

Doi: 10.46793/MAK2026.371P

## INFLUENCE OF NPK REGIMES ON WHEAT AGRONOMIC AND SOIL MICROBIOLOGICAL PARAMETERS

Stanka Pešić<sup>1\*</sup>, Danica Mićanović<sup>2</sup>, Dragan Božović<sup>1</sup>, Igor Vukelić<sup>3</sup>, Gordana Racić<sup>1</sup>

<sup>1</sup>Research and Development Institute "Tamiš", Pančevo, Serbia,

<sup>2</sup>Chamber of Commerce and Industry of Serbia, Serbia,

<sup>3</sup>Institute of Field and Vegetable Crops, Novi Sad, Serbia,

\*Corresponding author: [pesic@institut-tamis.rs](mailto:pesic@institut-tamis.rs)

**Abstract:** Wheat agronomic traits and soil microbial activity were closely shaped by NPK supply. Moderate to high fertilization improved plant height, thousand grain weight and yield, while the number of grains per spike remained relatively stable. Number of *Azotobacter* spp. and soil dehydrogenase activity increased with nutrient input, ammonifiers increased mainly at higher rates, and actinomycetes did not change significantly. Statistical results confirm the importance of balanced NPK management for enhancing both wheat productivity and soil biology.

**Keywords:** Agronomic traits, *Triticum aestivum* L., DHA

### INTRODUCTION

Wheat is one of the most extensively cultivated cereal crops globally, occupying a substantial share of agricultural land and serving as a cornerstone of global food production. According to recent estimates by the Food and Agriculture Organization (FAO), wheat has grown to nearly 220 million hectares worldwide, with a total annual output of approximately 779 million tons in 2023 (Murindangabo et al., 2025). These global patterns are translated to the regional scale. For instance, in the Republic of Serbia wheat production in 2023 reached 3.449 million tons, representing a 10.9% increase compared to the previous year, while the total sown area amounted to 682.246 ha (Dolijanović et al., 2025). Together, these figures highlight the strategic importance of wheat in national agriculture and its broader contribution to regional and global food security. Wheat has important role in human nutrition as the primary cereal that feeds over 50% of the world's population (Erenstein et al., 2022). Wheat grain is energy source, rich in carbohydrates like starch, and is also a significant source of protein, lipids, minerals, and fiber (Khalid et al., 2023). The quality and yield of wheat grain are influenced by numerous factors, including the wheat genotype, production conditions such as climate, the soil's physicochemical and biological characteristics, and the type of agricultural production (Filip et al., 2023). These factors determine the economic viability of wheat cultivation and impact food quality and safety which are key elements of sustainable economic and societal development (Durham and Mizik, 2021). Throughout the growing season, winter wheat exhibits substantial demands for mineral nutrients, especially nitrogen, which has the greatest impact on productivity (Hou et al., 2025). However, excessive nitrogen application can decrease yield and

contribute to agroecosystem pollution. Moreover, fertilizer use efficiency and final yield formation are strongly affected by weather conditions during the season and the specific characteristics of the production site (Liu et al., 2021). While synthetic NPK fertilization is widely adopted to enhance crop performance, its consequences for the soil biological community remain a critical research focus. Unbalanced or increased NPK inputs can affect natural nutrient cycling and suppress key functional groups of microorganisms, including nitrogen-fixing and phosphate-solubilizing bacteria. Assessing how different NPK doses influence soil biogenicity is essential for understanding nutrient-use efficiency and for identifying potential threats to long-term soil health, such as interrupting soil structure or reduced ecological resilience (Rai and Sarkar, 2025).

This work has been carried out to examine how wheat morphological and productive parameters and related soil microbial communities are influenced by different nutrient regimes, particularly nitrogen (N), phosphorus (P) and potassium (K). The analysis focuses on plant height, number of grains per spike, thousand-grain weight, and grain yield. The response of selected soil microbial activity indicators was also evaluated under field conditions.

