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Nitrogen-cycling bacteria of the typical soil types in Vojvodina (Serbia): insights into the relationship with soil chemical properties

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Summary: Soil quality monitoring is essential in agricultural regions such as the Autonomous Province of Vojvodina, Serbia. The abundance of bacterial functional groups involved in the nitrogen cycle presents a good indicator of nitrogen forms in soil and soil fertility. This study aimed to assess the abundances of selected bacterial functional groups across three different soil types in Vojvodina and to examine their correlation with soil chemical properties. Analyzed soil types (chernozem, solonchak, vertisol) were sampled at nine locations, with two agricultural and one control plot at each location. The abundances of nitrogen-fixing bacteria, ammonifiers, nitrifiers, denitrifiers, and total heterotrophic bacteria were determined. Results showed differences in the abundances of nitrogen-fixing bacteria, ammonifiers, and nitrifiers across different soil types. Chernozem had the highest abundance of nitrogen-fixing bacteria and ammonifiers. Denitrifiers were most abundant in solonchak, while vertisol had the highest abundance of nitrifiers and total heterotrophic bacteria. A statistically significant moderate correlation was observed between the abundance of bacteria and certain soil chemical properties. Namely, moderate negative correlation between nitrifiers and pH in KCl (r=-0.57), pH in H_2O (r=-0.53), and $CaCO_3$ content (r=-0.4) and moderate positive correlation between denitrifiers and P_2O_5 content (r=0.4) were determined. Moderate correlation of bacterial counts and soil properties could indicate that bacterial count variability is also linked to other factors, such as soil vegetation cover type, soil use, anthropogenic activities and climate change. Thus, bacterial functional groups could be useful as an indicator of overall soil health and fertility, especially in connection with nitrogen, as an essential element.
Keywords: nitrogen cycle, bacterial functional groups, soil chemical properties, agricultural soil, soil quality

Introduction

Soil represents the largest biodiversity reservoir on Earth (Bardgett & van der Putten, 2014), which is defined by its physical, chemical, and biological properties (Kennedy & Smith, 1995). Microorganisms, as a key part of the soil's ecosystem, significantly contribute to soil formation and fertility through their crucial roles in the soil, such as decomposing organic matter and facilitating nutrient cycling (Izquierdo *et al.*, 2005; Gougoulias *et al.*, 2014). A great diversity of microorganisms observed in soil is a consequence of the existence of numerous ecological niches, where different conditions prevail (Prosser, 2015). Each soil type hosts distinct microbial communities. However, cultivation practices frequently disrupt interactions within these communities, resulting in a decline in the number of microorganisms and their activities (Cardoso *et al.*, 2013). Chemical analyses of soil offer important insights into soil fertility (Milić *et al.*, 2011). However, chemical properties alone are not always reliable indicators of soil changes, as they tend to change only under extreme modification in the environment. The study of biological and biochemical properties is equally important (Filip, 2002). Since microorganisms respond to the smallest changes in the chemical properties of the habitats they inhabit, they can be used as bioindicators of soil quality, thereby contributing to its conservation and the improvement of agricultural crop yields (Fierer, 2017; Hermans *et al.*, 2017). The diversity of microorganisms in the soil is influenced both by their interactions with other organisms and by the effects of abiotic factors such as temperature, pH, moisture, oxygen, and the availability of nutrients. Reduced activity and abundance of microorganisms can indicate various processes that decrease soil fertility, among which soil degradation and contamination, including the increased concentration of heavy metals or organic substances, are particularly significant (Schloss & Handelsman, 2006).

