Agrochemical Responses and Exchange-Complex Buffering Capacity of Two Soils under Common Bean Cultivation (*Phaseolus vulgaris* L.)

Ana Katsarova[1], Mariana Hristova[2], Miladin Nazarkov[2], Iliana Ivanova[3], Tsvetina Paparkova[2], Ralitsa Gavrilova[4], Tsvetelina Metodieva[2]

1- University of Forestry, Faculty of Forestry, Sofia, Bulgaria
2 - N. Poushkarov Institute for Soil Science, Agrotechnology and Plant Protection, Agricultural Academy, Sofia, Bulgaria
3 - Institute of Agriculture and Seed Science "Obraztsov Chiflik", Agricultural Academy, Ruse, Bulgaria
4 - Institute of Ornamental and Medicinal Plants, Agricultural Academy, Sofia, Bulgaria

Corresponding author: Ana Katsarova, e-mail: anichrankina@gmail.com
Received: 15 April 2026 Accepted: 02 July 2026

Abstract

A two-year field study evaluated agrochemical responses and exchange-complex buffering under common bean cultivation on Fluvisol and Luvic Chernozem in Bulgaria. Treatments included Naturalis, Softgard, their combination and three Beauveria bassiana strains. Soil pH, mineral nitrogen, available phosphorus and potassium, humus content and exchange-complex indicators were assessed descriptively. Fluvisol had higher initial humus, phosphorus and potassium reserves and remained in the humus-rich class according to Penkov (1986), despite a moderate second-year decrease in measured humus. Luvic Chernozem had lower nutrient reserves, shifted to low humus status after cultivation and was characterized by a larger exchange complex. After the first year, mineral nitrogen, phosphorus and potassium increased in both soils; after the second year, available phosphorus declined most consistently. In Luvic Chernozem, the pH decrease and appearance of exchangeable Al indicated early acidification pressure that may have contributed to lower phosphorus availability. The results suggest that Fluvisol maintained fertility mainly through nutrient and organic-matter reserves, whereas Luvic Chernozem relied more on exchange-complex buffering. Treatment effects should be interpreted cautiously because soil analytical data were treatment-level composites.

Key words: chitosan, nutrient availability, cation exchange capacity, hydrolytic acidity, base saturation, humus status

Introduction

Common bean (*Phaseolus vulgaris L.*) is an important legume crop with nutritional and agronomic value. Its ability to contribute to nitrogen cycling through biological nitrogen fixation makes it relevant for sustainable cropping systems, but successful production still depends on adequate phosphorus and potassium supply, favorable soil reaction, water availability and appropriate management (Medendorp et al., 2022; Grzebisz et al., 2023; Ntatsi et al., 2020).

Biological products, microbial inoculants and biostimulants are increasingly used as components of sustainable nutrient management. They may stimulate nutrient transformation, root activity and rhizosphere processes, but their effects depend strongly on soil type, baseline fertility, moisture regime and complementary nutrient sources (Wabela et al., 2024; Kumar et al., 2026; Chen et al., 2026).

This soil-specific context is particularly important when contrasting soils are compared. Initial pH, nutrient reserves and humus content can influence both nutrient availability and the response to biological inputs. At the same time, exchange-complex characteristics determine how soils retain and buffer cations, respond to acidity development and maintain nutrient availability under cropping. Therefore, treatment effects should be interpreted together with initial soil status, buffering capacity and year conditions, especially when plot-level analytical replications are not available for all soil indicators.

The objective of this study was to evaluate changes in soil pH, mineral nitrogen, available phosphorus and potassium, humus content and exchange-complex characteristics under common bean cultivation after application of Naturalis, Softgard, their combination and selected *Beauveria bassiana* strains on Fluvisol and Luvic Chernozem under rainfed conditions.