## **MATERIAL AND METHODS**

### **Experimental Site Description**

Field experiments were conducted at an experimental station in the Research and Development Institute Tamiš, Pančevo, Serbia (44°56'23.395", 20°43'27.328") in 2022/23 growing season. Agrochemical analyses of the experimental field indicated that the soil type was chernozem, and it was characterized by an alkaline reaction. The content of calcium carbonate ( $\text{CaCO}_3$ ) was moderate, and the soil was well supplied with humus. Total nitrogen content was stable, while the amount of readily available phosphorus ( $\text{P}_2\text{O}_5$ ) indicated moderate to optimal availability. However, readily available potassium ( $\text{K}_2\text{O}$ ) was found at high levels. During the 2022/2023 growing season, the total amount of precipitation was above the long-term average, while mean temperatures throughout the season were consistently higher than normal for this time of year.

### **Experimental Design**

The experiment was arranged as a randomized complete block design with three replications. Six NPK regimes were included in the experiment, with each experimental plot measures 10x10 m (20 rows) (Table 1). An examination was carried out on a winter variety of common wheat, Apilco. Fertilization with all NPK mineral fertilizer treatments was performed manually by plots in the autumn, followed immediately by basic conservation tillage using a disc harrow (TO36/610). Pre-sowing soil preparation was conducted with a heavy harrow, while sowing was carried out mechanically using a seed drill. Fertilization with all NPK treatments was applied on 02 October 2022 (Table 1). Conservation tillage was carried out on 04 October 2022, followed by pre-sowing soil preparation on 14 October 2022. Sowing was performed on 21 October 2022. The first chemical protection treatment took place on 10 April 2023, and the second on 11 May 2023. Harvest was conducted on 11 July 2023. The seeding rate was 210 kg ha<sup>-1</sup>. The first chemical treatment was applied using Lodin (0.6 L ha<sup>-1</sup>) + Tezis (10 g ha<sup>-1</sup>) + Savate CS

(0.2 L ha<sup>-1</sup>), in the phase BBCH 47, to suppress *Lema melanopus*, *Erysiphe Graminis*, *Septoria* spp., and *Puccinia* spp. The second chemical treatment involved Ison (0.6 L ha<sup>-1</sup>) + Polux (0.3 L ha<sup>-1</sup>) (Table 2). Harvesting was performed with plot combines for harvesting, at the stage of physiological maturity when the grain moisture was below 14%.

Table 1. Fertilization treatments used in wheat experiments (kg ha<sup>-1</sup>).

| Treatment number | NPK treatment |       |       |
|------------------|---------------|-------|-------|
|                  | N-0           | P-0   | K-0   |
| <b>C</b>         | N-0           | P-0   | K-0   |
| <b>T1</b>        | N-50          | P-50  | K-50  |
| <b>T2</b>        | N-100         | P-50  | K-50  |
| <b>T3</b>        | N-100         | P-100 | K-100 |
| <b>T4</b>        | N-130         | P-50  | K-50  |
| <b>T5</b>        | N-130         | P-130 | K-130 |

### Morphological and Productive Traits Analysis

At the full maturity stage of wheat, about ten days before harvest, whole-plant samples were collected across all variants, in three replications, to study: plant height (PH), number of grains per spike (NGS), thousand-grain weight (TGW, g) and grain yield (t/ha). The samples were taken to the laboratory, the grains were separated from the husk, manually counted for each spike, and their grain weight per spike was measured using an analytical balance. Grain yields were measured for each variant and replication and converted into tons per hectare, based on 14% grain moisture.

### Microbiological Soil Analyses

Soil samples for microbiological analyses were collected from the rhizosphere zone of wheat at a depth of 0-10 cm. During each sampling, disposable gloves were used, and all equipment (spade and mixing tray) was disinfected with 70% ethanol prior to contact with soil. Composite samples were obtained by homogenizing multiple subsamples collected within each plot. A representative portion of the composite sample was immediately transferred into sterile, labeled polyethylene bags and transported under cold conditions to the laboratory. Microbiological analyses, were performed within 24 h of collection, as explained in Racić et al. (2017). Shortly, the colony-forming units (CFUs) of the numbers of ammonifiers (AMO), *Azotobacter* spp. (AZO), actinomycete (ACT) were determined by serial dilution and plating on selective media. The number of AZOs on nitrogen-free medium using the fertile drops method, the number of AMO on meat pepton agar (MPA), and actinomycete on synthetic medium. Incubation temperature was 28 °C, while the incubation time depended on the tested group of microorganisms. Soil was dried at 105 °C for 2 h, and the number of microorganisms was estimated as CFU g<sup>-1</sup> dry weight (DW). DHA was measured spectrophotometrically by the modified method according to Thalmann and expressed as µg TPF g<sup>-1</sup> soil (triphenylformazan g<sup>-1</sup> soil). All measurements were performed in three replicates.

