Preliminary report
Ratar. Povrt. 2026, 63(1): 10-21
doi: 10.5937/ratpov63-62142
Manuscript submitted: 14 October 2025
Manuscript accepted: 21 January 2026
Published online: 13 January 2026



# Trends in nitrogen use efficiency in a historical set of wheat cultivars in Serbia

**Jovana Timić[1]* · Milan Mirosavljević[1] · Vladimir Aćin[1] · Bojan Jocković[1] · Goran Jaćimović[2] · Ranko Čabilovski[2] · Maja Manojlović[2]**

[1]Institute of Field and Vegetable Crops, Novi Sad, Serbia
[2]University of Novi Sad, Faculty of Agriculture, Novi Sad, Serbia

*Corresponding author: jovana.timic@nsseme.com



**Summary:** Optimization of nitrogen (N) fertilizer use is a crucial factor for achieving high wheat yields while simultaneously improving the economic efficiency of production and reducing negative environmental impacts. The aim of this study was to determine the effect of two nitrogen fertilization levels on nitrogen use efficiency (NUE) and its components: nitrogen uptake efficiency (NUpE) and nitrogen utilization efficiency (NUtE) in wheat varieties developed between 1930 and 2015. The research was conducted at the experimental field of the Institute of Field and Vegetable Crops, Rimski Šančevi, Serbia on haplic chernozem (Aric). The results showed that analyzed traits (NUE, NUpE and NUtE) were significantly affected by variety, fertilization and their interaction. Fertilization had the greatest effect on the variability of the examined traits. Application of N resulted in a NUE of 49.1 kg grain / kg available N in soil per ha, while in the control treatment it reached 81.6 kg grain / kg available N in soil per ha. The lowest values of the analyzed traits in both treatments were observed in the oldest cultivar Banatka, while modern cultivars showed higher values. Under the control treatment without N application, the mean NUpE increased by 0.42 N in biomass / kg N available in soil. The cultivar Simonida had the highest NUtE in the control treatment, while nitrogen application it resulted in a 15 kg grain / kg N in biomass lower value. A positive linear relationship was established between the year of variety release and all three investigated traits, particularly under the control treatment. These results indicates that modern cultivars demonstrate improved NUE, NUpE and NUtE under conditions of low nitrogen availability compared with older cultivars.
**Key words:** nitrogen, NUE, yield, cultivar, *Triticum aestivum* L.

## Introduction

Global agricultural production faces significant challenges due to the continuous growth of the world population, increasing food demand, and changes in dietary patterns (Mălinaş et al., 2022). Wheat is one of the most important cereal crops in the world, and reaches an annual production of approximately 805 million tons, with continued growth expected in the near future (FAO, 2025). The Pannonian Plain, as a region in Southeast Europe, that includes Serbia, is recognized as one of the most important areas for winter wheat production (Jocković et al., 2022).

In recent years, wheat production in Serbia has become progressively more important, leading to an expansion of wheat - growing region. According to data from the Statistical Office of the Republic of Serbia (https://data.stat.gov.rs), in 2024 the area under wheat reached approximately 607 thousand hectares, which is about 25% higher than the ten-year average. Also, the average grain yield has increased from 4.3 t ha$^{-1}$ to 5.3 t ha$^{-1}$ over the past five years, indicating significant progress in crop production technology. The continuous increase in wheat yields is a result of intensive agricultural practices and the introduction of high-yielding cultivars into production (Peltonen-Sainio et al., 2009). Optimal management of mineral fertilization according to agroecological conditions is important, as it reduces the negative effects of climatic factors and enhances resistance to abiotic stresses such as extreme temperatures and drought (Jaćimović et al., 2023). Nitrogen (N) is one of the most expensive inputs and a key element for achieving high yields and protein content in cereals, and it is a central focus of modern research. During the second half of the 20th century, nitrogen use substantially increased due to the advancements associated with the Green Revolution (Mirosavljević et al., 2019). Over the past fifty years, the average level of nitrogen fertilizer application in cereal production has increased by approximately 52 kg ha$^{-1}$ according to global data (Ladha et al., 2016).

In the Pannonian Plain, nitrogen fertilizers are applied at high doses both before sowing and during the spring growing period (topdressing) before the stem elongation phase. However, it is estimated that only about 33% of the nitrogen applied to cereals is absorbed by the plants and incorporated into the harvested grain (Hawkesford et al., 2019), while the remaining N is lost from the soil by denitrification, volatilization, surface runoff, and leaching, causing negative influence on the environment (Cameron et al., 2013). Optimization of nitrogen fertilization is necessary to achieve a balance between high yields and the economic efficiency of production (King et al., 2003). One of the main objectives in cereal breeding programs is the improvement of nitrogen use efficiency (NUE) and the ability of genotypes to achieve high yields while optimizing the use of mineral nitrogen fertilizers (Hawkesford et al., 2019).

NUE can be evaluated trough different indices. According to Moll et al. (1982) NUE is defined as ratio of grain yield to the total nitrogen available in the soil and it includes two components: nitrogen uptake efficiency (NUpE) and nitrogen utilization efficiency (NUtE). Calculating and analyzing NUE is important in wheat breeding because it helps identify genotypes with an improved ability to allocate assimilates and nitrogen to the important parts of the plant (Congreves et al., 2021). Understanding the response of wheat cultivars to different nitrogen treatments is crucial for achieving high and stable yields while ensuring the rational use of nitrogen fertilizers.

With new wheat cultivars being introduced continuously, information on their response to different nitrogen treatments is often incomplete or unavailable. The main objective of this study was to examine the effect of two nitrogen fertilization levels on a historical set of 25 wheat cultivars in order to determine trends in NUE and its components, NUtE and NUpE. The results can provide a basis for defining future wheat breeding strategies aimed at improving nitrogen use efficiency and reducing its negative effects on environment.

## Materials and Methods

*Field experiment design and agronomic practice*

A trial with a historical set of winter wheat varieties was conducted at the experimental field of the Institute of Field and Vegetable Crops, Novi Sad, Rimski Šančevi, Serbia (45° 20' N, 19° 51' E, 84 m) during the 2022/2023 growing season. The experiment was established on haplic chernozem, the most common soil type in Vojvodina. Basic agrochemical analyses were performed in autumn using standard methods explained below, and the basic physical and chemical properties of the soil are given in Table 1. This soil is characterized by slightly alkaline reaction, as well as the good supply of easily available phosphorus (P) and potassium (K) and medium supply of N.