Soil microorganisms can be classified into functional groups based on their role in ecosystem processes. Microorganisms involved in nitrogen cycling are grouped into nitrogen-fixing bacteria, nitrifiers, denitrifiers, and ammonifiers. These groups are investigated based on their function rather than individual species traits (Cardoso *et al.*, 2013). Nitrogen is essential for life, as it is a key component of important compounds such as proteins, nucleic acids, and chlorophyll. Microorganisms play a central role in the nitrogen cycle by converting nitrogen into various forms that other organisms can easily absorb (Zhang *et al.*, 2020). Soil biogenicity, characterized by the abundance and activity of soil microorganisms, is fundamental to nutrient cycling processes that directly influence plant growth and crop yields. Nitrogen enters the cycle through biological fixation when nitrogen-fixing bacteria, such as *Azotobacter* species, convert atmospheric nitrogen into ammonia, enriching soil fertility and promoting plant development (Aasfar *et al.*, 2021). Nitrifiers, such as ammonia-oxidizing archaea and bacteria, oxidize ammonia to nitrate, a form readily absorbed by plants, thereby enhancing nitrogen use efficiency (Wang *et al.*, 2019). Denitrifying bacteria perform denitrification under oxygen-limiting conditions, impacting nitrogen availability and potentially contributing to nitrous oxide emissions and losses of this element from the soil, thus having a negative impact on agricultural production (Zhang *et al.*, 2020). Ammonifiers decompose organic matter, releasing ammonia and facilitating nutrient recycling within the soil. The balance and activity of these microbial populations are crucial for maintaining soil health and optimizing plant performance. Understanding the dynamics of these microorganisms within the soil ecosystem is essential for developing sustainable agricultural practices that enhance crop yields while preserving soil quality (Timofeeva *et al.*, 2023).

The Autonomous Province of Vojvodina is primarily an agricultural region, making an understanding of its soil quality essential for improving agricultural productivity. Assessing the physical, chemical, biological, and biochemical properties of the soil is crucial for determining its overall quality. Three soil types were selected for analysis in this study – chernozem, solonchak, and vertisol. The dominant soil type in Vojvodina is chernozem, highly fertile and productive soil accounting for about 60% of the total area (Živković *et al.*, 1972). Vertisol is another abundant fertile soil in Vojvodina, characterized by unfavorable structure due to high clay content (Milivojević *et al.*, 2011). Solonchak soil, characterized by poor chemical and physical properties, is unsuitable for intensive agriculture but can be used for extensive natural pastures (Grujić *et al.*, 2021). These soil types belong to different agricultural productivity groups, with chernozem and vertisol showing high agricultural output, with no restrictions and with some limitations, respectively. In contrast, solonchak has low agricultural potential due to significant restrictions. However, saline soils are vital for the unique endemic ecosystems they sustain, providing habitats for a diverse array of highly adapted organisms (Zeremski *et al.*, 2021).

The primary goal of this study was to evaluate the abundance of functional groups of microorganisms involved in the nitrogen cycle in three different soil types in Vojvodina and identify variations in these abundances across the soils. Additionally, the study aimed to establish relationships between the abundance of bacteria and soil chemical properties.

Material and methods

Study area and soil sampling

The study was conducted in northern Serbia, within the Autonomous Province of Vojvodina, focusing on chernozem, vertisol, and solonchak soils due to their regional prevalence and, in the case of solonchak, specific characteristics resulting from higher salt content (Appendix 1). Soil identification was conducted in two steps: first, Vojvodina's 1:50000 pedological map was consulted (Neugebauer *et al.*, 1971), and second, field and lab observations were conducted, subsequently classifying soils according to the WRB system (IUSS Working Group WRB, 2022). Three locations were chosen for each soil type, with samples taken from two agricultural plots and one uncultivated control plot at each location. Selected agricultural plots were under conventional tillage, with the exception of C5 (reduced tillage) and V4 (organic agriculture). Control plots, minimally impacted by human activity, included forests, meadows, and pastures and were selected for their close proximity and similarity to the agricultural plots. Soil samples were collected using the circular reference method (Bogdanović *et al.*, 2014), with 20-25 individual samples combined to create a composite representing each sampling site. Five composite samples were taken from each field plot. The sampling of chernozem and vertisol soils was conducted in spring in early stages of plant/crop growth when optimal microbial activity is expected to occur. Solonchak samples were collected in summer due to the elevated salt concentrations characteristic to solonchak soils in that time of the year. All samples were collected from a 30 cm depth using sterilized equipment. Samples were transported to the lab at 4°C and analyzed within 24 hours.

Soil chemical properties data

Soil chemical properties data used for statistical analyses in this paper have been published in Kuzmanović *et al.* (2024), in which methods for determination of soil chemical properties have also been described in detail.