### Statistical Analysis

Prior to statistical analysis, data were tested for normality using the Shapiro-Wilk test. All variables showed a normal distribution. Differences among NPK fertilization treatments

were evaluated using one-way ANOVA, and mean comparisons were performed using Tukey's post hoc test at a significance level of  $p \leq 0.05$ . Statistical analyses were conducted using SPSS software (version 27, IBM Corp., USA). Pearson correlation analysis was applied to assess relationships between agronomic traits and microbiological parameters. Principal component analysis (PCA) was used to explore multivariate relationships among treatments and was performed using Python (Python Software Foundation, Wilmington, USA).

## RESULTS AND DISCUSSION

The applied NPK regimes had significant effects on most of the agronomic and microbiological parameters of wheat. PH, NGS, TGW, and yield varied across treatments, which accompanied the changes recorded for the number of microbial groups investigated and DHA. PH, NGS, and TGW significantly differed between applied nutrient regimes (Table 2). The tallest plants were recorded in T2 (82.53 cm), followed by T4 and T5, treatments with higher doses of nutrient inputs, whereas the shortest plants were observed in C and T1 ( $\approx 72$  to 73 cm). Similar trends were evident for yield components: the higher NGS (2.18 grains spike<sup>-1</sup>) and TGW (46.97 g) were determined in T2, while T1 had the lowest values for both traits. These responses correspond to earlier findings demonstrating that mineral fertilization significantly increases plant height, spike fertility, and grain weight in wheat (Amjadian et al., 2021; Ivanova et al., 2024). Also, Irfan et al. (2018) demonstrated similar effects, reporting linear increases in plant height, NGS, and 100-grain weight with rising N-P<sub>2</sub>O<sub>5</sub> rates, with the highest values recorded at 150-110 kg N-P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>.

Table 2. Effect of different NPK fertilization treatments on wheat agronomic traits.

|           | PH (cm)                      | NGS                        | TGW (g)                     |
|-----------|------------------------------|----------------------------|-----------------------------|
| <b>C</b>  | 72.67±4.64 <sup>c</sup>      | 1.77 ± 0.61 <sup>ab</sup>  | 43.56 ± 8.66 <sup>bc</sup>  |
| <b>T1</b> | 72.6±7.58 <sup>bc</sup>      | 1.54 ± 0.68 <sup>b</sup>   | 37.63 ± 9.72 <sup>c</sup>   |
| <b>T2</b> | 82.53±4.52 <sup>ab</sup>     | 2.18 ± 0.67 <sup>a</sup>   | 46.97 ± 8.45 <sup>a</sup>   |
| <b>T3</b> | 77.03 ± 13.34 <sup>abc</sup> | 1.804 ± 0.72 <sup>ab</sup> | 42.79 ± 9.86 <sup>abc</sup> |
| <b>T4</b> | 80.63 ± 6.13 <sup>ab</sup>   | 1.91 ± 0.67 <sup>ab</sup>  | 42.23 ± 8.05 <sup>abc</sup> |
| <b>T5</b> | 82.37 ± 4.68 <sup>ab</sup>   | 1.86 ± 0.47 <sup>ab</sup>  | 43.82 ± 8.12 <sup>ab</sup>  |

Values represent mean ± standard deviation. Different letters within a column indicate statistically significant differences according to Tukey's test ( $p \leq 0.05$ ).