Table 1. Basic agrochemical analysis

| pH (KCl) | $CaCO_3$ (%) | Humus (%) | Total N (%) | *AL-$P_2O_5$ (mg/100g) | AL-$K_2O$ (mg/100g) |
|---|---|---|---|---|---|
| 7.2 | 4.9 | 2.80 | 0.184 | 22.0 | 24.0 |

*AL ammonium – lactate method (Egner & Riehm, 1958)

Total N in soil was determined using a CHNS analyzer (Elementar Vario EL, GmbH, Hanau, Germany). Available P ($P_2O_5$) and K ($K_2O$) (mg $100^{-1}$ g of soil) were extracted from the soil with an AL solution of 0.1 M ammonium – lactate and 0.4 M acetic acid, in the ratio of 1:20 (soil: solution) (Egner et al., 1960). The available P content was determined spectrophotometrically (Shimadzu, UV-2600), and K content by flame photometry (Jenway 6105, USA).

The field experiment was conducted using a split-plot design in three replications with the treatments randomly assigned. The long-term crop rotation at the experimental field trial includes cereals, maize, and soybean. This study included two levels of nitrogen fertilization: 0 kg $ha^{-1}$ (control, without nitrogen application) and 100 kg $ha^{-1}$. A set of 25 winter wheat varieties released in Serbia between 1930 and 2015 were evaluated (Table 2). These varieties represent the main historical and widely grown wheat cultivars in the Pannonian Plain and have been utilized in breeding programs in Yugoslavia, later Serbia, as well as in other countries across the region and beyond. The following varieties, Pobeda, Renesansa, Apache, Simonida, Sirtaki, NS 40S, Ingenio, and NS Obala, remain significant varieties in production, primarily playing a crucial role in the production of high-quality seed.

Table 2. The analyzed cultivars, country of origin and year of release

| Cultivar | Country of origin | Year of release |
|---|---|---|
| Banatka | Ukraine | 1930 |
| Bankuti 1205 | Hungary | 1931 |
| San Pastore | Italy | 1940 |
| Mara | Italy | 1947 |
| Novosadska 1439 | Serbia | 1953 |
| Bezostaya - 1 | Russia | 1959 |
| Bačka | Serbia | 1964 |
| Libellula | Italy | 1965 |
| Sava | Serbia | 1970 |
| Partizanka | Serbia | 1973 |
| Novosadska rana | Serbia | 1975 |
| Nizija | Serbia | 1979 |
| Jugoslavija | Serbia | 1980 |
| Skopljanka | Macedonia | 1982 |
| Lasta | Serbia | 1987 |
| Evropa 90 | Serbia | 1990 |
| Pobeda | Serbia | 1990 |
| Renesansa | Serbia | 1994 |
| Apache | France | 1998 |
| Simonida | Serbia | 2003 |
| Sirtaki | France | 2004 |
| NS 40S | Serbia | 2006 |
| Ingenio | France | 2006 |
| NS Mila | Serbia | 2014 |
| NS Obala | Serbia | 2015 |

Primary tillage was performed by plowing, followed by one pass with a multi-tiller and a seedbed cultivator. Sowing was carried out on 25 October 2022, with the target sowing rate of 550 viable seeds per square meter, as recommended for agroecological conditions of the southern Pannonian region. The size of each basic plot was 5 m in length and 1 m in width for each variety. The applied nitrogen fertilizer was ammonium nitrate ($NH_4NO_3$) at rate of 100 kg of active N $ha^{-1}$ in two applications. The first half, 50 kg N $ha^{-1}$ was applied pre-sowing in autumn, while the second half was applied as top-dressing before the stem elongation. The same amounts of P and K were applied to all treatments at a rate of 60 kg $ha^{-1}$ in autumn during primary tillage to avoid deficiency. Fertilizer application was performed on the same day for all 25 varieties. As needed, weeds, insect pests, and pathogens were controlled in spring using recommended pesticides.

*Plant material and statistical analysis*

During the growing season, the phenological stages of wheat were regularly monitored according to the Zadoks decimal code (Zadoks et al., 1974). The dates of anthesis and grain maturity were recorded for each tested variety, with sampling times adjusted to the phenology of each genotype. Plant material for nitrogen content analysis were collected from two central rows over a length of 1 m to avoid edge effects. After sampling, the rest of each plot was harvested using a specializes combine for experimental plots. Plant material was separated into spikes and the remaining biomass (vegetative part). Samples were dried at 60 °C for 72 h, after which the dry mass of all components was recorded. The dried plant material was ground to a fine powder using a laboratory mill. Nitrogen (N) concentration in the grain and vegetative parts was determined using Kjeldahl method (FOSS, 2009). Grain mass from the previously sampled row was added to the grain mass from the combined plot, and grain yield was adjusted to 13% moisture content. NUE (grain yield / N available in soil), NUpE (N uptake / N available in soil), and NUtE (grain yield / N uptake) were calculated according to Moll et al. (1982).

The effects of the analyzed factors were evaluated using analysis of variance (ANOVA) with the statistical software STATISTICA 10. The same software was also used for regression analysis. Differences between treatment means were compared using Tukey´s HSD test. Trends in the studied traits were analyzed using linear regression.

*Weather conditions*

Meteorological data for the 2022/23 growing season were obtained from the weather station at Rimski Šančevi, located near the experimental field. Basic parameters during the winter wheat growing period are presented in Figure 1.

The snowing period (October and the first half of November) was characterized by slightly higher temperatures compared with the long-term average for the site. At the beginning of October, precipitation was higher than in the second and third decades of the month. Increased rainfall during November and December provided sufficient moisture for germination and initial growth. Temperatures at the end of November and throughout December were close to the long–term average, whereas January and February experienced higher temperatures (up to 7 °C) along with slightly above–average precipitation for that time of year. The continuation of the growing season was promoted by above – average temperatures in March, which was drier than usual. During April and May, temperatures were slightly below average, while precipitation was considerably more favorable. In June significant decrease in rainfall led to drought conditions, resulting in accelerated grain maturation.

The weather conditions during the 2022/23 growing season were characterized by considerable variability, including a warm autumn – winter period, a relatively mild winter, sufficient rainfall in spring, and drought during the grain maturation stages.

**Results**

The results of the study revealed a significant effect of variety, fertilization, and their interaction on the variability of NUE, NUpE and NUtE in tested winter wheat varieties (Table 3). Fertilization showed the greatest impact on the overall variability of all three traits, accounting for more than half of the total variation in NUE and NUpE, while for NUtE, the contribution of fertilization was 49.9%. The effect of variety was highly significant for all examined traits, while the variety × fertilization interaction was highly significant for NUtE.