The abundance of selected bacterial functional groups

Two methods were used to determine the abundance of selected bacterial functional groups: the spread plate method on solid media and the most probable number (MPN) method on liquid media. Incubation was carried out at 26°C for 5 days for nitrogen-fixing bacteria, 7 days for ammonifiers, 10-15 days for nitrifiers, 7-10 days for denitrifiers, and 5-7 days for the total heterotrophic bacterial count. Nitrogen-fixing bacteria were counted using the spread plate method on Fjodor's medium (Anderson, 1965). For ammonifiers, nutrient broth was used, and after incubation, 10-15 µl of Nessler's reagent was added to detect ammonification by a color change from yellow to red. Nitrifiers were detected using a liquid medium that changes color from red to yellow as nitrification occurs (Saratchandra, 1979). Denitrifiers were quantified using the Giltaya medium, with anaerobic conditions achieved by overlaying the medium with sterile mineral oil (Alexander, 1965). The medium changes from green to blue during denitrification, and gas production is observed in the form of bubbles on the medium surface. The total heterotrophic bacterial count was determined using R2A broth, which supports heterotrophic bacteria. Bacterial growth was recorded based on turbidity in positive wells of a microtiter plate after incubation.

Statistical analysis

All statistical analyses were performed in R Studio (RStudio Team, 2021). Data manipulation was done using the *dplyr* package (Wickham *et al.*, 2023). Pearson's correlation coefficients between soil chemical properties and enzymatic activities were calculated with the *corr* package (Kuhn *et al.*, 2022), and their significance was assessed using the *corrplot* package (Wei & Simko, 2017). The Kruskal-Wallis test was applied to compare chemical properties and enzymatic activities across soil types, followed by Dunn's post-hoc test for pairwise comparisons. All visualizations were created using the *ggplot2* package (Wickham, 2016).

Results and discussion

The abundance of selected bacterial physiological groups

Nitrogen is one of the essential elements for living organisms, known to often limit plant growth in agroecosystems. Microorganisms involved in nitrogen biogeochemical transformations are crucial for the survival of any biocenosis (Zhang *et al.*, 2020). This study used cultivable methods to determine the abundance of selected physiological groups of bacteria involved in the nitrogen cycle, including ammonifiers, nitrifiers, denitrifiers, and nitrogen-fixing bacteria (diazotrophs) (Table 1, Figure 1). Additionally, the total number of heterotrophic bacteria was assessed in the samples.

The average abundance of diazotrophs significantly differed between chernozem and solonchak, while no significant differences were observed in vertisol samples compared to other two soils. In chernozem, the average abundance was $1.68 \cdot 10^6$ CFU/g of dry soil, with lower counts in control plots compared to agricultural ones. In vertisol, the average abundance was $0.68 \cdot 10^6$ CFU/g, with higher counts in control plots in Novi Bečej (V3) and Vršac (V9). In solonchak, the average was $0.78 \cdot 10^6$ CFU/g, with higher counts in control plots. Species from the genus *Azotobacter* and other free nitrogen-fixing bacteria convert atmospheric nitrogen into ammonia, enriching the soil. The findings in this study align with Govedarica *et al.* (1993), who reported the highest *Azotobacter* abundance in chernozem and fluvisol and the lowest in vertisol in Vojvodina. Agrochemical analyses in our study showed the lowest total nitrogen content in chernozem, likely stimulating nitrogen-fixing activity, while higher nitrogen content reduced fixation, as seen in vertisol. The average abundance of diazotrophs in Serbian agricultural soils was found to be $2.68 \cdot 10^6$ CFU/g (Marinković *et al.*, 2018), closely matching this study's results.

The average abundance of ammonifiers significantly differed between chernozem and vertisol samples. Chernozem samples had the highest abundance ($10.90 \cdot 10^4$ MPN/g of dry soil), with the lowest counts on two agricultural plots (C4 and C5) at Rimski Šančevi, likely due to lower organic matter content. Nitrogen fertilizer use also reduces this group's abundance (Mahal *et al.*, 2019). In vertisol, the average abundance was significantly lower at $1.21 \cdot 10^4$ MPN/g, while solonchak samples had the lowest at $0.78 \cdot 10^4$ MPN/g, except for two plots (S1 and S2) in Rančevo with higher counts. These results align with other studies reporting higher numbers in Rančevo and Kljajićevo compared to Trešnjevac (Vasin *et al.*, 2010). Ammonifiers are key indicators of soil quality due to their role in organic matter decomposition. Previous studies recorded much higher ammonifier abundance in chernozem ranging from 5.24 to 57.5 · 10^7 MPN/g (Brankov *et al.*, 2006; Govedarica *et al.*, 2001; Marinković *et al.*, 2012; Marinković *et al.*, 2007; Tintor *et al.*, 2007). The highest abundance in Serbia was found in uncultivated soils, followed by soils in organic farming, with the lowest in conventionally farmed soils (Marinković *et al.*, 2016). In Bačka, however, higher abundance was observed in cultivated soils compared to uncultivated ones (Tintor *et al.*, 2009). In Poland, ammonifier abundance ranged from 1.1 to 6.4 · 10^4 CFU/g, consistent with our findings (Wolińska *et al.*, 2016). Differences in abundances between studies likely stem from varying methods of assessment and media used for cultivation.