Wheat yield varied significantly among the applied regimes of NPK, with the lowest values in C (3.91 t ha<sup>-1</sup>) and T1 (4.13 t ha<sup>-1</sup>). Significant increases were determined for T2 and T3, for  $\approx 30\%$  in comparison to the control. However, the highest yields were recorded for T4 and T5, for  $\approx 55\%$  in comparison to the control (Table 3). Similar yield responses of wheat to increasing mineral fertilization have been reported in other studies, where high NPK rates (175-150-125kg N-P-Kha<sup>-1</sup>) increased grain yield by 50-60% over unfertilized plots, and moderate NP fertilization produced yield gains of roughly 30% compared with the control (Malghani et al., 2010; Samimi et al., 2016; Rusek et al., 2016). As only one genotype was used in our experiment, the observed variability in yield can be attributed primarily to differences in nutrient supply, which is consistent with factorial NPK experiments on single wheat genotypes showing significantly higher yields ( $\approx 6.3$  to 6.6 t

ha<sup>-1</sup>) at optimal NPK combinations compared with lower fertilization levels (Rawal et al., 2022).

Table 3. Grain yield of wheat varieties under different NPK fertilization treatments.

| YIELD (t ha <sup>-1</sup> ) |                        |
|-----------------------------|------------------------|
| <b>C</b>                    | 3.91±0.3 <sup>c</sup>  |
| <b>T1</b>                   | 4.13±0.44 <sup>c</sup> |
| <b>T2</b>                   | 5.55±0.27 <sup>b</sup> |
| <b>T3</b>                   | 5.74±0.22 <sup>b</sup> |
| <b>T4</b>                   | 6.96±0.29 <sup>a</sup> |
| <b>T5</b>                   | 6.81±0.23 <sup>a</sup> |

Values represent mean ± standard deviation. Different letters within a column indicate statistically significant differences according to Tukey's test (p ≤ 0.05).

Table 4. Effect of different NPK fertilization treatments on soil microbial parameters.

|           | <b>AZO (CFU ×10<sup>3</sup> g<sup>-1</sup>)</b> | <b>AMO (CFU ×10<sup>3</sup> g<sup>-1</sup>)</b> | <b>ACT (CFU ×10<sup>3</sup> g<sup>-1</sup>)</b> | <b>DHA (µg TPF g<sup>-1</sup> h<sup>-1</sup>)</b> |
|-----------|---|---|---|---|
| <b>C</b>  | 167.17±10.63 <sup>cd</sup>                      | 266.27±3.66 <sup>a</sup>                        | 26.35±5.88 <sup>a</sup>                         | 13.90±0.10 <sup>b</sup>                           |
| <b>T1</b> | 231.85±3.55 <sup>a</sup>                        | 275.81±33.91 <sup>a</sup>                       | 14.37±1.36 <sup>a</sup>                         | 14.33±0.68 <sup>b</sup>                           |
| <b>T2</b> | 194.46±8.15 <sup>bc</sup>                       | 313.97±30.03 <sup>a</sup>                       | 27.19±2.25 <sup>a</sup>                         | 22.3±1.25 <sup>a</sup>                            |
| <b>T3</b> | 231.15±25.65 <sup>a</sup>                       | 190.07±4.05 <sup>b</sup>                        | 21.40±8.21 <sup>a</sup>                         | 22.03±0.31 <sup>a</sup>                           |
| <b>T4</b> | 149.70±1.82 <sup>d</sup>                        | 286.17±1.38 <sup>a</sup>                        | 18.09±4.09 <sup>a</sup>                         | 23.53±3.21 <sup>a</sup>                           |
| <b>T5</b> | 223.67±12.07 <sup>ab</sup>                      | 264.70±10.90 <sup>a</sup>                       | 28.75±8.15 <sup>a</sup>                         | 24.03±1.75 <sup>a</sup>                           |

Values represent mean ± standard deviation. Different letters within a column indicate statistically significant differences according to Tukey's test (p ≤ 0.05)