Under fertilized conditions, the average NUE was 49.1 kg grain / kg available N in soil per ha, while the control (unfertilized) treatment showed a value of 81.6 kg grain / kg available N in soil per ha. In the unfertilized treatment, the lowest NUE was recorded in the variety Banatka (54.5 kg grain / kg available N in soil per ha), while the highest value of 93.4 kg grain / kg available N in soil per ha was observed in Sirtaki, followed by the varieties NS Mila and Apach. The old variety Banatka also showed the lowest NUE under fertilized conditions with a value of 36.1 kg grain / kg available N in soil per ha, while the modern varieties reached significantly higher values (NS 40S stood out at 60.3 kg grain / kg available N in soil per ha). The varieties Pobeda, Mara, and Sirtaki showed the greatest differences in NUE depending on the treatment, with values increasing by approximately 40 kg grain / kg available N in soil per ha in unfertilized plots compared to the fertilized. The smallest differences were observed in the varieties Banatka and Bankut -1205.

Comparison of NUpE values between old and modern wheat varieties revealed significant differences. An increase in the average value of 0.42 N in biomass / kg N available in soil was observed in the control treatment compared to the fertilized variant (Table 4). Under nitrogen fertilization, the lowest value was recorded for the old variety San Pastore (1.09 N in biomass / kg N available in soil), while NS 40S showed the highest value of 1.61 N in biomass / kg N available in soil. Modern variety NS Obala reached the highest value (1.98 N in biomass / kg N available in soil) in the control treatment, while Banatka and Jugoslavija showed the lowest values. The greatest difference in NUpE between treatments was observed for the variety Mara (0.73 N in biomass / kg N available in soil), while the smallest difference was found for Jugoslavija. The oldest variety in the experiment, Banatka, showed the lowest NUtE under unfertilized condition (34.6 kg grain / kg N in biomass), while the highest values were recorded for the variety Simonida, Jugoslavija, and Sirtaki. Under fertilization treatment, the lowest NUtE was recorded for the variety Novosadska 1439 (27.4 15 kg grain / kg N in biomass), followed by Banatka, while the highest value was reached by Bačka (41.9 N15 kg grain / kg N in biomass). Table 4 also highlights a significant variety × treatment interaction for the variety Simonida, which showed the highest NUtE under unfertilized conditions, but showed a 15 kg grain /kg N in biomass lower value under nitrogen fertilization.

A positive association was revealed between the year of variety release and all three examined traits, indicating that modern varieties demonstrate improved NUE and its components, NUpE and NUtE compared to older varieties. Figure 2 shows that the increase in NUE reached 0.236 kg grain / kg available N in soil per ha under fertilized conditions, while in the control treatment it was 0.352 kg grain / kg available N in soil per ha. Although modern varieties performed better under both treatments, varieties selected for high fertilizer doses did not show superior performance at low nitrogen levels. An increase in NUpE of 0.006 N in biomass / kg N available in soil was recorded in fertilized treatment, while in the control it was only 0.003 N in biomass / kg N available in soil (Figure 3). In this study, higher NUtE values were generally found in modern varieties. Figure 4 indicates a positive association between the year of variety release and NUtE under unfertilized conditions. An increase of 1.18 kg grain / kg N in biomass was recorded, while fertilized conditions showed no significant effect.

Table 3. Analysis of variance of NUE, NUpE and NUtE in a historical set of wheat varieties grown under different levels of nitrogen fertilizations

| Traits | Mean of square | | | | Sum of squares (SS) | | |
|---|---|---|---|---|---|---|---|
| | Genotype (G) | Treatment (T) | G X T | Error | Genotype (G) | Treatment (T) | G X T |
| NUE | 402.5** | 39516.8** | 47.5* | 35.9 | 17.9 | 73.3 | 2.1 |
| NUpE | 0.10** | 6.4** | 0.03** | 0.01 | 22.9 | 63.8 | 8.0 |
| NUtE | 60.4** | 3565.0** | 21.6* | 16.0 | 20.3 | 49.9 | 7.3 |

* significant at the 0.05 probability level, ** significant at the 0.01 probability level

Table 4. Average NUE, NUpE, and NUtE of wheat varieties (1930–2015) under two nitrogen fertilization levels

