
Feketićka	15.54	29.62	24.43	23.20	14.77	29.53	19.50	21.27
GV-6	17.10	27.25	13.50	19.28	16.18	31.98	14.44	20.87
GV-10	34.10	53.75	22.10	36.65	39.82	48.38	29.92	39.37
Sofija	22.15	52.27	6.57	27.00	18.41	48.26	6.57	24.41
Šumadinka	36.97	44.53	38.03	39.84	43.74	44.09	38.25	42.03
Average	24.10	38.35	17.97	26.81	25.73	37.49	18.52	27.25

Source: Authors' own research.

The minimum pollen tube length (225.6 μm) was observed in the cultivar 'Érdi Bötermö' at 17°C in 2024, while the maximum length (960.2 μm) was recorded in "Šumadinka" at 17°C in 2022 (Table 3). Opposite trends were observed with respect to incubation temperatures. Namely, four genotypes ("Érdi Bötermö", "Feketićka", "GV 6" and "Šumadinka") had higher pollen tube lengths at 17°C, whereas in the other two genotypes ("GV 10" and "Sofija"), higher values were recorded at 20°C.

Table 3. Pollen tube length (μm) of six sour cherry genotypes at 17°C and 20°C (2022–2024).

Genotype	17°C				20°C			
	2022	2023	2024	Average	2022	2023	2024	Average
Érdi Bötermö	767.1	576.7	225.6	523.1	657.3	601.2	265.0	507.8
Feketićka	833.6	735.2	535.2	701.3	725.4	801.9	556.4	694.6
GV-6	701.7	498.7	286.0	495.5	478.1	668.5	301.4	482.7
GV-10	523.0	355.8	240.5	373.1	629.5	545.9	401.7	525.7
Sofija	361.7	362.0	253.4	325.7	472.0	573.1	285.3	443.4
Šumadinka	960.2	716.5	585.2	754.0	878.2	686.4	312.9	625.8
Average	691.2	540.8	354.3	528.8	640.1	646.2	353.8	546.7

Source: Authors' own research.

A high percentage of germinated pollen does not necessarily correlate with a high growth rate of pollen tubes. This phenomenon has been previously observed in different fruit trees (Bolat and Pirlak, 1999; Miaja et al., 2000; Sharafi, 2011; Stosser et al., 1996), indicating that these two traits are genetically independent.

Table 4. Mean squares (MS) and variance components (%) from three-factorial ANOVA for pollen germination and pollen tube length.

Source of variation	df	*In vitro* pollen germination		Pollen tube length	
		MS	%	MS	%
Genotype (G)	5	1,897.35**	34.3	29,8605.4**	23.2
Year (Y)	2	3,606.14**	36.3	95,7885.8**	44.0
Temperature (T)	1	5.20ns	0.0[a]	8,647.4ns	0.0
G × Y	10	366.05**	22.9	32,613.8**	6.0
G × T	5	21.94ns	0.5	46,884.9**	8.3
Y × T	2	13.96ns	0.0	57,388.1**	4.5
G × Y × T	10	24.07*	1.8	12,639.7*	4.4
Error	72	10.58	4.3	5,384.6	9.7

[ns] not significant, * $p < 0.05$, ** $p < 0.01$, [a] negative values expressed as 0.
Source: Authors' own calculations.

As shown in Table 4, the ANOVA results indicate a significant effect of genotype and year, but no significant effect of temperature on the variability of pollen germination and pollen tube length. In addition, a significant influence of the G × Y and G × Y × T interactions on pollen germination was observed. For pollen tube length, all possible interactions were also significant.

Variance components analysis (Table 4) showed that year (36.3%), genotype (34.3%) and their interaction (22.9%) contributed most to the total variability of *in vitro* pollen germination. The variability of pollen tube length was mainly determined by year (44.0%) and genetic differences among sour cherry genotypes (23.2%). The remaining sources of variation accounted for less than 10% of the total variability of these traits.

Taking into consideration all three years and both incubation temperatures, it was shown that "Šumadinka" (40.9%) and "GV-10" (38.0%) had significantly the highest pollen germination, while "Érdi Bötermö" (15.2%) was characterised by the lowest pollen germination value (Figure 2). According to previous studies, the *in vitro* pollen germination in sour cherry was found to range between 7% and70% (Milutinovic et al., 1998), 24%–49% (Bolat and Pirlak, 1999), 29%–65% (Davarynejad et al., 2008), 19%–67% (Szpadzik et al., 2008), 43%–62% (Milatović and Nikolić, 2014) and 32.7%–57.4% (Feldmane et al., 2017). The results obtained in the present study were in accordance with the above-mentioned results. Regarding the years, the highest average pollen germination was recorded

in 2023 (37.9%), followed by 2022 (24.9%) and 2024 (18.2%). Radičević et al. (2021) also reported a significant influence of the year on pollen germination in the studied sour cherry cultivars.

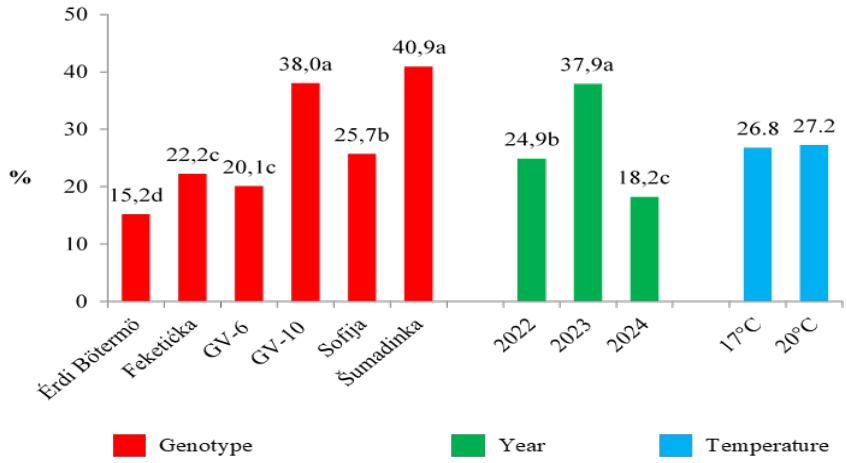


Figure 2. Mean values for the main factors (genotype, year and temperature) for *in vitro* pollen germination (%). Different letters indicate statistically significant differences ($p<0.05$) according to the Tukey's test.

Source: Authors' analysis.

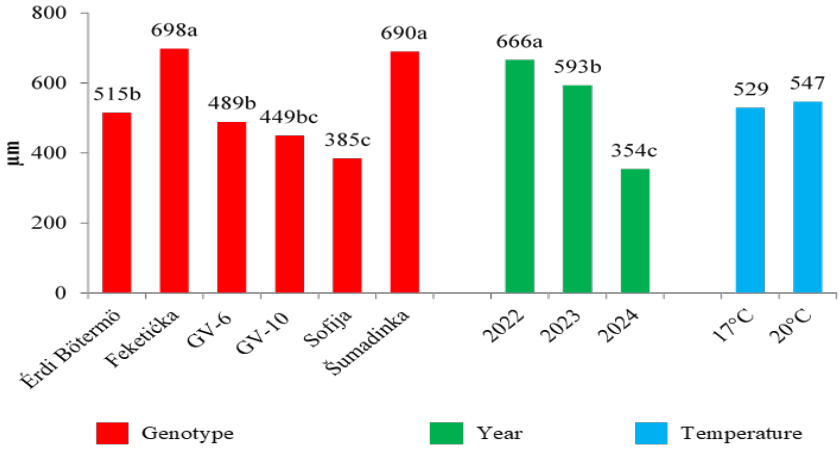


Figure 3. Mean values for the main factors (genotype, year and temperature) for pollen tube length (µm). Different letters indicate statistically significant differences ($p<0.05$) according to the Tukey's test.

Source: Authors' analysis.

Pollen tube growth showed a similar trend to that of pollen germination with respect to the main factors (Figure 3). This trait was modified not only by the genotype but also by weather conditions during the winter and spring periods of the study years. On average, “Feketićka” (698 μm) exhibited the longest pollen tubes, whereas “Sofija” (385 μm) had the shortest. Pollen tube length in 2023 (593 μm) was significantly higher than in 2024 (354 μm), but significantly lower than in 2022 (666 μm).

Several studies on the effect of temperature on sour cherry pollen germination have been published (Cerović and Ružić, 1992; Nenadovic-Mratinic, 1996; Pirlak, 2002; Hedhly et al., 2004; Milatović and Nikolić, 2014). According to these studies, the maximum pollen germination percentage and pollen tube length were obtained at a temperature of around 20°C. In our study, the absence of significant differences in pollen germination and tube length due to incubation temperature confirmed that both tested temperatures were within the optimal range.

Conclusion

The study contributes to the understanding of the factors influencing flowering phenology and pollen quality in sour cherry genotypes, which is essential for improving breeding programmes and optimising cultivation conditions. The obtained results show that both genetic factors and air temperatures influenced the flowering time. Frost conditions in March 2022 delayed flowering across all genotypes, while high temperatures in March/April 2024 caused explosive flowering. There was a wide variation in terms of pollen germination and pollen tube length. Variation in these characters was determined not only by genotype but also strongly influenced by environmental factors. Incubation temperatures (17°C and 20°C) did not significantly affect pollen germination or tube length, confirming that these temperatures were within the optimal range. Due to low pollen quality, “Érdi Bötermö”, “Feketićka” and “GV 6” were unlikely to achieve satisfactory yield after self-pollination and probably required appropriate pollinators for optimal fruit set.

Acknowledgements

This paper was supported by the Science Fund of the Republic of Serbia, GRANT No. 7739716: Genetic potential of Serbian autochthonous cherry genotypes for temperature-adaptable reproductive behavior and nutraceutical value—CherrySeRB, and by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contracts No. 451-03-34/2026-03/200116 and 451-03-33/2026-03/200045).

References

Annicchiarico, P. (2002). Genotype × environment interactions: challenges and opportunities for plant breeding and cultivar recommendations. FAO Plant Production and Protection Paper No. 174, FAO, Rome.

Beltrán, R., Valls, A., Cebrián, N., Zornoza, C., García Breijo, F., Reig Armiñana, J., Garmendia, A., & Merle, H. (2019). Effect of temperature on pollen germination for several *Rosaceae* species: influence of freezing conservation time on germination patterns. *PeerJ, 7,* e8195.

Bolat, I., & Pirlak, L. (1999). An investigation on pollen viability, germination and tube growth in some stone fruits. *Turkish Journal of Agriculture and forestry, 23*(4), 383–388.

Cerović, R. (1991). Citogenetičke osobine višnje u odnosu na polen. *Genetika, 23*(3), 247–258.

Cerović, R., & Ružić, Đ. (1992). Pollen tube growth in sour cherry (*Prunus cerasus* L.) at different temperatures. *Journal of Horticultural Science, 67*, 333–340.

Corneanu, M., Mineață I., & Golache I. E. (2021). Pollen viability and germination capacity of sweet cherry cultivars in the climate conditions of Romanian Northeastern area. *Lucrări ştiinţifice seria horticultură, 64*(2), 37–42.

Davarynejad, G. H., Szabó, Z., Nyéki, J., & Szabó, T. (2008). Phenological stages, pollen production level, pollen viability and in vitro germination capability of some sour cherry cultivars. *Asian Journal of Plant Sciences, 7,* 672–676.

Feldmane, D., Ruisa, S., Pole, V., Butac, M. M., & Militaru, M. (2017). Fruit set of several sour cherry cultivars in latvia influenced by weather conditions before and during flowering. *Proceedings of the Latvian Academy of Sciences. Section B. Natural, Exact, and Applied Sciences, 71*(3), 178–183.

Fotirić, Akšić, M., Cerović, R., Ercişli, S., & Jensen, M. (2016). Microsporogenesis and meiotic abnormalities in different 'Oblacinska' sour cherry (*Prunus cerasus* L.) clones. *Flora, 219,* 25–34.

Fotirić, Akšić, M., Rakonjac, V., Nikolić, D., Čolić, S., Milatović, D., Ličina, V., & Rahović, D. (2014). Effective pollination period in 'Oblačinska' sour cherry clones. *Genetika, 46*(3), 671–680.

Hedhly, A., Hormaza, J. I., & Herrero, M. (2005). Influence of genotype – temperature interaction on pollen performance. *Journal of Evolutionary Biology, 18*(6), 1494–1502.

Hedhly, A., Hormaza, J. I., & Herrero, M. (2004). Effect of temperature on pollen tube kinetics and dynamics in sweet cherry, *Prunus avium* (*Rosaceae*). *American Journal of Botany, 91,* 558–564.

Irenaeus, K. S. T., & Mitra, S. K. (2014). Understanding the pollen and ovule characters and fruit set of fruit crops in relation to temperature and genotype-a review. *Journal of Applied Botany and Food Quality, 87*, 157–167.

Lukić, M., Marić, S., Radičević, S., Milošević, N., Đorđević, M., & Leposavić, A. (2015). Current condition and prospects of fruit growing in the Republic of Serbia. *Journal of Mountain Agriculture on the Balkans, 18*(3), 541–573.

Meier, U. (2018). Growth stages of mono- and dicotyledonous plants: BBCH monograph. *Open Agrar Repositorium, 16.*

Miaja, M. L., Radicati, L., Porporato, M., Caramiello, R., Fossa, V., & Vallania, R. (2000). Morpho-physiological observations on pollen of sour cherry (*Prunus cerasus* L.) cultivars. *Acta Horticulturae, 514,* 311–320.

Milatović, D. P., & Nikolić, D. T. (2014). The effect of temperature on pollen germination and pollen tube growth of sour cherry cultivars. *Journal of Agricultural Sciences, 59*(1), 45–52.

Milošević, N., Glišić, I., Radičević, S., Marić, S., Đorđević, M., Milošević, T., Rakonjac, V., & Barać, G. (2022). An overview of Serbian autochthonous genotype selection in *Prunus* genus. *Journal of Pomology, 56,* 69–77.

Milutinovic, M., Rakonjac, V., & Nikolic, D. (1998). Functionality of pollen and fruit set in sour cherry cultivars. *Acta Horticulturae, 468,* 591–594.

Nenadovic-Mratinic, E. (1996). The influence of temperature, sucrose concentration and time on pollen germination and pollen tube growth in sour and sweet cherry. *Acta Horticulturae, 410,* 443–448.

Nikolić, D., Rakonjac, V., & Fotirić-Akšić, M. (2012). The effect of pollenizer on the fruit set of plum cultivar Čačanska najbolja. *Journal of Agricultural Sciences, 57*(1), 9–18.

Nyéki, J., Soltész, M., & Szabó, Z. (2008). Morphology, biology and fertility of flowers in temperate zone fruits. Academic Publisher, Budapest.

Osterman, J., Mateos-Fierro, Z., Siopa, C., Castro, H., Castro, S., & Eeraerts, M. (2024). The impact of pollination requirements, pollinators, landscape and management practices on pollination in sweet and sour cherry: A systematic review. *Agriculture, Ecosystems & Environment, 374,* 109163.

Parfitt, D. E., & Ganeshan, S. (1989). Comparison of procedures for estimating viability of Prunus pollen. *HortScience, 24*(2), 354–356.

Pirlak, L. (2002). The effects of temperature on pollen germination and pollen tube growth of apricot and sweet cherry. *Gartenbauwissenschaft, 67,* 61–64.

Radičević, S., Ognjanov, V., Marić, S., & Barać, G. (2021). The effect of genotype and temperature interaction on pollen performance in the pistils of autochthonous sour cherry cultivar 'Feketićka'. *Zemdirbyste-Agriculture, 108*(3), 271–278.

Rakonjac, V., Nikolić, D., Čolić, S., Glišić, I.S., Đorđević, M., Popovska, M., & Radičević, S. (2025). Investigation of pollen morphology and viability of sweet and sour cherry genotypes by multivariate analysis. *Microscopy research and technique, 88*(1), 42–52.

Sharafi, Y. (2011). *In vitro* pollen germination in stone fruit tree of *Rosaceae* family. *African Journal of Agricultural Research, 6*(28), 6021–6026.

Stosser, R., Hartman, W., & Anvari, S. F. (1996). General aspects of pollination and fertilization of pome and stone fruits. *Acta Horticulturae, 423,* 15–22.

Szpadzik, E., Jadczuk-Tobjasz, E., & Łotocka, B. (2008). Preliminary evaluation of pollen quality, fertility relations and fruit set of selected sour cherry cultivars in polish conditions. *Acta Agrobotanica, 61,* 71–77.

Uzun, A., Pinar, H., Gun, E., Yaman, M., & Yilmaz, S. (2018). Assessment of pollen quality of some apricot and cherry cultivars. *Current Trends in Natural Sciences, 7*(13), 292–296.

Received: 6 March 2025
Accepted: 11 March 2026

KLIJAVOST POLENA I DUŽINA POLENOVE CEVČICE KAO POKAZATELJI UTICAJA TEMPERATURE NA GENOTIPOVE VIŠNJE

Vera S. Rakonjac[1], Slavica D. Čolić[2*], Slađana A. Marić[3], Milena R. Đorđević[3], Ivana S. Glišić[3] i Sanja M. Radičević[3]

[1]Univerzitet u Beogradu, Poljoprivredni fakultet, Beograd, Srbija
[2]Institut za primenu nauke u poljoprivredi, Beograd, Srbija
[3]Institut za voćarstvo, Čačak, Srbija

R e z i m e

Cilj ovog istraživanja bio je da se utvrdi uticaj genotipa, faktora spoljašnje sredine tokom tri uzastopne godine (2022–2024) i temperature inkubacije (17°C i 20°C) na klijavost polena *in vitro* i dužinu polenovih cevčica kod višnje, uz istovremeno praćenje fenofaze cvetanja. Kao material korišćeno je šest genotipova višnje i to: dve sorte stvorene u Republici Srbiji („Sofija" i „Šumadinka"), jedna introdukovana sorta ("Érdi Bötermö"), jedna autohtona sorta („Feketićka") i dve perspektivne selekcije („GV-6" i „GV-10"). Fenofaza cvetanja je prikazana kroz početak, puno i kraj cvetanja. Da bi se utvrdila klijavost i dužina polenove cevčice, nakon ekstrakcije, polen je zasejan u Petrijeve posude na agarozno-saharoznu hranljivu podlogu i inkubiran na dve različite temperature tokom 24 h. Dobijeni rezultati su pokazali da je vreme cvetanja variralo između godina kako u pogledu datuma tako i u pogledu dužine trajanja. Klijavost polena i*n vitro* kretala se od 3,16% do 53,75%, dok se dužina polenove cevčice kretala od 225,6 μm do 960,2 μm. Ispoljene razlike između većine genotipova višnje bile su statistički značajne za klijanje polena i za dužinu polenovih cevčica. Takođe, razlike su bile značajne i između godina, dok temperature inkubacije nisu značajno uticale na varijabilnost ovih osobina. Značajan uticaj mnogih interakcija ustanovljen na osnovu analize varijanse ukazuje da je odgovor genotipova na uslove sredine bio različit, što se može objasniti razlikama u njihovoj stabilnosti. Poznavanje klijavosti polena i rasta polenovih cevčica ima ključnu ulogu u razumevanju vrednosti sorte kao oprašivača i sa aspekta komercijalnog gajenja i sa aspekta oplemenjivanja.

Ključne reči: *Prunus cerasus*, fenofaza cvetanja, klijavost polena *in vitro*, dužina polenove cevčice.

Primljeno: 6. marta 2025.
Odobreno: 11. marta 2026.

[*]Autor za kontakt: e-mail: slavicacol@yahoo.com

Journal of Agricultural Sciences (Belgrade) https://doi.org/10.2298/JAS2601027M
Vol. 71, No. 1, 2026 UDC: 631.67(479.24)
Pages 27-42 Original scientific paper

CHALLENGES TO EFFICIENT WATER USE IN AGRICULTURE IN AZERBAIJAN

Ramina R. Mustafayeva*, Ruhiyya M. Gambarova, Yegana A. Abbasova, Sabina H. Huseynova and Shahriyar A. Maharramov

Department of Agricultural Economics, Azerbaijan State Agricultural University, Ganja, Azerbaijan

Abstract: Sustainable food production increasingly depends on water resources and their rational and efficient use. Due to global climate change and desertification, freshwater shortages will become even more acute. Azerbaijan is a country extremely vulnerable to water shortages due to limited internal water resources, high dependence on transboundary rivers, growing climate risks, and the inefficiency of existing water infrastructure. Water scarcity is a key obstacle to agricultural development in the country, and existing irrigation systems are characterised by significant water losses and low efficiency. Given the above, the aim of our study is to identify problems of inefficient water use in agriculture and propose solutions. To assess the level of rational water use in agriculture, we examined indicators such as water withdrawal and consumption, water use for irrigation and agriculture, water losses due to economic activities, the impact of changes in average annual temperature on crop water needs, and the distribution of water resources by region. The results showed that significant water losses pose a serious problem for the agricultural sector and require immediate solutions.

Key words: water resources, agriculture, irrigation, climate change, water losses, efficiency.

Introduction

In the current context of demographic challenges, climate change, and intensifying competition for land and water resources, sustainable agricultural production increasingly depends on water resources and their rational and efficient use and conservation. This primarily involves the development and management of irrigation, including the efficient use of water resources in agriculture and the provision of water supply. Achieving food security is a priority in many countries, and agriculture must conserve water resources not only to feed a growing population but also for other purposes.

*Corresponding author: e-mail: ramina.mustafayeva@adau.edu.az

Global forecasts indicate that demand for freshwater will increase significantly in the coming decades due to population growth, changing diets, economic development, urbanisation, and climate change. According to the FAO, 3.2 billion people worldwide currently live in agricultural areas experiencing severe or very severe water stress, with 1.2 billion living in areas of severe water stress (FAO, 2020). Increasing competition for scarce water resources leads to tensions and conflicts between stakeholders, exacerbating inequalities in access to water, particularly for vulnerable groups.

Agriculture accounts for 70% of total global freshwater consumption, but in some developing countries this figure can reach 90% (UN, 2024). With global food demand expected to grow by 60% by 2050, agricultural water demand is only set to increase (FAO, 2017). Water scarcity poses a serious threat to life, livelihoods, and business stability (World Resources Institute, 2019). Over the past 50 years, global agricultural production has nearly tripled, and the area under cultivation has increased by 12%. More than 40% of this increase in food production comes from irrigated land, the area of which has doubled. Research indicates that the area of irrigated land increases by 0.6% per year (FAO, 2011).

Factors contributing to water scarcity include population growth and socioeconomic development, which increase demand for this valuable natural resource. The situation is exacerbated by the expected impacts of climate change, such as unpredictable rainfall and water supply. Income growth and urbanisation are leading to increased demand for water from industry, energy, and services, as well as changing diets, leading to greater demand for water-intensive foods such as meat and dairy. It is estimated that growing 1 kg of grain requires 1 to 3 tonnes of water, while producing a kilogram of beef requires up to 15 tonnes of water. The FAO estimates that providing a person with their daily food supply requires 2,000 to 5,000 litres of water (FAO, 2017).

The relevance of this study stems from the fact that Azerbaijan's water resources are limited compared to other countries in the South Caucasus, accounting for only 15% of the region's total. Approximately 70% of the country's annual water resources originate outside its borders, posing a high risk to water security. Climate change, increasing water consumption in neighbouring countries, and unstable river flows are weakening the resilience of agriculture. Under these circumstances, improving the economic efficiency of water use is becoming a strategic imperative.

In recent years, Azerbaijan has experienced longer droughts, uneven precipitation distribution, and rising temperatures. These factors, along with increasing agricultural water demand, are increasing irrigation costs and threatening farmers' incomes. Agriculture accounts for 80–85% of the country's freshwater resources. However, most irrigation systems are outdated, losses are high, and the yields of many crops are below potential (Smita, 2024). This

demonstrates the economic inefficiency of water use and highlights the need to increase the cost of production per cubic metre of water.

In this regard, a quantitative assessment of the economic efficiency of water use, regional differences, and the economic impact of water-saving technologies is relevant. Taking this into account, the aim of our study is to identify problems related to the irrational use of water resources in agriculture and to determine ways to address them.

The study examined a large number of articles and reports on the topic. Among the researchers' works are studies on the impact of climate change on water availability (Liu et al., 2022), the rational use of water in rural areas (Turan et al., 2023), the implementation of sustainable irrigation, the potential use of accumulated water reserves for irrigation (Schmitt et al., 2022), and issues related to the efficient use of virtual water (Yawson et al., 2013). The reviewed works predominantly focus on either global assessments of water scarcity, behavioural aspects of water use, or the technological potential for sustainable irrigation. However, the economic efficiency of water resource use in Azerbaijan's agriculture, taking into account climatic factors, institutional reforms, regional differences, and the dynamics of SDG 6.4.1 indicators, remains insufficiently studied.

Current water management problems significantly hinder agricultural development. Due to global warming and desertification, the freshwater shortage will become even more acute. Water scarcity reflects a shift from an engineering perspective, aimed at increasing supply to meet demand, to an economic perspective, that is, the efficient use of available water resources (Frone et al., 2012). To mitigate and address these issues, it is necessary to transition to managed water consumption and use water resources more efficiently. The objective of this study is to provide a comprehensive assessment of agricultural water use efficiency in Azerbaijan during 2010–2024, with particular attention to irrigation losses, climatic pressures, and structural constraints in water management.

Material and Methods

This study is based on a comprehensive analysis of secondary quantitative and qualitative data related to water resource use in agriculture in Azerbaijan. The empirical database includes official statistical data from the State Statistical Committee of the Republic of Azerbaijan, sectoral reports from the Ministry of Agriculture, and international datasets provided by the Food and Agriculture Organization of the United Nations (FAO), including the AQUASTAT – FAO's Global Information System on Water and Agriculture, as well as analytical materials from the World Bank and the World Resources Institute.

The study also incorporates national legal and policy documents regulating water management, with particular attention to the National Strategy on the Efficient Use of Water Resources (NSEUWR, 2024) and institutional reforms in the water sector. These documents are used to assess the regulatory and strategic framework governing agricultural water use.

The comparative analysis, based on national statistical data, covers the period 2010–2024, allowing us to identify medium- and long-term trends in water withdrawal, consumption, and water efficiency under changing climatic and economic conditions. A regional perspective was applied to capture spatial disparities in water availability and irrigation efficiency across the main economic regions of the country.

To assess the rationality and efficiency of water use in agriculture, a system of key indicators was employed, including: total water withdrawal from natural sources, water consumption by sector, with a focus on agriculture and irrigation, water losses during abstraction and transportation, water use efficiency indicators, and irrigation water supply per hectare of cultivated land. The agricultural water efficiency indicator was calculated using the internationally accepted SDG 6.4.1 methodology. To assess the impact of climate change on agricultural water demand, data on temperature anomalies and precipitation trends were analysed based on graphical and percentage comparisons in relation to irrigation volumes and crop water requirements. This enables identification of linkages between rising temperatures, increased evapotranspiration, and growing pressure on the irrigation system.

The methodological approach combines descriptive statistical analysis, comparative analyses, and trend analyses. Descriptive statistics were used to characterise the structure of water use and losses by sector. Comparative analyses were applied to evaluate differences in water availability, dependence and stress between Azerbaijan and other South Caucasus countries, as well as between regions within the country. Trend analysis was employed to examine temporal changes in water withdrawal consumption, irrigation demand, and water use efficiency indicators. The integrated use of statistical, comparative, and climate-related analyses provides a multidimensional assessment of water use efficiency in agriculture and allows identification of key structural and institutional factors contributing to water losses and inefficient water management.