Differences among the varieties influenced the examined microbiological parameters, including numbers of AZO, AMO, ACT, and DHA (Table 4). Our results are in accordance with a global meta-analysis by Geisseler and Scow (2014), who showed that mineral fertilization increases microbial biomass carbon by an average of 15.1%. Likewise, Allison and Martiny (2008) demonstrated that the composition of microbial communities responds sensitively to the rates of N, P, and K application. In our experiment, number of *Azotobacter* spp. ranged from 149.70×10<sup>3</sup> to 231.85×10<sup>3</sup> CFU g<sup>-1</sup>, with the highest values recorded in T1 and significantly lower numbers in T4. The significant increase of 22% in comparison to the control was determined for T5. Similarly, number of AZO under fertilized conditions have been reported in sugar beet and other arable crops, where NPK combined with organic inputs maintained or slightly stimulated AZO compared to unfertilized controls (Mrkovački et al., 2003; Shrestha et al., 2025). The highest AMO counts were recorded in T2 (313.97 CFU ×10<sup>3</sup> g<sup>-1</sup>), followed by C, T1, T4 and T5, which showed comparable values. The lowest AMO measurement was observed in T3 (190.07 CFU ×10<sup>3</sup> g<sup>-1</sup>). Roljević-Nikolić et al. (2022) found that AMO number is on average 119.3 ×10<sup>3</sup> to ×10<sup>5</sup> g<sup>-1</sup> depending on fertilization and wheat subspecies, with organic and biofertilizer treatments increasing ammonifier number up to 56% relative to controls. These trends align with our observation that T2 showed significantly higher AMO counts than T3, suggesting that fertilization regime and soil conditions modulate ammonifier populations in wheat systems. ACT number ranged from 14.37 to 28.75 CFU ×10<sup>3</sup> g<sup>-1</sup>. The highest ACT value was measured

in T5 while the lowest was found in T1. These findings are consistent with the results reported by Li et al. (2022), who showed that actinomycetes, fungi, bacterial PLFA contents, and total PLFAs increased under P fertilization (NP and NPK) compared with unfertilized control samples. DHA activity significantly differed among treatments. The analysis of the DHA activity showed clear differences among the examined variants. The greatest DHA values were recorded in T5, followed by T2, T3 and T4. Significantly lower enzyme activity was detected in control and T1. The treatment which showed the highest DHA value corresponded to the treatment with the largest dose of NPK applied (N<sub>130</sub>P<sub>130</sub>K<sub>130</sub>), where the activity increased by 57.84% compared with the control. Our results are consistent with the findings of Roljević-Nikolić et al. (2022) that fertilization treatments significantly enhance microbial functional activity in the rhizosphere. Akmal et al. (2012), reported that the NP fertilizer treatment led to a 22.0% higher dehydrogenase activity compared to the unfertilized control. Moreover, Dhiman et al. (2019) reported the highest DHA value (44.1 µg TPF g<sup>-1</sup> soil 24 h<sup>-1</sup>) in plots receiving 100% NPK together with farmyard manure in the surface layer, indicating that combined nutrient and organic inputs can enhance microbial oxidative activity more strongly than mineral fertilization alone. These findings correspond with long-term studies showing that NPK fertilization enhances microbial activity and enzymatic functioning (Guo et al., 2020). The observed responses of *Azotobacter* and actinomycetes also reflect the microbial behaviour described by Kaur et al. (2017), who concluded that enhanced microbial activity and improved plant growth under enriched nutrient conditions.

The correlation matrix showed different relationships between agronomic parameters and microbiological indicators. TGW and the NGS showed a strong positive correlation ( $r = 0.91$ ), confirming results of Minov et al. (2024) found highly positive correlations between the weight of grains per spike and the number of grains per spike ( $r = 0.852$ ), as well as between grain yield and TGW ( $r = 0.928$ ) and NGS ( $r = 0.793$ ) in wheat field trials, confirming that increases in both TGW and NGS are associated with improved yield potential. YLD showed a strong association with DHA ( $r = 0.88$ ), suggesting that increased microbial oxidative activity contributed to improved grain formation. PH had positive correlations with TGW ( $r = 0.57$ ), YLD ( $r = 0.59$ ) and DHA ( $r = 0.66$ ), indicating that taller plants generally produced heavier grains and higher yields. Actinomycetes showed moderate correlations with NGS and TGW, whereas *Azotobacter* spp. had weak associations with agronomic parameters. These relations are in line with earlier studies reporting that enzymatic activity and nitrogen-transforming microbial populations are important indicators of soil fertility and crop productivity (Guo et al., 2020; Wang et al., 2023).