The average abundance of nitrifiers significantly differed between vertisol (6.92 · 10^3 MPN/g) and solonchak (3.35 · 10^3 MPN/g) samples, while no significant differences were observed in chernozem (4.68 · 10^3 MPN/g). Nitrifier counts are generally low, even in fertile agricultural soils, rarely exceeding a few thousand bacteria per gram (Winogradsky, 1949). Data on nitrifier abundance in Vojvodina soils are scarce. Šatohina *et al.* (2000) reported nitrifier counts in chernozem ranging from 0.8 to 3.7 · 10^3 MPN/g, consistent with this study's findings. Heterotrophic nitrification is more intense in acidic forest soils with a high C/N ratio compared to agricultural soils (Killham, 1990) and tends to increase with higher carbon-to-nitrogen ratios, which can help manage this process (Zhang *et al.*, 2011). Consequently, acidic soils such as vertisol, have a higher abundance of nitrifiers.

No statistically significant differences in denitrifier abundance were observed across different soil types. Govedarica *et al.* (2001) found that denitrifier activity increases with soil compaction and depth due to reduced oxygen levels. This explains the higher denitrifier counts in our study observed in uncultivated, compacted soils, as well as in solonchak, often used as pasture, where grazing further compacts the already poor soil structure (Drewry *et al.*, 2008). Compaction is particularly severe in clay-rich soils (Rahman *et al.*, 2021), which explains the higher denitrifier abundance in vertisol observed in this study.

The total number of aerobic heterotrophic bacteria did not differ significantly among soil types. In chernozem, the average count was 1.75 · 10^7 MPN/g. In vertisol, the average was 2.73 · 10^7 MPN/g, with higher counts in agricultural plots, particularly V4 (organic farming) and V8 (conventional farming of pumpkins) at 4.81 · 10^7 and 17.49 · 10^7 MPN/g, respectively. The increased bacterial count in soils under organic farming has already been confirmed in the Vojvodina region (Mrkovački *et al.*, 2012). The presence of plastic mulch, like in plot V8, probably increases surface soil moisture and temperature, which increases microbial activity. In solonchak, the average count was the lowest (0.94 · 10^7 MPN/g), with control plots generally having lower counts, except in Kljajićevo. Past studies also reported lower bacterial counts in solonchak, likely due to its poor physical and chemical properties (Vasin *et al.*, 2010). Compared to our results, most studies have reported significantly higher bacterial counts in chernozem, ranging from 13.7 to 356 · 10^7 CFU/g of soil (Brankov *et al.*, 2006; Čuvardić *et al.*, 2004; Marinković *et al.*, 2007, 2012; Tintor *et al.*, 2007; Živanov *et al.*, 2020). These differences are likely to be due to the use of various methods and substrates for determining bacterial counts. A bacterial count (1.49 · 10^7 CFU/g of soil) similar to the one in our study was observed in chernozem in Ukraine (Demyanyuk *et al.*, 2020). The increased bacterial count in most arable plots compared to control plots is likely due to enhanced porosity of the topsoil, leading to better aeration and consequently a dominance of aerobic microorganisms (Linn & Doran, 1984). Govedarica *et al.* (2001) reported much higher bacterial counts in loose chernozem compared to compacted soil in the Vojvodina region. Results at the national level also show higher bacterial counts in soil under conventional agriculture (3.29 · 10^7 CFU/g of soil) compared to uncultivated land (2.82 · 10^7 CFU/g of soil), while the highest counts are observed in soil under organic farming (3.41 · 10^7 CFU/g of soil) (Marinković *et al.*, 2016). Tintor *et al.* (2009) studied different land use practices in southern Bačka, finding the highest bacterial counts in arable land used for crops and gardens, and the lowest in forest and uncultivated land, supporting the theory that microbial counts increase in soils continuously influenced by various agricultural practices (Linn & Doran, 1984), such as tillage, which lead to soil mixing and better aeration.