Results and Discussion

Azerbaijan is among the countries with high water vulnerability, which is due to limited internal water reserves, high dependence on transboundary rivers (up to 70% of water resources are generated outside the country), as well as increasing climate risks, and the inefficiency of existing water infrastructure (World Bank, 2024). Azerbaijan's renewable freshwater reserves amount to 26.2 billion m^3, of

which 8.4 billion m^3 come from groundwater, 4.6 billion m^3 from local river flows, and 13.2 billion m^3 from transboundary surface waters. Of the renewable freshwater reserves 17.8 billion m^3 come from surface freshwater resources (NSEUWR, 2024).

Surface water resources are concentrated primarily in rivers. Seventy-five percent of Azerbaijan's territory lies within the Kura River basin. Approximately 70% of river water resources originate in neighbouring countries, while the remainder (local runoff) comes from internal rivers. During dry years, transboundary water resources sharply decline. At the same time, the water resources of the Kura and Araz rivers are significantly reduced as a result of their absorption by water intake structures in neighbouring countries. This creates serious difficulties in meeting the country's water needs.

Groundwater in Azerbaijan is of high quality. Namely, 16–17% of the water entering rivers ends up in groundwater. More than 2 billion m^3 of groundwater are used annually for agricultural irrigation and residential water supply. The total capacity of usable groundwater is estimated at 8–9 billion m^3 per year.

It should be noted that Azerbaijan is the most vulnerable country in the South Caucasus in terms of water resources. For comparison, Table 1 presents the main indicators of water resources in the countries of the South Caucasus, providing a reliable description.

Table 1. Distribution of water resources among the countries of the South Caucasus.

Indicators	Azerbaijan	Georgia	Armenia
Area	86,600 km^2	69,700 km^2	29,800 km^2
Population	10.3 million people	3.7 million people	3.09 million people
Renewable water resources	26.2 billion m^3	63 billion m^3	8 billion m^3
Number of rivers including	8,359 850 (number of rivers longer than 5 km) 24 (number of rivers longer than 100 km)	26,060 16 (number of rivers longer than 100 km)	9,480 379 (number of rivers longer than 10 km)
Large rivers	Kura (length 1,515 km), Araz (1,072), Samur	Kura, Rioni	Araz, Akhuryan
Groundwater reserves	8–9 billion m^3	18 billion m^3	4 billion m^3
Number of reservoirs	140	43	74
Water resources per capita	1,313 m^3/person/year	16,189 m^3/person/year	2,652 m^3/person/year
Water dependence	70%	8.2%	11.7%
Water stress	57.53%	4.21%	61.97%

Source: Authors' elaboration based on data from National Statistical Committees of countries and AQUASTAT – FAO's Global Information System on Water and Agriculture.

According to the data, Azerbaijan, despite its larger territory and population, has limited renewable water resources compared to Georgia, resulting in low per capita water availability (1,313 m³) and high water dependence (70%). Although Azerbaijan has many rivers, only a few are large and abundant, and groundwater reserves are limited. In contrast, Georgia is characterised by the most favourable water availability in the region: a high volume of renewable water resources, low water dependence (8.2%), and a minimal level of water stress (4.21%) create a sustainable water management system (AQUASTAT, 2025). Armenia occupies an intermediate position, but has the highest level of water stress (61.97%) despite relatively modest resources and a highly vulnerable water sector. Overall, the data confirm that the issue of rational water use, particularly in agriculture, is structurally and strategically significant for Azerbaijan.

The Kura and the Araz are the largest rivers in the Caucasus and the main sources of fresh water, irrigation, and hydroelectric power. The Kura River originates in Turkey, flows through Georgia, and then through Azerbaijan. It passes through the Kura-Araz Lowland and empties into the Caspian Sea. The total length of the Kura River is 1,515 km, of which 906 km are within the territory of the Republic of Azerbaijan. The main reservoirs, dams, and hydroelectric power plants are built on the Kura River (Figure 1).

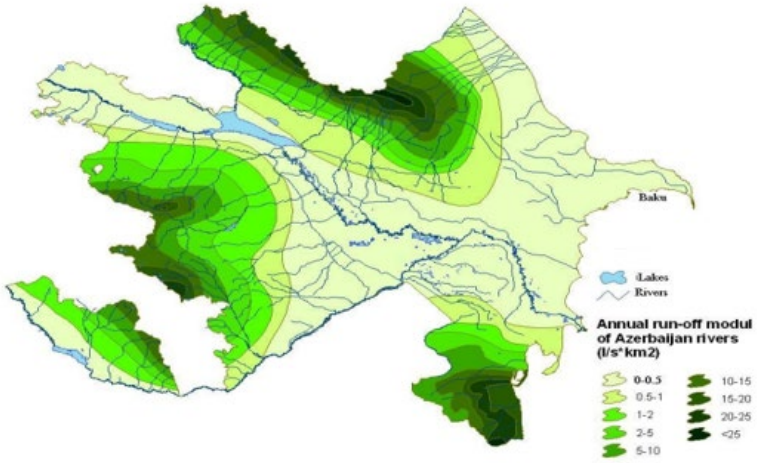


Figure 1. Annual run-off module of Azerbaijan rivers.
Source: National Water Strategy of the Republic of Azerbaijan.

The specific features of Azerbaijan's water resources include their limited size, the uneven distribution of internal rivers, the formation of approximately 70% of surface water resources in neighbouring states, and the serious pollution of river waters already flowing into the country (Verdiyev, 2012).

The main indicators reflecting the level of efficient use of the water resources

A comparative analysis of water consumption indicators in Azerbaijan for the period 2010–2024 reveals a number of persistent structural trends and emerging challenges in national water resources management (Figure 2). According to statistics, water withdrawal from natural sources has generally increased, rising from 11.6 billion m^3 in 2010 to a peak of 13.8 billion m^3 in 2022. This growth reflects growing demand driven by population dynamics, agricultural expansion, and economic activity. However, a significant decline in 2023 followed by a partial recovery in 2024 indicates the increasing sensitivity of water withdrawal to climate variability and hydrological constraints, highlighting the growing pressure on available water resources. Total water consumption shows a similar upward trend until 2021–2022, increasing from 7.7 billion m^3 in 2010 to over 10.5 billion m^3 in 2022 (SSC, 2025). After this peak, consumption declines slightly and stabilises in 2023–2024. The divergence between water withdrawals and consumption in recent years suggests improved reuse, reduced losses, or demand adjustments, but may also reflect supply constraints rather than simply improved efficiency.

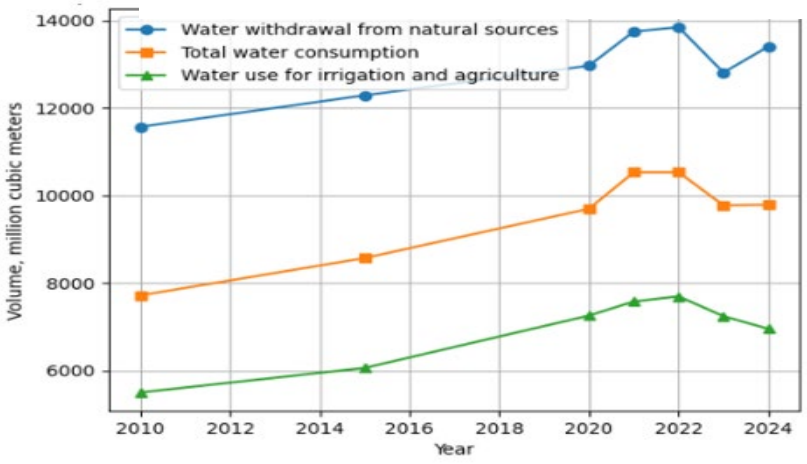


Figure 2. Comparative dynamics of water use indicators in Azerbaijan (2010–2024).
Source: The State Statistical Committee of the Republic of Azerbaijan
https://www.stat.gov.az/source/environment/?lang=en

It should be noted that water use for irrigation and agriculture remains the dominant component of total water consumption throughout the period. Its share consistently exceeds two-thirds of total consumption, increasing from 5.5 billion m^3 in 2010 to a peak of 7.7 billion m^3 in 2022, before declining to 7.0 billion m^3 in 2024.

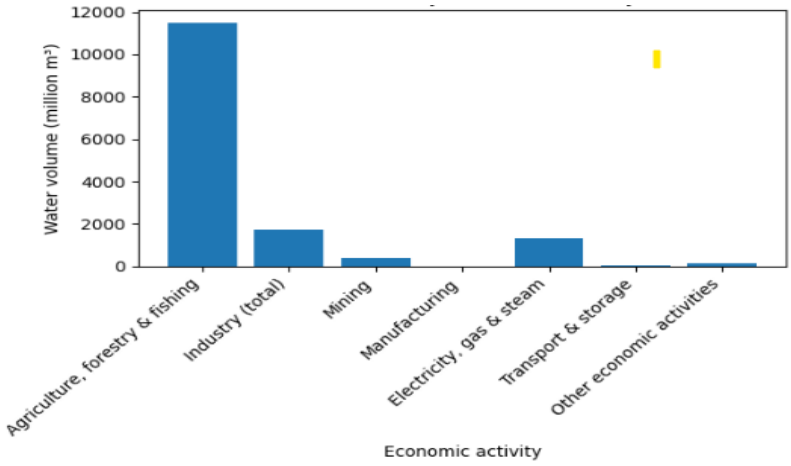
This confirms the structurally high dependence of Azerbaijan's water balance on the agricultural sector and highlights the crucial role of irrigation efficiency in ensuring water security. The gap between water withdrawal and effective consumption remains significant, indicating persistent losses during abstraction, transportation, and distribution. Although this gap narrowed somewhat after 2022, its overall magnitude points to systemic inefficiencies in water infrastructure and management practices, particularly in irrigation networks.

Irrigation efficiency

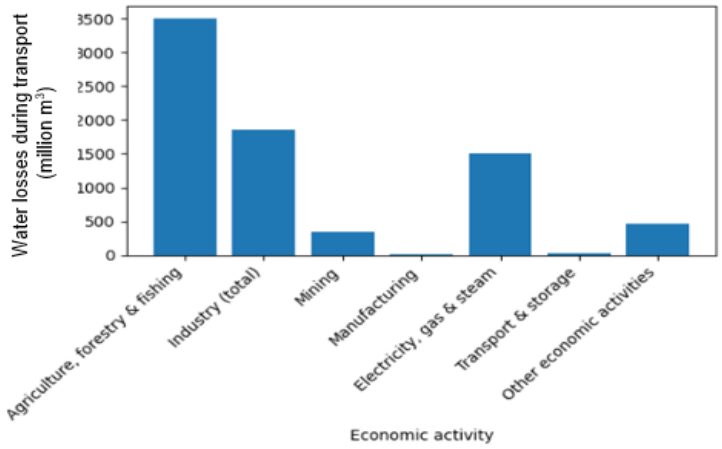
Irrigated agriculture plays a crucial role in agricultural production in the country. The total area of irrigated land is 1.45 million ha, of which 77.5% is arable land, 8.6% is used for perennial crops, and 13.9% is used for other purposes such as hayfields, pastures, household plots, etc. Water resources used for irrigation amount to approximately 7.2 billion m^3 per year. Up to 17% of the republic's irrigated land is irrigated with groundwater, 20% with water from reservoirs built outside the riverbeds, and the remaining 63% with water from reservoirs built on the Kura and Araz rivers, as well as through canals running from the rivers themselves (Gurbanov et al., 2019). Irrigation water in agriculture comes primarily from two sources: 1) water supplied through canals; 2) water obtained from subartesian wells. Namely, 83% of the country's arable land is irrigated from surface sources (NSEUWR, 2024). Since groundwater is close to the surface in the main irrigated areas, irrigation systems with drainage networks are used in intensively cultivated areas to prevent soil salinisation and maintain soil fertility. The introduction of innovative irrigation systems in predominantly irrigated areas is rare.

Figure 3(a) shows that agriculture, forestry, and fisheries are the primary water consumers, accounting for the vast majority of total water withdrawals (over 11.4 billion m^3). This confirms the high water intensity of the agricultural sector, largely driven by irrigation needs. The industrial sector is the second largest water consumer, with particularly large volumes generated by electricity, gas, and steam production, reflecting the need for cooling and industrial processes. However, water withdrawals from industry remain significantly lower than those from agriculture.

Water losses during transportation are strongly sectoral (Figure 3(b)). Agriculture, forestry, and fisheries are the dominant sources of losses, accounting for the overwhelming majority of total water losses during delivery. In agriculture, water losses during transportation amount to 3.6 billion m^3, accounting for 30% of the total water used in agriculture and 25% of the water withdrawn from reservoirs. This indicates the high deterioration of irrigation canals, significant seepage and evaporation losses, and the low level of technological modernisation in water management infrastructure.



(a)



(b)

Figure 3. Water withdrawal (a) and losses (b) by economic activity, 2024.
Source: The State Statistical Committee of the Republic of Azerbaijan.
https://www.stat.gov.az/source/environment/?lang=en.

Water losses in other economic activities are insignificant. Overall, the loss structure highlights that improving water use efficiency in agriculture is a key resource for reducing water losses and strengthening the country's water security. Priority measures should include reconstructing irrigation networks, implementing water-saving technologies, and strengthening water loss monitoring. The

government supports this approach and provides subsidies. Currently, these subsidies are available to farmers with large land holdings, but they should be expanded. Improving water resource management is fundamental to increasing agricultural production.

Overall, the observed dynamics indicate that although Azerbaijan has managed to expand water consumption to meet economic and agricultural needs, this expansion has increased pressure on natural water resources. The predominance of agriculture in water consumption makes digital water management technologies, modernisation of irrigation systems, and demand-driven regulation key priorities for improving economic efficiency and ensuring the long-term sustainability of water use.

Impact of rising temperature

The data shows a steady seasonal increase in average temperatures during the spring–summer period and a decrease in autumn and winter. In recent years, there has been a trend toward higher summer peaks and warmer springs. The maximum temperature occurs in July–August (25–27°C), and the start of the growing season is shifting to an earlier date (Figure 4). According to the latest research, the average temperature in Azerbaijan increased by 1.40 degrees between 1991 and 2017, while the amount of precipitation in Azerbaijan decreased by an average of 14%. The number of hot days (with maximum temperatures above 35°C) per year has increased from 10 to 15 over the last 30 years.

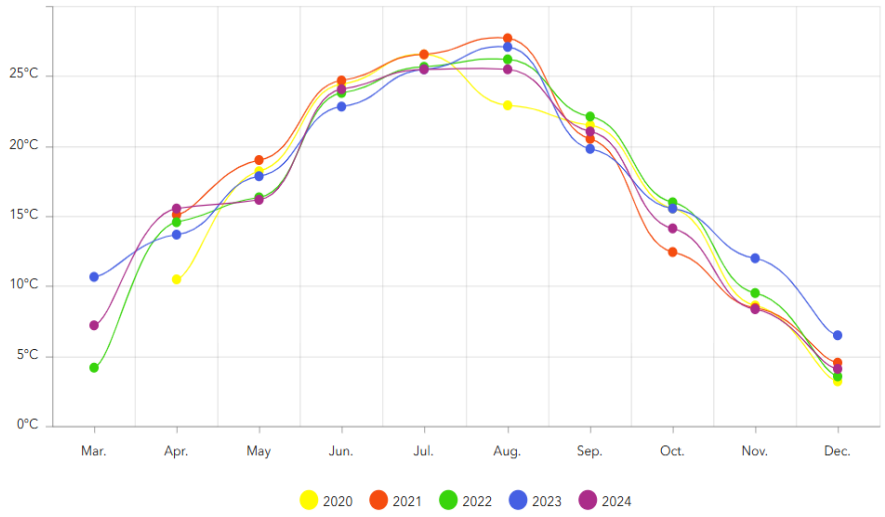


Figure 4. Temperature anomalies for the years 2020–2024 (CR, 2025).
Source: Space Monitoring of the Effects of Global Climate Change Climate Report.

A descriptive interpretation of the parallel trends reveals that rising temperatures directly increase evaporation and transpiration, reducing available surface and soil water resources and increasing crop water demands, especially during critical summer growth phases. If the irrigation patterns remain unchanged, this leads to increased water losses and reduced water use efficiency. At the same time, the risk of drought, soil overheating, and reduced yields increases due to insufficient water supply. Drought completely destroyed 68,600 ha of crops in 2020, 42,200 ha in 2021, 101,400 ha in 2022, and 178,300 ha in 2023 (SSC, 2025). Under these conditions, the following measures are crucial:

- transition to water-saving irrigation methods (drip irrigation, sprinkler irrigation with controlled irrigation);
- adjustment of irrigation schedules to account for earlier warming;
- introduction of drought-resistant varieties and digital water management systems.

The distribution of the water resources in the country

The distribution of water resources in the republic is extremely uneven. Many regions experience severe water shortages because the distribution of productive forces does not correspond to the natural water supply. Ninety percent of crop yields are achieved through irrigation. The majority of irrigated land is located in the Central Aran (30,699 ha), Guba-Khachmaz (17,180 ha), Mil-Mugan (16,162 ha), and Shirvan-Salyan (16,257 ha) economic regions. The highest irrigation efficiency rates in the country are observed in the Mil-Mugan, Nakhchivan, and Shirvan-Salyan economic regions (SSC, 2025).

According to research, fruit orchards are the most water-intensive crops in our republic, requiring an average of 4,400 m^3 of water per hectare. Other crops, such as forage crops and cotton, require 3,250 m^3 of water, while wheat and barley require 1,320 m^3. Obviously, these figures can vary depending on the crop and climate conditions, and water consumption increases in arid regions.

The predominance of small farms in the country's agriculture results in the low adoption of modern technologies. The problem is that traditional surface and flood irrigation methods are primarily used. Most irrigation and drainage networks run along earthen channels and are open-air systems, leading to significant water losses, the rise of mineralised groundwater in the crop layers, and salinisation of adjacent lands. More than a third of irrigated land (565,000 ha) is mechanically irrigated, including 349,400 ha by electrified systems, 68,200 ha by diesel pumping stations, and 147,700 ha by subartesian wells.

The efficiency of irrigation systems in Azerbaijan is low – approximately 37% (reflecting inefficient canals and water losses due to outdated infrastructure) (Smita, 2024). According to the Ministry of Agriculture, innovative irrigation

systems have been implemented on 126,000 ha of land in the country to date, accounting for 12% of the total area.

To accelerate this process, the government is increasing its support, and from this year, the subsidy level for locally produced equipment has been increased to 60%. This will make modern systems more accessible to farmers, expand the country's production potential, create new jobs, and reduce dependence on imported technology.

In addition to underutilisation, water quality is deteriorating. Intensive water use in agriculture leads to surface and groundwater pollution. Chemically contaminated water percolates through the soil, affecting the quality of rivers and reservoirs. Azerbaijan faces the challenge of optimising water use to ensure sustainable development with limited water resources. Water consumption, particularly in agriculture, remains high, and the country is working to improve water management and reduce environmental risks (Suleymanov, 2023). Active development of water conservation programmes, including modernising infrastructure and improving irrigation systems is necessary. Cooperation with international organisations enables the country to apply modern water management methods.

It should be noted that crop production is not the only water consumer in agriculture. Livestock farming, particularly in its industrial form, requires the use of large volumes of water from rivers, lakes, and other water bodies, significantly affecting the condition of these bodies of water and the environment as a whole. Industrial livestock farming is a major water consumer: producing 1 m^3 of milk requires 5 m^3 of water, and 1 tonne of meat requires 20,000 m^3 of water. Furthermore, maintaining sanitary and hygienic conditions on farms consumes significant amounts of water. Consequently, the continuous growth of agricultural production, on the one hand, leads to increased consumption of natural resources, and on the other hand, to the generation of large quantities of waste and wastewater on livestock farms and complexes, poultry farms, and other agricultural facilities (Ibragimov et al., 2021).

Measures for improving the efficiency of water resources use

Water resources in Azerbaijan are state property. At the national level, various organisations are responsible for the regulation, monitoring, exploitation, and scientific research of water resources. The Ministry of Ecology and Natural Resources is responsible for water policy and water resource protection. The Ministry of Ecology and Natural Resources carries out quantitative and qualitative monitoring of surface water, ensures protection from pollution, and is also responsible for the use and protection of groundwater.

To improve the efficiency of water resource management, water management activities, and land reclamation, as well as to improve the organisation of land reclamation and irrigation work, the State Agency for Water Resources of Azerbaijan was established in 2023. The Agency is the central executive body responsible for organising activities in the fields of water intake, treatment, transportation, and water supply in Azerbaijan. It also oversees the operation of state drainage and irrigation systems.

To introduce digitalisation into the country's annual water resource management balance, improve the efficiency of water resource assessment in key water management systems and facilities, and improve water resource use, accounting, and management, a decision was made to transition to "Electronic Water Resources Management". This system includes the implementation of real-time electronic monitoring mechanisms, including continuous monitoring of subartesian and artesian wells, strengthening data-driven decision-making and promoting sustainable water resource management.

The adoption of the National Strategy for the Efficient Use of Water Resources (until 2040) has become one of the main stages in the system of measures for the efficient use of water resources, with an emphasis on irrigation and land reclamation (NSEUWR, 2024).

According to calculations, water use efficiency in agriculture shows a steady and consistent upward trend over the period 2016–2024. The indicator increased from 0.52 USD/m^3 in 2016 to 1.09 USD/m^3 in 2024, more than doubling over nine years (Figure 5). This positive trend indicates a gradual increase in the economic value generated per cubic metre of water withdrawn.

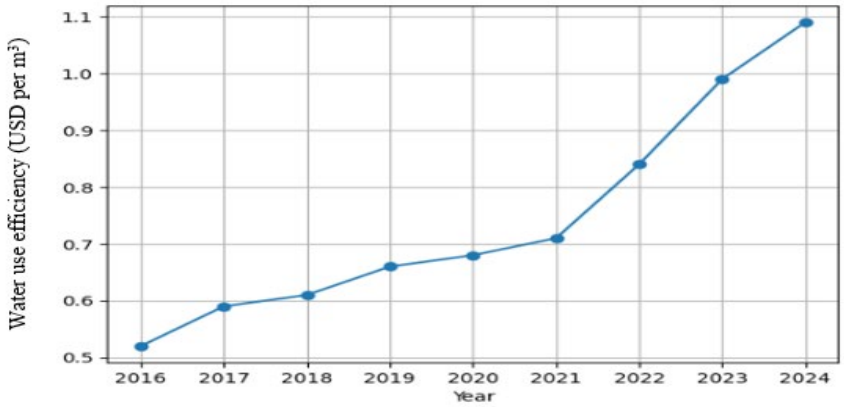


Figure 5. Water use efficiency in agriculture (2016–2024).
Source: Authors' calculations.

The improvement is attributed to structural shifts in agricultural production, partial modernisation of irrigation infrastructure, improved water management practices, and institutional reforms in the water sector. Overall, the results confirm an improvement in water productivity. However, given the still low absolute level of USD/m^3 compared to water-efficient economies, further modernisation and efficiency-enhancing measures remain necessary.

Conclusion

The country's shortage of freshwater resources, climate change, and the observed increase in average temperatures in recent years, along with significant reductions in surface water resources, river water content, and precipitation, primarily from neighbouring countries, as well as rapid population growth, rising living standards, and economic development, including agriculture, have led to increased water demand. These processes require urgent measures to ensure water security in the country.

The findings of the study confirm that water use remains one of the most critical constraints on sustainable agricultural development in Azerbaijan. Limited internal freshwater resources, high dependency on transboundary rivers, increasing climate variability, and outdated irrigation infrastructure collectively intensify water consumption, while substantial losses occur during water abstraction, conveyance, and field application, indicating persistent structural inefficiency in the water management system.

The analysis demonstrates that rising air temperatures and more frequent drought events significantly increase crop water requirements and exacerbate pressure on already limited water resources. Under existing irrigation practices, these climatic changes lead to higher evaporation losses, declining water productivity, and increased vulnerability of agricultural output. Although recent investments in canal rehabilitation, pipeline systems, and modern irrigation technologies have improved water efficiency, their overall impact remains constrained by uneven adoption, institutional weaknesses, and limited access for small and medium-size farms.

The study highlights that further improvement in agricultural water use efficiency requires an integrated approach combining physical modernisation of irrigation infrastructure, wider dissemination of water-saving technologies, and the expansion of digital water management and monitoring systems. Strengthening economic incentives, improving governance and coordination among water management institutions, and aligning regional water allocation with natural resource availability are equally important. Ensuring the efficient use of water resources is not only a technical necessity but also a strategic condition for enhancing agricultural resilience, food security, and long-term water sustainability in Azerbaijan under increasing climate and resource pressure.

References

AQUASTAT-FAO's Global Information System on Water and Agriculture (2025). SDG 6.4.2. Water Stress. Retrieved November 12, 2025, from https://data.apps.fao.org/aquastat/?lang=en

CR (2025). Space Monitoring of the Effects of Global Climate Change on the Republic of Azerbaijan. Climate Report. Retrieved December 20, 2025, from Climate Report.

FAO (2011). The State of the World's Land and Water Resources for Food and Agriculture (SOLAR): Managing systems at risk.

FAO (2017). Sustainable Food and Agriculture A report produced for the G20 Presidency of Germany. Rome. https://openknowledge.fao.org/server/api/core/bitstreams/b48cb758-48bc-4dc5-a508-e5a0d61fb365/content.

FAO (2020). The State of Food and Agriculture 2020. Overcoming water challenges in agriculture. Rome. https://doi.org/10.4060/cb1447en.

Frone, D. F., Frone, S., & Stoian, M. (2012). Objectives and Challenges of Water Demand Management. Scientific Papers. Series *Management, Economic Engineering in Agriculture and rural development, 12*(3), 47–50.

Gurbanov, M. F., Gurbanov, F. M., & Hasanov, A. V. (2019). Some problems of irrigation water use. *Collection of scientific works of the "AzHveM" EIB*, (39), 199–210. https://www.anl.az/down/meqale/elmi_eser_azhmeib/2019/xxxix/785648(meqale).pdf

Ibragimov, A. G., Borulko, V. G., & Lukyanova, I. A. (2021). Livestock and the Environment. *Agrarian Science, 353*(10). 46–49. https://doi.org/10.32634/0869-8155-2021-353-10-46-49.

Liu, X., Liu, W., Tang, Q., Liu, B.,Wada, Y., & Yang, H. (2022). Global agricultural water scarcity assessment incorporating blue and green water availability under future climate change. *Earth's Future*, *10*, 1–16. https://doi.org/10.1029/2021EF002567.

NSEUWR (2024). National strategy on the efficient use of water resources. Baku, October 10.

Schmitt, R. J. P., Rosa L, & Daily, G. C. (2022). Global expansion of sustainable irrigation limited by water storage. *Proceeding of the National Academy Sciences, 119*(47), 1–10. https://doi.org/10.1073/pnas.2214291119.

Smita, M. (2024). Azerbaijan – Transitioning to Efficient Water Sector Institutions and Programs for Addressing Water Security Challenges (English). Washington, D.C. World Bank Group. http://documents.worldbank.org/curated/en/099082024072036955

Suleymanov, F. (2023). The Role of Climate Change on Water Resources Management in the Southern Caucasus in the Post-Conflict Period. *Environmental Sciences Proceedings, 25*(1), 43. https://doi.org/10.3390/ECWS-7-14165

SSC (2025). The State Statistical Committee of Azerbaijan Republic. Retrieved December 20, 2025, 2025, from https://www.stat.gov.az/source/digital_development/?lang=en

Turan, O., Kadagan, O., & Gurbuz, I. B. (2023). Farmers Water Usage Preferences and their Attitude Towards Excessive Irrigation. Scientific Papers. Series *Management, Economic Engineering in Agriculture and rural development, 23*(1), 861–868.