Material and Methods

Site description and experimental design

Field experiments were conducted over two consecutive years (2023-2024) on two contrasting soil types in Bulgaria: Fluvisol located near Sofia and Luvic Chernozem located in the Ruse region. The test crop was common bean (*Phaseolus vulgaris L.*), variety Obraztsov Chiflik 12.

The experimental plots measured 10 m² per treatment, with a total field area of 300 m². The treatments were: Control without treatment, Naturalis (*Beauveria bassiana* ATCC 74040), Softgard (chitosan-based biostimulant), Naturalis + Softgard, *B. bassiana* strain 339, *B. bassiana* strain 538 and *B. bassiana* strain 730. The selected *B. bassiana* strains have plant-growth-promoting traits such as indole-3-acetic acid production, chitinase activity and siderophore synthesis.

Soil sampling and analytical methods

Composite soil samples were collected before the experiment and after harvest during both growing seasons. The samples were air-dried, sieved through a 2 mm sieve and analyzed for selected agrochemical and physicochemical indicators.

Soil pH was determined potentiometrically in a soil-water suspension according to ISO 10390:2010. Mineral nitrogen was determined as the sum of ammonium and nitrate nitrogen using the method of Keeney and Bremner (1966). Available phosphorus and

potassium were determined by the acetate-lactate method of Ivanov (1984). Humus content was determined by the modified Tyurin method, following Kononova (1966), Filcheva and Tsadilas (2002) and Filcheva et al. (2018).

Cation exchange capacity, hydrolytic acidity, exchangeable calcium and magnesium, exchangeable aluminum and base saturation were determined according to the method of Ganev and Arsova (1980). These indicators were used to characterize the exchange complex and to assess the buffering capacity of the two soil types.

Statistical analysis and interpretation

The available analytical dataset consisted of initial soil characteristics and treatment-level values after the first and second growing seasons. Data processing included descriptive statistics, graphical analysis and exploratory multivariate analysis. Mean, standard deviation, minimum and maximum values were calculated across treatments for each soil type and sampling stage. Absolute and relative changes from the initial soil status and treatment differences relative to the untreated control were also calculated. Humus status was interpreted according to Penkov (1986), using the following classes: poor humus content below 1%, low humus content from 1 to 2%, medium humus content from 2 to 3%, and humus-rich soils above 3%. Because plot-level replicated analytical values were not available for all soil indicators, no analysis of variance or post-hoc treatment ranking was applied. Principal component analysis was used only as an exploratory visualization of the relationships among agrochemical indicators and exchange-complex characteristics, not as a test for statistically significant treatment differences.

Results and Discussion

Initial soil characteristics

The two experimental soils differed markedly before the start of the trial (Table 1). Luvic Chernozem was slightly acidic and had lower available phosphorus, potassium and humus content. According to the humus-status classification of Penkov (1986), its initial humus content of 2.02% corresponded to the medium humus class. Fluvisol had near-neutral pH and substantially higher available phosphorus, potassium and humus. Its initial humus content of 3.93% placed it in the humus-rich class. These baseline differences are important for interpreting subsequent treatment responses because the same biological input may act differently depending on initial soil fertility, soil reaction and organic matter status.

Table 1. *Initial soil agrochemical characteristics before the experiment*

Soil type	Mineral nitrogen, mg kg^{-1}	P_2O_5, mg 100 g^{-1}	K_2O, mg 100 g^{-1}	Humus, %
Luvic Chernozem	12.96	6.85	30.11	2.02
Fluvisol	12.96	45.78	50.16	3.93

Note: Initial values represent baseline soil conditions before treatment application and should not be treated as treatment replications.

Descriptive statistics after vegetation

The descriptive statistics in Table 2 show the variation among treatment-level values within each soil and year. In the first year, mean mineral nitrogen, available phosphorus and available potassium were higher than the initial values in both soils. In the second year, available phosphorus declined in both soils, while potassium declined moderately. Mineral

nitrogen remained above the initial value on average. Humus showed a soil-specific pattern: Luvic Chernozem remained in the low humus class after vegetation, whereas Fluvisol retained high humus status, although with greater treatment-level variability in 2024. Thus, nutrient availability and measured humus content did not change in parallel and should not be interpreted as a single depletion process.