Figure 1. Heatmap of Pearson correlation coefficient ( $r$ ) among wheat agronomic traits and soil microbial parameters

The PCA based on PH, NGS, TGW, and YLD explained a substantial proportion of total variability (with a cumulative total of 89.7%; PC1 = 62.3%; PC2 = 27.4%) (Figure 2). Treatments T4 and T5 were grouped in the positive part of the diagram, closely aligned with YLD and PH vectors. This indicates that these variants combined positive contributions from multiple YLD components. Treatments C and T1 were positioned in the opposite quadrant, reflecting their lower values for all agronomic traits. The TGW and NGS vectors were closely aligned, supporting their strong correlation and shared contribution to yield formation.

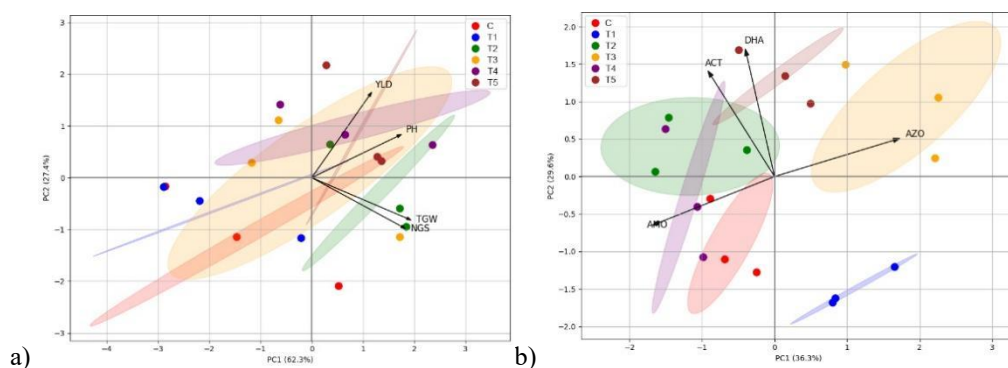


Figure 2. **a)** Principal component analysis (PCA) of wheat agronomic traits (PH, NGS, TGW, yield) under different NPK fertilization treatments. **b)** Principal component analysis (PCA) of soil microbial parameters (AZO, AMO, ACT, DHA) under different NPK fertilization treatments.

The PCA including AZO, AMO, ACT and DHA accounted for 65.9% of total variability (PC1 = 36.3%; PC2 = 29.6%). Treatments T2, T4, and T5 were positioned near the DHA and actinomycetes vector, corresponding to their higher enzymatic and microbial activity. T3 were associated more closely with *Azotobacter* spp. number, while treatments C and T1 were grouped together in the region reflecting low microbial activity, particularly for DHA and actinomycetes. These findings align with long-term fertilization studies indicating that microbial abundance and enzyme activity are strongly influenced by nutrient regimes (Guo et al., 2020; Li et al., 2022).

When agronomic and microbiological indicators were jointly analyzed, treatments formed three distinct groups. T4 and T5 were positioned in the quadrant associated with higher values of grain yield, plant height, and DHA indicating a positive interaction between soil biological activity and crop performance. T2 and T3 formed an intermediate group with average values for both agronomic and microbiological parameters. C and T1 were grouped in the area associated with lower values for most parameters. These clusters reflect the integrated influence of NPK fertilization on plant performance and soil microbial functioning, which is also confirmed in the literature (Amjadian et al., 2021; Mikos-Szymańska et al., 2018).

## CONCLUSION

Our results demonstrate that while moderate fertilization substantially improves several agronomic traits, higher nutrient inputs are required to maximize yield and stimulate soil microbial activity. The combined ANOVA and Tukey test results confirm the importance

of balanced NPK management for enhancing both wheat productivity and soil biology, with implications for sustainable nutrient management in wheat-based cropping system.

## ACKNOWLEDGMENT

This research was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, grant number 451-03-136/2025-03/200054.