| | NUE | | NUpE | | NUtE | |
|---|---|---|---|---|---|---|
| Variety | 0 N* | 100 N | 0 N | 100 N | 0 N | 100 N |
| Banatka | 54.5$^{g-m}$ | 36.1$^{m}$ | 1.58$^{f-l}$ | 1.21$^{o-r}$ | 34.6$^{g-j}$ | 29.8$^{ij}$ |
| Bankut 1205 | 60.7$^{d-j}$ | 40.0$^{k-m}$ | 1.61$^{e-k}$ | 1.12$^{qr}$ | 37.7$^{b-j}$ | 35.7$^{e-j}$ |
| San Pastore | 71.2$^{b-h}$ | 42.2$^{j-m}$ | 1.72$^{b-i}$ | 1.09$^{r}$ | 41.5$^{a-i}$ | 38.7$^{b-j}$ |
| Mara | 82.2$^{a-c}$ | 42.2$^{j-m}$ | 1.85$^{a-e}$ | 1.12$^{qr}$ | 44.5$^{a-h}$ | 37.5$^{b-j}$ |
| Novosadska 1439 | 63.1$^{c-i}$ | 37.6$^{lm}$ | 1.69$^{c-i}$ | 1.37$^{k-p}$ | 37.5$^{b-j}$ | 27.4$^{j}$ |
| Bezostaja 1 | 74.6$^{a-g}$ | 42.2$^{j-m}$ | 1.73$^{b-h}$ | 1.12$^{qr}$ | 43.2$^{a-i}$ | 37.6$^{b-j}$ |
| Bačka | 81.4$^{a-c}$ | 49.0$^{i-m}$ | 1.70$^{b-i}$ | 1.17$^{p-r}$ | 47.9$^{a-g}$ | 41.9$^{a-i}$ |
| Libelula | 75.9$^{a-f}$ | 42.7$^{j-m}$ | 1.65$^{d-j}$ | 1.12$^{qr}$ | 46.0$^{a-h}$ | 38.1$^{b-j}$ |
| Sava | 84.3$^{ab}$ | 50.2$^{i-m}$ | 1.81$^{a-f}$ | 1.25$^{n-r}$ | 46.6$^{a-h}$ | 40.0$^{a-j}$ |
| Partizanka | 86.6$^{ab}$ | 48.5$^{i-m}$ | 1.84$^{a-e}$ | 1.35$^{l-q}$ | 47.0$^{a-h}$ | 35.9$^{e-j}$ |
| Novosadska rana | 86.1$^{ab}$ | 51.6$^{h-m}$ | 1.77$^{a-g}$ | 1.48$^{i-n}$ | 48.6$^{a-f}$ | 34.9$^{g-j}$ |
| Nizija | 79.8$^{a-e}$ | 43.0$^{i-m}$ | 1.64$^{d-j}$ | 1.27$^{m-r}$ | 48.7$^{a-f}$ | 33.9$^{h-j}$ |
| Jugoslavija | 79.3$^{a-e}$ | 48.3$^{i-m}$ | 1.58$^{f-l}$ | 1.42$^{j-o}$ | 50.2$^{ab}$ | 34.1$^{h-j}$ |
| Skopljanka | 80.5$^{a-d}$ | 52.9$^{h-m}$ | 1.82$^{a-f}$ | 1.51$^{h-m}$ | 44.3$^{a-h}$ | 35.0$^{g-j}$ |
| Lasta | 86.6$^{ab}$ | 58.6$^{f-k}$ | 1.75$^{a-h}$ | 1.54$^{g-l}$ | 49.6$^{a-d}$ | 38.1$^{b-j}$ |
| Evropa 90 | 81.8$^{a-c}$ | 50.6$^{i-m}$ | 1.85$^{a-e}$ | 1.48$^{i-n}$ | 44.2$^{a-h}$ | 34.1$^{hj}$ |
| Pobeda | 89.6$^{ab}$ | 48.5$^{i-m}$ | 1.91$^{a-c}$ | 1.28$^{m-r}$ | 46.9$^{a-h}$ | 37.8$^{b-j}$ |
| Renesansa | 90.3$^{ab}$ | 53.5$^{h-m}$ | 1.88$^{a-d}$ | 1.51$^{h-m}$ | 48.0$^{a-g}$ | 35.3$^{f-j}$ |
| Apač | 91.7$^{a}$ | 57.2$^{f-l}$ | 1.88$^{a-d}$ | 1.58$^{f-l}$ | 49.0$^{a-e}$ | 36.3$^{c-j}$ |
| Simonida | 88.1$^{ab}$ | 52.9$^{h-m}$ | 1.68$^{c-i}$ | 1.42$^{j-o}$ | 52.4$^{a}$ | 37.4$^{b-j}$ |
| Sirtaki | 93.4$^{a}$ | 52.6$^{h-m}$ | 1.88$^{a-d}$ | 1.39$^{k-p}$ | 49.8$^{a-c}$ | 38.0$^{b-j}$ |
| NS 40S | 88.4$^{ab}$ | 60.3$^{e-j}$ | 1.91$^{a-c}$ | 1.61$^{e-k}$ | 46.2$^{a-h}$ | 37.4$^{b-j}$ |
| Ingenio | 86.5$^{ab}$ | 53.8$^{h-m}$ | 1.75$^{a-h}$ | 1.54$^{g-l}$ | 49.5$^{a-d}$ | 35.0$^{g-j}$ |
| NS Mila | 92.7$^{a}$ | 57.0$^{f-l}$ | 1.94$^{ab}$ | 1.51$^{h-m}$ | 47.9$^{a-g}$ | 37.8$^{b-j}$ |
| NS Obala | 90.5$^{ab}$ | 57.0$^{f-l}$ | 1.98$^{a}$ | 1.58$^{f-l}$ | 45.8$^{a-h}$ | 36.2$^{d-j}$ |
| Average | 81.6A | 49.1B | 1.78A | 1.36B | 49.9A | 36.2A |

* Different letters indicate significant differences ($p < 0.05$, Tukey test). 0 N = control (no nitrogen); 100 N = fertilization with 100 kg N $ha^{-1}$

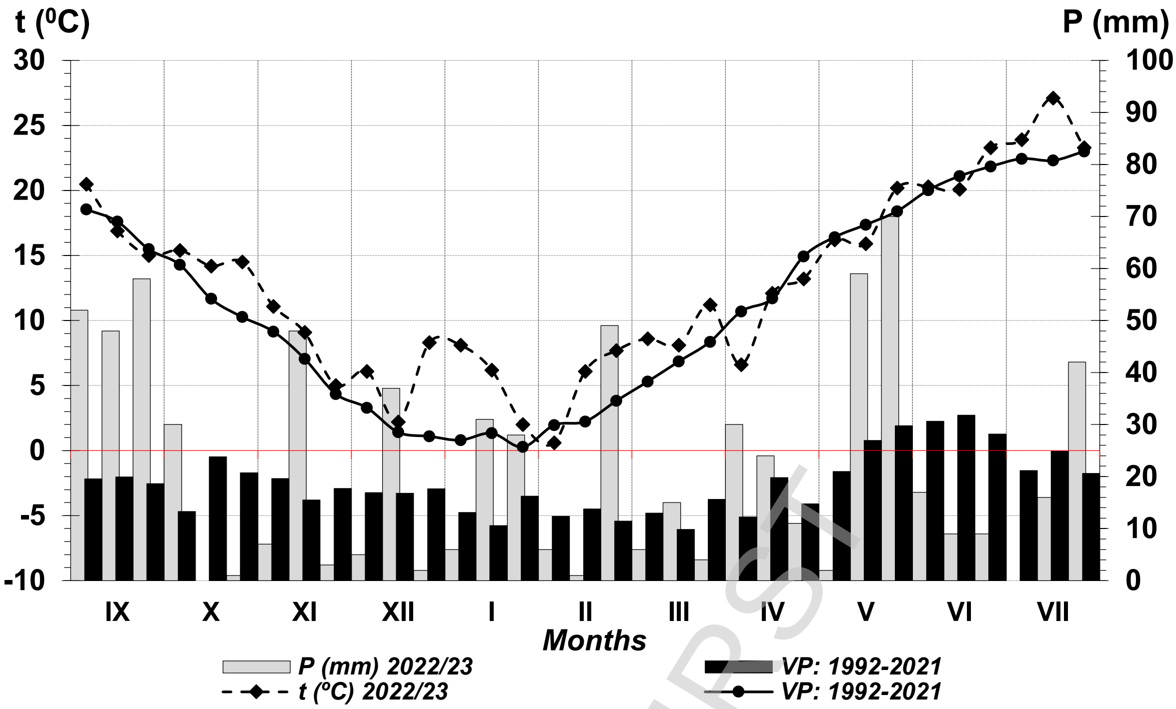


Figure 1. Monthly average daily precipitations and temperatures during the examinated period