Verdiyev, R. (2012). Water Resources Expert Baku, National Water Strategy of the Republic of Azerbaijan. June 2012. https://unece.org/fileadmin/DAM/env/water/npd/Water_Strategy_Rafig_Verdiyev.pdf

United Nations (2024). The United Nations World Water Development Report 2024: Water for Prosperity and Peace. UNESCO, Paris. https://unesdoc.unesco.org/ark:/48223/pf0000388948

World Bank (2024). Azerbaijan: General Water Security Assessment. Washington, DC: World Bank. Retrieved December 05, 2025, https://documents.worldbank.org.

World Resources Institute (2019). Updated Global Water Risk Atlas reveals top water-stressed countries and states. https://www.wri.org/

Yawson, D. O., Mulholland, B., Ball, T., Mohan, S., & White, P. (2013). Food security in a water-scarce world: making virtual water compatible with crop water use and food trade. Series *Management, Economic Engineering in Agriculture and rural development, 13*(2), 431–444.

Received: 8 February 2026
Accepted: 24 February 2026

IZAZOVI EFIKASNOG KORIŠĆENJA VODE U POLJOPRIVREDI U AZERBEJDŽANU

Ramina R. Mustafayeva*, Ruhiyya M. Gambarova, Yegana A. Abbasova, Sabina H. Huseynova i Shahriyar A. Maharramov

Department of Agricultural Economics, Azerbaijan State Agricultural University, Ganja, Azerbaijan

R e z i m e

Održiva proizvodnja hrane sve više zavisi od vodnih resursa i njihovog racionalnog i efikasnog korišćenja. Usled globalnih klimatskih promena i dezertifikacije, nestašica slatke vode postaće još izraženija. Azerbejdžan je zemlja izuzetno ranjiva na nestašicu vode zbog ograničenih unutrašnjih vodnih resursa, velike zavisnosti od prekograničnih reka, rastućih klimatskih rizika i neefikasnosti postojeće vodne infrastrukture. Nestašica vode je ključna prepreka razvoju poljoprivrede u zemlji, a postojeće sisteme za navodnjavanje karakterišu značajni gubici vode i niska efikasnost. S obzirom na navedeno, cilj našeg istraživanja je da identifikujemo probleme neefikasnog korišćenja vode u poljoprivredi i predložimo rešenja. Da bismo procenili nivo racionalnog korišćenja vode u poljoprivredi, ispitali smo pokazatelje kao što su zahvatanje i potrošnja vode, korišćenje vode za navodnjavanje i poljoprivredu, gubici vode usled ekonomskih aktivnosti, uticaj promena prosečne godišnje temperature na potrebe useva za vodom i raspodela vodnih resursa po regionima. Rezultati su pokazali da značajni gubici vode predstavljaju ozbiljan problem za poljoprivredni sektor i zahtevaju hitna rešenja.

Ključne reči: vodni resursi, poljoprivreda, navodnjavanje, klimatske promene, gubici vode, efikasnost.

Primljeno: 8. februara 2026.
Odobreno: 24. februara 2026.

*Autor za kontakt: e-mail: ramina.mustafayeva@adau.edu.az

Journal of Agricultural Sciences (Belgrade)
Vol. 71, No. 1, 2026
Pages 43-59

https://doi.org/10.2298/JAS2601043M
UDC: 631.445.4:631.82(477)
Original scientific paper

THE N:K RATIO IN CHERNOZEM AND CROPS UNDER DIFFERENT FERTILISATION PRACTICES AND CLIMATE CHANGE

Mykola M. Miroshnychenko, Yevheniia Yu. Hladkikh*, Olesia P. Volosheniuk and Anatoly O. Khristenko

National Scientific Center "Institute for Soil Science and Agrochemistry Research named after O. N. Sokolovsky", Kharkiv, Ukraine

Abstract: Despite nutrient stoichiometry is widely applied to assess plant nutrition, agronomists in Ukraine traditionally use absolute test values. To address this gap, the temporal variability of the N:K ratio in soil and plant tissues was considered in a long-term field experiment (1971–2017) investigating the effects of different potassium fertilisation systems on crop rotation productivity in the northeastern Ukraine (Kharkiv region). The study compared the aftereffect of a high potassium background (1800 kg ha^{-1}) and the systematic application of mineral fertilisers (NPK) at single and double rates within the crop rotation. Available K in Chernozem was positively correlated with annual precipitation, influencing the stoichiometric balance in plant tissues. Under dry conditions, the N:K ratio narrowed significantly, particularly with potassium-only fertilisation. In contrast, balanced NPK application maintained an N:K ratio comparable to that observed under optimal moisture conditions. The relationship between available K and water highlights the need to use stoichiometric relationships, including the N:K ratio, for balanced plant nutrition in the context of climate change. Overall, potassium fertilisation enhanced crop rotation productivity and contributed to a more stable nutrient ratio balance.

Key words: available potassium content, N:K ratio, Chernozem, fertilisers, climate change.

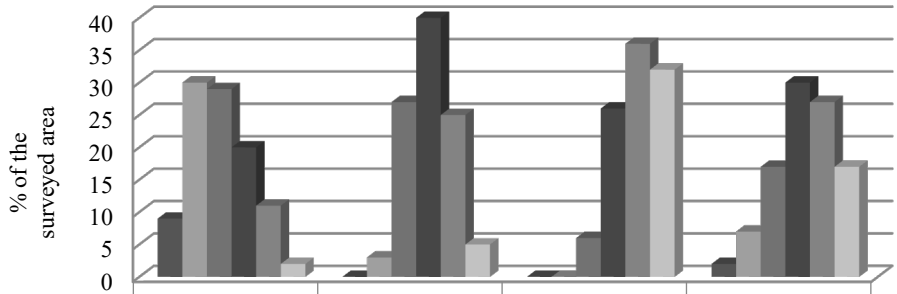
Introduction

Balanced crop nutrition is critical to global food security in the context of climate change, as it strongly influences plants' water use efficiency (Roy et al., 2006). Among the basic nutrients, potassium is as significant as nitrogen and phosphorus, especially for plant enzyme systems (Marschner, 2012; DaCosta and Huang, 2006), transpiration, water balance, and root moisture absorption, which are crucial for increasing plant resistance to droughts or spring frosts (Galmés et al., 2007; Kaldenhoff et al., 2008). Potassium deficiency inhibits protein synthesis, leading to the disrupted nitrogen metabolism.

*Corresponding author: e-mail: ye.hladkikh@ukr.net

Unfortunately, around 20% of agricultural soils worldwide are potassium deficient, especially in East Asia, Southeast Asia, Latin America and sub-Saharan Africa (Brownlie et al., 2024). Despite varying data reliability, the global trend over recent decades has shown that more potassium is removed from soil than is applied (Zörb et al., 2014). Large agricultural areas are reportedly deficient in 'crop-available' soil potassium (Römheld and Kirkby, 2010). Negative soil potassium balances lead to crop yield losses (Murrell et al., 2021) and to the depletion of crop-available potassium, thereby threatening crop productivity and food security in many countries (Sheldrick et al., 2002).

The available potassium content in soils of Ukraine varies widely due to the different mineralogy and hydrothermal conditions. According to the latest agrochemical survey, more than 55% of the studied area has an increased and high level of available potassium (Figure 1). According to the current Ukrainian gradation system for soil potassium availability, soils are categorised based on their available potassium content (determined by the Chirikov method).



	Polissya	Forest steppe	Steppe	Ukraine as a whole
Very low	9	0	0	2
Low	30	3	0	7
Medium	29	27	6	17
Increased	20	40	26	30
High	11	25	36	27
Very high	2	5	32	17

Figure 1. Distribution of arable land in Ukraine by the available potassium supply, %.
Source: Institute for Soil Protection of Ukraine, 2020.

The following ranges are used: very low (<20 mg/kg of soil), low (21–40 mg/kg), medium (41–80 mg/kg), increased (81–120 mg/kg), high (121–180 mg/kg), and very high (>180 mg/kg). Moisture deficiency, even in soils with a very high potassium content, can limit potassium uptake by plants. As a result, the effectiveness of potassium fertilisers in Ukraine tends to decrease from the more

humid western regions toward the drier eastern and south-eastern regions (Khristenko and Istomina, 2013). Overall, the potassium deficit in the arable soils of Ukraine ranges from 11.2 to 43.2 kg per ha (Figure 2).

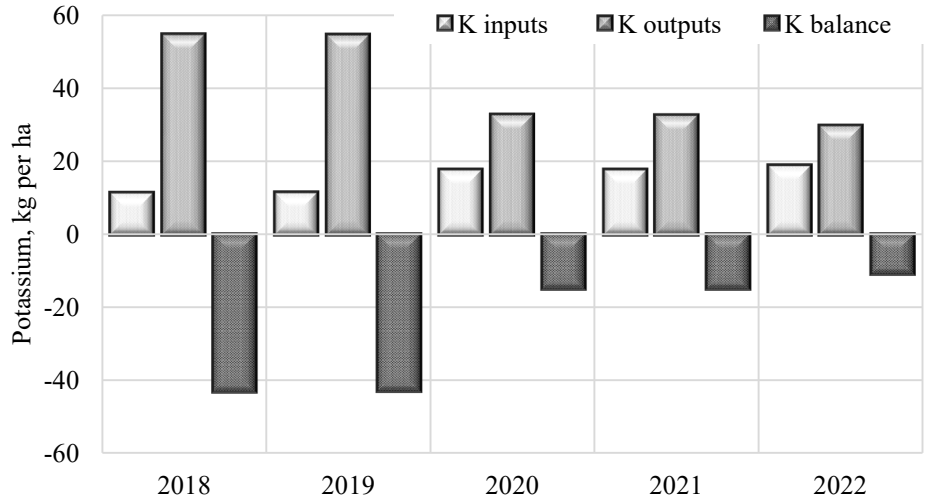


Figure 2. Dynamics of potassium balance in the arable land of Ukraine (2018–2022).
Source: Authors' systematization based on data from the State Statistics Service of Ukraine.

Unfortunately, since 2017, no official information has been available on the supply of potassium fertilisers from domestic producers; therefore, current demand is met entirely through imports. In 2023, the total application of mineral fertilisers in Ukraine amounted to 0.99 million tonnes of nutrients in active substance, including 0.18 million tonnes of K_2O (State Statistics Service of Ukraine, 2023). Nitrogen fertilisers strongly dominate the structure of fertiliser use, resulting in an N:K ratio of 1:0.18. This ratio is considerably wider than the global average (1:0.37) and the average reported for developed countries (1:0.55) (Li et al., 2019).

Previous studies have shown that the balance of nutrients in the soil may exert a stronger influence on plant biomass than their absolute concentrations (Bakare and Osemwota, 2021; Ji et al., 2022). Therefore, investigating the temporal dynamics of the N:K ratio in Ukrainian Chernozems is of particular importance.

A better understanding of how environmental changes affect soil K availability and plant uptake is essential for sustainable soil management. Therefore, we investigated the dynamics of soil potassium in relation to changes in weather conditions, particularly precipitation, as well as temporal variability in the N:K ratio. In addition, we assessed the effects of different potassium fertilisation systems on crop productivity and the N:K ratio across various crops.

Material and Methods

This study was conducted in the long-term field experiments established in 1969 at the Grakivske Experimental Farm, NSC "ISSAR named after O.N. Sokolovsky", in the Kharkiv region of Ukraine. The field experiment was established after ploughing up a 40-year fallow. The coordinates of the field experiment are 49˚46′ N, 39˚40′S. The soil is a *Luvic Chernozem* heavy loam (IUSS Working Group WRB, 2022). Before the experiment began, the arable soil layer had a pH_{KCl} of 5.4, SOC of 2.32%, a clay content of 50–52%, 45 mg per kg available P_2O_5, and 80 mg per kg available K_2O (both determined by the Chirikov method). In 1969–70, medium, elevated, and high levels of nitrogen (N), phosphorus (P), potassium (K), and NPK background were created by applying high rates of mineral fertilisers: three-fold application of 200, 400 and 600 kg/ha. These experimental backgrounds were established to assess the effect and aftereffect of high rates of various mineral fertilisers on chernozem soil fertility indicators, and to determine the duration of these aftereffects. The six-field crop rotation included peas-with-oats for green fodder, winter wheat, sugar beet, barley, maize silage and, again, winter wheat. Further, mineral fertilisers were applied to these backgrounds systematically according to the crop needs: $N_{60}P_{60}K_{60}$ (single dose) or $N_{120}P_{120}K_{120}$ (double dose) for wheat; $N_{90}P_{90}K_{90}$ or $N_{180}P_{180}K_{180}$, respectively, for sugar beet and maize silage. Peas-with-oats and barley were affected by the fertilisers applied to the previous crop. Since 1989, all experimental plots have been divided into two parts: one half continued to be fertilised systematically, and the other half simulated the crop production without fertiliser, studying their aftereffects. Each experimental plot covered 148.5 m², and the study was performed in triplicate.

Soil samples were collected from the 0–20-cm layer in triplicate to determine mineral nitrogen (N) and available potassium (K). Each composite sample consisted of six individual subsamples (1 dm³ each). Available potassium was determined by the Chirikov method following extraction with 0.5 N CH_3COOH. Nitrate nitrogen (NO_3^-–N) was measured photometrically using disulfophenolic acid, while ammonium nitrogen (NH_4^+–N) was determined photometrically with the Nessler's reagent.

Nitrogen and potassium contents in plant material were determined according to the Measurement Method "Plants. Determination of total forms of nitrogen, phosphorus, potassium in a single portion of plant material" (MBB 31-497058-019-2005), which describes the procedure for determining total nitrogen, phosphorus, and potassium in plant samples. The method is based on the digestion of organic matter with boiling sulphuric acid in the presence of a catalyst, resulting in the formation of ammonium salts. Nitrogen and potassium were subsequently quantified in the hydrolysate using a Spekol spectrophotometer. Plant samples were analysed after harvest.

The classification of years as dry or wet in the field experiment was based on the total annual precipitation. Years with less than 500 mm of precipitation were defined as dry, whereas those with more than 500 mm were classified as wet. The threshold of 500 mm was selected because it approximates the long-term climatic norm for large parts of Ukraine, particularly within the forest-steppe and steppe zones, where annual precipitation typically ranges around this value. In these regions, total precipitation below 500 mm is generally associated with soil moisture deficits and an increased risk of drought stress for crops, while precipitation above this level is usually sufficient to ensure favourable moisture conditions during the growing season. This binary classification allowed a clear comparison of soil nutrient dynamics and crop responses under contrasting moisture conditions.

To assess long-term patterns in precipitation distribution between warm and cold periods (1970–2017), the time series data were smoothed using robust regression. This approach was applied to minimise the influence of random extreme precipitation events that could distort trend estimation. Unlike ordinary least squares regression, robust regression reduces the weight of observations with large residuals through an iterative reweighting procedure, thereby limiting the impact of anomalously wet or dry years while retaining all observations in the dataset. This method allowed for a more stable estimation of long-term trends in precipitation distribution between seasonal periods without excluding extreme climatic events. The smoothed values were subsequently used to analyse temporal variability and to compare precipitation patterns between warm and cold seasons.

Statistical analysis was performed using STATISTICA 13.5.0.17. Analysis of variance (ANOVA) was conducted, and treatment means were compared using the least significant difference (LSD) test at $P < 0.05$.

Results and Discussion

Over the 55 years of the experiment, the contents of mineral nitrogen and available potassium in the soil were measured a different number of times – 42 and 99 measurements, respectively. A synthesis of these data indicates a clear relationship with annual precipitation. As shown in Figure 3A, the correlation between precipitation and mineral nitrogen in Chernozem was stronger than that between precipitation and available potassium (Figure 3B).

During periods of increased rainfall, nitrate forms of nitrogen are readily transported with soil moisture, so the total amount of precipitation has a strong influence on the dynamics of mineral nitrogen in the arable layer. In contrast, potassium is subject to non-exchangeable fixation. Depending on soil texture and mineralogical composition, the fixation capacity for potassium can vary widely (Murrell et al., 2021). Although Ukrainian Chernozems are characterised by high natural fertility, they also exhibit intensive fixation of potassium by clay minerals.

Consequently, precipitation dynamics exert a weaker influence on the content of available potassium in Chernozem compared with mineral nitrogen.

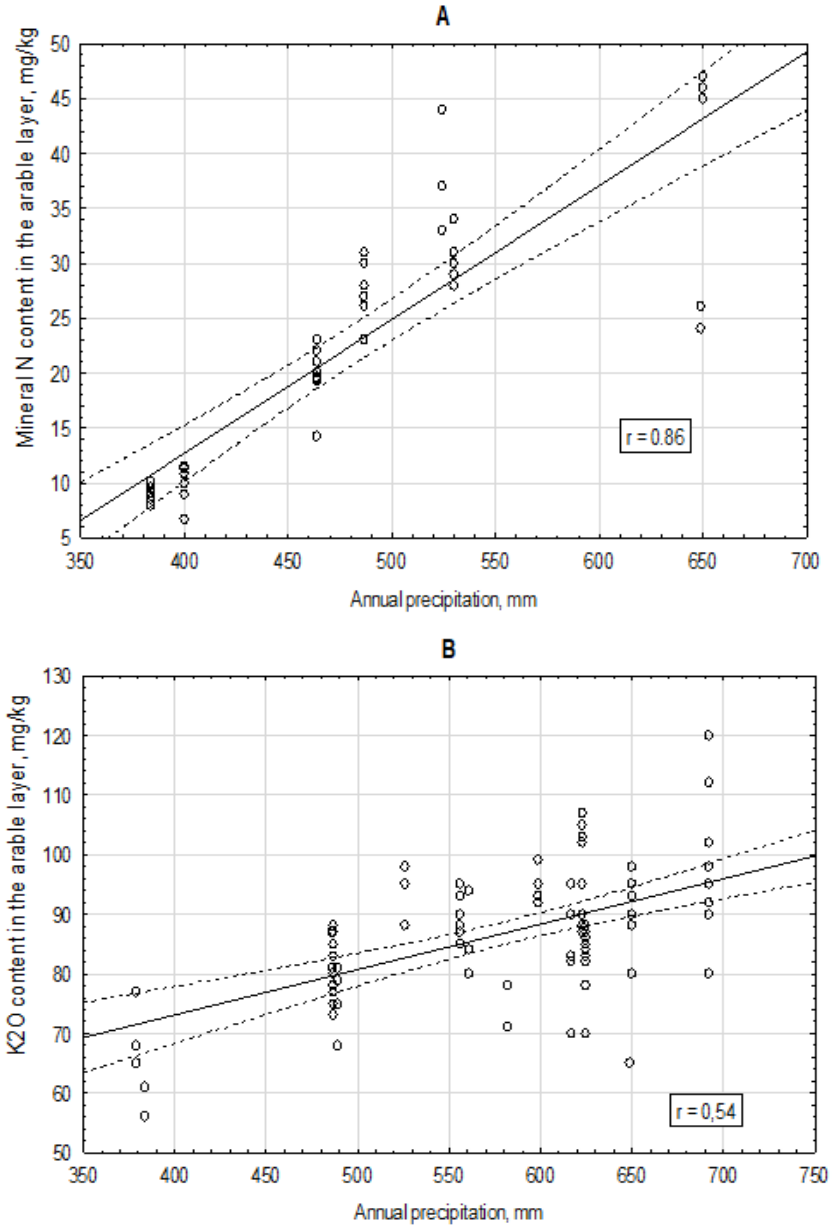


Figure 3. Relationship between the contents of N (A) and K (B) in the arable soil layer and annual precipitation.
Source: Authors' systematization based on own original research.

According to the regression analysis, an increase in annual precipitation of 50 mm was associated with an increase in mineral nitrogen content of 6 mg N kg^{-1}, whereas the content of available potassium increased by only 3.8 mg K_2O kg^{-1}. The relatively large dispersion of the experimental data around the regression line can be explained by the heterogeneity of the dataset, which included measurements obtained under different fertilisation regimes: unfertilised plots, as well as plots receiving single and double doses of NPK fertilisers.

According to Adamenko (2019), the average annual precipitation in Ukraine has decreased by 7–12% over recent decades, mainly during the June–September period. Observations from our long-term field experiment partially support this trend (Figure 4). A robust regression approach was used to smooth random outliers in the dataset. This analysis revealed cyclical fluctuations in annual precipitation. At the same time, an overall decreasing trend was observed, primarily due to reduced precipitation during the warm season. In contrast, precipitation during the cold season tends to increase.

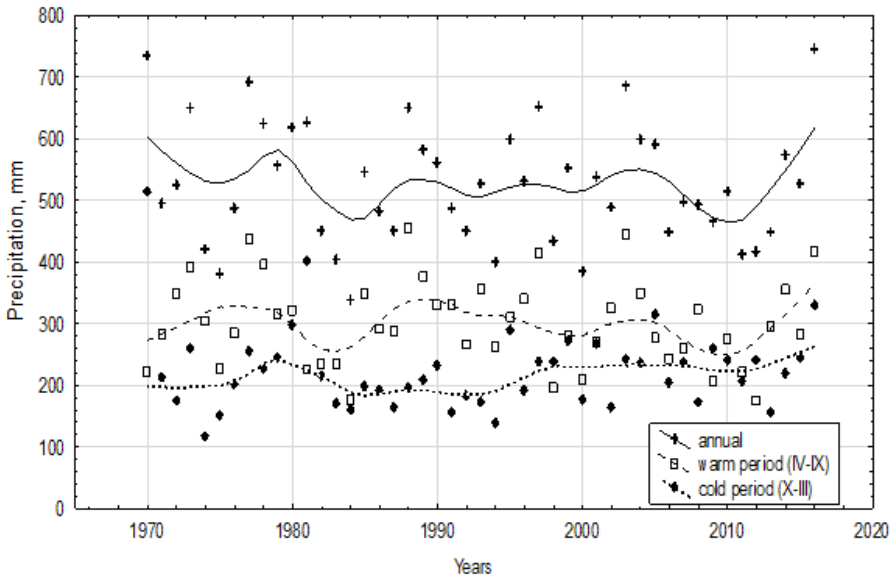


Figure 4. Distribution of precipitation during warm and cold periods (1970–2017).
Source: Authors' systematization based on own original research.

Statistical analysis revealed a significant change in the soil N:K ratio over time (Figure 5). Between 1970 and 1989, when very high fertiliser doses were applied three times to establish the agrochemical background, the average N:K ratio ranged from 0.35 to 0.40. These results demonstrate that a specific nutrient

balance in the soil can be deliberately established through the systematic fertiliser application. During this period, the variability of the N:K ratio increased substantially. This reflects the different processes governing nitrogen and potassium in the soil, including plant uptake, fixation, and migration. Since 1989, the soil N:K ratio has declined markedly, mainly due to greater losses of mineral nitrogen compared with potassium.

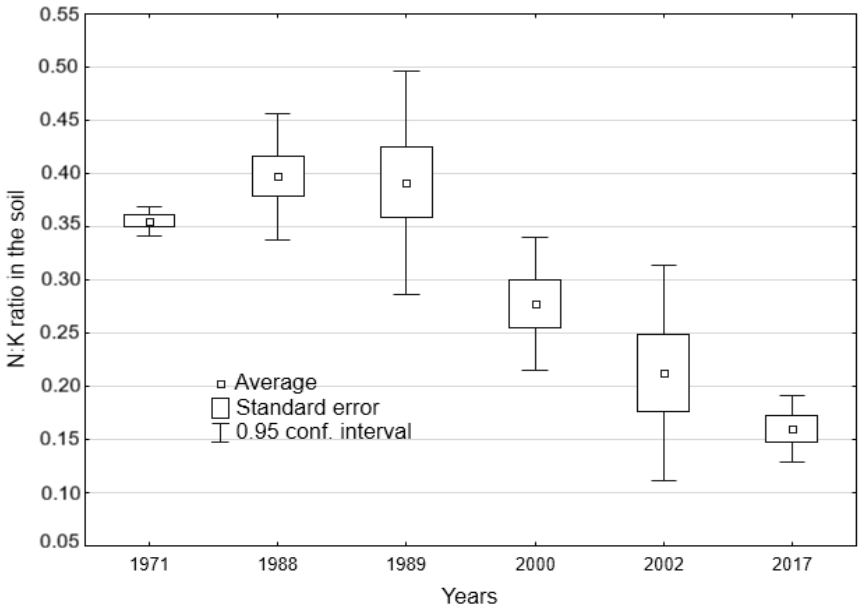


Figure 5. Long-term dynamics of the N:K ratio in the arable layer of Chernozem soil (1971–2017).
Source: Authors' systematization based on own original research.

In recent decades, prolonged droughts during the growing season have become more frequent in Ukraine. This trend negatively affects the efficiency of potassium uptake even in soils with a high content of available potassium (Khristenko and Istomina, 2013). At the same time, results from our long-term experiment indicate a positive crop response to potassium fertilisation (Figure 6). On average, over the period 1971–2017, the yield of cereal grains (barley and wheat) under a high potassium background exceeded that of the unfertilised control but did not surpass 4.5 t per ha. As shown earlier, the high potassium background (1800 kg per ha) significantly increased crop yields at the beginning of the experiment; however, this positive effect gradually diminished over time without annual fertiliser application (Nosko and Hladkikh, 2011). In contrast, the systematic application of single and double doses of mineral fertilisers, including

potassium fertilizers, increased the crop rotation yield to 5.5–6.5 t per ha in feed units, in proportion to the applied fertiliser dose (Figure 6).