Table 1. Descriptive statistics parameters for the abundance of selected bacterial groups. Statistically significant differences between the mean values of bacterial abundance for the three soil types are indicated by different letters (dm – dry matter)

Soil type	Parameter	Bacterial group				
		Diazotrophs ·10^6 CFU/g dm	Ammonifiers ·10^4 MPN/g dm	Nitrifiers ·10^3 MPN/g dm	Denitrifiers ·10^5 MPN/g dm	Total heterotrophic bacteria ·10^7 MPN/g dm
Chernozem	Mean	1.68 **a**	10.90 **a**	4.68 **ab**	1.73 **a**	1.75 **a**
	St. dev.	0.92	6.98	1.91	1.53	1.23
	Minimum	0.46	0.89	2.64	0.47	0.60
	Maximum	3.01	19.16	8.00	4.44	4.11
	Sample variance	0.84	48.65	3.64	2.35	1.51
Solonchak	Mean	0.78 **b**	0.78 **b**	3.35 **a**	7.85 **a**	0.94 **a**
	St. dev.	0.96	1.22	0.74	5.36	0.45
	Minimum	0.05	0.12	1.91	1.32	0.07
	Maximum	3.06	3.09	4.66	15.79	1.41
	Sample variance	0.93	1.49	0.54	28.71	0.20
Vertisol	Mean	0.68 **ab**	1.21 **ab**	6.92 **b**	5.10 **a**	2.73 **a**
	St. dev.	0.34	0.58	3.53	6.60	5.73
	Minimum	0.25	0.46	2.77	0.09	0.06
	Maximum	1.22	1.99	13.10	16.31	17.49
	Sample variance	0.12	0.33	12.45	43.59	32.88