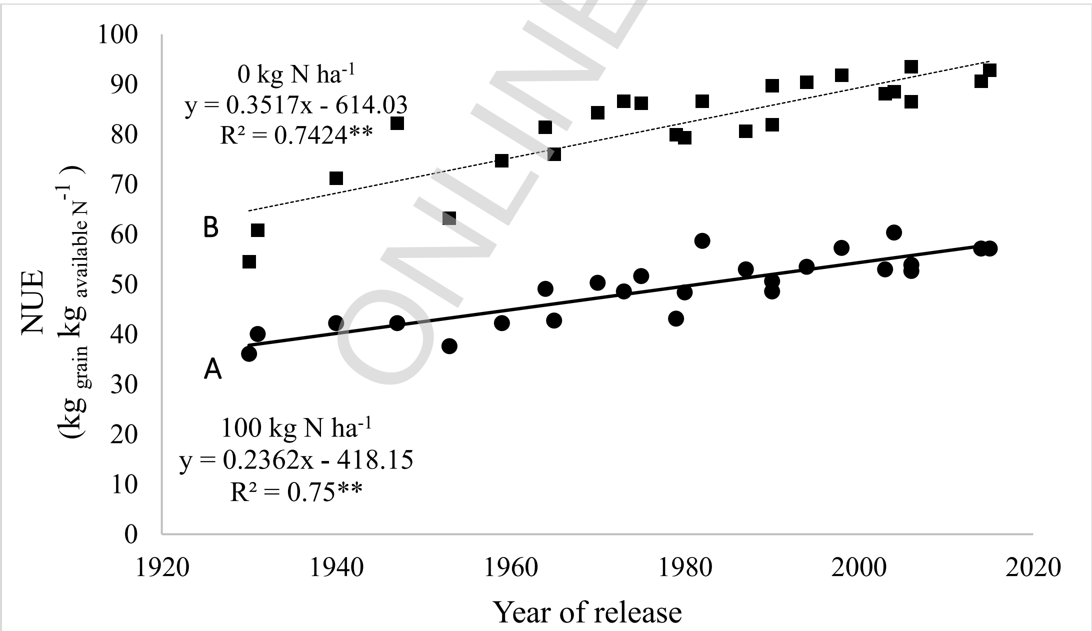


Figure 2. Linear regression between year of variety release and NUE (A – 100 N = fertilization with 100 kg N ha$^{-1}$; B – 0 N = control (no nitrogen))

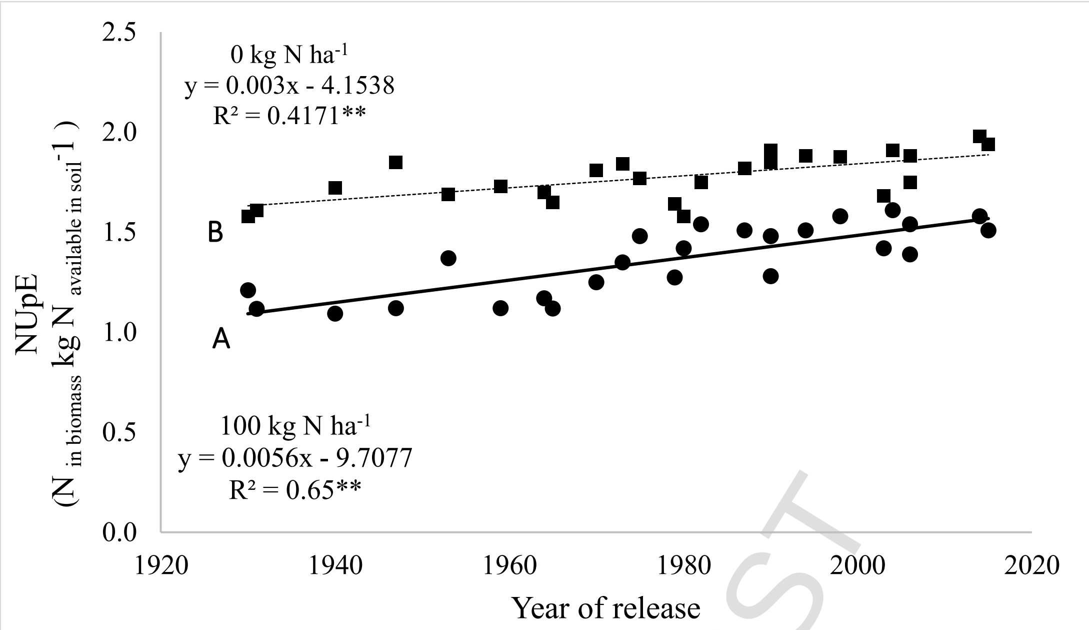


Figure 3. Linear regression between year of variety release and NUpE (A – 100 N = fertilization with 100 kg N $ha^{-1}$; B – 0 N = control (no nitrogen))