The standard deviation and range describe variability among treatments, not plot-level experimental error. Therefore, the table should be interpreted as an objective description of the observed treatment-level spread and not as evidence for statistically significant differences.

Table 2. *Descriptive statistics of soil indicators after vegetation*

Soil type	Sampling stage	Mineral nitrogen, mg kg^{-1}	P_2O_5, mg 100 g^{-1}	K_2O, mg 100 g^{-1}	Humus, %
Luvic Chernozem	After year 1	19.07 ± 6.20 (11.23-28.51)	10.97 ± 0.69 (9.89-11.80)	37.74 ± 2.89 (33.83-42.88)	1.61 ± 0.21 (1.31-1.96)
Luvic Chernozem	After year 2	15.70 ± 3.48 (10.60-21.60)	5.07 ± 0.46 (4.60-5.70)	26.90 ± 2.35 (22.60-30.60)	1.25 ± 0.10 (1.11-1.42)
Fluvisol	After year 1	17.00 ± 5.37 (10.74-25.92)	52.76 ± 6.30 (42.40-61.82)	53.72 ± 3.54 (48.76-58.09)	4.05 ± 0.11 (3.93-4.26)
Fluvisol	After year 2	16.43 ± 4.55 (11.50-23.60)	23.90 ± 3.29 (20.30-30.10)	45.03 ± 7.87 (34.30-58.70)	3.64 ± 0.61 (2.86-4.65)

Note: Values are mean ± standard deviation, with minimum-maximum values in parentheses. The statistics describe variation among treatment-level values.

Mean change from the initial soil status

The change from the initial soil status provides a clearer view of the main year-related tendencies (Table 3). In Luvic Chernozem, available phosphorus increased after the first year but was below the initial level after the second year. In Fluvisol, available phosphorus increased slightly after the first year but decreased strongly after the second year. This decline occurred while Fluvisol still maintained high humus status; therefore, the lower second-year phosphorus values are more appropriately interpreted as the combined result of crop uptake, year conditions and limited nutrient replenishment rather than as a direct consequence of organic matter depletion.

The humus data require cautious interpretation. According to Penkov (1986), Luvic Chernozem shifted from the medium humus class before the experiment to low humus status after the first and second growing seasons. In contrast, Fluvisol remained humus-rich on average in both years after vegetation, with mean humus values of 4.05% in 2023 and 3.64% in 2024. Although the second-year mean was lower than the initial value, most treatment-level values remained above 3%, and only one value was in the upper part of the medium humus class. Therefore, the corrected data do not support an interpretation of early organic matter depletion in Fluvisol. The change should be reported as moderate interannual variation in measured total humus. Total humus changes slowly and can be affected by spatial heterogeneity of composite samples, sampling timing, crop residue management, moisture regime and analytical uncertainty. Without plot-specific baseline values and replicated analytical error, the mechanism of this change cannot be attributed to the biological products alone.

Table 3. *Mean change from the initial soil status*

Soil type	Sampling stage	Δ mineral nitrogen	Δ P_2O_5	Δ K_2O	Δ humus
Luvic Chernozem	After year 1	+6.11 (+47.1%)	+4.12 (+60.1%)	+7.63 (+25.3%)	-0.41 (-20.1%)
Luvic Chernozem	After year 2	+2.74 (+21.1%)	-1.78 (-26.0%)	-3.21 (-10.7%)	-0.77 (-38.0%)
Fluvisol	After year 1	+4.04 (+31.2%)	+6.98 (+15.2%)	+3.56 (+7.1%)	+0.12 (+3.1%)
Fluvisol	After year 2	+3.47 (+26.8%)	-21.88 (-47.8%)	-5.13 (-10.2%)	-0.29 (-7.4%)

Note: Values show absolute and percentage change relative to the initial soil status. Soil pH is presented with the exchange-complex indicators in Table 4 to avoid duplication.