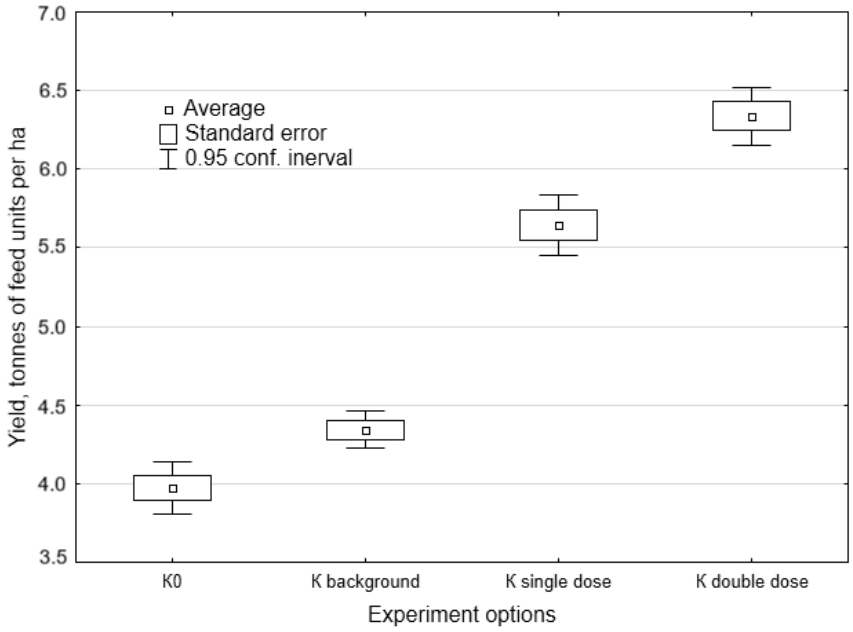
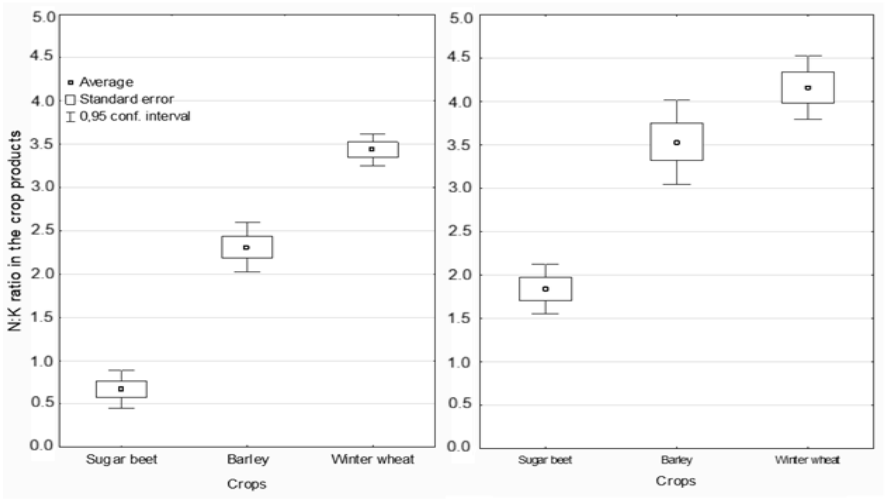
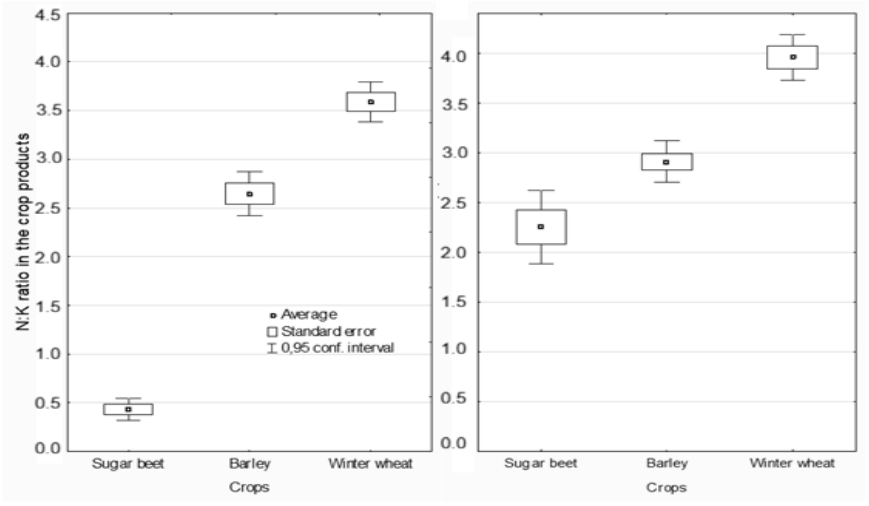


Figure 6. Crop rotation yield depending on the potassium fertiliser options.
Source: Authors' systematization based on own original research.

Our experiment demonstrates a clear dependence of the crop N:K ratio on both the soil N:K ratio and precipitation. To examine this relationship, the dataset for 1971–2017 was divided into years with adequate and insufficient moisture. The results showed that under dry conditions, the N:K ratio in plant tissues of crops was significantly lower in both the K_0 treatment and under the high potassium background (Figure 7). In cereal grains (barley and wheat), the decrease in the N:K ratio in tissues under dry conditions occurred mainly due to reduced nitrogen uptake by plants (by 1.2–1.4 times), while the potassium concentration remained relatively constant. In sugar beet, the decrease in the N:K ratio was caused by a sharp decline in nitrogen concentration (by 3.2–3.5 times) combined with a simultaneous increase in potassium concentration (by 1.8–2.0 times). This pattern likely reflects growth inhibition of sugar beet under insufficient water supply: although potassium concentration increases in plant tissues, the total potassium uptake by the crop remains considerably lower.



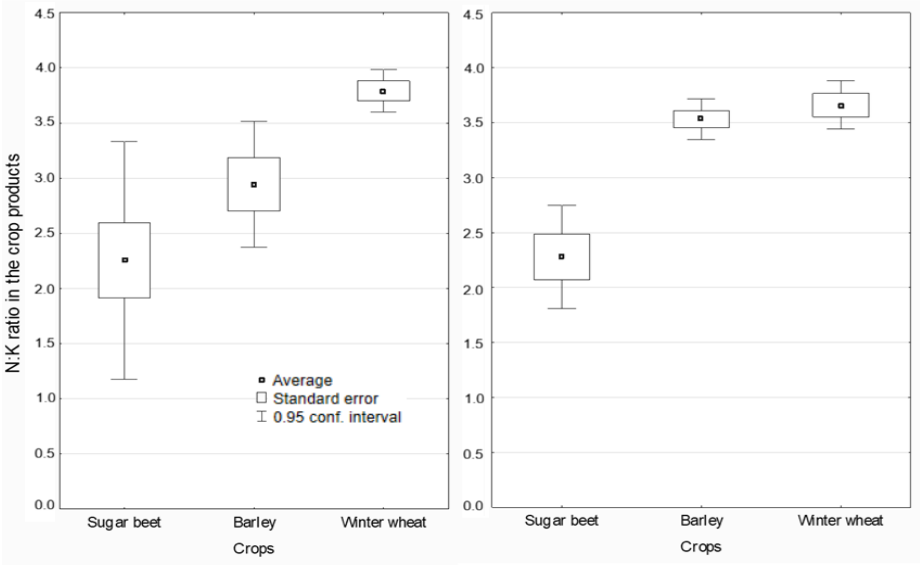
A



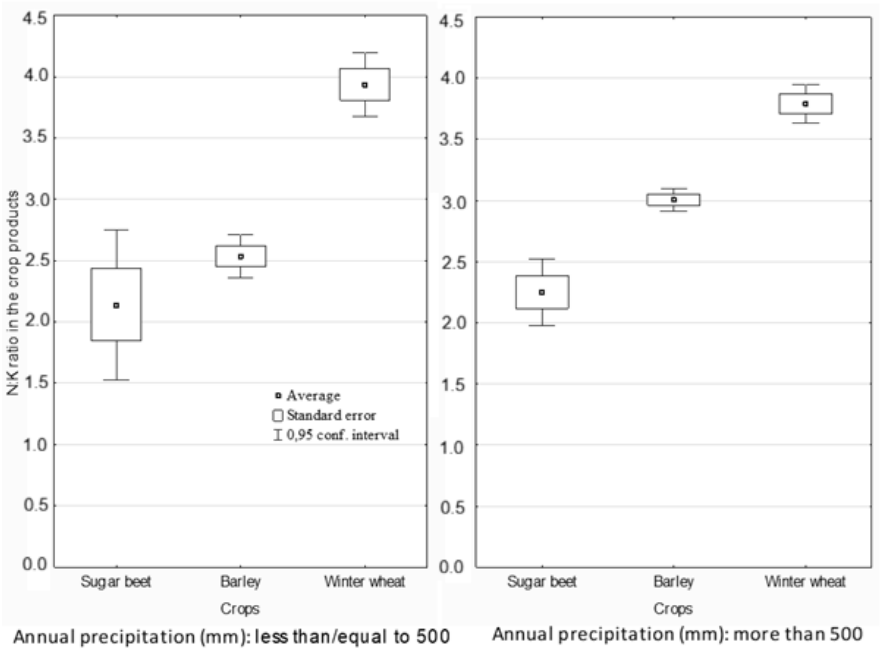
B

Figure 7. N:K ratio in plant tissues during years with different annual precipitation for the treatments: (A) K0 (no K application) and (B) K background fertilisation.
Source: Authors' systematization based on own original research.

With systematic fertilisation (single and double K rates), the N:K ratio in plant tissues of sugar beet roots and winter wheat grain remained stable regardless of precipitation (Figure 8).



A



B

Figure 8. N:K ratio in crops during years with different levels of annual precipitation: (A) single K application and (B) double K application.
Source: Authors' systematization based on own original research.

This finding highlights the importance of balanced plant nutrition, as complete fertilisers (NPK) with a constant N:K ratio were applied in these treatments. Under these conditions, the N:K ratio in plant tissues was close to the standard values reported for nutrient uptake by crops (2.6 for sugar beet, 3.4 for barley, and 4.3 for winter wheat) (Baliuk et al., 2011). In contrast, in the K_0 treatment and under the potassium background without systematic fertilisation, the N:K ratio in crop products corresponded to these standard values only under optimal moisture conditions.

It is known that the broad-scale patterns of soil K reserves are predominantly controlled by climates (Francos et al., 2016; Pogromska, 2021). Temperature and precipitation determine the availability and uptake of essential nutrients, leading to their fluctuations over time (Su et al., 2019). Li et al. (2021) have found that precipitation and temperature affect soil potassium variations both directly and indirectly by influencing key soil properties. Hence, the seasonal dynamics of nutrient content in the soil might be quite high. On the contrary, the study by Kariuki et al. (2010) in eastern Oklahoma concluded that temporal variability did not exist for Mehlich 3 P and K but was significant for nitrogen (NO_3-N).

Our results from the long-term field experiment (Figure 3B) also demonstrate a strong correlation between the content of available soil potassium and precipitation dynamics, with reduced humidity leading to lower potassium concentrations. This is likely related to biological and geochemical processes, such as fixation, release, and weathering, which alter soil K levels (Dixon et al., 2016). Consequently, climate change leading to increased aridity limits nutrient availability and, in turn, alters nutrient ratios in plant tissues (Briat et al., 2020).

In general, numerous studies across different soil types have shown that the soil N:P:K ratio significantly affects the availability and uptake efficiency of these elements by plants, and consequently influences overall crop yield and quality (Ziadi et al., 2008; Luo et al., 2016; Briat et al., 2020; Bakare and Osemwota, 2021; Ji et al., 2022). In particular, Briat et al. (2020) concluded that plant critical levels and potassium uptake dynamics largely depend on soil nitrogen supply, indicating strong N:K interactions. Bakare and Osemwota (2021) also observed that the soil N:P:K ratio affects the availability of N and K in maize. A similar pattern was observed in our field experiment, where the N:K ratio in plant tissues was significantly lower under dry conditions without nitrogen application on a potassium background, compared with optimal moisture (Figure 6). In contrast, systematic NPK fertiliser application brought the N:K ratio in plant tissues closer to standard nutritional values, regardless of annual precipitation (Figure 7). The standard values of nutrient content in plant tissues adopted in Ukraine are given in the publication by Baliuk et al. (2011).

The positive effects of potassium are known not only in terms of plant quality, particularly under weather stress, but also in terms of yield. Mouttaqi et al. (2022)

and Malakouti and Majidi (2019) demonstrated that potassium fertilisation positively influences agronomic performance, including key characteristics of durum wheat, such as yield and thousand-grain weight. Other studies have shown that applying K fertilisers increases seed yield in mung bean and improves important yield components, including thousand-seed weight, plant height, seeds per pod, and first pod height (Eroğlu and Önder, 2023; Chantal et al., 2019). In our long-term field experiment (Figure 5), different potassium fertilisation strategies also had a positive impact on cereal grain productivity (barley and wheat). Even the application of potassium fertilisers alone, as a base dressing or through residual effects, significantly increased yield compared with the control (K0).

Our research highlights the increasing importance of balanced potassium nutrition for plants under conditions of global climate change. The close relationship between plant K status and water availability underscores the need to examine potassium in the context of its stoichiometric relationships with other nutrients. As noted by Sardans and Peñuelas (2015), potassium uptake is strongly dependent on water availability, while at the same time K plays a key role in plant water-use strategies. This creates a paradox: the greater the plant's demand for potassium under drought conditions, the more limited its uptake becomes. In this context, maintaining an adequate supply of available potassium in the root zone may serve as an important buffer against the effects of spring and summer droughts. This statement is consistent with the findings of other researchers regarding the role of potassium fertilisation under conditions of insufficient moisture. Grzebisz et al. (2013) have demonstrated that inadequate K supply during critical growth stages of wheat, maize, and sugar beet reduces the development of yield components. Improving potassium nutrition under water-deficit conditions also enhances plant access to other essential resources, including nitrogen and water. A similar effect of potash fertilisation on legumes was reported by Nisha and Narender (2022).

The need to balance nitrogen and potassium nutrition stems from the physiological roles of these elements in plant growth. Both N and K are highly dynamic in the plant–soil system and play key roles in photosynthesis and the subsequent transport of assimilates. Imbalances in their levels within photosynthetic organelles can lead to excessive or insufficient assimilation, ultimately affecting sugar metabolism and photosynthetic carbon assimilation (Shah et al., 2024). Shu et al. (2024) have reported that net photosynthetic rate, stomatal conductance, and intercellular CO_2 concentration initially increase and then decline with increasing N application, whereas K fertilisation has a positive effect on these parameters. Results from our long-term field experiment clearly demonstrate that systematic NPK fertiliser application prevented imbalances between nitrogen and potassium in both soil and plant tissues.

Conclusion

The content of available potassium in the Chernozem of Ukraine is positively correlated with the annual amount of precipitation. However, over recent decades, average precipitation has declined, contributing to a gradual decrease in the N:K ratio in these soils. Quantitatively, an increase in annual precipitation of 50 mm was associated with an increase in mineral nitrogen of 6 mg/kg, whereas the corresponding rise in K_2O was only 3.8 mg/kg, indicating a more pronounced response of nitrogen availability to improved moisture conditions. Balanced fertilisation was found to stabilise the N:K ratio in plant tissues. Under dry growing-season conditions, the absence of fertilisation or the application of potassium fertilisers alone narrowed the N:K ratio. In contrast, systematic application of NPK fertilisers maintained the N:K ratio within the standard range, and under these conditions the ratio was not affected by annual precipitation variability. Overall, high efficiency was demonstrated for various potassium fertilisation systems, including the application of elevated potassium doses to build up soil reserves. These approaches contributed significantly to enhanced crop rotation productivity, confirming the agronomic and ecological importance of balanced potassium management in Chernozem soils. Studies have shown that improving balanced potassium nutrition in plants is particularly important in the context of global climate change, as it enhances the uptake of other essential resources, including nitrogen and water.

References

Adamenko, T. (2019). *Climate change and agriculture in Ukraine*. Bonn: German-Ukrainian agropolitical dialogue. APD. German Ministry of Food and Agriculture (in Ukrainian). 36 p. URL: https://climateadapt.enefcities.org.ua/wp-content/uploads/2022/10/zmina-klimatu-ta-silske-gospodarstvo-v-ukrayini.pdf

Bakare, A. O., & Osemwota, I. O. (2021). Influence of N:P:K Ratios in Soils on Growth, Nutrient Availability and Yield of Maize *(Zea mays L.). Asian Journal of Soil Science and Plant Nutrition, 7*(3), 28–40. https://doi.org/10.9734/ajsspn/2021/v7i330115

Baliuk, S. A., Grekov, V. O., Lisovyi, M. V., & Komarista, A. V. (2011). *Calculation of the balance of humus and nutrients in the agriculture of Ukraine at different levels of management*. Kharkiv: City Printing House, 30 p. (in Ukrainian).

Briat, J. F., Gojon, A., Plassard, C., Rouached, H., & Lemaire, G. (2020). Reappraisal of the central role of soil nutrient availability in nutrient management in light of recent advances in plant nutrition at crop and molecular levels. *European Journal of Agronomy*, *116*, article number 126069. https://doi.org/10.1016/j.eja.2020.126069

Brownlie, W. J., Alexande, P., Maslin, M., Cañedo-Argüelles, M., Sutton, M. A., & Spears, B. M. (2024). Global food security threatened by potassium neglect. *Nature Food, 5*, 111–115. https://doi.org/10.1038/s43016-024-00929-8

Chantal, K., Ong'or, B. T. I., Salvator, K., Fulgence, N., & Norbert, A. (2019). Effects of potassium fertilizer on bean growth and yield parameters. *International Journal of Advances in Scientific Research and Engineering (IJASRE), 5*(1), 1–7. https://doi.org/10.31695/IJASRE.2019.33001

DaCosta, M., & Huang, B. R. (2006). Osmotic adjustment associated with variation in bentgrass tolerance to drought stress. *Journal of the American Society for Horticultural Science, 131*, 338–344.

Dixon, J., Chadwick, O., & Vitousek, P. (2016). Climate Driven Thresholds For Chemical Weathering In Post Glacial Soils Of New Zealand. *Journal of Geophysical Research: Earth Surface*, *121*, 1619–1634. https://doi.org/10.1002/2016JF003864

Eroğlu, A. S., & Önder, M. (2023). Effects of potassium doses on yield and important agricultural properties of mung bean [*Vigna radiate (L.) Wilczek*] genotypes. *Selcuk Journal of Agriculture and Food Sciences, 37*(1), 52–63. https://doi.org/10.15316/SJAFS.2023.007

Francos, M., Pereira, P., Alcaniz, M., Mataix-Solera, J., & Ubeda, X. (2016). Impact of an intense rainfall event on soil properties following a wildfire in a Mediterranean environment (North-East Spain). *Science of The Total Environment*, *572*, 1353–1362. https://doi.org/10.1016/j.scitotenv.2016.01.145

Galmés, J., Pou, A., Alsina, M.M., Tomàs, M., Medrano, H., & Flexas, J. (2007). Aquaporin expression in response to different water stress intensitiehs and recovery in Richter-110 (*Vitis* sp.): Relationship with ecophysiological status. *Planta*, *226*, 671–681. https://doi.org/10.1007/s00425-007-0515-1

Grzebisz, W., Gransee, A., Szczepaniak, W., & Diatta, J. (2013). The effect of potassium fertilization on water-use efficiency in crop plants. *Journal of Plant Nutrition and Soil Science*, *176*, 355–374. https://doi.org/10.1002/jpln.201200287

Institute for Soil Protection of Ukraine (2020). *Periodic report on the state of soils on agricultural lands of Ukraine based on the results of the 10th round (2011–2015) of agrochemical soil survey*. (in Ukrainian). I.P. Yatsuk (Ed.). Kyiv. 207 p. https://media.iogu.gov.ua/literatura/periodically/3_2020.pdf

IUSS Working Group WRB (2022). *World reference base for soil resources, 4th edition.* Vienna: International Union of Soil Sciences. URL: https://www.isric.org/sites/default/files/WRB_fourth_edition_2022-12-18.pdf

Ji, C., Liu, H., Cha, Z., Lin, Q., & Feng, G. (2022). Spatial-Temporal Variation of N, P, and K Stoichiometry in Cropland of Hainan Island. *Agriculture*, *12,* 39. https://doi.org/10.3390/agriculture12010039

Kaldenhoff, R., Ribas-Carbo, M., Flexas, J., Lovisolo, C., Heckwolf, M., & Uehlein, N. (2008). Aquaporins and plant water balance. *Plant, Cell and Environment*, *31*, 658-666. https://doi.org/10.1111/j.1365-3040.2008.01792.x

Kariuki, S., Schroder, J., Zhang, H., Hanks, T., McGrath, J. M., & Payton, M. E. (2010). Temporal Variability of Soil Property Dynamics in a Grazed Pasture. *Communications in Soil Science and Plant Analysis, 41*, 2744–2754. https://doi.org/10.1080/00103624.2010.518265

Khristenko, A. O., & Istomina, Y. O. (2013). Soil and climatic conditions of Ukraine and the effectiveness of potassium fertilizers. *Bulletin of agricultural science*, *8*, 10–13. (in Ukrainian). URL: https://agrovisnyk.com/oldpdf/visnyk_08_2013.pdf

Li, T., Liang, J., Chen, X., Wang, H., Zhang, S., Pu, Y., Xu, X., Li, H., Xu, J., Wu, X., & Liu, X. (2021). The interacting roles and relative importance of climate, topography, soil properties and mineralogical composition on soil potassium variations at a national scale in China. *CATENA*, 196, 104875. https://doi.org/10.1016/j.catena.2020.104875

Li, Z., Zhang, R., Xia, S., Wang, L., Liu, C., Zhang, R., Fan, Z., Chen, F., & Liu, Y. (2019). Interactions between N, P and K fertilizers affect the environment and the yield and quality of satsumas. *Global Ecology and Conservation,* 19, e00663. https://doi.org/10.1016/j.gecco.2019.e00663

Luo, X., Mazer, S. J., Guo, H., Zhang, N., Weiner, J., & Hu, S. (2016). Nitrogen:phosphorous supply ratio and allometry in five alpine plant species. *Ecology and Evolution, 22,* 6(24), 8881–8892. https://doi.org/10.1002/ece3.2587

Malakouti, M. J., & Majidi, A. X. (2019). Effect of Potassium Fertilizers Management on Some Quantitative and Qualitative Characteristics of Wheat. *Water and Soil, 33*, 635–645. https://doi.org/10.22067/jsw.v0i0.79599

Marschner, P. (2012). *Marschner's Mineral Nutrition of Higher Plants*. UK, London: Academic Press, 178–189. https://doi.org/10.1016/C2009-0-63043-9

Mouttaqi, A., Mnaouer, I., Nilahyane, A., Belcaid, M., Ibourki, M., Lazaar, K., Diatta, L., Devkota, K. P., Kouisni, L., & Hirich, A. (2022). How Does Organic Amendment and NPK Fertilization Improve Forage Yield of Cereals under Salinity and Arid Conditions? Case of Moroccan Sahara. *Environmental Sciences Proceedings, 16*, 51. https://doi.org/10.3390/environsciproc2022016051

Murrell, T. S. Mikkelsen, R. L., Sulewski, G., Norton, R., & Thompson, M. L. (2021). *Improving Potassium Recommendations for Agricultural Crops*. Springer International, 455 p. https://doi.org/10.1007/978-3-030-59197-7

Nisha, K., & Narender, S. (2022). Managing Water Stress by Potassium Fertilizer in Legumes for Sustainable Agricultural Intensification: A Review. *Legume Research - An International Journal, 45*(7), 793–803. https://doi.org/10.18805/LR-4094

Nosko, B. S., & Hladkikh, Y. Y. (2011). The aftereffect of mineral fertilizers on the potassium fund of typical chernozem (in Ukrainian). *Bulletin of agricultural science*, *10*, 14–16.

Pogromska, Y. A. (2021). The content of exchangeable potassium in the soil depending on the method of tillage and meteorological factors (in Ukrainian). *AgroChemistry and Soil Science*, *91*, 41–48. https://doi.org/10.31073/acss91-05

Römheld, V., & Kirkby, E. A. (2010). Research on potassium in agriculture: needs and prospects. *Plant and Soil, 335*, 155–180. https://doi.org/10.1007/s11104-010-0520-1

Roy, R. N., Finck, A., Blair, G. J., & Tandon, H. S. (2006). *Plant nutrition for food security: A guide to integrated nutrient management.* FAO Fert & Plant Nutrition Bulletin, Food and Agriculture Organization of the United Nations, Rome, Italy, from https://openknowledge.fao.org/handle/20.500.14283/a0443e

Sardans, J., & Peñuelas, J. (2015). Potassium: a neglected nutrient in global change. *Global Ecology and Biogeography*, *24*, 261–275. https://doi.org/10.1111/geb.12259

Shah, I. H., Jinhui, W., Li, X., Hameed, M. K., Manzoor, M. A., Li, P., Zhang, Yi., Niu, Q., & Cgang, L. (2024). Exploring the role of nitrogen and potassium in photosynthesis implication for sugar: Accumulation and translocation in horticultural crops. *Scientia Horticulturae*, *327*, 112832. https://doi.org/10.1016/j.scienta.2023.112832

Sheldrick, W. F., Syers, J. K., & Lingard, J. (2002). A conceptual model for conducting nutrient audits at national, regional, and global scales. *Nutrient Cycling in Agroecosystems, 62*, 61–72. https://doi.org/10.1023/A:1015124930280

Shu, X., Jin, M., Wang, S., Xu, X., Deng, L., Zhang, Z., Zhao, X., Yu, J., Zhu, Y., Lu, G., & Lv, Z. (2024). The Effect of Nitrogen and Potassium Interaction on the Leaf Physiological Characteristics, Yield, and Quality of Sweet Potato. *Agronomy,* 14*,* article number 2319. https://doi.org/10.3390/agronomy14102319

State Statistics Service of Ukraine (2023). *Agriculture, forestry and fisheries of Ukraine. Use of fertilizers and pesticides for the 2023 crop harvest* (in Ukrainian). https://www.ukrstat.gov.ua/ (accessed 07/2024)

Su, B., Zhao, G., Dong, C., & Chen, X. (2019). Scale characteristics and effects on spatial variability of soil available nutrients. *Applied Engineering in Agriculture, 35*, 221–230. https://doi.org/10.13031/aea.12963

Ziadi, N., Bélanger, G., Cambouris, A., Tremblay, N., Nolin, M. C., & Claessens, A. (2008). Relationship between phosphorus and nitrogen concentrations in spring wheat. *Agronomy Journal, 100*, 80–86. https://doi.org/10.2134/agrojnl2007.0119er

Zörb, C., Senbayram, M., & Peiter, E. (2014). Potassium in agriculture – status and perspectives. *Journal of Plant Physiology, 171*, 656–669. https://doi.org/10.1016/j.jplph.2013.08.008

Received: 25 April 2025
Accepted: 14 March 2026

ODNOS N:K U ČERNOZEMU I USEVIMA PRI RAZLIČITIM PRAKSAMA ĐUBRENJA I U USLOVIMA KLIMATSKIH PROMENA

Mykola M. Miroshnychenko, Yevheniia Yu. Hladkikh*, Olesia P. Volosheniuk i Anatoly O. Khristenko

National Scientific Center "Institute for Soil Science and Agrochemistry Research named after O. N. Sokolovsky", Kharkiv, Ukraine

R e z i m e

Iako se stehiometrija hranljivih materija široko primenjuje u proceni ishrane biljaka, agronomi u Ukrajini tradicionalno koriste apsolutne rezultate istraživanja. Da bi se prevazišao ovaj jaz, razmatrana je vremenska varijabilnost odnosa N:K u zemljištu i biljnim tkivima u dugoročnom poljskom ogledu (1971–2017) ispitivanjem uticaja različitih sistema đubrenja kalijumom na produktivnost plodoreda u severoistočnoj Ukrajini (Harkovska oblast). U istraživanju je upoređivan rezidualni uticaj visokog početnog nivoa kalijuma (1800 kg ha^{-1}) i sistematske primene mineralnih đubriva (NPK) u jednostrukim i dvostrukim dozama u okviru plodoreda. Dostupni K u černozemu bio je u pozitivnoj korelaciji sa godišnjom količinom padavina, što je uticalo na stehiometrijsku ravnotežu u biljnim tkivima. U sušnim uslovima, odnos N:K se značajno sužavao, posebno pri đubrenju samo kalijumom. Nasuprot tome, uravnotežena primena NPK đubriva održavala je odnos N:K uporedivim sa onim koji se javlja u uslovima optimalne vlažnosti. Odnos između raspoloživog kalijuma i vode ukazuje na potrebu korišćenja stehiometrijskih odnosa, uključujući i odnos N:K, radi uravnotežene ishrane biljaka u kontekstu klimatskih promena. Uopšteno gledano, đubrenje kalijumom poboljšalo je produktivnost plodoreda i doprinelo je stabilnijoj ravnoteži odnosa hranljivih materija.

Ključne reči: sadržaj raspoloživog kalijuma, odnos N:K, černozem, đubriva, klimatske promene.

Primljeno: 25. aprila 2025.
Odobreno: 14. marta 2026.