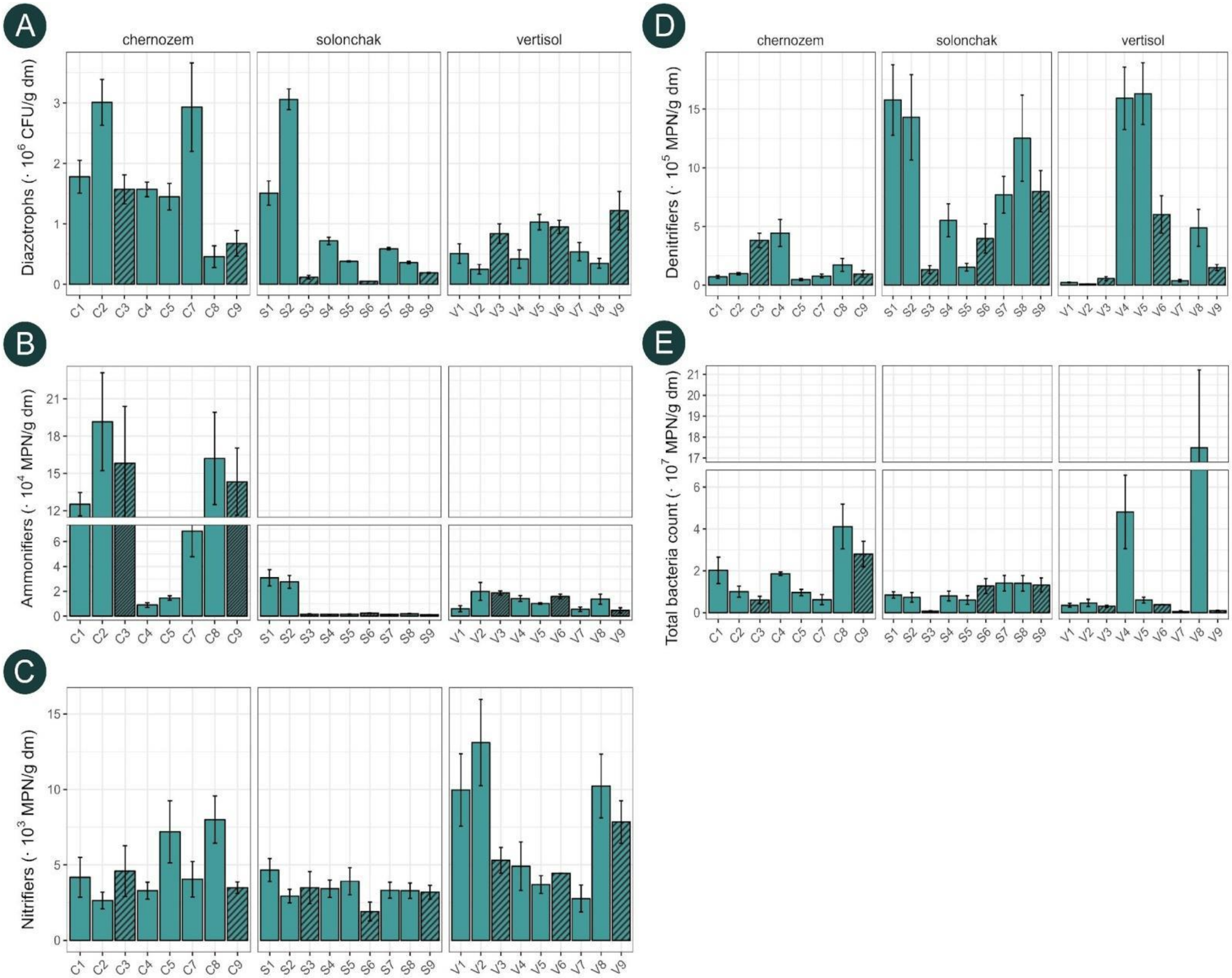

Figure 1. The abundance of selected bacterial groups: A) diazotrophs, B) ammonifiers, C) nitrifiers, D) denitrifiers, E) total heterotrophic bacteria; ▨ - control plots (dm – dry matter)

Correlation between the abundance of bacteria and soil chemical properties

A linear correlation between selected functional groups of bacteria and the chemical properties of the soil was also analyzed. In most cases, the correlation was weak, very weak, or not detected (Figure 2). The abundance of nitrogen fixers showed weak, very weak, or no correlation with chemical soil properties. Cookson *et al.* (2006) found that soil texture, pH, and nitrogen and carbon contents are important predictors of nitrogen flux, which indicates the activity of nitrogen-fixing bacteria. In our study, a weak but statistically significant correlation was recorded between the abundance of diazotrophs and organic carbon.

It is well established that the abundance of ammonifiers correlates with organic carbon and total nitrogen contents (Suttner & Alef, 1988). This relationship was confirmed in our findings about organic carbon, with a statistically significant negative correlation. In the case of nitrifiers, a moderate negative correlation was observed with both pH in KCl and pH in H_2O. Carlyle *et al.* (1990) noted that the abundance of nitrifiers is influenced by soil pH and organic matter content, while Sauvé *et al.* (1999) identified these two parameters as the most critical. Our results confirm the significance of soil pH; however, no statistically significant correlation was found between nitrifier abundance and organic matter content.

A moderate negative correlation was recorded between the abundance of denitrifiers and the content of P_2O_5. Previous research observed a significant correlation between the abundance of this group of microorganisms and soil pH, as well as organic carbon content in arable soils (Šimek, Cooper, Picek, & Santrůcková, 2000). In addition to pH, total nitrogen, organic matter, and phosphorus content were found to influence the abundance of denitrifiers (Yin et al., 2015). In our study, a correlation between denitrifier abundance and these soil properties was noted; however, except in the case of phosphorus, it was weak (total N, organic C, organic matter, K_2O) or very weak (pH value).

Previous studies have shown significant correlations between the total heterotrophic bacterial count and both organic matter content and pH (Gray & Wallace, 1957; Higashida & Takao, 1986). In our study, a weak negative statistically significant correlation was found with organic matter, while the correlation with pH was not statistically significant.