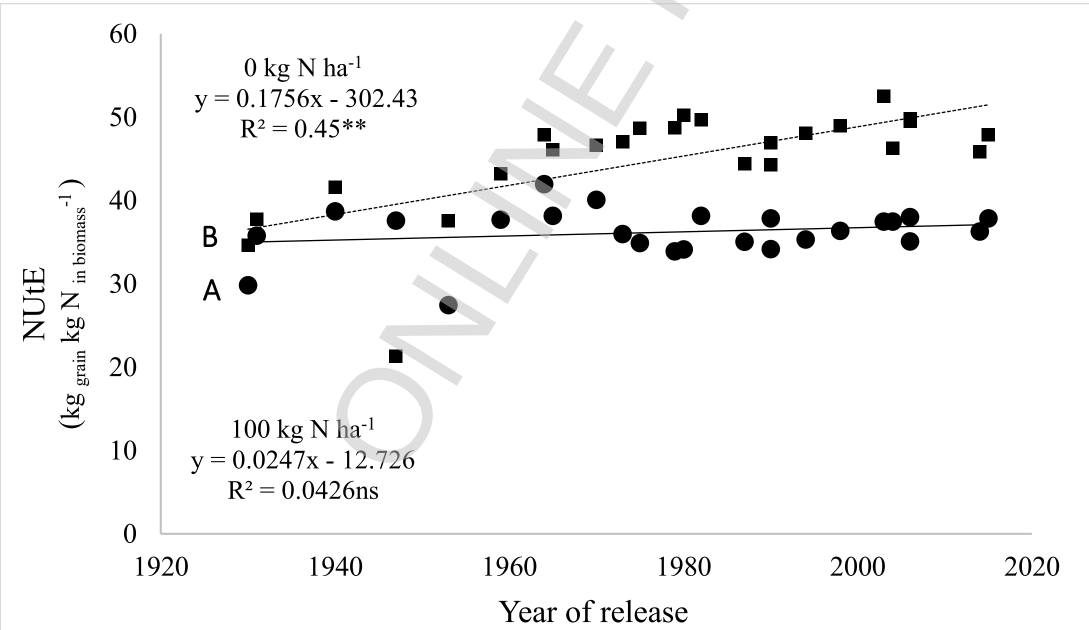


Figure 4. Linear regression between year of variety release and NUtE (A – 100 N = fertilization with 100 kg N $ha^{-1}$; B -0 N = control (no nitrogen))



**Discussion**

Conventional wheat production requires a continuous availability of nitrogen, as both grain yield and quality directly depend on the application of nitrogen fertilizers (Yokamo et al., 2023). In addition to appropriate production technologies, achieving high yields requires the improvement of wheat cultivars through breeding and selection programs. The climatic conditions of the Pannonian Plain, which includes Serbia, are characterized by high variability across different seasons (productive years), often representing a limiting factor in grain yield production (Jocković et al., 2010). The significant genotypic variation among wheat varieties requires understanding their responses under different growing conditions for selecting the best–adapted material and for achieving a balance between grain yield, environmental sustainability, and economic profitability (Barraclough et al., 2010).

Results of this study show that NUE values varied across the applied treatments. The application of 100 kg N $ha^{-1}$ reduced NUE compared with the control treatment, which is consistent with the findings of Kröbel et al. (2012) and Mahjourimaid et al. (2016) who previously reported that higher soil nitrogen levels decrease NUE in wheat. The decrease in NUE may be due to nitrogen leaching, limited or less efficient use of available nitrogen, or other factors that reduce grain yield (Hawkesford, 2014). Also, our results confirmed the presence of genetic variability in nitrogen use efficiency among the examined wheat cultivars. The observed genotypic variation in NUE reflects differences in nitrogen uptake and its effective use (Yadeta et al., 2009). Guttieri et al. (2017), pointed out that modern wheat cultivars show improved NUE parameters compared with older cultivars. Results of this study are consistent with this, as the oldest cultivar Banatka had the lowest NUE. Wheat breeders select genotype with higher grain yield potential under specific conditions, indirect improvement in NUE is observed, suggesting that further increase can be expected (Mirosavljević et al., 2019). The number and length of roots are important for effective nitrogen uptake, and genetic variation in root traits can strongly influence NUE and its components, since a well–developed root system allows the plant to access nitrogen more efficiently (Lupini et al., 2012; Raigar et al., 2022). A higher nitrogen harvest index indicates more efficient transfer of absorbed nitrogen to the grain (Hawkesford, 2017), while the "stay-green" trait helps maximize nitrogen use during critical growth stages of wheat.

The results of this study showed higher NUpE values in the control treatment (1.78 N in biomass / kg N available in soil) compared with the treatment treated with nitrogen fertilizer (1.36 N in biomass / kg N available in soil). These findings are consistent with Todeschini et al. (2016), who showed variation in nitrogen uptake efficiency among different wheat cultivars. The modern cultivars, released between 2006 and 2015 showed an increase in NUpE of 0.21 N in biomass per kg N available in soil under unfertilized treatment compared with nitrogen fertilized conditions. Since higher NUpE values are often observed under conditions of limited nitrogen availability, this allows for the selection of cultivars with better performance under different fertilization treatments. Since NUpE is high at low nitrogen levels, it is important to improve the through breeding programs for sustainable and low input systems. NUpE is an important factor for wheat grain yield by affecting the total amount of nitrogen taken up by the plant (Chen et al., 2022). Nitrogen accumulation before the critical anthesis stage is crucial for grain yield and largely depends on root system development, so genetic differences in root traits indirectly influence NUPe values (Ranjan et al., 2023).

The results of this study showed that NUtE increased by about 14 kg grain per kg N in biomass under the unfertilized treatment compared with the nitrogen fertilized treatment. Similar results were reported in Brazil (Todeschini et al., 2016), where an increase in soil nitrogen reduced NUtE. However, the authors pointed out the importance of this parameter and its role in total nitrogen utilization. Mosleth et al. (2020) also highlighted the key role of NUtE for improving total NUE when wheat is grown under low soil nitrogen conditions, noting that this component is important for increasing grain protein content, which ultimately affecting wheat quality. Considering that grain protein content and wheat grain yield are often negatively correlated (Da Silva et al., 2014), simultaneously improving NUtE and protein quality represents an important challenge for breeders (Chen et al., 2022). Although in this study higher NUtE values were generally observed in modern cultivars, Biel et al. (2021) reported that older cultivars can achieve higher NUtE due to their ability to efficiently translocate nitrogen from vegetative tissues to the grain and their resilience to environmental stress. It is also important to consider how NUtE relates to photosynthetic activity, as modern cultivars have increased photosynthetic capacity, which can improve NUtE even in low nitrogen levels (Hawkesford, 2017).

The analysis of old and modern wheat cultivars showed a significant interaction between cultivar and soil nitrogen level, highlighting the effects of breeding and agronomic practices. Modern cultivars, adapted to intensive production, do not necessarily perform best under low nitrogen doses. Incorrect fertilizer application, such as high nitrogen rates on cultivars that respond less effectively or low nitrogen rates on cultivars with high requirements, can limit the full genetic yield potential of wheat (Mirosavljević et al., 2019). Modern cultivars show higher NUE and its components, particularly under the unfertilized treatment, indicating a greater ability to use nitrogen efficiently when it is limited. This allows for optimal nitrogen uptake and distribution throughout the plant, reduces nitrogen losses, and helps optimize fertilizer costs in wheat production (Ivić et al., 2021).