*Autor za kontakt: e-mail: ye.hladkikh@ukr.net

Journal of Agricultural Sciences (Belgrade)
Vol. 71, No. 1, 2026
Pages 61-72

https://doi.org/10.2298/JAS2601061Z
UDC: 634.75(497.11)"2016/2021"
Original scientific paper

FORECAST OF THE EXPORT OF FRESH STRAWBERRIES FROM THE REPUBLIC OF SERBIA USING THE ARIMA MODEL

Vladimir D. Zdravković*, Svjetlana D. Janković Šoja and Dejana J. Vučković

University of Belgrade, Faculty of Agriculture, Belgrade, Serbia

Abstract: Regarding the export of fruit intended for fresh consumption, fresh strawberries are among the leading export products of the Republic of Serbia. The main export market for fresh strawberries is the Russian Federation, where an average of 8,447 tonnes of strawberries were exported in the period from 2016 to 2021, which is about 89% of the total export. In the past five years, the export of strawberries from the Republic of Serbia has halved, as a result of the loss of the dominant Russian Federation market. If this trend continues, the Republic of Serbia will lose $10.3 million a year in foreign trade, while the drop in exports will increase supply on the domestic market, leading to a drop in prices and negatively affecting the profitability of this production. The aim of this paper is to find a model that best describes future trends in the export of this fruit using the ARIMA model. The long-term monitoring of exports by the Statistical Office of the Republic of Serbia enables the prediction of this parameter in the coming years. The analysis established that, for the period from 2001 to 2022, the ARIMA (3, 1, 6) model is adequate for forecasting future trends in the export of this fruit. Forecasts suggest that exports of fresh strawberries from the Republic of Serbia will continue to decline in the coming years.

Key words: ARIMA models, strawberry export, forecasting, Box-Jenkins modelling strategy, Republic of Serbia.

Introduction

Fruit production has an important place in the economy of the Republic of Serbia. A large number of people are employed in the production, processing, and trade of fruit, as well as in activities that rely on this branch of agriculture (catering, tourism, and the chemical industry). In some parts of Serbia, especially in hilly and mountainous areas, fruit production is the main source of income for many farms (Milić et al., 2013). According to the data from the Statistical Office of the Republic of Serbia, the area of used agricultural land in the Republic of Serbia in 2021 was 3.5 million hectares, of which 182,084 hectares were

*Corresponding author: e-mail: vzdravkovic@agrif.bg.ac.rs

orchards, accounting for only 5.2% of the total usable agricultural land. This is a relatively small area, considering the extremely favourable conditions for growing fruit trees.

In recent years, fruit production in Serbia has expanded significantly. In addition to the increase in orchard area, this growth includes the introduction of modern fruit tree cultivation technologies based on practices from developed fruit growing regions in Europe (Keserović et al., 2016). The natural conditions of the country of Serbia, including climate and soil, are extremely favourable for the successful cultivation of various types of fruit trees, especially strawberries (Dimitrijević et al., 2021).

After the raspberry, the strawberry is the most abundant berry fruit in Serbia. According to the total area under perennial crops, strawberry ranked sixth in 2022 with 7,039 hectares (www.stat.gov.rs). The strawberry is the most important berry fruit, primarily due to its high profitability, the early crop establishment and the very early ripening time (it is the first fruit to ripen in our region after a long winter). Strawberries are suitable for fresh consumption, freezing, and as raw material for industrial processing (Nikolić and Milivojević, 2015).

Strawberry production in Serbia is mainly concentrated in Mačva, the Danube Region, South Serbia, and part of Pomoravlje. According to the 2012 agricultural census, the largest areas under strawberry cultivation were in the following municipalities: Šabac (292 ha), Varvarin (184 ha), Kruševac (160 ha), Grocka (130 ha) and Leskovac (122 ha).

The emergence of new varieties, the introduction of modern technology for growing strawberries, as well as the development of modern cold storage facilities for storing and transporting fruits, have significantly increased the export of fresh strawberries from Serbia, bringing substantial benefits to agricultural producers and the agricultural sector. However, in recent years, the export of this fruit from the Republic of Serbia has declined.

This paper analyses the current state of the most important parameters in the strawberry trade in Serbia. The aim is to use the ARIMA (autoregressive integrated moving average) model and, based on the available data on strawberry exports from 2001 to 2022, to forecast future export trends. This will help create a clearer picture of the future movement of the strawberry exports, enabling the development of possible strategies and reducing the risk for producers. The long-term monitoring of fresh strawberry exports by the Statistical Office of the Republic of Serbia allows for the prediction of this variable in the coming years. Forecasting export trends could provide guidelines to competent institutions for implementing appropriate agricultural policy measures.

Material and Methods

The data for this paper were obtained from the databases of the Statistical Office of the Republic of Serbia, which provided information on the export trends of fresh and frozen strawberries from 2001 to 2022. The databases of the Food and Agriculture Organization (FAO) and the World Bank (WITS) were used to analyse the most important parameters of strawberry production and trade in Serbia and globally. In addition to these sources, numerous domestic and international scientific and professional publications relevant to the research topic were used.

The time series analysis of fresh strawberry exports was carried out using the statistical package "EViews 12 SV". The Box-Jenkins modelling strategy was applied to analyse previous export trends, and to forecast future trends. The goal of the Box-Jenkins modelling strategy is to select an appropriate ARIMA model that satisfactorily describes the tendencies of a particular time series dataset. This approach consists of three phases: model identification, model parameter evaluation and model adequacy verification (Mladenović and Nojković, 2015).

The use of the ARIMA model and the Box-Jenkins modelling strategy has produced reliable results for predicting future trends in the production and turnover of agricultural products, as demonstrated by numerous scientific papers by both domestic and foreign authors. Goyal et al. (2021) forecasted the agricultural sector exports in India, Erlina and Rialdi (2020) forecasted the value of coffee exports in Indonesia, Đoković et al. (2019) forecasted maize yield, Jaiswal and Bhattacharjee (2022) forecasted pork exports, Farooqi (2014) forecasted exports and imports in Pakistan, Paul et al. (2013) also forecasted meat exports, and Melekşen and Eyduran (2017) predicted a reduction in the area and production of strawberries in Turkey.

Results and Discussion

Analysis of strawberry trade in the Republic of Serbia

After apples and peaches (including nectarines), fresh strawberries rank third in export value among fresh fruit exports (www.stat.gov.rs). According to World Bank data, in 2021, Serbia ranked 15th globally in fresh strawberry exports, with 8,286 tons. When it comes to processed strawberries, Serbia ranked 16th, exporting 6,591 tonnes,. The main importers of fresh and processed strawberries from the Republic of Serbia are presented in the following tables (Tables 1 and 2).

For years, the largest importer of fresh Serbian strawberries has been the Russian Federation. From 2016 to 2021, an average of 8,447,077 kg of fresh strawberries were exported to the Russian market annually. Poland ranks second, with 4.97%, while Belarus ranks third (1.71%). Nine other countries together import less than 5% of fresh strawberries from Serbia.

Table 1. The main importers of fresh strawberries from the Republic of Serbia for the period 2016–2021 (average).

No.	Country	Quantity (kg)	Percentage (%)	Export unit price ($)
1.	Russian Federation	8,447,077	88.96	1.91
2.	Poland	472,000	4.97	1.83
3.	Belarus	162,196	1.71	1.71
4.	Montenegro	82,719	0.87	1.62
5.	Croatia	65,448	0.69	1.97
6.	Romania	58,885	0.62	1.39
7.	Germany	51,980	0.54	1.91
8.	Austria	27,662	0.29	1.86
-	Other countries	126,846	1.34	1.76
	Total	9,495,150	100	1.89

Source: Authors' calculations based on the WITS data.[†]

The average export unit price of strawberries in the observed period was $1.89/kg. Russia imports about 50,000 tonnes of strawberries annually, with Serbia supplying one-fifth of its total needs. The largest exporter of strawberries to the Russian market is Turkey (18,000 t), followed by Serbia (8,000 t), Belarus (5,000 t), Moldova (2,000 t), China (2,000 t), and Egypt (1,800 t) (WITS). A significant increase in Serbian strawberry exports to the Russian market occurred after the European Union had imposed sanctions on Russia in 2014.

Table 2. The main importers of processed strawberries from the Republic of Serbia in the period 2016–2021 (average).

No.	Country	Quantity (kg)	Percentage (%)	Export unit price ($)
1.	Germany	1,227,018	22.10	1.83
2.	France	945,702	17.03	2.24
3.	Austria	457,418	8.24	1.98
4.	Netherlands	405,992	7.31	2.26
5.	Russia	399,699	7.20	2.06
6.	Belgium	347,126	6.25	3.34
7.	Italy	204,058	3.68	2.32
8.	Sweden	188,972	3.40	2.61
-	Other countries	1,326,245	23.89	2.31
	Total	5,552,230	100.00	2.32

Source: Authors' calculations based on the WITS data.

Processed strawberries include any form of cooked or uncooked strawberries, as well as frozen strawberries, regardless of whether they contain sugar or other sweeteners. Based on WITS data, the main importer of processed strawberries from

[†]WITS – "World Integrated Trade Solution" – trade software created by the World Bank that helps in searching various international trade databases.

Serbia is Germany, with France and Austria in second and third place, respectively. The highest export unit price for processed strawberries was achieved in trade with Belgium ($3.34). In addition to these countries, there are 28 other countries for which there is evidence of imports of some form of processed strawberries from Serbia. Among them, Bosnia and Herzegovina, Switzerland, Croatia, Greece, Slovenia, and Portugal stand out in terms of import volume.

In recent years, starting from 2017 (Figure 1), a decline in the export of fresh strawberries from Serbia has been observed. This is best illustrated by the fact that in 2022, for the first time in 10 years, the export volume of frozen strawberries surpassed that of fresh strawberries. A drastic drop in the export of fresh strawberries occurred in 2022. The main reason for this is the difficulty of exporting strawberries to the Russian market, which is the dominant market, due to the war in Ukraine and the sanctions imposed by other countries against Russia. This made transportation much more difficult and expensive, thereby increasing the selling price of strawberries from Serbia. In addition, one reason is the strengthening of Russian agriculture and the rapid expansion of strawberry cultivation areas. In the past five years alone, strawberry production in Russia has increased by 36,400 tonnes, which, for comparison, is 6,000 tonnes more than the total strawberry production in the Republic of Serbia.

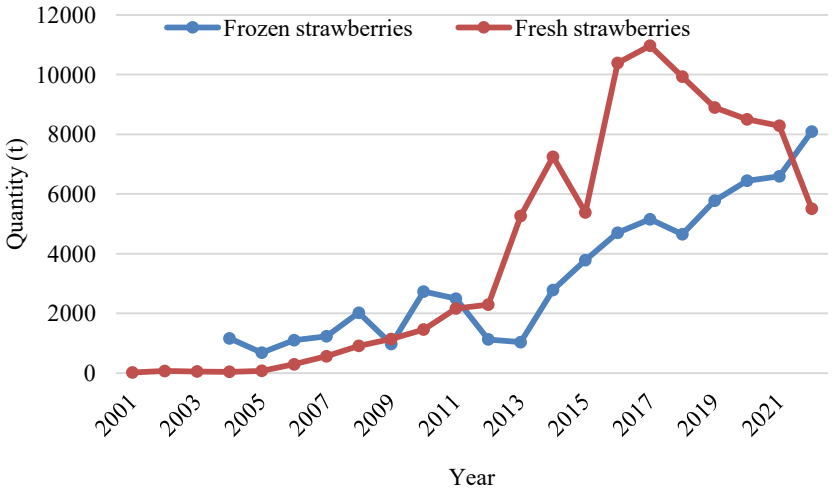


Figure 1. Export of fresh and frozen strawberries from the Republic of Serbia in the period 2001–2022 (in tonnes).
Source: Authors' own preparation.

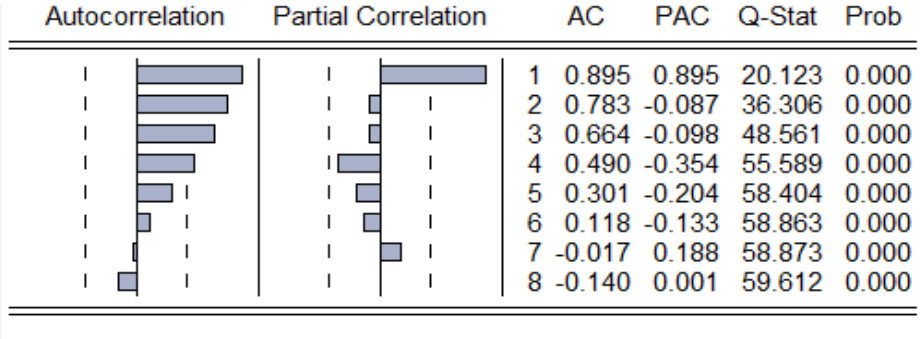
Considering the greater economic importance of fresh strawberries (due to the higher purchase price for producers), the export trend of fresh strawberries will be

forecast. For comparison, in previous years the price of strawberries for processing ranged from $0.60 to $1.00 per kilogram, while the price of fresh strawberries intended for export ranged from $1.00 to $2.00 per kilogram.

Forecast of the export of fresh strawberries from Serbia

The first stage of the Box-Jenkinson time series modelling strategy involves analysing a graphical representation of a time series to determine whether the series is stationary or non-stationary. Based on the graphical display, only a rough estimate can be made; therefore, formal statistical testing should also be carried out. Analysing the graphic display (Figure 1), it can be seen that the series had an increasing trend and no pronounced seasonal variations. It can also be observed that the series had no structural break.

By analysing the ordinary and partial autocorrelation (Figure 2), it was established that the time series most likely had an ordinary unit root (the ordinary autocorrelation function decreased constantly and slowly, and the partial autocorrection was significant only at the first lag).



	AC	PAC	Q-Stat	Prob
1	0.895	0.895	20.123	0.000
2	0.783	-0.087	36.306	0.000
3	0.664	-0.098	48.561	0.000
4	0.490	-0.354	55.589	0.000
5	0.301	-0.204	58.404	0.000
6	0.118	-0.133	58.863	0.000
7	-0.017	0.188	58.873	0.000
8	-0.140	0.001	59.612	0.000

Figure 2. Correlogram of the ordinary and partial autocorrelation functions for the series of fresh strawberry exports during the period 2001–2022.
Source: Authors' own work using the statistical package "EViews 12 SV".

To confirm that the time series had a unit root, the unit root test (Dickey-Fuller test) was performed.

In the first iteration, two hypotheses were proposed:

H_0: The time series has at least one unit root.

H_1: The time series is stationary.

The answer to which hypothesis to accept was obtained by comparing the test statistic with the critical value. To compare a test statistic with a critical value, two conditions must be met:

1) The last included variable must be statistically significant (except in the zero step), and

2) There must be no residual autocorrelation.

Regression of the first difference on a constant found that the constant is not statistically significant. Therefore, to test the null hypothesis mentioned above, the τ_μ test statistic was used. Comparing the test statistic with the critical value gave:

DF(0) τ_μ= -1.138033 > $DF\tau_\mu{}^{\text{crit}}_{5\%} = -3.012$, on which basis the hypothesis H_0 was accepted.

Before confirming that a series had a unit root, one must check whether the series might have two unit roots.

In the second iteration, two hypotheses were set:

H_0: The time series has two unit roots, against the hypothesis.

H_1: The time series has exactly one unit root.

Comparing the test statistic with the critical value gave:

DFTμ(0) = -4.121583 < $DFT\mu^{krit}_{5\%}$ = -3.012363, on which basis hypothesis H_1 was accepted.

This confirms that the series had exactly one unit root. The first difference of the time series export of fresh strawberries was then modelled and ARIMA (3, 1, 6) was chosen as an adequate model. The estimated parameters of the model are shown in Table 3.

Table 3. Estimated parameters of the ARIMA model (3, 1, 6).

Variable	Coefficient	Std. error	t-statistic	Prob.
AR(3)	0.777835	0.280324	2.774774	0.0135
MA(6)	-0.923048	0.394991	-2.336883	0.0328
R-squared	0.381828	Mean dependent var		303.3889
Adjusted R-squared	0.343192	SD dependent var		1,731,615
SE of regression	1,403,364	Akaike info criterion		17.43557
Sum squared resid	31,510,908	Schwarz criterion		17.53450
Log likelihood	-154.9201	Hannan-Quinn criterion.		17.44921
Durbin-Watson Stat	2.565231			
Inverted AR roots	.92	-.46-80i	-.46+.80i	
Inverted AR roots	.99	.49+.85i	.49-.85i	-.49-.85i
	-.49+.85i	-.99		

Source: Authors' calculation using the statistical package "EViews 12 SV".

For the model to be adequate for prediction, the residuals of the estimated model should be normally distributed and unautocorrelated. The assumption of

normality of the residuals was checked using the Jarque–Bera test statistic (JB test statistic).

If the calculated value of the JB test statistic is less than the corresponding critical value (5.99 at the 5% significance level), the residuals can be considered normally distributed. In addition to the JB test, standard statistical packages usually provide a p-value in addition to the test statistic value. In practice, the obtained p-value is most often compared with 0.05 or 0.10. To conclude that the residuals do not deviate from the normal distribution, the p-value of the JB statistic must be greater than 0.05 (Mladenović and Nojković, 2015).

The results of the residual normality test (Figure 3) show that the residuals were normally distributed because JB = 0.205051 was less than the critical value of 5.99, that is, the corresponding p-value of 0.90255 was greater than the 0.05 significance level.

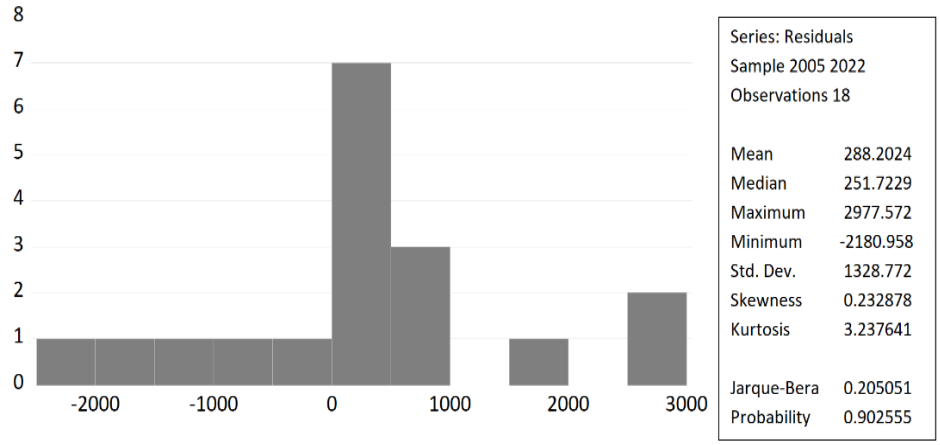


Figure 3. Histogram of residuals from the estimated ARIMA model (3, 1, 6).
Source: Authors' own work using the statistical package "EViews 12 SV".

After the model has been identified, evaluated, and checked for adequacy, a forecast can be made, i.e., forecasting the trend of strawberry exports over the next five years. The forecast of fresh strawberry exports using the ARIMA model (3, 1, 6) for the period from 2023 to 2027 is shown in Table 4.

Table 4. Forecast of trends in the export of fresh strawberries for the period 2023–2027.

Year	Forecast (tonnes)
2023	5,722
2024	5,036
2025	4,886
2026	4,359
2027	4,906

Source: Authors' forecasts based on the ARIMA model.

The forecast indicates a slight increase in exports in 2023 (5,722 t) compared to 2022 (5,505 t), and that the downward trend in exports will continue in the following years, with a slight increase again in 2027 (Figure 5).

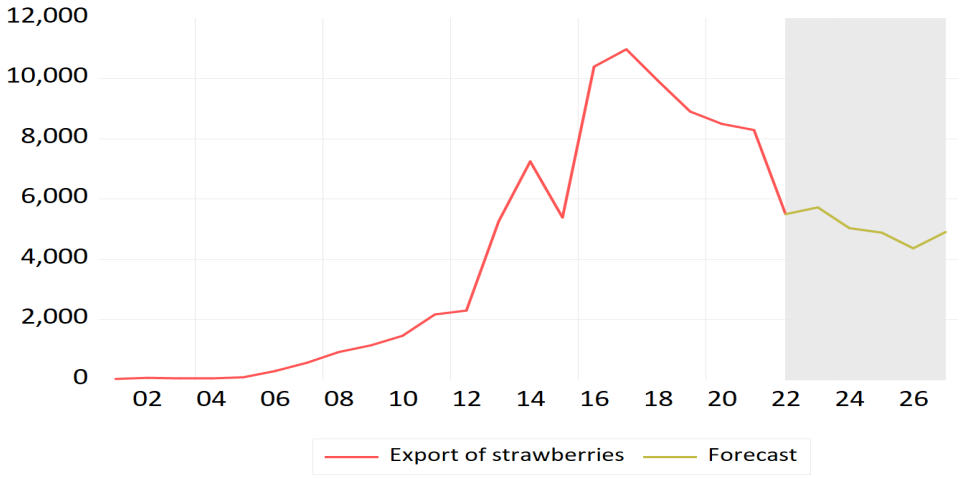


Figure 4. Presentation of fresh strawberry exports in Serbia with export forecasts for the period 2023–2027.
Source: Authors' own work using the statistical package "EViews 12 SV".

Conclusion

Fruit production is characterised by numerous specificities (production takes place in the open field, high dependence on climatic and soil conditions, the specificity of plants that, during their life cycle, experience periods of increasing and decreasing fertility, etc.) which are reflected in regular and stable yields. All this makes agricultural production uncertain and difficult to predict. However, the analysis of time series and the use of the ARIMA model, including the well-known

Box-Jenkins modelling strategy, have shown that it is possible to predict future trends in the production and turnover of agricultural products with relatively small deviations.

In this paper, a forecast was made for the export of fresh strawberries for the period 2023–2027. The projected value for the exported amount of strawberries in 2022 (4,898 t) was slightly lower than the realised value in 2022 (5,505 t). The deviation percentage for the exported quantity of strawberries was 11.02%. Based on the small percentage of deviation, it can be concluded that the chosen model, and therefore the forecast for the next period, could be relatively reliable.

The forecast for strawberry exports for the period 2023–2027 shows a slight increase in exports in 2023 (5,722 t), followed by a continued decline in subsequent years. According to the forecast, a slight increase in exports can be expected in 2027 (4,906 t). Official data from the Statistical Office of the Republic of Serbia indicate that strawberry exports amounted to 4,377 t in 2023 and 2,723 t in 2024, showing that total exports were significantly lower than forecast. The sharp decline in exports can be attributed to the unstable conditions affecting strawberry exports to the Russian market due to the Russia–Ukraine war. Additionally, the introduction of further sanctions packages by the EU against the Russian Federation further complicated strawberry exports. Transportation costs increased substantially due to changes in trade routes, while refrigerated lorries experienced longer delays at border crossings, which also negatively affected the quality of chilled strawberries.

In the past five years, the export of fresh strawberries has halved, decreasing from 10,967 tonnes in 2017 to 5,505 tonnes in 2022.

Considering that the average export unit price of strawberries is $1.9/kg (WITS), this indicates a loss of the Republic of Serbia of $10.3 million in foreign trade annually. In addition, the decrease in fresh strawberry exports from Serbia will increase the supply of strawberries on the domestic market, leading to a drop in purchase prices and significantly affecting the profitability of production. Competent institutions should respond to such shocking data by investigating the issue more deeply and, through the implementation of adequate measures and strategies, prevent further declines in exports. One option could be to gradually listen to and adapt to the needs of other markets.

Acknowledgments

The article was developed as part of the research activities conducted under the 2026 Contract on the Implementation and Financing of Scientific Research, concluded between the Faculty of Agriculture, University of Belgrade, and the Ministry of Education of the Republic of Serbia (Contract No. 451-03-34/2026-03/200116).

References

Dimitrijević, B., Bulatović, B., Rajić, Z., & Zdravković, V. (2021). Economic profitability of Loch Ness blackberry production on a family farm. In S. Jelić, & M. Nedeljković (Eds.), *Proceedings of the scientific conference with international participation "Village and Agriculture"*, (pp. 187–208). University of Bijeljina, Bijeljina.

Đoković, J., Munćan, M., & Paunović, T. (2019). Forecasting maize yield in the Republic of Serbia by using Box-Jenkins methodology. *Agricultural Economics, 66*(2), 525–540. https://doi.org/10.5937/ekoPolj1902525D

Erlina, R., & Rialdi, A. (2020). Forecasting model of agriculture commodity of value export of coffee: application of Arima model. *Journal Teknik Pertanian Lampung, 9*(3), 257–263. https://doi.org/10.23960/jtep-l.v9i3.257-263

Farooqi, A. (2014). ARIMA model building and forecasting on imports and exports of Pakistan. *Pakistan Journal of Statistics and Operations Research, 10*(2), 157–168. https://doi.org/10.18187/pjsor.v10i2.732

Goyal, M., Agarwal, S., Goyal, S. K., & Agarwal, N. (2021). Forecasting of Indian agricultural exports using ARIMA model. *Asian Journal of Research in Business Economics and Management, 11*(8), 11–15. https://doi.org/10.5958/2249-7307.2021.00010.4

Jaiswal, P., & Bhattacharjee, M. (2022). Understanding the potential of livestock market with special reference to the export of pork meat from India: A study of time-series analysis using arima-based forecasting method. *Asian Journal of Dairy and Food Research, 41*(3), 293–297. https://doi.org/10.18805/ajdfr.DR-1797

Keserović, Z., Magazin, N., Milić, B., & Dorić, M. (2016). *Fruit growing and viticulture (part of fruit growing)*. University of Novi Sad, Faculty of Agriculture, Novi Sad.

Melekşen, A., & Eyduran, S. P. (2017). Forecasting harvest area and production of strawberries using time series analyses. *Journal of Agricultural Faculty of Gaziosmanpaşa University (JAFAG), 34*(3), 18–26. https://doi.org/10.13002/jafag4298

Milić, D., Kalanović-Bulatović, B., & Veljković, B. (2013). *Management and organization of fruit and viticulture production*. University of Kragujevac, Faculty of Agriculture, Čačak.

Mladenović, Z., & Nojković, A. (2015). *Applied analysis of time series - second edition*. University of Belgrade, Faculty of Economics, Belgrade.

Nikolić, M., & Milivojević, J. (2015). *Strawberry fruits - cultivation technology*. University of Belgrade – Faculty of Agriculture, Belgrade.

Paul, R. K., Panwar, S., Sarkar, S. K., Kumar, A., Singh, K. N., Farooqi, S., & Choudhary, V. K. (2013). Modeling and forecasting of meat exports from India. *Agricultural Economics Research Review, 26*(2), 249–256.

Statistical Office of the Republic of Serbia (2012). Agriculture Census – Agriculture in the Republic of Serbia, *Fruit Growing*, 41, Statistical Office of the Republic of Serbia, Belgrade.

https://www.stat.gov.rs/ ; Accessed on 15.01.2024.

https://wits.worldbank.org/; Accessed on 01.12.2023.

Received: 13 March 2024
Accepted: 4 February 2026

PROGNOZA IZVOZA SVEŽIH JAGODA IZ REPUBLIKE SRBIJE PRIMENOM ARIMA MODELA

Vladimir D. Zdravković*, Svjetlana D. Janković Šoja i Dejana J. Vučković

Univerzitet u Beogradu, Poljoprivredni fakultet, Beograd, Srbija

R e z i m e

Kada se govori o izvozu voća namenjenog potrošnji u svežem stanju, sveža jagoda predstavlja jedan od vodećih izvoznih proizvoda Republike Srbije. Glavno izvozno područje svežih jagoda je Ruska Federacija, u kojoj se u periodu od 2016. do 2021. godine prosečno izvozilo 8.447 tona jagoda, što je oko 89% ukupnog izvoza. U poslednjih pet godina izvoz jagoda iz Republike Srbije je prepolovljen, što je posledica gubitka dominantnog tržišta Ruske Federacije. Ukoliko se nastavi ovakav trend, Republika Srbija bi u spoljnotrgovinskom prometu gubila 10,3 miliona dolara godišnje, dok bi pad izvoza prouzrokovao rast ponude na domaćem tržištu, što bi izazvalo pad cena i odrazilo se negativno na profitabilnost ove proizvodnje. Osnovni cilj rada je da se primenom ARIMA modela pronađe model koji bi na najbolji način opisao buduća kretanja izvoza ovog voća. Praćenje dugogodišnjeg kretanja izvoza od strane Republičkog zavoda za statistiku daje mogućnost predviđanja ovog parametara u narednim godinama. Analizom je ustanovljeno da je za vremenski period od 2001. do 2022. godine model ARIMA (3, 1, 6) adekvatan za predviđanje budućih kretanja izvoza ovog voća. Prema projekcijama, u narednim godinama očekuje se dalji pad izvoza svežih jagoda iz Republike Srbije.