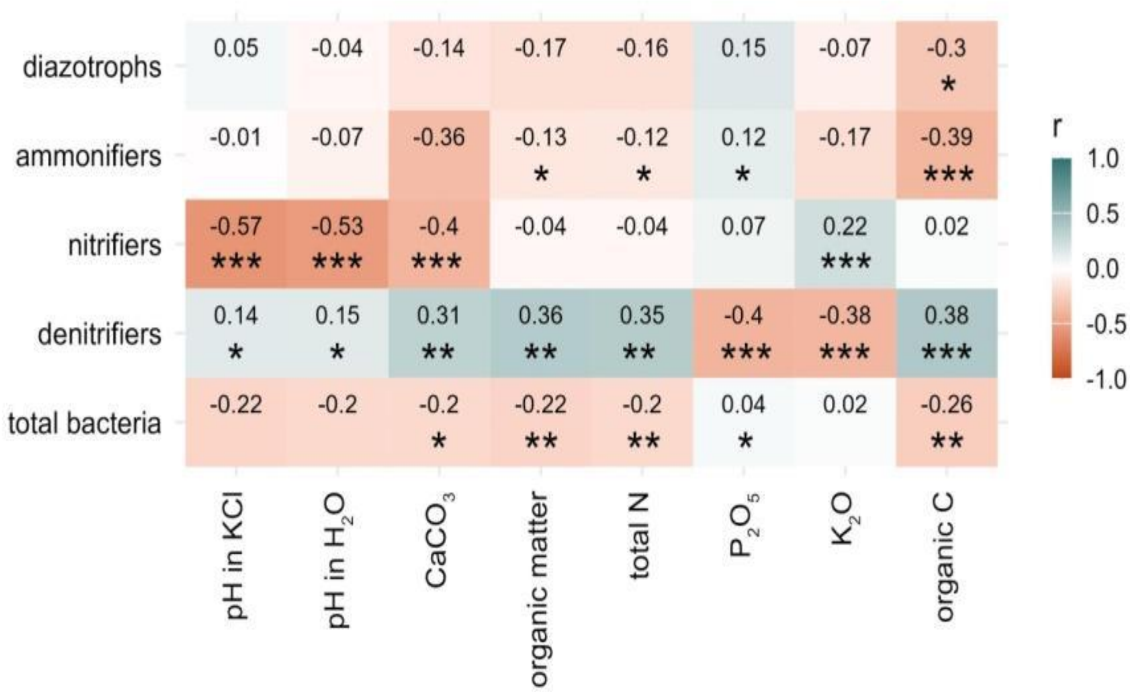

Figure 2. Correlation between selected groups of bacteria and soil chemical properties.
* p ≤ 0,05, ** p ≤ 0,01, *** p ≤ 0,001

Appendix 1. Description of sampled agricultural plots, including location, soil type, brief plot description, and coordinates (Kuzmanović et al., 2024)

Field plot ID	Location	Soil type	Plot description	Coordinates	
				Lat.	Lon.
C1	Rimski Šančevi 1	chernozem	agricultural, wheat	45.323533	19.845817
C2	Rimski Šančevi 1	chernozem	agricultural, corn	45.319593	19.918322
C3	Rimski Šančevi 1	chernozem	control, forest	45.326413	19.858557
C4	Rimski Šančevi 2	chernozem	agricultural, wheat	45.329126	19.845849
C5	Rimski Šančevi 2	chernozem	agricultural, wheat	45.324289	19.847339
C7	Futog	chernozem	agricultural, corn	45.245382	19.696786
C8	Futog	chernozem	agricultural, wheat	45.246626	19.696785
C9	Futog	chernozem	control, forest	45.240622	19.699131
V1	Novi Bečej	vertisol	agricultural, orchard	45.583608	20.086958
V2	Novi Bečej	vertisol	agricultural, sunflower	45.581293	20.086911
V3	Novi Bečej	vertisol	control, meadow in the forest	45.579718	20.086729
V4	Mužlja	vertisol	agricultural, organic, wheat	45.289950	20.272072
V5	Mužlja	vertisol	agricultural, wheat	45.301575	20.275848
V6	Mužlja	vertisol	control, meadow	45.307951	20.258690
V7	Vršac	vertisol	agricultural, vineyard	45.105204	21.329008
V8	Vršac	vertisol	agricultural, pumpkin	45.103016	21.331516
V9	Vršac	vertisol	control, forest	45.105761	21.330247
S1	Rančevo	solonchak	agricultural, soybean	45.869438	19.125111
S2	Rančevo	solonchak	agricultural, corn	45.866464	19.126623
S3	Rančevo	solonchak	control, pasture	45.867231	19.121985
S4	Kljajićevo	solonchak	agricultural, wheat	45.736836	19.262121
S5	Kljajićevo	solonchak	agricultural, wheat	45.736168	19.264500
S6	Kljajićevo	solonchak	control, pasture	45.736830	19.264342
S7	Trešnjevac	solonchak	agricultural, corn	45.982334	20.000062
S8	Trešnjevac	solonchak	agricultural, wheat	45.981869	20.000192
S9	Trešnjevac	solonchak	control, pasture	45.984553	19.999160