## Conclusion

The result of this study showed a significant effect of cultivar, fertilization, and their interaction on the variability on NUE and its components NUpE and NUtE. The lowest values of the traits were mostly observed in the oldest cultivar Banatka, while modern cultivars demonstrated higher values. A significant yearly increase in these traits was also noted, particularly under the unfertilized treatment, indicating that modern cultivars are able to use nitrogen more efficiently. These results highlight the importance of improving NUE in wheat through breeding programs to improve both economic efficiency and environmental sustainability of nitrogen use in agriculture.

**Author contributions:** J. T.: Conceptualization, Writing - original draft; M. Mirosavljević: Methodology, Formal analysis; V. A.: Investigation; B. J.: Visualization; G. J.: Writing - review & editing; R. Č.: Validation; M. Manojlović: Supervision

**Funding statement:** The study was conducted as a part of a long-term project "Improving Nitrogen Use Efficiency in Winter Wheat in Vojvodina", grant number 142-451-2551/2021-01/02, funded by the Provincial Secretary for Higher Education and Scientific Research, AP Vojvodina, Serbia.

**Competing interests` statement:** No competing interests were disclosed.



## References

Barrachlough, P., Howarth, J., Jones, J., Lopez-Bellido, R., Parmar, S., Shepherd, C., & Hawkesford, M. (2010). Nitrogen efficiency of wheat: genotypic and environmental variation and prospects for improvement. *European Journal of Agronomy*, 33 (1): 1-11. https://doi.org/10.1016/j.eja.2010.01.005

Biel, W., Jaroszewska, A., Stankowski, S., Sobolewska, M., & Kępińska-Pacelik, J. (2021). Comparison of yield, chemical composition and farinograph properties of common and ancient wheat grains. *European Food Research and Technology*, 247: 1525-1538. https://doi.org/10.1007/s00217-021-03729-7

Cameron, K.C., Di, H.J., & Moir, J.L. (2013). Nitrogen losses from the soil/plant system: a review. *Annals of Applied Biology,* 162, 145-173. https://doi.org/10.1111/aab.12014

Chen, Y., Wang, K., Chen, H., Yang, H., Zheng, T., Huang, X., & Fan, G. (2022). Simultaneously genetic selection of wheat yield and grain protein quality in rice-wheat and soyabean-wheat cropping systems through critical nitrogen efficiency-related traits. *Frontiers in Plant Science*, 13. https://doi.org/10.3389/fpls.2022.899387

Congreves, K.A., Otchere, O., Ferland, D., Farzadfar, S., Williams, S., & Arcand, M.M. (2021). Nitrogen Use Efficiency Definitions of Today and Tomorrow. *Frontiers in Plant Science*, 12. https://doi.org/10.3389/fpls.2021.637108

Da Silva, C., Benin, G., Bornhofen, E., Todeschini, M., Dallo, S., & Sassi, L. (2014). Characterization of Brazilian wheat cultivars in terms of nitrogen use efficiency. *Bragantia*, 73, 87-96. https://doi.org/10.1590/brag.2014.012

Egner, H., & Riehm, H. (1958). Die ammoniumlaktatessigsäure-methode zur bestimmung ger leichtlöslichen phosphorsäure in karbonathaltigen böden. *Agrochimica*, 3 (1): 49-65.

Egner, H., Riehm, H., & Domingo, W.R. (1960). Investigations of the chemical soil analysis as a basic for the evaluation of nutrient status in soil II: Chemical extraction methods for phosphorus and potassium determination. *K. Lantbruksakad Ann*, 26: 195-215.

FAO (2025). World food situation. FAO (https://www.fao.org/worldfoodsituation/csdb/en/) Accessed 29 August 2025.

Guttieri, J., Frels, K., Regassa, T., Waters, B.M., & Baenziger, P.S. (2017). Variation for nitrogen use efficiency trait in current and historical great plains hard winter wheat. *Euphytica*, 213 (4): 87. https://doi.org/10.1007/s10681-017-1869-5

Hawkesford, M. (2017). Genetic variation in traits for nitrogen use efficiency in wheat. *Journal of Experimental Botany*, 68 (10): 2627-2632. https://doi.org/10.1093/jxb/erx079

Hawkesford, M.J. (2014). Reducing the reliance on nitrogen fertilizer for wheat production. *Journal of Cereal Science*, 59(3): 276-283. https://doi.org/10.1016/j.jcs.2013.12.001

Hawkesford, M.J., & Griffithis, S. (2019). Exploiting genetic variation in nitrogen use efficiency for cereal crop improvement. *Current Opinions in Plant Biology,* 49, 35-42. https://doi.org/10.1016/j.pbi.2019.05.003

Ivić, M., Grljušić, S., Plavšin, I., Dvojković, K., Lovrić, A., Rajković, B., Maričević, M., Černe, M., Popović, B., Lončarić, Z., Bentley, A.R., Swarbreck, S.M., Šarčević, H., & Novoselović, D. (2021). Variation for Nitrogen Use Efficiency Traits in Wheat Under Contrasting Nitrogen Treatments in South-Eastern Europe. *Frontiers in Plant Science*, 12: 682333. https://doi.org/10.3389/fpls.2021.682333

Jaćimović, G., Aćin, V., Mirosavljević, M., Brbaklić, Lj., Vujić, S., Dunđerski, D., & Šeremešić, S. (2023). Effects of combined long-term straw return and nitrogen fertilization on wheat productivity and soil properties in the wheat-maize-soybean rotation system in the Pannonian Plain. *Agronomy*, 13 (6), 1529. https://doi.org/10.3390/agronomy13061529

Jocković, B., Mirosavljević, M., Momčilović, V., Dražić, T., Mikić, S., Aćin, V., Ilin, S., & Živančev, D. (2022). The contribution of stay green traits to the breeding progress of the Pannonian wheat. *Field Crops Research*, 287, 108649. https://doi.org/10.1016/j.fcr.2022.108649

Jocković, B., Mladenov, N., Hristov, N., & Aćin, V. (2010). Varijabilnost agronomskih svojstava pšenice [Variability of agronomic traits in wheat]. *Selekcija i Semenarstvo*, 16 (2), 17-26.