Ključne reči: ARIMA modeli, izvoz jagoda, predviđanje, Boks-Džekinsova strategija modeliranja, Republika Srbija.

Primljeno: 13. marta 2024.
Odobreno: 4. februara 2026.

*Autor za kontakt: e-mail: vzdravkovic@agrif.bg.ac.rs

Journal of Agricultural Sciences (Belgrade) https://doi.org/10.2298/JAS2601073M
Vol. 71, No. 1, 2026 UDC: 004.738.5:631
Pages 73-91 Original scientific paper

USE OF YOUTUBE FOR DIFFUSION OF INNOVATIVE AGRICULTURAL TECHNOLOGIES: A DIGITAL SELF-HELP APPROACH TO THE FARMERS

Mohummed Shofi Ullah Mazumder[1*], Fatema Wadud[2] and Sushama Barua[1]

[1]Department of Agricultural Extension & Information System, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh
[2]Department of Agricultural Marketing, Dhaka, Bangladesh

Abstract: The diffusion of innovative agricultural technologies is essential for improving productivity, food security, and rural livelihoods in developing countries, where conventional extension services often face financial and institutional constraints. This study investigates the role of YouTube as a digital self-help platform for farmers in rural Bangladesh, emphasising its effectiveness in disseminating agricultural information and the factors influencing its adoption. A cross-sectional survey of 276 farmers was conducted in *Rangunia* Upazila (sub-district) under the Chattogram district. Data was collected using a structured questionnaire and analysed using regression analysis. After considering Variance Inflation Factor (VIF) value, multivariate logistic regression was conducted. The results show that YouTube adoption is significantly associated with education, effective farm size, and agricultural extension contact. Farmers using YouTube reported higher agricultural knowledge, greater incomes, and more diversified farming practices than non-users. Additionally, YouTube was widely used for weather forecasts, disaster preparedness, peer learning, post-harvest management, and market engagement, underscoring its multifunctional role. Overall, platforms such as YouTube, when supported by improved ICT access, affordable digital resources, and targeted training, can significantly enhance agricultural knowledge and technology adoption among Bangladeshi farmers, thereby promoting sustainable rural development.

Key Words: Role of YouTube; adoption and adaptation; self-help approach; VIF, multivariate logistic regression.

Introduction

Agriculture remains central to livelihoods, food security, and structural transformation in developing economies. Despite its importance, productivity growth among smallholder farmers continues to be constrained by limited access to

*Corresponding author: e-mail: shofikeron@gmail.com

timely, reliable, and context-specific information (Barrett et al., 2020). Agricultural transformation increasingly depends not only on technological innovation but also on effective systems for knowledge dissemination and adoption (Fabregas et al., 2019). In many developing countries, however, public extension systems are underfunded, understaffed, and unable to provide personalised advisory services at scale (Birner et al., 2021). These structural limitations have intensified the search for alternative, scalable, and cost-effective communication channels.

The rapid expansion of information and communication technologies (ICTs) has reshaped agricultural knowledge systems. Digital platforms facilitate faster information exchange, reduce transaction costs, and support interactive and decentralised learning (Trendov et al., 2019). Empirical evidence suggests that ICT-enabled advisory services can significantly enhance farmers' knowledge, influence behavioural change, and improve adoption rates of recommended technologies (Van Campenhout et al., 2021). Beyond formal advisory services, digital tools increasingly enable peer-to-peer learning and farmer-driven knowledge exchange, thereby redefining traditional extension paradigms (Klerkx et al., 2019).

Within this evolving digital ecosystem, social media platforms have emerged as influential instruments of agricultural communication. Unlike traditional top-down extension models, social media enables interactive engagement, user-generated content, and rapid dissemination of experiential knowledge (Daum, 2021). Among these platforms, YouTube is particularly significant due to its audiovisual format, which enhances observational learning and reduces uncertainty associated with innovation adoption. Video-mediated extension approaches have been shown to improve comprehension, retention, and behavioural outcomes among smallholder farmers (Bentley et al., 2019). The ability to visually demonstrate production techniques, input application methods, and farm management practices strengthens farmers' confidence in adopting new technologies.

The YouTube content accessed by farmers in rural Bangladesh encompassed a mix of innovative agricultural technologies and conventional farming practices. Channels such as *Krishi Bioscope*, *Dipto Krish*, and *Krisna* provide localised and practical guidance, including demonstrations of modern seed varieties, mechanised planting methods, integrated pest management, organic fertiliser use, and water-saving irrigation techniques, all representing innovative agricultural technologies. At the same time, many videos also cover traditional practices, such as seasonal cropping schedules, soil preparation, composting, and livestock care, which, while widely practised, remain important for effective farm management. Farmers reported using YouTube for both technical learning and reinforcement of existing knowledge, indicating that the platform serves a dual role: introducing novel techniques and providing accessible guidance on conventional practices. This

combination allows farmers to compare new methods with familiar practices, evaluate their applicability, and adopt innovations more confidently.

Bangladesh provides a compelling context to examine these dynamics. As a predominantly agrarian economy undergoing digital transformation, the country has invested heavily in expanding ICT infrastructure and promoting digital service delivery in rural areas. Nevertheless, disparities in digital literacy, infrastructure access, and socio-economic resources continue to shape farmers' engagement with digital platforms. YouTube channels focusing on agriculture, often managed by extension agents, agribusiness actors, NGOs, and experienced farmers, have gained substantial popularity. Yet, despite the platform's increasing visibility, systematic empirical evidence regarding its role in agricultural technology diffusion remains limited.

In particular, little is known about how farmers perceive the credibility and influence of YouTube as an advisory source, whether they distinguish between general educational content and innovative technological knowledge, and which socio-demographic factors affect its effective use. Addressing these questions is critical for understanding whether YouTube serves merely as an informal information source or as a transformative digital self-help mechanism within agricultural innovation systems. This study therefore investigates the socio-demographic and farm-level determinants influencing farmers' use of YouTube for agricultural technology adoption in Bangladesh. It specifically examines: (a) the socio-economic profiles of farmers engaging with YouTube; (b) the extent to which YouTube facilitates innovation diffusion; (c) farmers' perceptions of its credibility and influence; and (d) the key factors shaping its adoption and intensity of use. By situating YouTube within broader debates on digital agriculture and innovation systems, the study contributes to emerging scholarship on decentralised, platform-mediated agricultural extension.

Social media platforms used by farmers

Social media platforms have increasingly disrupted traditional agricultural communication systems by facilitating two-way communication, real-time interaction, and participatory knowledge exchange. Empirical studies demonstrate that farmers worldwide are actively integrating digital platforms into their agricultural practices to seek, share, and apply information relevant to production, marketing, and risk management (Malik and Ansari, 2024). Research from multiple contexts shows that social media enhances access to agricultural knowledge, reduces information lags, and supports peer networks that complement formal extension systems (Alizada et al., 2024). The democratisation of agricultural knowledge through these platforms also challenges the traditional hierarchical flow of information dominated by extension agents and formal institutions (Gwelo, 2025). These developments are consistent with innovation systems and diffusion

frameworks, where digital platforms enhance observability, trialability, and reinvention of agricultural practices.

Farmers' usage of social media varies by platform type, reflecting both communication affordances and contextual needs. Multiple studies consistently identify Facebook, WhatsApp, and YouTube as the most widely adopted platforms for agricultural information exchange and community engagement (Malik and Ansari, 2024). Facebook groups provide spaces for networking, market linkages, and shared learning, enabling farmers to interact with peers and stakeholders across geographical boundaries. WhatsApp is valued for its immediacy and low data requirements, often serving as a channel for localised advisory services and rapid problem-solving among farmer groups. YouTube offers powerful visual learning opportunities, allowing farmers to view demonstration videos on agricultural techniques, machinery use, and pest management strategies, thereby increasing both comprehension and adoption of innovations. Recent qualitative research based on uses and gratifications theory further reveals that farmers actively engage with social media to meet various informational and social needs, including agricultural problem-solving, peer interaction, professional development, and evaluation of alternative practices (Ahmad et al., 2025). Moreover, video-based content has strengthened farmers' ability to interpret and apply complex innovations, especially where literacy levels vary.

Despite the positive trends, social media adoption is mediated by structural and socio-economic factors. Studies from India and other developing contexts indicate persistent challenges related to digital literacy, limited awareness of relevant platforms, and inadequate digital infrastructure, particularly in remote rural areas (Malik and Ansari, 2024). These constraints reduce the potential of social media to function as a fully inclusive advisory system. Research highlights that younger, more educated farmers tend to adopt these tools more readily, while older and less educated farmers face considerable barriers to effective use. Additionally, the quality of information and exposure to misinformation pose risks. Without mechanisms for content duration or verification, farmers may receive inaccurate guidance, complicating decision-making processes. These factors underscore that social media should be viewed as a complementary tool rather than a replacement for formal extension services, particularly in contexts where digital divides persist.

Although numerous studies document farmers' use of social media for communication and extension support, the specific role of video platforms particularly YouTube as self-directed learning environments remains insufficiently examined. Existing research largely frames social media as an extension delivery tool rather than investigating how farmers independently search for, interpret, and apply video-based content to solve practical production challenges. This distinction is critical because self-directed learning implies proactive knowledge seeking and

autonomous decision-making. Video platforms uniquely facilitate visual and experiential learning essential for agricultural technologies that require demonstration. However, empirical evidence on how such multimedia engagement translates into grassroots innovation adoption among farmers remains limited. Consequently, understanding YouTube's role in shaping autonomous learning and technology diffusion represents an important frontier in digital extension research.

Influence of demographic characteristics on social media familiarity and usage

Many factors influence technology adoption, with demographic variables such as age, gender, education, and experience playing a significant role in the acceptance and use of social media platforms (Lubua and Pretorius, 2018). Different age groups tend to have varied perceptions of social media based on their needs and exposure. Suchiradipta and Saravanan (2016) have found that younger people are more likely to use social media for agricultural information, while older rural men use it less. However, Joshi and Dhaliwal (2019) have observed that middle-aged and older farmers also actively use social media for learning and marketing agricultural innovations. Gender also affects technology adoption, as men and women often have different societal roles influencing their use of new technologies (Yonazi et al., 2012). Some studies show that men rely less on support when adopting technology (Talat et al., 2013), while others report men use social media more for agricultural extension services than women (Ghosh et al., 2021). Education is a key factor, with higher education levels linked to better understanding and use of agricultural technologies through social media (Zondo and Ndoro, 2024). Farm size has also been identified as influencing social media use for technology adoption, although findings are mixed (Ghosh et al., 2021; Joshi and Dhaliwal, 2019).

This review shows that demographic characteristics influence social media use in agriculture. However, no specific studies have examined the use of the digital self-help approach via YouTube for agricultural technology diffusion. Although there are studies on platforms such as Facebook, WhatsApp, YouTube, and Instagram for agricultural innovation, there is a notable gap in research focusing on YouTube's role, particularly in Bangladesh. This study aims to address that gap.

Material and Methods

Study design and sampling methodology

This study employed a cross-sectional survey design to systematically document and list the factors that influence farmers' use of YouTube to adopt innovative agricultural technologies in rural Bangladesh. The study was conducted in *Rangunia* Upazila (Sub-district) of Chattogram district, where most people are

engaged in farming activities. *Rangunia* Upazila (sub-district) comprises fifteen unions, and the present study was conducted purposively in five selected villages from four unions: '*Pomra*, *Parua*, *Padua*, *Mariamnagar* and *Chandraghona*'. In collaboration with the Upazila (sub-district) Agricultural Extension Office and the relevant Sub-Assistant Agriculture Officer (SAAO), we compiled a list of active farmers from all five villages in the study area. This list served as the primary sampling frame, ensuring that only individuals actively engaged in agricultural practices were included in the population. The total number of active farmers across the five villages in the sub-district was 3,067. This group includes both YouTube users and non-users, but all are active farmers. To ensure representativeness and statistical precision, the sample size of 276 farmers was determined by applying the formula given by Yamane (1967). In calculating the sample size, a 5% precision level, 50% degree of variability, and a Z value of 2.57 at a 99% confidence level were chosen, using the following formula:

$$n = \frac{Z^2 P\,(1-P)N}{Z^2 P\,(1-P)N + N\,(e)^2}$$

where: n=sample size, N=population size, e=the level of precision, Z=the value of the standard normal variable at the chosen confidence level, and P=the proportion or degree of variability. The sample size from each village was determined using a proportionate random sampling technique. Of the total sample of 276, it was found that 162 individuals were YouTube users, and 114 were non-users, based on a single question. A reserve list of 30 farmers was also prepared so that these farmers could be interviewed if those in the original sample were unavailable at the time of the interview.

Data collection tools and procedure

For the quantitative component, a structured questionnaire was designed to collect data from farmers. A close-ended questionnaire was used to gather information on socio-economic factors, agricultural resources, and training-related aspects. An open-ended questionnaire was also used for certain variables. The questionnaire was pre-tested among 20 farmers from a village not included in the study area, ensuring clarity, reliability, and cultural relevance. Feedback from the pre-test informed minor revisions to improve the questionnaire. All data were collected from 19 January 2021 to 20 February 2021. The data collection was carried out by a team of five enumerators under the supervision of the researcher. The enumerators were local graduate students with prior experience in conducting surveys and interviews in agricultural contexts. Each enumerator received five days

of training from the researcher on the study objectives, the questionnaire content, and ethical considerations, including obtaining informed consent from participants. The enumerators conducted face-to-face interviews with the farmers, recording the responses manually using hard copy questionnaires and pens. Upon completion of the fieldwork, the enumerators carefully transferred the collected data into Microsoft Excel. The researcher implemented cross-checking and verification procedures for all responses to ensure accuracy and consistency during data entry and to minimise transcription errors.

Variable selection and measures

The explanatory variables in this study were adapted from similar published studies conducted in Bangladesh (Table 1).

Table 1. Measurement of the variables.

Variable	Measurement	Measuring unit
Age	1 for 1 year of age	Years
Crop-focused farming	1 for yes, 0 for no	Score
Livestock-focused farming	1 for yes, 0 for no	Score
Aquaculture-focused farming	1 for yes, 0 for no	Score
Education	Number of years of schooling (1 for each year of schooling)	Score
Effective farm size	Hectare (1 for 1 hectare of land)	Hectare
Farming experience	Number of years (1 for each year of experience)	Years
Annual family income	1 for 1000 tk	BDT
Agricultural extension media contact	5-point Likert scale (4 for regular contact; 3 for frequent contact; 2 for occasional contact;1 for rare contact; and 0 for no contact)	Score
Agricultural knowledge	1 for a full answer to each question; and 0.5 for a partial answer to each question	Score
Use of digital self-help approach (YouTube)	5-point Likert scale (4 for regular use; 3 for frequent use; 2 for occasional use;1 for rare use; and 0 for no use)	Score

Source: Authors' systematisation based on using different measuring units

Conceptual framework

The conceptual framework for this study is presented in Figure 1. This illustrates the use of YouTube for the diffusion of innovative agricultural

technologies and helps to explain the relationships between variables, identify patterns, and develop research questions. The framework helps to ensure that research is logically sound and grounded in established theory.

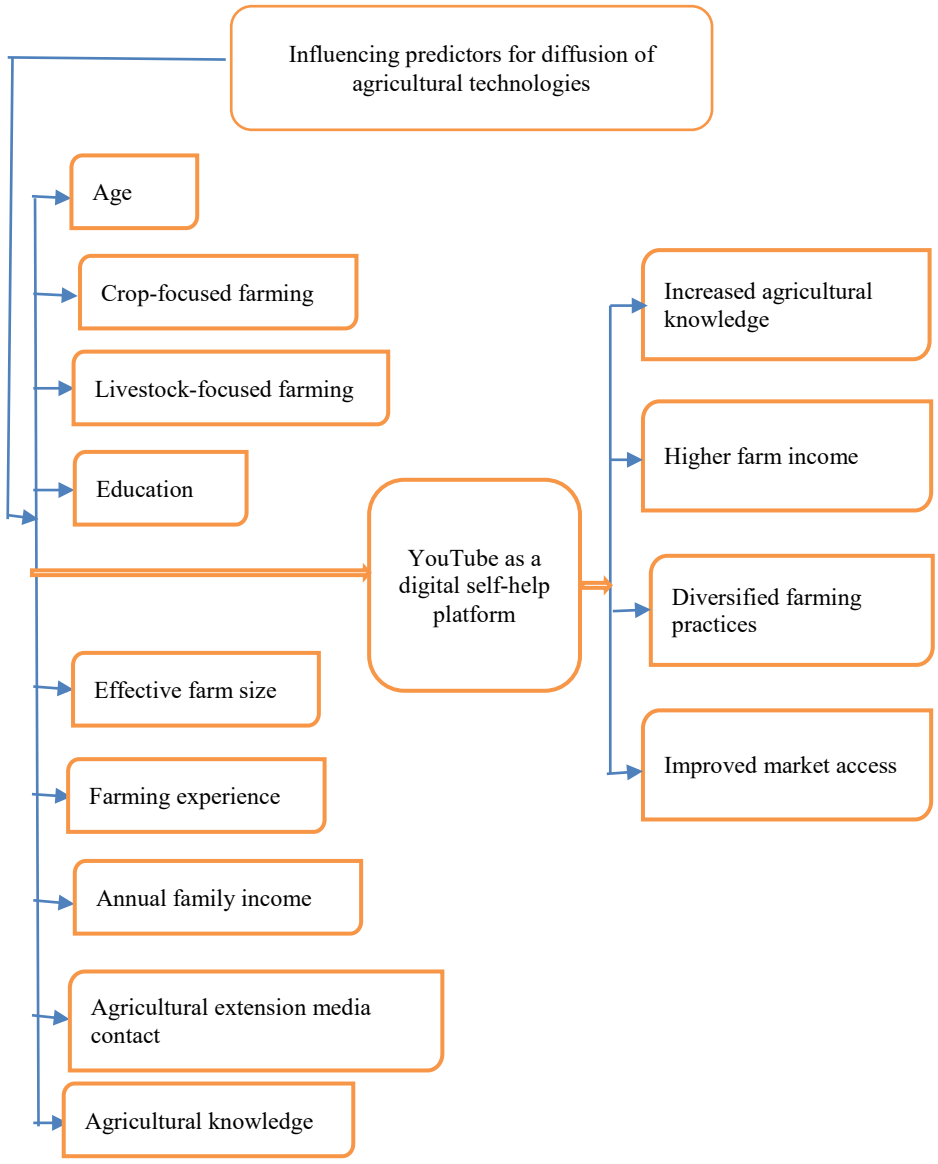


Figure 1. A schematic diagram showing the proposed study: how does YouTube facilitate the diffusion of innovative agricultural technologies through a digital self-help approach?

Source: Authors' systematisation based on review study

Statistical modelling

All statistical analyses were performed using Python. The analysis employed Python libraries, including pandas, NumPy, and SciPy for descriptive statistics, and stats models and scikit-learn for regression analysis. Descriptive statistics, such as frequencies, percentages, means, and standard deviations (SDs), were calculated to summarise the quantitative data. The extent of farmers' use of the digital self-help approach (YouTube) was considered as the outcome variable to develop an Ordinary Least Squares (OLS) model to identify related explanatory variables and predict their level of contribution to the diffusion of innovative agricultural technology. A p-value of less than 0.05 was considered statistically significant. The multiple regression model used in this analysis was:

$$Y_i = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 + b_7x_7 + b_8x_8 + e$$

where Y_i represents the use of the digital self-help approach (YouTube) by the farmers; x_1 is their age; x_2 is educational level; x_3 is family size; x_4 is the effective farm size; x_5 is the farming experience; x_6 is annual family income; x_7 is agricultural extension media contact; and x_8 is the agricultural knowledge. Then, b_1, b_2, b_3, b_4, b_5, b_6, b_7 and b_8 are the regression coefficients for the respective independent variables, and "e" represents random error, which is normally and independently distributed with a mean of zero and constant variance. The variance inflation factor (VIF) was calculated for each explanatory variable to test for multicollinearity. Since all VIF values were below 2, no explanatory variables were excluded from the models.

Results and Discussion

Comparison of socioeconomic characteristics of YouTube users and non-users

The results in Table 2 show clear socioeconomic differences between YouTube users and non-users. Farmers identified as YouTube users had higher mean education levels, larger effective farm sizes, higher annual family incomes, greater agricultural extension media contact scores, and higher agricultural knowledge scores compared to non-users. These differences were statistically significant ($p < 0.001$). The largest differences were observed in education (15.3 vs. 6.5 years), effective farm size (3.1 vs. 0.9 hectares), and annual family income (335,117.9 vs. 211,648.7 BDT). This indicates that farmers with higher educational attainment and greater economic resources were more represented in one of the two groups. Similarly, higher extension media contact (22.2 vs. 18.5) and agricultural knowledge scores (21.0 vs. 18.9) suggest that exposure to agricultural information and existing knowledge levels differ between the groups.

Table 2. Comparison of socioeconomic characteristics by YouTube usage among farmers.

Variable	Overall respondents (n = 276)	YouTube users (n = 162)	YouTube non-users (n = 114)
Age, mean (SD)	45.2 (14.3)	45.2 (14.3)	45.2 (14.3)
Crop-focused farming, n (%)			
No	179 (100.0)	122 (68.2)	57 (31.8)
Yes	97 (100.0)	40 (41.2)	57 (58.8)
Livestock-focused farming, n (%)			
No	185 (100.0)	127 (68.6)	58 (31.4)
Yes	91 (100.0)	35 (38.5)	56 (61.5)
Aquaculture-focused farming (base group), n (%)			
No	184 (100.0)	128 (69.6)	56 (30.4)
Yes	92 (100.0)	34 (37.0)	58 (63.0)
Education, mean (SD)	10.1 (5.9)	6.5 (4.9)	15.3 (2.6)
Effective farm size (hectares), mean (SD)	1.8 (1.4)	0.9 (0.8)	3.1 (1.0)
Farming experience (years), mean (SD)	13.2 (10.3)	16.4 (12.0)	8.7 (3.8)
Annual family income (BDT), mean (SD)	262,646.9 (176,425.7)	211,648.7 (178,100.1)	335,117.9 (146,726.2)
Agricultural extension media contact, mean (SD)	20.0 (2.8)	18.5 (2.5)	22.2 (1.4)
Agricultural knowledge, mean (SD)	19.8 (2.1)	18.9 (2.3)	21.0 (0.8)

Source: Authors' calculation based on face-to-face data collection.

Differences were also observed across farming orientations (crop, livestock, and aquaculture). The distribution of users and non-users varied within these categories, indicating that enterprise focus may be associated with YouTube use, although no causal relationship can be inferred from these data. Age showed no difference between the two groups, as the mean age was identical. This suggests that age alone may not distinguish YouTube users from non-users in this sample.

Overall, the findings demonstrate that YouTube use was associated with variations in education, farm size, income, extension contact, and agricultural knowledge. The results describe group differences but do not establish causality. Further analysis would be required to determine whether these characteristics directly influence digital platform use or are correlated with other underlying factors.

Distribution of YouTube usage frequency

Table 3 presents the distribution of YouTube usage frequency among the respondents.

Table 3. Adjusted odds ratios (ORs) and 95% confidence intervals (CIs) for Factors.

Influencing agricultural practices			
Variable	Adjusted OR	95% CI	p-value
Age	1.07	0.98 – 1.17	0.135
Crop-focused farming	3.11	0.19 – 51.77	0.430
Livestock-focused farming	13.39	0.33 – 536.56	0.168
Aquaculture-focused farming (base group)	103.94	1.01 – 10690.37	0.049 **
Education	2.37	1.34 – 4.20	0.003 **
Effective farm size	57.47	2.99 – 1104.79	0.007 **
Farming experience	0.62	0.37 – 1.05	0.075
Annual family income	1.00	1.00 – 1.00	0.313
Agricultural extension media contact	3.74	1.08 – 12.92	0.037 **
Agricultural knowledge	3.40	0.85 – 13.61	0.084

Source: Authors' calculation based on face-to-face data collection.

The logistic regression results in Table 3 indicate that education, effective farm size, aquaculture-focused farming, and agricultural extension media contact were significantly associated with the outcome variable. Education showed a positive and statistically significant association (OR = 2.37, 95% CI: 1.34–4.20, p = 0.003). This suggests that higher educational attainment was associated with increased likelihood of the outcome. Effective farm size was also positively associated with the outcome (OR = 57.47, 95% CI: 2.99–1104.79, p = 0.007). Although statistically significant, the wide confidence interval indicates substantial variability in the estimate and suggests that the magnitude of the effect should be interpreted with caution. Aquaculture-focused farming (compared with the base category) showed a significant association (OR = 103.94, 95% CI: 1.01–10690.37, p = 0.049). However, the extremely wide confidence interval suggests high uncertainty in the estimate. Agricultural extension media contact was positively associated with the outcome (OR = 3.74, 95% CI: 1.08–12.92, p = 0.037), indicating that farmers with greater extension media contact were more likely to experience the outcome. In contrast, age, crop-focused farming, livestock-focused farming, annual family income, farming experience, and agricultural knowledge were not statistically significant at the 5% level.

Overall, the findings indicate that education level, farm size, aquaculture engagement, and extension media contact were statistically associated with the outcome in this model. However, the wide confidence intervals for some variables suggest variability in the estimates, and causal relationships cannot be inferred from these results.

Distribution of frequency level of YouTube use among the users

It reveals that the most common usage pattern was 2–3 times per week, reported by 30% of participants, suggesting moderate and routine engagement with the platform. A further 22% used YouTube 4–5 times weekly, while 18% accessed it almost daily (6–7 times a week), highlighting a significant proportion of regular users. Meanwhile, 20% of individuals used the platform less than twice a week, indicating a lower level of engagement. Notably, 10% of respondents reported using YouTube more than 7 times per week, reflecting a small group of highly active users who may watch content multiple times daily (Figure 2).