Conclusion

This study provides valuable insights into the relationship between nitrogen-cycling bacteria and soil chemical properties across different soil types in Vojvodina, Serbia. The results highlight significant differences in the abundance of bacterial functional groups in analyzed soils. Chernozem soils, known for their high fertility, showed the highest abundance of nitrogen-fixing bacteria and ammonifiers, essential for soil nitrogen replenishment and organic matter decomposition. Vertisol soils were characterized by the highest abundance of nitrifiers and total heterotrophic bacteria. In contrast, solonchak soils exhibited higher denitrifier abundance, reflecting the influence of their specific chemical properties, particularly salinity, on bacterial communities. Moderate correlations were observed between bacterial abundance and chemical properties such as pH and phosphorus content, indicating that bacterial communities are not only influenced by soil type but also by specific chemical properties. While this study provides valuable insights as it is, the future analyses should include more soil samples, and assess temporal variations in bacterial communities. Additionally, other environmental factors that could play a significant role in shaping bacterial communities, such as temperature fluctuations, should be analyzed. Due to the limitations of traditional cultivation methods, modern molecular methods such as quantitative real-time PCR should be applied in future research.

Despite these limitations, the findings of this study have important practical applications. The identification of bacterial functional groups as potential bioindicators of soil quality, particularly nitrogen availability, can contribute to the development of more targeted soil management strategies. By monitoring bacterial communities, farmers and agricultural policymakers can make informed decisions to enhance soil fertility, optimize fertilizer use, and promote sustainable agricultural practices. These insights are particularly relevant for improving soil health and ensuring long-term crop yield sustainability in Vojvodina and similar agricultural regions.

Author contributions: conceptualization — DT, JV, SM, DR; data curation — AK, DT, KK, JN, JV, SM, DR; formal analysis — AK, DT, KK, JN, JV, SM, DR; funding acquisition —- SM, DR: investigation — AK, DT, KK, SM; methodology — AK, DT, JN, JV, SM, DR; project administration — SM, DR; supervision — DT, SM, DR; visualization — AK; writing — original draft — AK; writing — review and editing - AK, DT, KK, JN, JV, SM, DR.

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Bakterije azotnog ciklusa u tipičnim zemljištima Vojvodine (Srbija) i njihov odnos sa hemijskim osobinama zemljišta

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Sažetak: Monitoring kvaliteta zemljišta je od suštinskog značaja u poljoprivrednim regionima, poput Autonomne pokrajine Vojvodine. Zastupljenost funkcionalnih grupa bakterija uključenih u kruženje azota predstavlja dobar pokazatelj formi azota u zemljištu i plodnosti zemljišta. Cilj ovog rada bio je da se proceni brojnost odabranih funkcionalnih grupa bakterija u tri različita tipa zemljišta u Vojvodini i ispita njihova korelacija sa hemijskim osobinama zemljišta. Analizirani tipovi zemljišta (černozem, solončak, vertisol) uzorkovani su na devet lokacija, pri čemu su na svakoj lokaciji obuhvaćene dve poljoprivredne parcele i jedna kontrolna parcela. Utvrđene su brojnosti azotofiksatora, amonifikatora, nitrifikatora, denitrifikatora i ukupnih heterotrofnih bakterija. Rezultati su ukazali na razlike u brojnosti azotofiksatora, amonifikatora i nitrifikatora između različitih tipova zemljišta. Černozem je imao najveću brojnost azotofiksatora i amonifikatora. Denitrifikatori su bili najbrojniji u solončaku, dok je vertisol imao najveću brojnost nitrifikatora i ukupnih heterotrofnih bakterija. Utvrđena je statistički značajna umerena korelacija između brojnosti bakterija i određenih hemijskih osobina zemljišta. Konkretno, zabeležena je umerena negativna korelacija između nitrifikatora i pH u KCl (r=-0,57), pH u H_2O (r=-0,53) i sadržaja $CaCO_3$ (r=-0,4), kao i umerena pozitivna korelacija između denitrifikatora i sadržaja P_2O_5 (r=0,4). Umerena korelacija između brojnosti bakterija i osobina zemljišta može ukazivati na to da je varijabilnost brojnosti bakterija povezana i sa drugim faktorima, kao što su tip vegetaciijskog pokrivača, način korišćenja zemljišta, antropogene aktivnosti i klimatske promene. Stoga, funkcionalne grupe bakterija mogu biti korisne kao pokazatelji opšteg zdravlja i plodnosti zemljišta, naročito u vezi sa azotom kao esencijalnim elementom.

Ključne reči: ciklus azota, funkcionalne grupe bakterija, hemijske osobine zemljišta, poljoprivredno zemljište, kvalitet zemljišta