Exchange-complex characteristics and buffering capacity

The physicochemical dataset added a mechanistic layer to the interpretation of macronutrient dynamics (Table 4). Luvic Chernozem was characterized by a larger adsorption complex, with T8.2 remaining close to 30 meq 100 g^{-1} and TCA around 24-25 meq 100 g^{-1} during the experimental period. Exchangeable Ca and Mg also remained high, and base saturation stayed close to 80%. These values indicate that the soil retained a strong cation-buffering capacity, even when pH decreased in the second year.

Table 4. *Mean exchange-complex characteristics of the two soils before the experiment and after the 2023 and 2024 growing seasons*

Soil type	Stage	pH H2O	8.2	CA	8.2	Exchangeable Al	Ca + Mg	Base saturation, %
Luvic Chernozem	Before vegetation	6.00	0.33	3.83	6.10	0.07	24.13	79.94
Luvic Chernozem	After year 1	6.06	0.89	4.74	5.86	0.00	25.03	81.01
Luvic Chernozem	After year 2	5.80	0.19	4.37	5.96	0.21	24.11	80.25
Fluvisol	Before vegetation	6.87	6.70	3.57	1.63	0.00	14.93	90.29
Fluvisol	After year 1	6.61	8.67	4.11	4.56	0.00	14.94	80.17
Fluvisol	After year 2	6.59	7.87	5.34	2.53	0.00	16.19	90.63

Note: T8.2, TCA, H8.2, exchangeable Al and Ca + Mg are expressed in meq 100 g^{-1}. Ca + Mg is the sum of exchangeable calcium and magnesium. Values are mean values calculated across treatment-level observations.

In 2024, however, Luvic Chernozem showed early signs of acidification pressure. Soil pH decreased to about 5.8 and exchangeable Al appeared, with a mean value of 0.21 meq 100 g^{-1}. This pattern may help explain the decline in available phosphorus, because lower pH and the presence of reactive Al can promote phosphate fixation and reduce the pool of plant-

available P. The buffering system was therefore still active, but part of its capacity was involved in neutralizing acidity stress rather than only supporting nutrient retention.

Fluvisol showed a contrasting pattern. It had a smaller exchange complex, with T8.2 around 17-18 meq 100 g^{-1}, but it maintained near-neutral pH and no exchangeable Al. Its higher humus content and larger available P and K reserves suggest that fertility was primarily supported by organic matter-associated nutrient pools and available nutrient reserves rather than by a large cation exchange complex. The second-year decline in available phosphorus occurred without a comparable decline in humus class; therefore, it should be discussed mainly in relation to nutrient removal, seasonal conditions and the need for nutrient replenishment.

Treatment response relative to the untreated control after the second year

The comparison with the untreated control within the same soil type and sampling year avoids treating the initial soil value as a replicated baseline for every treatment (Table 5). In the second year, Naturalis + Softgard showed the most favorable descriptive response for available phosphorus and potassium in Fluvisol, while strain 730 showed the highest positive difference for mineral nitrogen and also a positive difference for potassium. In Luvic Chernozem, Softgard showed the largest positive difference for mineral nitrogen, while differences in available phosphorus and potassium were relatively small.

No single treatment consistently improved all indicators in both soils. This supports a cautious interpretation: biological products may contribute to nutrient mobilization and rhizosphere activity, but the response remains dependent on soil type, year conditions, initial nutrient status and buffering capacity. The available data are not sufficient for a definitive statistical ranking of treatments.