## REFERENCES

- Akmal, M., Altaf, M. S., Hayat, R., Hassan, F.U., Islam, M. (2012). Temporal changes in soil urease, alkaline phosphatase and dehydrogenase activity in rainfed wheat field of Pakistan. *Journal of Animal and plant Sciences*, 22(2).
- Allison, S.D., Martiny, J.B. (2008). Resistance, resilience, and redundancy in microbial communities. *Proceedings of the National Academy of Sciences*, 105(supplement\_1), 11512-11519.
- Amjadian, M., Hassani, A., Hafezian, M. (2021). Effects of fertilizer management systems on growth and balance of nutrients in wheat cultivation. *Central Asian Journal of Plant Science Innovations*, 2(2), 56-69.
- Dhiman, D., Sharma, R., Sankhyan, N. K., Sepehya, S., Sharma, S. K., Kumar, R. (2019). Effect of regular application of fertilizers, manure and lime on soil health and productivity of wheat in an acid Alfisol. *Journal of Plant Nutrition*, 42(19), 2507-2521.
- Dolijanović, Ž., Roljević Nikolić, S., Šeremešić, S., Jug, D., Biljić, M., Pešić, S., Kovačević, D. (2025). Effects of Conservation Tillage and Nitrogen Management on Yield, Grain Quality, and Weed Infestation in Winter Wheat. *Agronomy*, 15, 1742.
- Durham, T.C., Mizik, T. (2021). Comparative economics of conventional, organic, and alternative agricultural production systems. *Economies*, 9(2), 64.
- Erenstein, O., Jaleta, M., Mottaleb, K.A., Sonder, K., Donovan, J., Braun, H.J. (2022). Global trends in wheat production, consumption and trade. In *Wheat improvement: food security in a changing climate*. Cham: Springer International Publishing, 47-66.
- Filip, E., Woronko, K., Stępień, E., Czarniecka, N. (2023). An overview of factors affecting the functional quality of common wheat (*Triticum aestivum* L.). *International journal of molecular sciences*, 24(8), 7524.
- Geisseler, D., Scow, K.M. (2014). Long-term effects of mineral fertilizers on soil microorganisms- A review. *Soil Biology and Biochemistry*, 75, 54-63.
- Guo, Z., Wan, S., Hua, K., Yin, Y., Chu, H., Wang, D., Guo, X. (2020). Fertilization regime has a greater effect on soil microbial community structure than crop rotation and growth stage in an agroecosystem. *Applied Soil Ecology*, 149, 103510.
- Hou, P., Li, B., Cao, E., Liu, Z., Li, Y., Sun, Z., Ma, C. (2025). Optimizing nitrogen and phosphorus fertilizer application for wheat yield on alkali soils: Mechanisms and effects. *Agronomy*, 15(3), 734.
- Irfan, M., Abbas, M., Shah, J.A., Memon, M.Y. (2018). Grain yield, nutrient accumulation and fertilizer efficiency in bread wheat under variable nitrogen and phosphorus regimes. *Journal of Basic & Applied Sciences*, 14, 80-86.
- Ivanova, A.M., Atanasova, P.N., Konsulova-Bakalova, M.I. (2024). Winter wheat varieties responsiveness to soil and foliar fertilization. In *BIO Web of Conferences*. EDP Sciences, 122, p. 01027.
- Kaur, H., Gosal, S.K., Walia, S.S. (2017). Synergistic effect of organic, inorganic and biofertilizers on soil microbial activities in rhizospheric soil of green pea. *Annual Research & Review in Biology*, 12(4), 1-11.