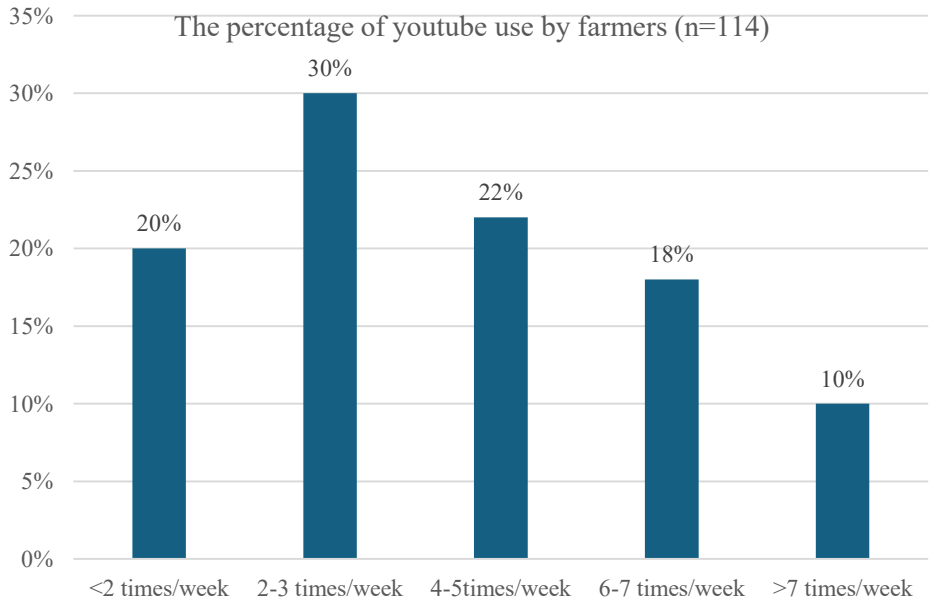


Figure 2. The percentage of YouTube use by farmers (n=162).
Source: Authors' calculation based on face-to-face data collection.

Figure 2 shows the distribution of YouTube usage frequency among farmers (n = 162). These results indicate that the majority of farmers used YouTube at least a few times per week, suggesting that the platform was integrated into their routine, although daily use was less common. Moderate usage suggests selective and purposeful engagement with content rather than passive or continuous use. The data also suggest that YouTube was accessible to farmers as a flexible tool for agricultural information, allowing repeated viewing and on-demand learning.

While usage patterns varied, the frequency distribution indicates that most farmers interacted with the platform regularly enough for it to serve as a supplementary source of agricultural knowledge, complementing traditional extension services.

Overall, these findings highlight that YouTube was a consistently used digital resource among farmers, with moderate frequency reflecting its practical integration into their weekly activities. Future initiatives aimed at improving digital access, providing relevant local content, and supporting efficient platform use could help maintain and enhance engagement.

Distribution of YouTube users based on their purpose

The findings highlight the multifunctional role of YouTube in supporting farmers' agricultural practices and livelihoods.

Table 4. YouTube as a multifunctional tool for farmers: insights into usage purposes (n=162).

Purposes of YouTube use by farmers	Value	Percentage (%)
Acquiring agricultural expertise and technical training through YouTube videos	110	96.5%
Accessing weather forecasts and disaster preparedness information	90	78.9%
Engaging in the exchange of farming knowledge and experiences with peers	87	76.3%
Receiving guidance on best practices for post-harvest management	75	65.8%
Obtaining updates on agricultural regulations and government services	70	61.4%
Identifying sources of support for acquiring agricultural inputs	82	71.9%
Accessing and sharing pricing information for farming supplies	70	61.4%
Connecting with buyers for the sale of farm goods	60	52.6%
Promoting agricultural products through online marketing strategies	40	35.1%

Source: Authors' calculation based on face-to-face data collection.

Table 4 shows that farmers used YouTube for a variety of purposes related to agricultural practices. The majority (96.5%) reported using the platform for acquiring technical knowledge and training, followed by accessing weather forecasts and disaster preparedness information (78.9%) and exchanging knowledge with peers (76.3%). Other common purposes included sourcing agricultural inputs (71.9%), post-harvest management (65.8%), accessing market information (61.4%), connecting with buyers (52.6%), and promoting products online (35.1%).

These results indicate that YouTube was primarily used as a source of agricultural knowledge and technical guidance. Peer-to-peer knowledge exchange also represented a notable component of usage, suggesting that farmers use the platform to complement formal learning and extension services. Additionally, a substantial portion of farmers used YouTube for market-related purposes, such as

finding buyers and sharing pricing information, indicating its growing relevance along the agricultural value chain.

Overall, the findings demonstrate that YouTube served multiple functions for farmers, including technical learning, risk preparedness, and market engagement. The platform was integrated into farmers' practices and provided a flexible, on-demand source of information, with usage patterns reflecting both learning and practical application needs. These insights highlight the role of digital platforms as accessible tools for agricultural information and support, particularly where traditional extension services may be limited.

Contribution of the selected characteristics of the farmers to their use of the digital self-help approach (YouTube)

In this study, eight characteristics of the respondents were selected, with each characteristic treated as an independent variable. The null hypothesis states that there is no significant contribution of the selected characteristics, namely age, level of education, family size, effective farm size, farming experience, annual family income, agricultural extension media contact, and agricultural knowledge to the farmers' use of the digital self-help approach (YouTube).

Table 5. Multiple regression analysis showing the contribution of the selected characteristics of the farmers to their use of the digital self-help approach (YouTube).

Dependent Variable	Independent variables	B	SE B	B	T	Sig. T
Use of digital self-help approach (YouTube)	Age	-.048	.041	-.11	-1.17	.245
	Level of education	.043	.085	.036	.510	.612
	Family size	-.08	.164	-.03	-.495	.622
	Effective farm size	1.12	.570	.145	1.97	.052*
	Farming experience	.102	.050	.214	2.06	.042*
	Annual family income	.017	.005	.282	3.23	.002**
	Agricultural extension media contact	.434	.210	.204	2.06	.042*
	Agricultural knowledge	.626	.315	.216	1.98	.050*

**significant at 1% level; *significant at 5% level; R2=0.67; adjusted R2=0.64; F=19.52 and P=0.00; Source: Authors' calculation based on face-to-face data collection.

Multiple regression analysis was conducted to determine the contribution of eight selected characteristics to farmers' use of the digital self-help approach (YouTube). The overall model was statistically significant ($F = 19.52$, $p < 0.001$), with $R^2 = 0.67$ and adjusted $R^2 = 0.64$, indicating that 64% of the variation in farmers' use of YouTube was explained by the included variables. Among the

eight independent variables, five were found to have a statistically significant contribution: Annual family income (B = 0.017, β = 0.282, p = 0.002) was significant at the 1% level and showed the strongest standardised effect. Farming experience (B = 0.102, β = 0.214, p = 0.042), agricultural extension media contact (B = 0.434, β = 0.204, p = 0.042), agricultural knowledge (B = 0.626, β = 0.216, p = 0.050), and effective farm size (B = 1.12, β = 0.145, p = 0.052) were marginally significant at approximately the 5% level. The standardised beta (β) coefficients indicate that annual family income had the highest relative contribution among the significant predictors, followed by agricultural knowledge, farming experience, and extension media contact. Effective farm size showed a comparatively smaller effect.

Overall, the findings suggest that farmers' economic capacity, experience, knowledge level, and exposure to extension media were associated with their use of YouTube as a digital self-help approach, whereas demographic factors such as age (p=0.245), education (p=0.612), and family size (p=0.622) were not statistically significant in this model. Joshi and Dhaliwal (2019) found that age and education significantly influenced YouTube usage in agriculture at the 1% level, while Sebotsa et al. (2020) reported contrasting findings, with YouTube use not significantly affecting youth engagement in agriculture (p = 0.226), highlighting variability across contexts.

The regression results (Table 5) indicate that annual family income, farming experience, agricultural extension media contact, agricultural knowledge, and (marginally) effective farm size were statistically associated with farmers' use of YouTube as a digital self-help approach. Among these variables, annual family income made the strongest relative contribution. In contrast, age, education, and family size were not significant predictors in the model.

The strong association between annual family income and YouTube use suggests that economic capacity remained a key determinant of digital engagement in agriculture. Farmers with greater financial resources are more likely to afford smartphones, internet connectivity, and data services, which are necessary for accessing video-based platforms. This finding aligns with broader evidence that digital technology adoption in agriculture is often shaped by resource endowment and the capacity to invest in complementary inputs (Fabregas et al., 2019). In this context, YouTube use appears not merely as a behavioural choice but as an outcome influenced by structural economic factors.

The marginal significance of effective farm size further supports the role of farm resource endowment. Larger farms may have stronger incentives to seek productivity-enhancing information and may perceive greater returns from accessing online agricultural content. Although its statistical contribution is smaller than that of income, the direction of the relationship suggests that commercially oriented farmers may be more inclined to utilise digital advisory tools. The positive

effects of farming experience, agricultural knowledge, and extension media contact indicate that informational and experiential capital facilitate digital platform use. Farmers who are more experienced or better connected to extension systems may possess greater capacity to identify relevant content, assess its credibility, and apply it effectively. This pattern suggests that YouTube functions as a complementary source of information within existing knowledge networks rather than as a substitute for traditional extension services.

Overall, the findings underscore that farmers' engagement with YouTube for agricultural learning was shaped by both socioeconomic and informational characteristics. Although digital platforms offer additional opportunities for technology dissemination, their utilisation appears conditioned by farmers' financial capacity and prior exposure to agricultural information. Future research should further explore whether increased use of digital self-help platforms leads to measurable improvements in technology adoption and farm performance.

Limitations

First, the cross-sectional design captures associations rather than causal relationships, limiting the ability to infer whether YouTube use directly improved technology adoption or productivity. Second, the sample was restricted to 276 farmers from a single Upazila in Bangladesh. Third, the study focused primarily on quantitative determinants and did not explore qualitative aspects. Finally, there is a need for longitudinal studies to capture dynamic adoption trends. Further work might also be needed to cross-check the reliability of respondents' comments.

Conclusion

The findings indicate that YouTube functioned as a valuable digital self-help platform for farmers, but its use was strongly influenced by socioeconomic and informational factors. Significant differences between users and non-users were observed in education, farm size, income, extension media contact, and agricultural knowledge. Farmers with greater economic resources and stronger information networks were more likely to use the platform, while age showed no meaningful difference. Most users accessed YouTube moderately (two to five times per week), suggesting purposeful and routine engagement. The platform served multiple functions, including technical training, weather information, peer exchange, and market-related activities, demonstrating its integration into farmers' agricultural decision-making processes. Regression results showed that annual family income was the strongest predictor of YouTube use, followed by farming experience, agricultural knowledge, extension media contact, and effective farm size. These findings suggest that financial capacity and prior exposure to agricultural

information played key roles in enabling digital engagement. Overall, while YouTube offered important opportunities for agricultural learning and market participation, access and use remained uneven. Promoting digital inclusion and strengthening links between digital platforms and extension services may help ensure broader benefits for farmers.

Acknowledgements

This research was personally conceived, conducted, and completed by the authors. The study was self-funded, with no external financial support from public, commercial, or not-for-profit funding agencies. The authors gratefully acknowledge the personal commitment, time, and resources invested in the successful completion of this work.

References

Ahmad, B., Wahid, F., & Shafqat, H. (2025). Use of social media among farmers: Uses and gratification approach. *Pakistan Journal of Media Sciences, 6*(1), 1–11.

Alizada, M. N., Sravana, K., & Prasad, S. (2024). Digital innovations in agricultural extension: Exploring the role of ICT and social media in information dissemination. *International Journal of Novel Research and Development, 9*(8), b501–b518. http://doi.one/10.1729/Journal.41053

Barrett, C. B., Christiaensen, L., Sheahan, M., & Shimeles, A. (2020). Structural transformation and agricultural productivity in low-income economies: Evidence and implications for policy. *Annual Review of Resource Economics, 12*, 265–285. https://doi.org/10.1146/annurev-resource-110119-032913

Bentley, J. W., Chandra, C., Chadare, F. J., Okry, F., & Van Mele, P. (2019). Smallholders download and share videos from the internet to learn about sustainable agriculture. *International Journal of Agricultural Sustainability, 17*(1), 1–14. https://doi.org/10.1080/14735903.2019.1567246

Birner, R., Daum, T., & Pray, C. (2021). Who drives the digital revolution in agriculture? A review of supply-side trends, players and challenges. *Applied Economic Perspectives and Policy, 43*(4), 1260–1285. https://doi.org/10.1002/aepp.13145

Daum, T. (2021). Social media in agricultural extension: Concepts and challenges. In A. B. Smith & C. D. Jones (Eds.), *Handbook on Agricultural Extension and Rural Development* (pp. 123–145). Routledge.

Fabregas, R., Kremer, M., & Schilbach, F. (2019). Realizing the potential of digital development: The case of agricultural advice. *Science, 366*(6471), eaay3038. https://doi.org/10.1126/science.aay3038

Ghosh, M. K., Hasan, S. S., Maria, U., Akon, S., Ali, H., Moheuddin, M., & Al Noman, A. (2021). Social media in agricultural extension services: Farmers and extension agents' perspective. *European Journal of Humanities and Social Sciences, 1*(5), 36–43. https://doi.org/10.24018/ejsocial.2021.1.5.143

Gwelo, F. A. (2025). Social media apps and the democratisation of agricultural knowledge. *Journal of the Knowledge Economy* (2025). https://doi.org/10.1007/s13132-025-02837-z

Joshi, D., & Dhaliwal, R. K. (2019). Utilization of social media by farming community: A case from Punjab state. *Indian Journal of Extension Education, 55*(1), 47–52.

Klerkx, L., Jakku, E., & Labarthe, P. (2019). A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda. *NJAS – Wageningen Journal of Life Sciences, 90*, 100315. https://doi.org/10.1016/j.njas.2019.100315

Lubua, E. W., & Pretorius, P. D. (2018). Factors influencing the adoption of social media by small and medium enterprises: The role of demographics. *South African Journal of Information Management, 21*(1), Article a959. https://doi.org/10.4102/sajim.v21i1.959

Malik, A., & Ansari, M. A. (2024). Farmers' use of social media and constraints faced: A study in Uttarakhand, India. *Asian Journal of Agricultural Extension, Economics & Sociology, 42*(8), 92–100. https://doi.org/10.9734/ajaees/2024/v42i82535

Sebotsa, K. O., Nkurumwa, A. O., & Kyule, M. (2020). Effect of utilization of social media platforms on youth participation in agriculture in Njoro Sub-county, Kenya. *International Journal of Agricultural Extension, 8*(3), 235–250. https://doi.org/10.33687/008.03.3400

Suchiradipta, B., & Saravanan, R. (2016). Social media: Shaping the future of agricultural extension and advisory services (GFRAS Working Paper). Global Forum for Rural Advisory Services (GFRAS).

Talat, A., Azar, S., & Yousaf, M. W. (2013). Investigating social commerce as an alternate model for online commerce in developing countries: A case of Pakistani economy. *Pakistan Journal of Commerce and Social Sciences, 7*(1), 223–242. https://jes.ac.pk/index.php/jes/article/view/563

Trendov, N. M., Varas, S., & Zeng, M. (2019). Digital technologies in agriculture and rural areas: Status report. Food and Agriculture Organization of the United Nations (FAO).

Van Campenhout, B., Spielman, D. J., & Lecoutere, E. (2021). Information and communication technologies to provide agricultural advice to smallholder farmers: Experimental evidence from Uganda. *American Journal of Agricultural Economics, 103*(1), 317–337. https://doi.org/10.1002/ajae.12089

Yamane, T. (1967). Statistics: An introductory analysis (2nd ed.). Harper & Row.

Yonazi, J., Kelly, T., Halewood, N., & Blackman, C. (2012). The transformational use of information and communication technologies in Africa. World Bank. https://doi.org/10.1596/978-0-8213-9539-2

Zondo, T., & Ndoro, T. (2024). Evaluating the Influence of Socioeconomic Factors on Smallholder Farmer's Social Media Adoption in the Nkomazi Local Municipality, Mpumalanga Province. *South African Journal of Agricultural Extension, 52*(1), 20–47. https://doi.org/10.17159/2413-3221/2024/v52n1a13764

Received: 21 January 2026
Accepted: 18 February 2026

UPOTREBA JUTJUBA ZA ŠIRENJE INOVATIVNIH POLJOPRIVREDNIH TEHNOLOGIJA: DIGITALNI PRISTUP PODRŠKE POLJOPRIVREDNICIMA

Mohummed Shofi Ullah Mazumder[1*], Fatema Wadud[2] i Sushama Barua[1]

[1]Department of Agricultural Extension & Information System, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh
[2]Department of Agricultural Marketing, Dhaka, Bangladesh

R e z i m e

Širenje inovativnih poljoprivrednih tehnologija je od suštinskog značaja za poboljšanje produktivnosti, prehrambene sigurnosti i uslova života u ruralnim sredinama zemalja u razvoju, gde se javne savetodavne službe često suočavaju sa finansijskim i institucionalnim ograničenjima. Ova studija istražuje ulogu Jutjuba kao digitalne platforme za podršku poljoprivrednicima u ruralnim područjima Bangladeša, naglašavajući njegovu efikasnost u širenju informacija iz oblasti poljoprivrede i faktore koji utiču na njihovo usvajanje. Transverzalno istraživanje je sprovedeno među 276 poljoprivrednika u Ranguniji Upazili (podokrug) u okrugu Čatogram. Podaci su prikupljeni korišćenjem strukturiranog upitnika i analizirani primenom regresione analize. Nakon razmatranja vrednosti VIF-a, sprovedena je multivarijaciona logistička regresija. Rezultati pokazuju da je usvajanje Jutjuba značajno povezano sa obrazovanjem, efektivnom veličinom gazdinstva i kontaktom sa poljoprivrednim savetodavnim službama. Poljoprivrednici koji koriste Jutjub pokazali su viši nivo poljoprivrednog znanja, ostvaruju veće prihode i primenjuju raznovrsnije poljoprivredne prakse u odnosu na one koji ga ne koriste. Pored toga, Jutjub je bio široko korišćen za praćenje vremenske prognoze, pripremu za prirodne nepogode, učenje od drugih poljoprivrednika, upravljanje nakon žetve/berbe i angažovanje na tržištu, što ističe njegovu višestruku ulogu. Sveukupno posmatrano, platforme kao što je Jutjub, uz unapređen pristup IKT-ma, pristupačne digitalne resurse i ciljane obuke, mogu značajno unaprediti znanje iz oblasti poljoprivrede i usvajanje tehnologija među poljoprivrednicima u Bangladešu, čime se podstiče održivi ruralni razvoj.

Ključne reči: uloga Jutjuba, usvajanje i prilagođavanje; pristup podršci; faktor inflacije varijanse (engl. *Variance Inflation Factor* – VIF); multivarijaciona logistička regresija.

Primljeno: 21. januara 2026.
Odobreno: 18. februara 2026.

*Autor za kontakt: e-mail: shofikeron@gmail.com

INSTRUCTIONS FOR AUTHORS

GENERAL INFORMATION

The *Journal of Agricultural Sciences (Belgrade*) is an international scientific journal, published quarterly (four issues per year) by the Faculty of Agriculture, University of Belgrade. The journal publishes scientific papers in the following agricultural areas: Field and Vegetable Crop Sciences, Fruit Science and Viticulture, Animal Sciences, Soil Management, Plant Protection, Agricultural Engineering, Food Technology, and Agricultural Economics.

The journal publishes original papers that have not been published previously, including original scientific papers, review articles and preliminary communications. The journal is Open Access.

The journal accepts manuscripts written in both English and Serbian. Authors are encouraged to submit manuscripts in English; however, submissions in Serbian are also accepted. For manuscripts written in English, British English is preferred. In addition to this, for such papers a summary in Serbian is mandatory and should be provided at the end of the manuscript. For authors from other countries, the publisher provides the translation into Serbian.

MANUSCRIPT SUBMISSION

Authors warrant that the manuscript is their original contribution, that it has not been published previously, and that it is not under consideration for publication elsewhere. Parallel submission of the same manuscript to another journal is considered unethical and will result in immediate rejection. The paper that has already been published elsewhere cannot be reprinted in the *Journal of Agricultural Sciences (Belgrade)*.

Authors bear full responsibility for the content of the manuscript, including the accuracy of data, the validity of results, and the proper use of sources. Any use of previously published material (figures, tables, or text excerpts) must be accompanied by appropriate permission from the copyright holder. If such permission is not provided, the material will be treated as the authors' original work.

The use of artificial intelligence (AI) tools must be transparently disclosed. AI tools cannot be listed as authors under any circumstances. AI tools may be used exclusively for the creation of AI-assisted, but not AI-generated content and their use is permitted only for language editing or technical assistance. For further instructions related to the use of AI, please consult the *Use of Artificial Intelligence (AI)* section on the Journal website.

Manuscripts previously posted as preprints may be submitted and will be considered for peer review. However, if the manuscript is accepted for publication,

the preprint version must be removed from all publicly accessible platforms prior to the publication of the final article.

Authors should be aware that only manuscripts that are fully prepared in accordance with these Instructions will be considered for further processing.

Manuscripts must be submitted exclusively through the journal's submission system: http://aseestant.ceon.rs/index.php/jas/user

Authors are invited to submit two separate files: (1) an anonymised manuscript, without any information that could identify the author(s), to ensure compliance with the double-blind peer review process; and (2) a title page, submitted as a separate file, which should include: article title, full list of authors with affiliations, and contact information for the corresponding author.

By submitting a manuscript, the authors agree to comply with the Editorial Policies of the *Journal of Agricultural Sciences (Belgrade)*.

REVIEW PROCESS

Upon submission, all manuscripts undergo an initial editorial screening. At this stage, the manuscript is evaluated in terms of scope, scientific relevance, and technical compliance with the journal guidelines. Manuscripts that do not meet the technical requirements or clearly fall outside the journal's scope will be returned to the authors without being sent for peer review. All submissions are also subject to plagiarism screening.

The *Journal of Agricultural Sciences (Belgrade)* uses a double-blind peer review system for all papers. Each manuscript is reviewed by at least two reviewers, who act independently and are not aware of each other's identities. The reviewers are selected solely based on their relevant expertise for evaluating the manuscript. In case that the reviewers' decisions are contradictory or otherwise substantially incompatible, additional reviewers may be assigned. The final decision on the acceptance of the manuscript for publication rests solely with the Editor-in-Chief.

TECHNICAL PREPARATION OF MANUSCRIPT

Manuscripts must be prepared in electronic form using MS Word (.doc or .docx). The page setup should be as follows: A4 format (210 × 297 mm), margins set to 55 mm (top and bottom) and 40 mm (left and right), header 4 cm, footer 1.25 cm, portrait orientation.

The entire text of the manuscript should be written in Times New Roman, font size 11, with single line spacing and justified alignment. Paragraphs should be indented (first-line indentation of 0.75 cm), and no additional spacing should be inserted before or after paragraphs. Page numbering should not be used.

Authors are advised to ensure consistency throughout the manuscript in terms of formatting, terminology, and style.

Types and structure of papers

The types of papers include original scientific papers, review articles, and preliminary communications.

Original scientific papers should present previously unpublished results of original research. These papers should provide a clear research objective, an appropriate methodology, and a well-structured presentation and interpretation of results. The recommended length of such papers is between 8 and 16 pages.

Review article contains an original, detailed, and critical review of a research problem or area to which the author has contributed, as evidenced by at least 10 self-citations. This article should be 15 to 20 pages in length.

Preliminary communications are shorter contributions that present original but limited or preliminary research results. Although shorter in length (2 to 6 pages), these papers must follow the same structure and quality standards as original scientific papers.

The required sections for Original scientific paper and Preliminary communication are: Title of the paper, Name(s) of author(s), Affiliation(s), Abstract, Keywords, Introduction, Material and Methods, Results and Discussion, Conclusion, Acknowledgements, References and Summary in Serbian (if the manuscript is submitted in English and *vice versa*). The required sections of each Review article are as follows: Title of the paper, Name(s) of author(s), Affiliation(s), Abstract, Keywords, Introduction, Analysis and discussion of a certain topic, Conclusion, References and Summary in Serbian (if the manuscript is submitted in English and *vice versa*).

Title, authors and affiliations

The title of the paper should be concise, precise, and informative, clearly reflecting the content of the study. Authors are encouraged to use terms that facilitate indexing and retrieval. The title should be written in capital letters, centred, and without bold formatting.

The names should be written one line below the title, in lower-case letters, centred and bolded. First name, middle initial(s) and last (family) name of all authors, in the original form, should be provided. The corresponding author should be designated with an asterisk as the superscript, after the last (family) name, and his/her e-mail address should be given in a footnote, at the bottom of the first page of the manuscript.

The affiliation should be written one line below the title, in lower-case letters, centred and without bold formatting. The full name of the institution for each author should be provided, including the town and country. In cases where authors

are affiliated with different institutions, appropriate numbering should be used to clearly indicate affiliations.

Abstract and keywords

The abstract is a concise, informative overview of the manuscript and serves as a general introduction to the topic. The abstract should be written as a single paragraph, without subheadings, and should contain between 200 and 250 words. References, tables, and figures should not be included.

Keywords should be placed immediately after the abstract and written in lowercase, separated by commas, with a full stop at the end. They should consist of three to ten terms that best describe the content of the paper.

Introduction

The Introduction should provide sufficient background information, including relevant previous research, in order to clearly define the research problem and justify the study. All subheadings should be formatted in Times New Roman, font size 11, bold, centred, with only the first letter capitalized, and one line of spacing before and after each subheading. When citing references in the text, the author's name and the year of publication should be provided. Authors must ensure that all references cited in the text are included in the reference list and that all references listed are cited in the text.

Material and Methods

The material and methods should be clearly outlined, explaining all procedures applied in the paper. Standard methods should be described briefly; detailed explanations are required only for modifications or new procedures. Papers with an experimental design should include a clear description of the statistical methods used for data analysis. This section, as well as the *Results and Discussion* section, if needed, may comprise subparts.

Results and Discussion

In the part Results and Discussion data obtained on the basis of observation and conducted experiments should be interpreted. In the comment of the results, references should be quoted at the end of the paper, providing the comparison between the obtained results and previous knowledge of the certain area.

Conclusion

The Conclusion should summarise the key findings and their significance, focusing on the main outcomes rather than repeating numerical results already presented in the *Results and Discussion* section. Potential future directions or applications may also be briefly indicated. References should not be included.

Acknowledgements

Acknowledgements should include the title and number of the project or program under which the manuscript was prepared, as well as the name of the funding institution. This section should be placed between the *Conclusion* and *References* sections.

References

The *References* section should include only papers cited in the main text. In-text citations should include the author(s)' last name and year as follows: one author – Simmons (2025) or (Simmons, 2025); two authors – Kenkel and Holcomb (2024) or (Kenkel and Holcomb, 2024); three or more authors – Milone et al. (2024) or (Milone et al., 2024).

When citing multiple papers simultaneously, they should be listed chronologically. Multiple citations should be separated by a semicolon (;) within brackets, and by a comma (,) outside brackets.

Multiple papers by the same author should be listed chronologically; if published in the same year, using letters: 2005a, 2005b, 2005c, etc.

Personal communications or unpublished works should be avoided unless necessary, and, if cited, should appear only in the text (e.g., Brown, personal communication) and not in the *References* section.

The references, cited in the main text, must appear in the *Reference* section, listed alphabetically by author and without numbering. Multiple papers by the same author should be arranged with single-author papers first, followed by co-authored papers, chronologically, within each category.

Each reference should include: the author(s)' last name, initials, year of publication in brackets, title of the paper, journal title, volume, issue, and page range. For books, include the publisher and place of publication. The APA (Publication Manual of the American Psychological Association) citation style should be used.

The References should be formatted in Times New Roman, font size 9, not bold, justified, with paragraph spacing: before/after 0 pt, line spacing: single, indentation: hanging 0.75 cm.