Table 5. *Treatment response relative to the control after the second year*

Soil type	Treatment	Δ mineral nitrogen	Δ P_2O_5	Δ K_2O	Δ humus
Luvic Chernozem	Naturalis	+4.40	+1.00	-0.60	+0.13
Luvic Chernozem	Softgard	+11.00	+1.00	+3.60	-0.10
Luvic Chernozem	Naturalis + Softgard	+3.20	+0.30	-4.40	-0.02
Luvic Chernozem	Strain 339	+7.50	+0.40	+0.40	-0.07
Luvic Chernozem	Strain 538	+3.80	-0.10	-0.30	-0.18
Luvic Chernozem	Strain 730	+5.80	+0.00	+0.60	-0.03
Fluvisol	Naturalis	+7.30	+1.20	+2.30	+1.40
Fluvisol	Softgard	+0.50	-3.40	-3.40	+0.03
Fluvisol	Naturalis + Softgard	+6.60	+6.00	+15.70	+0.71
Fluvisol	Strain 339	-1.20	-3.80	-8.70	-0.40
Fluvisol	Strain 538	+2.00	-1.30	+0.50	+0.10
Fluvisol	Strain 730	+10.90	-0.10	+7.80	+0.78

Note: Values are absolute differences from the untreated control within the same soil type and sampling year. Strains 339, 538 and 730 refer to *Beauveria bassiana*. Positive values indicate higher values than the control; negative values indicate lower values than the control. Soil pH is presented in the exchange-complex section.

Exploratory multivariate analysis

Since the dataset did not contain replicate analytical values for each treatment, multivariate analysis was used only to visualize the structure of the data and to support interpretation of soil-specific patterns. PCA was performed on standardized treatment-level values for macronutrients, humus and exchange-complex indicators. Therefore, the ordination

should be interpreted as an exploratory pattern rather than as evidence of statistically significant treatment separation.

The first two principal components explained 79.6% of the total standardized variance (PC1 = 66.3%; PC2 = 14.3%). The PCA score plot separated the observations mainly according to soil type and year. Fluvisol observations were positioned on the positive side of PC1, while Luvic Chernozem observations were positioned on the negative side. Because the figure is presented as a score plot, it should be read as a visualization of sample grouping and not as a direct loading-based interpretation of individual parameters.