- Khalid, A., Hameed, A., Tahir, M.F. (2023). Wheat quality: A review on chemical composition, nutritional attributes, grain anatomy, types, classification, and function of seed storage proteins in bread making quality. *Frontiers in Nutrition*, 10, 1053196.
- Li, W., Kuzyakov, Y., Zheng, Y., Liu, M., Wu, M., Dong, Y., Li, Z. (2022). Effect of long-term fertilisation on enzyme activities and microbial community composition in the rice rhizosphere. *Acta Agriculturae Scandinavica, Section B-Soil & Plant Science*, 72(1), 454-462.
- Liu, D., Song, C., Fang, C., Xin, Z., Xi, J., Lu, Y. (2021). A recommended nitrogen application strategy for high crop yield and low environmental pollution at a basin scale. *Science of the Total Environment*, 792, 148464.
- Malghani, A.L., Malik, A.U., Sattar, A., Hussain, F., Abbas, G., Hussain, J. (2010). Response of growth and yield of wheat to NPK fertilizer. *Sci. Int*, 24(2), 185-189.
- Minov, I., Ilijeva, V., Ruzdik, N.M. (2024). Yield and yield components in some wheat varieties (*Triticum aestivum* L.) grown in Kocani region. *Journal of Agriculture and Plant Sciences*, 22(2), 45-51.
- Mrkovački, N.B., Mezei, S.M., Čačić, N.A. (2003). Population dynamics of *Azotobacter chroococcum* in sugarbeet rhizosphere depending on mineral nutrition. *Zbornik Matice srpske za prirodne nauke*, 104, 91-97.
- Murindangabo, Y.T., Hoang, T.N., Habarurema, I., Konvalina, P., Niyibituronsa, M., Byukusenge, P., Mbasabire, P., Uwihanganye, J., Bwimba, R., Ntezimana, M.G. (2025). Linking Yield, Baking Quality, and Rheological Properties to Guide Sustainable Improvement of Rwandan Wheat Varieties. *Agriculture*, 15, 2160.
- Mikos-Szymańska, M., Borowik, M., Wyzńska, M., Rusek, P. (2018). Effects of different fertilizer treatments on grain yield and yield components of spring wheat. *Research for rural development*, 2, 100-106.
- Raćić, G., Körmöczy, P., Kredics, L., Raičević, V., Mutavdžić, B., Vrvčić, M., Panković D. (2017). Effect of the edaphic factors and metal content in soil on the diversity of *Trichoderma* spp.. *Environmental Science and Pollution Research*, 24(4), 3375-3386.
- Rai, A., Sarkar, S. (2025). Adapting Soil and Nutrient Management to a Changing Climate: Emerging Innovations and Policy Priorities. In *Drought and Heat Stress in Agriculture: Implications, Mitigation and Policy Approaches*. Singapore: Springer Nature Singapore, 279-313.
- Rawal, N., Pande, K.R., Shrestha, R., Vista, S.P. (2022). Nutrient use efficiency (NUE) of wheat (*Triticum aestivum* L.) as affected by NPK fertilization. *Plos one*, 17(1), e0262771.
- Roljević, N.S., Dolijanović, Ž.K., Kovačević, D.Đ., Oljača, S.I., Majstorović, H.J. (2022). Soil biogenicity in the rhizosphere of different wheat genotypes under the impact of fertilization treatment. *Journal of Agricultural Sciences (Belgrade)*, 67(4), 367-380.
- Rusek, P., Mikos-Szymanska, M., Karsznia, M., Sienkiewicz-Cholewa, U., Igras, J. (2016). The effectiveness of nitrogenphosphorus fertilization in winter wheat (*Triticum aestivum* L.) cultivation. *Bulgarian Journal of Agricultural Science*, 22(5), 752-755.
- Samimi, A.S., Thomas, T. (2016). Effects of different levels of NPK on yield by wheat (*Triticum aestivum* L.). *International Journal of Multidisciplinary Research and Development*, 3(5), 224-227.
- Shrestha, A., Thapa, S., Shrestha, R.K., Shrestha, A., Awasthi, P., Ranabhat, S. (2025). Effect of *Azotobacter* in Association with Other Nutrient Sources on Soil Properties in Maize (*Zea mays*) Field of Nawalpur, Nepal. *Turkish Journal of Agriculture-Food Science and Technology*, 13(5), 1241-1247.
- Wang, L., Hamel, C., Lu, P., Wang, J., Sun, D., Wang, Y., Gan, G.Y. (2023). Using enzyme activities as an indicator of soil fertility in grassland-an academic dilemma. *Frontiers in Plant Science*, 14, 1175946.