Examples

Periodicals

Bekić Šarić, B., Paraušić, V., & Nastić, L. (2025). E-Agrar platform: assessment of benefits and usage challenges from the perspective of beekeepers in Serbia. *Journal of Agricultural Sciences*, *70*(2), 205–218. https://doi.org/10.2298/JAS2502205B

Books

Lang, T., & Heasman, M. (2015). *The Global Battle for Mouths, Minds and Markets* (2nd ed.). London: Routledge. https://doi.org/10.4324/9781315754116

Book chapter

Fajardo-García, G., & Soler-Tormo, F. (2016). The credit cooperative system in Spain. In S. Karafolas (Ed.), *Credit cooperative institutions in European countries* (pp. 213–232). Springer. https://doi.org/10.1007/978-3-319-28784-3_11

Proceedings

Iakovlev, D., Kolesnikov, A., & Jugović, M. (2025). Forecasting of the tractors fuel consumption with machine learning methods based on remote monitoring data. In A. Dragićević, & M. Milanović (Eds.), *Proceedings of the 7th International Symposium on Agricultural Engineering - ISAE 2025* (pp. 19–24). University of Belgrade – Faculty of Agriculture. https://doi.org/10.5937/ISAE25019I

Thesis

Singh, N. K. (1985). *The structure and genetic control of endosperm proteins in wheat and rye*. University of Adelaide.

Report

Ballard, J. (1998). *Some significant apple breeding stations around the world*. Selah, Washington.

Website

Platnick, N. I. (2010). The world spider catalog, version 10.5. http://research.amnh.org/entomology/spiders/catalog/index.html *American Museum of Natural History*. Retrieved February 12, 2016, from http://research.amnh.org/entomology/spiders/catalog/index.html

Tables

Tables should be created within the text of the article and numbered with Arabic numerals in order of appearance. Tables should be clear, simple, and unambiguous. The vertical sections should be avoided, and the number of columns should be limited so that the table does not exceed a maximum width of 13 cm (Right-click on the table: Table Properties – preferred width – 13 cm – Measure in: Centimetres).

The title of the table should be placed above the table, single-spaced, justified, ending with a full stop. Complete text within the table cells should be in Times New Roman, font size 9, with paragraph spacing before/after 0 pt, line spacing: single. A source and a detailed explanation of abbreviations, symbols, and signs used in the table should be provided below the table. Each table must be referenced in the text.

Example

Table 1. Volume and dynamics of Serbia's foreign trade in meat and meat preparations, 2020–2024.

	Average (t)	Min (t)	Max (t)	CV (%)
Export (000 USD)	105,693	97,583	114,098	5.74
Import (000 USD)	260,256	180,337	343,095	27.52
Trade balance (000 USD)	-154,563	-76,815	-245,513	-47.95
Coverage rate (%)	43.4	57.4	28.4	-

Source: Authors' calculations

Illustrations

All illustrations, including diagrams, photographs and charts, are referred to as figures and should be placed in the text. Graphs and diagrams should be computer-drawn using Times New Roman, font size 9, with a maximum width of 13 cm to ensure legibility and clarity after size reduction. Excessive colours should be avoided. The detailed legend without abbreviations for each graph and diagram should be provided. The photographs must be of high quality, submitted in TIF or JPG format, and will be printed in black and white.

The title of each illustration should be centred, single-spaced, placed one line below the illustration, ending with a full stop. Each illustration should be mentioned in the text. Source for each figure should be provided below the title.

Example

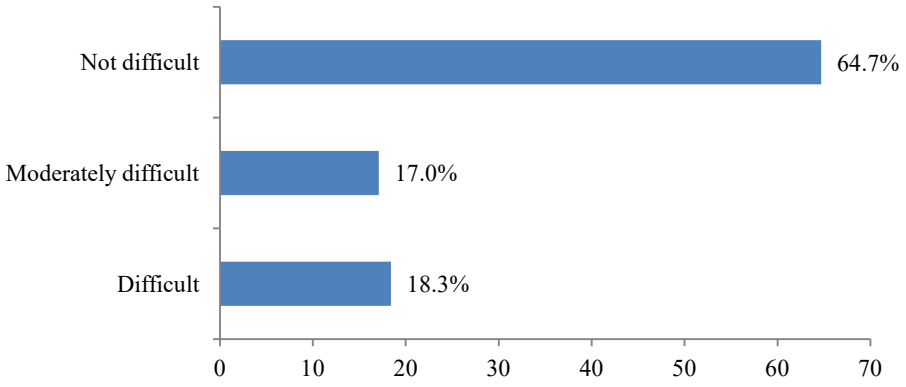


Figure 1. The difficulty of using the eAgrar platform, answer structure, 2023.
Source: Survey results. Authors' calculations

Abbreviations and units

Only standardized abbreviations should be used in the paper. Units of measurement should be expressed using the International System of Units (SI). The abbreviations may be used for other expressions, provided these expressions are stated in full when first mentioned with the abbreviation in brackets. Numbers from one to nine may be written in words; all others should be expressed numerically. Abbreviations should not be used in the article title.

Nomenclature

International standards (IUPAC, IUB, ICN, etc.) should be followed for chemical, biochemical, taxonomic, and genetic terms.

Formulae

All formulae and equations in the paper should be prepared using the Microsoft Word Equation Editor or MathType. The meaning of all symbols should be provided immediately after the equation in which they first appear. Equations should be numbered consecutively with Arabic numerals in parentheses, aligned to the right-hand side. Each equation must be referred to in the text as Eq. (1), Eq. (2), etc.

At the end of the manuscript, a Serbian version of the title, authors' names, affiliations, abstract, and keywords should be provided. For foreign authors, the translation into Serbian will be provided by the Editorial Office.

Editorial Board
Journal of Agricultural Sciences

UPUTSTVO AUTORIMA

OPŠTE INFORMACIJE

Časopis *Journal of Agricultural Sciences (Belgrade)* je međunarodni naučni časopis koji izdaje Poljoprivredni fakultet Univerziteta u Beogradu i izlazi kvartalno (četiri puta godišnje). Časopis objavljuje naučne radove iz sledećih oblasti: ratarstvo i povrtarstvo, voćarstvo i vinogradarstvo, zootehnika, melioracije zemljišta, zaštita bilja, poljoprivredna tehnika, prehrambena tehnologija i agroekonomija.

Časopis objavljuje originalne, prethodno neobjavljene radove, i to: originalne naučne radove, pregledne radove i prethodna saopštenja. Časopis je dostupan u režimu otvorenog pristupa.

Radovi se mogu podnositi na engleskom i srpskom jeziku. Preporučuje se podnošenje radova na engleskom jeziku, ali će se prihvatati i radovi na srpskom jeziku. Ako su radovi na engleskom jeziku, prednost se daje britanskoj varijanti ovog jezika. Pored toga, na kraju ovih rukopisa obavezno se dostavlja rezime na srpskom jeziku. Za autore iz inostranstva prevod na srpski jezik obezbeđuje izdavač.

SLANJE RUKOPISA

Autori garantuju da rukopis predstavlja njihov originalan doprinos, da nije objavljen ranije i da se ne razmatra za objavljivanje na drugom mestu. Istovremeno predavanje istog rukopisa u više časopisa predstavlja kršenje etičkih standarda, što ga isključuje iz daljeg razmatranja za objavljivanje u časopisu. Rad koji je već objavljen na nekom drugom mestu ne može biti preštampan u časopisu *Journal of Agricultural Sciences (Belgrade)*.

Autori snose punu odgovornost za sadržaj rukopisa, uključujući tačnost podataka, validnost rezultata i pravilno korišćenje izvora. Upotreba prethodno objavljenog materijala (slika, tabela ili delova teksta) mora biti praćena odgovarajućom dozvolom nosioca autorskih prava. Materijal za koji takvi dokazi nisu dostavljeni smatraće se originalnim delom autora.

Upotreba alata zasnovanih na veštačkoj inteligenciji (AI) mora biti jasno naznačena. AI alati ni pod kojim okolnostima ne mogu biti navedeni kao autori. Njihova upotreba dozvoljena je isključivo za kreiranje AI-potpomognutog, ali ne i AI-generisanog sadržaja. Pored toga, upotreba AI alata je dozvoljena samo u svrhu jezičke obrade ili tehničke podrške. Za dodatne informacije o upotrebi AI alata, pogledati odeljak *Use of Artificial Intelligence (AI)* na sajtu časopisa.

Rukopisi koji su prethodno objavljeni kao preprint mogu se podneti i biće razmatrani u postupku recenzije. Međutim, u slučaju prihvatanja rada za

objavljivanje, preprint verzija mora biti uklonjena sa svih javno dostupnih platformi pre objavljivanja konačne verzije rada.

Autori treba da imaju u vidu da će u dalji postupak ući isključivo rukopisi koji su u potpunosti pripremljeni u skladu sa ovim uputstvima.

Rukopisi se podnose isključivo putem sistema: http://aseestant.ceon.rs/index.php/jas/user

U procesu prijave rada, autori treba da dostave dva odvojena fajla: (1) anonimni rukopis, bez podataka koji mogu otkriti identitet autora, u skladu sa principima dvostruko anonimne recenzije; i (2) naslovnu stranu kao poseban fajl, koja sadrži naslov rada, kompletan spisak autora sa afilijacijama i kontakt podatke autora za kontakt.

Podnošenjem rukopisa autori prihvataju uredničku politiku časopisa *Journal of Agricultural Sciences (Belgrade)*.

RECENZENTSKI POSTUPAK

Nakon prijema, svi rukopisi prolaze preliminarnu proveru u redakciji. U ovoj fazi procenjuje se usklađenost rada sa tematikom časopisa, njegova naučna relevantnost i tehnička pripremljenost u skladu sa uputstvima za autore. Rukopisi koji ne ispunjavaju tehničke zahteve ili ne odgovaraju tematici časopisa biće vraćeni autorima bez upućivanja na recenziju. Svi radovi podležu i proveri na plagijat.

Journal of Agricultural Sciences (Belgrade) primenjuje postupak dvostruko anonimnog recenziranja svih radova. Svaki rukopis recenziraju bar dva recenzenta. Recenzenti deluju nezavisno jedni od drugih, a njihov identitet je međusobno nepoznat. Recenzenti se biraju isključivo prema tome da li raspolažu relevantnim znanjima za ocenu rukopisa. U slučaju značajnih neslaganja u mišljenjima recenzenata, mogu se angažovati dodatni recenzenti. Konačnu odluku o prihvatanju rukopisa za objavljivanje donosi glavni urednik.

TEHNIČKA PRIPREMA RUKOPISA

Rukopisi se pripremaju u programu MS Word (.doc ili .docx). Strane treba da budu podešene na sledeći način: format A4 (210 × 297 mm), margine 55 mm (gore i dole) i 40 mm (levo i desno), *header* 4 cm, *footer* 1,25 cm, orijentacija stranice *portrait*.

Celokupan tekst rada piše se fontom Times New Roman, veličine 11, sa jednostrukim proredom i obostranim poravnanjem. Pasusi treba da budu uvučeni (uvlačenje prvog reda 0,75 cm), bez dodatnog razmaka pre i posle pasusa. Strane ne treba numerisati.

Autori su dužni da obezbede doslednost u celom rukopisu u pogledu formatiranja, terminologije i stila.

Vrste i struktura radova

Vrste radova su originalni naučni radovi, pregledni radovi i prethodna saopštenja.

Originalni naučni radovi sadrže prethodno neobjavljene rezultate sopstvenih istraživanja. Ovi radovi treba da imaju jasno definisan cilj istraživanja, odgovarajuću metodologiju i jasno strukturirano izlaganje i tumačenje rezultata. Preporučeni obim ovih radova je od 8 do 16 strana.

Pregledni rad sadrži originalan, detaljan i kritički prikaz istraživačkog problema ili područja u kome je autor ostvario određeni doprinos, vidljiv na osnovu najmanje 10 autocitata. Obim ovog rada treba da iznosi od 15 do 20 strana.

Prethodna saopštenja su kraći radovi koji prikazuju originalne rezultate istraživanja manjeg obima ili preliminarnog karaktera. Preporučeni obim ovih radova je dve do šest strana i moraju pratiti istu strukturu i standarde kvaliteta kao originalni naučni radovi.

Obavezna poglavlja originalnog naučnog rada i prethodnog saopštenja su: naslov rada, imena autora, naziv ustanove autora, sažetak, ključne reči, uvod, materijal i metode, rezultati i diskusija, zaključak, zahvalnica, literatura i rezime na srpskom jeziku (ako je rad na engleskom i obrnuto). Obavezna poglavlja preglednog rada su: naslov rada, imena autora, naziv ustanove autora, sažetak, ključne reči, uvod, analiza i diskusija određene teme, zaključak, literatura i rezime na srpskom jeziku (ako je rad na engleskom i obrnuto).

Naslov rada, imena autora i naziv ustanove

Naslov rada treba da bude sažet, precizan i informativan, i da jasno odražava sadržaj istraživanja. U interesu je autora da se u naslovu koriste reči prikladne za indeksiranje i pretraživanje. Naslov se piše velikim slovima, centrirano, bez bolda.

Imena se pišu jedan red ispod naslova, malim slovima, centrirano i boldovano. Navodi se puno ime, srednje slovo i prezime svih autora, u originalnom obliku. Autor za kontakt označava se zvezdicom u superskriptu, iza prezimena, a njegova e-mail adresa navodi se u fusnoti prve stranice članka.

Afilijacija se piše jedan red ispod naslova, malim slovima, centrirano, bez bolda. Navodi se pun naziv ustanove za svakog autora, uključujući mesto i državu. Ukoliko su autori iz različitih institucija, koriste se odgovarajuće numeričke oznake radi jasnog povezivanja autora i njihovih afiliacija.

Sažetak i ključne reči

Sažetak je kratak informativni prikaz sadržaja članka. Predstavlja opšti uvod u temu i pruža kratak prikaz glavnih rezultata i njihovih implikacija. Piše se bez odeljaka i podnaslova. Sastavni delovi sažetka su cilj istraživanja, metode, rezultati i zaključak. Sažetak treba da ima od 200 do 250 reči. Upotrebu skraćenica treba svesti na minimum, a reference, tabele i slike ne smeju se navoditi.

Ključne reči se navode neposredno ispod sažetka, pišu se malim slovima, razdvojene zarezima, sa tačkom na kraju. Broj ključnih reči može biti od tri do deset i predstavljaju termine ili fraze koje najbolje opisuju sadržaj članka.

Uvod

Uvod treba da sadrži dovoljno informacija, uključujući relevantna prethodna istraživanja, kako bi se jasno definisao istraživački problem i objasnilo šta se datim istraživanjem želi postići. Svi podnaslovi pišu se fontom Times New Roman, veličine 11, bold, centrirano, sa jednim razmakom pre i posle svakog podnaslova. Prilikom citiranja referenci u tekstu navode se prezime autora i godina publikovanja. Svi radovi citirani u tekstu navode se u spisku literature i svi radovi navedeni u poglavlju *Literatura* moraju biti citirani u tekstu.

Materijal i metode

Materijal i metode treba izložiti jasno uz objašnjenje svih primenjenih postupaka u radu. Opšte poznate metode izložiti kratko, dok se detaljnije objašnjavaju samo izmene ili ukoliko se odstupa od ranije objavljenih postupaka. Radovi eksperimentalnog karaktera moraju sadržati jasan opis statističkih metoda korišćenih za obradu podataka. U ovom poglavlju, kao i u poglavlju *Rezultati i diskusija*, po potrebi se mogu navesti i podpoglavlja.

Rezultati i diskusija

U poglavlju *Rezultati i diskusija* interpretiraju se podaci dobijeni na osnovu zapažanja i izvršenih eksperimenata. U komentaru rezultata treba se pozivati na literaturu koja se navodi na kraju rada, čime se obezbeđuje poređenje dobijenih rezultata sa dosadašnjim saznanjima u toj oblasti.

Zaključak

U zaključku treba ukratko navesti najznačajnije rezultate i njihov značaj. Izbegavati nabrajanje rezultata istraživanja sa ponavljanjem brojčanih vrednosti koji su već navedeni u poglavlju *Rezultati i diskusija*. Po potrebi se mogu naznačiti i mogući pravci daljih istraživanja ili primene. Zaključak ne sme da sadrži reference.

Zahvalnica

Zahvalnica treba da sadrži naziv i broj projekta, odnosno naziv programa u okviru koga je rad nastao, kao i naziv institucije koja je finansirala projekat ili program. Navodi se između *Zaključka* i *Literature*.

Literatura

Poglavlje *Literatura* treba da sadrži samo radove citirane u glavnom tekstu. Citiranje u tekstu vrši se navođenjem prezimena autora i godine publikovanja, na sledeći način: jedan autor se navodi kao Simmons (2025) ili (Simmons, 2025), dva

autora se navodi kao Kenkel i Holcomb (2024) ili (Kenkel i Holcomb, 2024), a tri i više autora se navodi kao Milone et al. (2024) ili (Milone et al., 2024).

Ako se za određeni problem istovremeno citira više radova onda se oni hronološki nabrajaju. Odvajanje većeg broja citiranih radova van zagrade vrši se zarezom (,) a u zagradi tačkom i zarezom (;).

Ako se citira više radova istog autora oni se navode hronološkim redom, a ukoliko su objavljeni u istoj godini, dodaju se oznake: 2005a, 2005b, 2005c itd.

Citate ličnih komunikacija i neobjavljenih podataka treba izbegavati, osim ako je to apsolutno neophodno. Takvi citati bi trebali da se pojave samo u tekstu (npr. Brown, lična komunikacija), ali ne i u *Literaturi*.

Svi radovi citirani u tekstu moraju biti navedeni u delu *Literatura*, po abecednom redu prema prezimenu autora, bez numeracije. Ako se citira veći broj radova istog autora najpre se navode radovi kada je autor sam, a zatim radovi u koautorstvu, hronološki po godinama unutar svake kategorije.

Svaka referenca treba da sadrži: prezime autora, početno slovo imena, godinu izdanja u zagradi, naslov rada, naziv časopisa, volumen, broj časopisa i broj stranica (prva-poslednja). Prilikom citiranja knjiga navodi se izdavač i mesto izdavanja. U časopisu se koristi APA (Publication Manual of the American Psychological Association) citatni stil.

Spisak literature treba da bude formatiran fontom Times New Roman, veličine 9, bez bolda, obostrano poravnat, bez razmaka pre i posle pasusa, sa jednostrukim proredom i uvučenim drugim redom (indentation 0,75 cm).

Primeri navođenja referenci

Rad u časopisu

Bekić Šarić, B., Paraušić, V., & Nastić, L. (2025). E-Agrar platform: assessment of benefits and usage challenges from the perspective of beekeepers in Serbia. *Journal of Agricultural Sciences*, *70*(2), 205–218. https://doi.org/10.2298/JAS2502205B

Knjiga

Lang, T., & Heasman, M. (2015). *The Global Battle for Mouths, Minds and Markets* (2nd ed.). London: Routledge. https://doi.org/10.4324/9781315754116

Poglavlje u knjizi

Fajardo-García, G., & Soler-Tormo, F. (2016). The credit cooperative system in Spain. In S. Karafolas (Ed.), *Credit cooperative institutions in European countries* (pp. 213–232). Springer. https://doi.org/10.1007/978-3-319-28784-3_11

Zbornik

Iakovlev, D., Kolesnikov, A., & Jugović, M. (2025). Forecasting of the tractors fuel consumption with machine learning methods based on remote monitoring data. In A. Dragićević, & M. Milanović (Eds.), *Proceedings of the 7th International Symposium on Agricultural Engineering - ISAE 2025* (pp. 19–24). University of Belgrade – Faculty of Agriculture. https://doi.org/10.5937/ISAE25019I

Teza

Singh, N. K. (1985). *The structure and genetic control of endosperm proteins in wheat and rye*. University of Adelaide.

Izveštaj

Ballard, J. (1998). *Some significant apple breeding stations around the world*. Selah, Washington.

Website

Platnick, N. I. (2010). The world spider catalog, version 10.5. http://research.amnh.org/entomology/spiders/catalog/index.html *American Museum of Natural History*. Retrieved February 12, 2016, from http://research.amnh.org/entomology/spiders/catalog/index.html

Tabele

Tabele treba da se nalaze na odgovarajućem mestu u tekstu i numerišu se arapskim brojevima po redosledu pojavljivanja. Tabele treba da budu jasne, jednostavne i pregledne. Treba izbegavati vertikalne linije, a broj kolona ograničiti tako da širina tabele ne prelazi 13 cm.

Naslov tabele navodi se sa jednim redom razmaka iznad tabele, poravnat obostrano i sa tačkom na kraju. Tekst unutar tabele piše se fontom Times New Roman, veličine 9, sa jednostrukim proredom. Ispod tabele treba dati izvor, kao i detaljno objašnjenje skraćenica, simbola i oznaka korišćenih u tabeli. Svaka tabela mora biti pomenuta u tekstu.

Primer

Tabela 1. Obim i dinamika spoljne trgovine mesom i prerađevinama od mesa u Srbiji, 2020–2024.

	Prosek (t)	Minimum (t)	Maksimum (t)	CV (%)
Izvoz (000 USD)	105.693	97.583	114.098	5,74
Uvoz (000 USD)	260.256	180.337	343.095	27,52
Bilans (000 USD)	-154.563	-76.815	-245.513	-47,95
Stopa pokrivenosti uvoza izvozom (%)	43,4	57,4	28,4	-

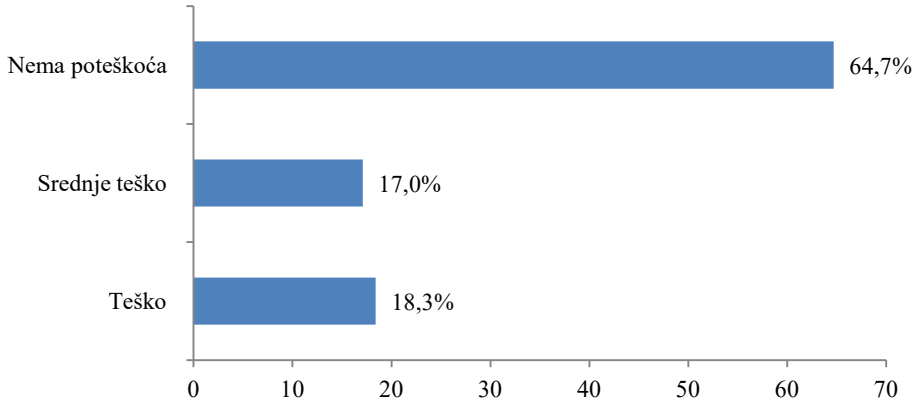
Izvor: Obračun autora

Ilustracije

Sve ilustracije, uključujući dijagrame, fotografije i grafikone, označavaju se kao slike i treba da budu postavljene u tekstu. Grafikoni i dijagrami treba da budu pripremljeni na računaru, koristeći font Times New Roman, veličina 9, sa maksimalnom širinom od 13 cm, kako bi ostali čitki i jasni i nakon redukcije veličine. Treba izbegavati prekomernu upotrebu boja. Za svaki grafikon i dijagram treba dati detaljnu legendu bez skraćenica. Fotografije moraju biti visokog kvaliteta, dostavljene u TIF ili JPG formatu i biće štampane u crno-beloj tehnici.

Naslov svake slike treba da bude centriran, sa jednostrukim proredom, postavljen sa jednim redom razmaka ispod slike, sa tačkom na kraju. Svaka slika mora biti pomenuta u tekstu. Izvor za svaku sliku navodi se ispod naslova.

Primer



Slika 1. Teškoće u korišćenju platforme eAgrar, struktura odgovora, 2023.
Izvor: Obrada autora na osnovu sprovedenog istraživanja.

Skraćenice i jedinice

U radu treba koristiti samo standardne skraćenice. Merne jedinice treba izražavati u internacionalnom sistemu jedinica (SI). Skraćenice se mogu koristiti i za druge izraze pod uslovom da se ti izrazi navedu u punom obliku prilikom prvog pominjanja u tekstu, sa skraćenim oblikom u zagradi. Vrednosti od jedan do devet se izražavaju slovima, a ostali brojevi isključivo numerički. U naslovu rada ne treba koristiti skraćenice.

Nomenklatura

Međunarodni standardi (IUPAC, IUB, ICN itd.) treba da se primenjuju za hemijske, biohemijske, taksonomske i genetičke termine.

Formule

Sve formule i jednačine u radu moraju biti urađene pomoću programa *Microsoft Word Equation Editor* ili *MathType*. Prilikom pisanja jednačina treba dati značenje svih simbola odmah posle formule u kojoj se simbol prvi put koristi. Formule treba da budu numerisane arapskim brojevima, serijski u zagradama, na desnoj strani. Svaka jednačina mora biti pomenuta u tekstu kao Eq. (1), Eq. (2), itd.

Na kraju rukopisa navode se naslov rada, imena autora, afiliacije, sažetak i ključne reči na srpskom jeziku. Za strane autore, prevod na srpski jezik obezbeđuje redakcija.

Redakcioni odbor časopisa
Journal of Agricultural Sciences

List of Reviewers for 2025

Journal of Agricultural Sciences (Belgrade)

The Editorial Board of the Journal of Agricultural Sciences (Belgrade) would like to express its sincere gratitude to all reviewers who contributed to the evaluation of manuscripts in 2025. Their time, expertise, and dedication have been essential in maintaining the quality and integrity of the journal.

Abdelghani Nabloussi, National Institute of Agricultural Research, Rabat, Morocco

Adesola Lateef Nassir, Olabisi Onabanjo University, Ogun, Nigeria

Adeyemi Badmus, Obafemi Awolowo University, Osun, Nigeria

Amina Belguendouz, Nour Bachir University Center of El Bayadh, Institute of Natural and Life Sciences, Bayadh, Algeria

Andrzej Łachacz, University of Warmia and Mazury in Olsztyn, Faculty of Agriculture and Forestry, Olsztyn, Poland

Bojan Jocković, Institute of Field and Vegetable Crops, Novi Sad, Serbia

Darwin Pangaribuan, University of Lampung, Faculty of Agriculture, Lampung, Indonesia

Deborah Oluyemisi Opaleke, University of Ilorin, Faculty of Agriculture, Ilorin, Nigeria

Dragan Radivojević, University of Belgrade, Faculty of Agriculture, Belgrade, Serbia

Dragan Živančev, Institute of Field and Vegetable Crops, Novi Sad, Serbia

Dragana Mihajlović, University of Belgrade, Faculty of Agriculture, Belgrade, Serbia

Dušan Kovačević, University of Belgrade, Faculty of Agriculture, Belgrade, Serbia

Edyta Đermić, University of Zagreb, Faculty of Agronomy, Zagreb, Croatia

Emmanuel Oluwakayode Ajayi, National Horticultural Research Institute, Ibadan, Nigeria

Ghassan Hamdi, University of Diyala, College of Agriculture, Baqubah, Iraq

Ivan Ravza, Slovak University of Agriculture, Nitra, Slovakia

Jelena Marinković, Institute of Field and Vegetable Crops, Novi Sad, Serbia

Jelena Ovuka, Institute of Field and Vegetable Crops, Novi Sad, Serbia

Jitka Hamáčková, University of South Bohemia, Faculty of Fisheries and Protection of Waters, České Budějovice, Czech Republic

Jordan Marković, Institute for Forage Crops, Kruševac, Serbia

Ljiljana Bošković Rakočević, University of Kragujevac, Faculty of Agronomy, Čačak, Serbia

CIP - Каталогизација у публикацији
Народна библиотека Србије, Београд

63

JOURNAL of Agricultural Sciences / editor in chief Marija Nikolić. - Vol. 44, no. 1 (1999)- . - Belgrade : University of Belgrade, Faculty of Agriculture, 1999- (Belgrade : Faculty of Agriculture). - 24 cm

Tromesečno. - Je nastavak: Review of Research work at the Faculty of Agriculture = ISSN 0354-3498. - Drugo izdanje na drugom medijumu: Journal of Agricultural Sciences (Belgrade. Online) = ISSN 2406-0968
ISSN 1450-8109 = Journal of Agricultural Sciences (Belgrade)
COBISS.SR-ID 169380871