King, J., Gay, A., Sylvester-Bradley, R., Bingham, I., Foulkes, J., Gregory, P., & Robinson, D. (2003). Modelling cereal root systems for water and nitrogen capture: towards an economic optimum. *Annals of Botany*, 91, 383-390. https://doi.org/10.1093/aob/mcg033

Kröbel., R., Campbell, C.A., Zentner, R.P., Lemke, R., Desjardins, R.L., & Karmi-Zindashty, Y. (2012). Effect of N, P and cropping frequency on nitrogen use efficiencies of spring wheat in the Canadian semi-arid prairie. *Canadian Journal of Plant Sciences,* 92 (1): 141-154. https://doi.org/10.4141/cjps2011-067

Ladha, J.K., Tirol-Padre, A., Reddy, C.K., Cassman, K.G., Verma, S., Powlson, D.S., Van Kessel, C., Richter, D.D., Chakraborty, D., & Pathak, H. (2016). Global nitrogen budgets in cereals: a 50-year assessment for maize, rice, and wheat production system. *Scientific Reports*, 6, 19355. https://doi.org/10.1038/srep19355

Lupini, A., Preiti, G., Badagliacca, G., Abenavoli, M.R., Sunseri, F., Monti, M., & Bacchi, M. (2021). Nitrogen use efficiency in durum wheat under different nitrogen and water regimes in the Mediterranean Basin. *Frontiers in Plant Science*, 11. https://doi.org/10.3389/fpls.2020.607226

Mahjourimajd, S., Kuchel, H., Langride, P., & Okamoto, M. (2016). Evaluation of Australian wheat genotypes for response to variable nitrogen application. *Plant and Soil*, 399 (1-2): 247–255. https://doi.org/10.1007/s11104-015-2694-z

Mălinaş, A., Vidican, R., Rotar, I., Mălinaş, C., Moldovan, C.M., & Proorocu, M. (2022). Current status and future prospective for nitrogen use efficiency in wheat (*Triticum aestivum* L.). *Plants*, 11 (2), 217. https://doi.org/10.3390/plants11020217

Mirosavljević, M., Aćin, V., Sabadoš, V., & Dorotić, D. (2019). Variation in nitrogen use efficiency of winter wheat. *Genetika*, 51 (3): 1165-1174. https://doi.org/10.2298/GENSR1903165M

Moll, R.H., Kamprath, E.J., & Jackson, W. (1982). Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization. *Agronomy Journal*, 74, 562-564.

Mosleth, E.F., Lillehammer, M., Pellny, T.K., Wood, A.J., Riche, A.B., Hussain, A., Griffiths, S., Hawkesford, M.J., & Shewry, P.R. (2020). Genetic variation and heritability of grain protein deviation in European wheat genotypes. *Field Crops Research*, 255: 107896. https://doi.org/10.1016/j.fcr.2020.107896

Peltonen-Sainio, P., Jauhiainen, L., & Laurila, I.P. (2009). Cereal yield trends in northern European conditions: changes in yield potential and its realization. *Field Crops Research*, 110, 85-90. https://doi.org/10.1016/j.fcr.2008.07.007

Raigar, O.P., Mondal, K., Sethi, M., Singh, M.P., Singh, J., Kumari, A., Priyanka & Sekhon, B.S. (2022). Nitrogen use efficiency in wheat: genome to field. In Mahmood-ur-Rahman Ansari (ed.) *Wheat.* IntechOpen, https://doi.org/10.5772/intechopen.103126

Todeschini, M.H., Milioli, A.S., Trevizan, D.M., Bornhofen, E., Finatto, T., Storck, L., & Benin, G. (2016). Nitrogen use efficiency in modern wheat cultivars. *Soil and Plant Nutrition,* 75(3). https://doi.org/10.1590/1678-4499.385

Yadeta, A., Juskiw, P., Good, A., Nyachiro, J., &Helm, J. (2009). Genetic variability in nitrogen use efficiency of spring barley. *Crop Science*, 49(4): 1259-1269. https://doi.org/10.2135/cropsci2008.09.0566

Yokamo, S., Irfan, M., Huan, W., Wang, B., Wang, Y., Ishfaq, M., Lu, D., Chen, X., Cai, Q., & Wang, H. (2023). Global evaluation of key factors influencing nitrogen fertilization efficiency in wheat: a recent meta-analysis (2000-2022). *Frontiers in Plant Science*, 14. https://doi.org/10.3389/fpls.2023.1272098

**Promene u efikasnosti upotrebe azota kod istorijske kolekcije sorti pšenice u Srbiji**

**Jovana Timić · Milan Mirosavljević · Vladimir Aćin · Bojan Jocković · Goran Jaćimović · Ranko Čabilovski · Maja Manojlović**

**Sažetak**: Optimizacija primene azotnih đubriva predstavlja ključni faktor za postizanje visokih prinosa pšenice, uz istovremeno unapređenje ekonomske efikasnosti proizvodnje i smanjenja negativnog uticaja na životnu sredinu. Cilj ovog istraživanja je bilo ispitivanje uticaja dva nivoa đubrenja azotom na efikasnost upotrebe azota (NUE) i njenih komponenti: efikasnost usvajanja azota (NUpE) i efikasnost iskorišćenja azota (NUtE), kod sorti pšenice stvorenih u periodu 1930–2015. godina. Eksperiment je izveden na oglednom polju Instituta za ratarstvo i povrtarstvo, Rimski Šančevi, na zemljištu tipa černozem. Rezultati su pokazali da su sve tri ispitivane osobine (NUE, NUpE, i NUtE) značajno zavisile od sorte, đubrenja, kao i od njihove interakcije, pri čemu je tretman đubrenjem ispoljio najveći uticaj na varijabilnost osobina. U uslovima proizvodnje sa primenom azota, prosečna vrednost NUE je iznosila 49,1 kg zrna/kg dostupnog N, dok je na kontrolnoj varijanti dostigla od 81,6 kg zrna/kg dostupnog N. Najniže vrednosti ispitivanih osobina u oba tretmana su zabeležene kod najstarije sorte Banatka, dok su se savremene sorte istakle višim vrednostima. Povećanje prosečne vrednosti NUpE na kontrolnom tretmanu bez primene N je iznosilo 0,42 kg N u biomasi/kg dostupnog N u odnosu na đubrenu varijantu. Sorta Simonida se istakla sa najvišom vrednošću NUtE na kontrolnom tretmanu, dok je pri primeni azota ispoljila nižu vrednost biomase za 15 kg zrna/kg N. Ustanovljena je pozitivna veza između godine priznavanja sorti i sve tri ispitivane osobine, posebno na kontrolnom tretmanu što ukazuje da moderne sorte imaju poboljšane vrednosti NUE i njenih komponenti NUpE i NUtE pri ograničenoj dostupnosti azota u poređenju sa starijim sortimentom.

**Ključne reči:** azot, NUE, prinos, pšenica, sorta, Srbija *Triticum aestivum* L.