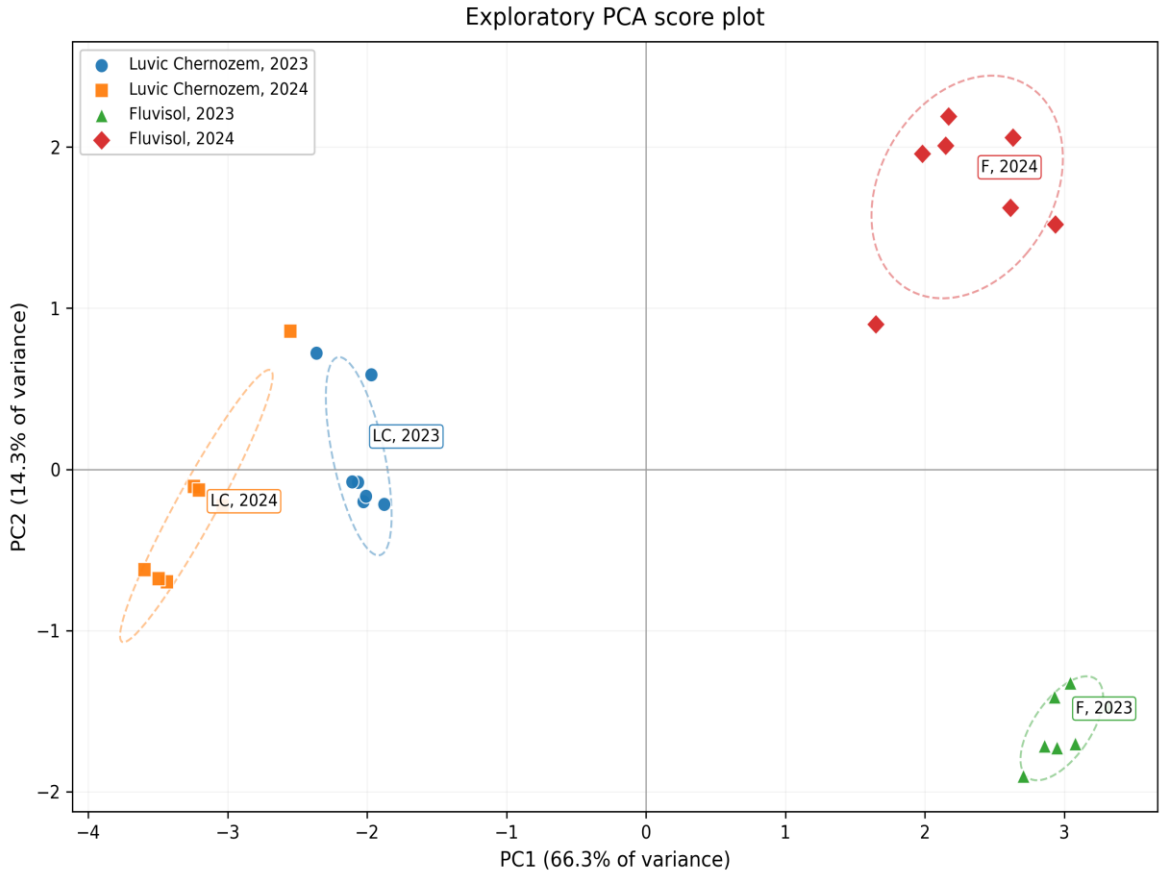


Fig. 1. *Exploratory principal component score plot of standardized agrochemical and exchange-complex indicators. Points represent treatment-level observations grouped by soil type and year; dashed ellipses show the visual grouping tendency. The analysis is descriptive and does not represent a significance test among treatments.*

The PCA pattern supports the interpretation that the two soils had different overall agrochemical and exchange-complex profiles. The separation of Fluvisol observations reflects the combined influence of higher nutrient reserves, near-neutral reaction and higher humus status, whereas the separation of Luvic Chernozem reflects the stronger role of exchange-complex characteristics and acidification-related indicators. This graphical approach is useful for presenting the joint behavior of soil indicators without implying significant differences among treatments.

Integrated interpretation of macronutrient availability and buffering capacity

The integration of macronutrient data with exchange-complex characteristics indicated a soil-specific differentiation in fertility-maintenance mechanisms. Fluvisol was characterized by higher humus content and larger reserves of available phosphorus and potassium. According to Penkov (1986), Fluvisol remained humus-rich on average throughout the experimental period, including after the second growing season. This supports the interpretation that its fertility status was primarily associated with organic matter-related nutrient pools and available nutrient reserves. Organic matter may have contributed to nutrient supply through mineralization processes and improved retention of plant-available forms, but the observed decline in available phosphorus in 2024 indicates that these reserves still require balanced replenishment under crop uptake.

In contrast, Luvic Chernozem was characterized by higher T8.2 and TCA values and higher exchangeable Ca and Mg contents, but by lower available phosphorus and lower humus status after cultivation. This indicates that the fertility of this soil was less dependent on the size of immediately available nutrient and organic matter reserves and more strongly controlled by the capacity of the exchange complex to retain and regulate cation availability. Such behavior is consistent with the well-developed adsorption complex typical of Chernozemic soils, but the second-year data also show that this buffering capacity does not fully prevent acidity-related constraints on phosphorus availability.

Hydrolytic acidity (H8.2) behaved as an important indicator of the balance between acidity development and base-cation saturation. Its relationship with soil pH, exchangeable Al and base saturation suggests an antagonistic interaction between acidity development and exchange-complex saturation by basic cations. In Luvic Chernozem, the decrease in pH during the second year, together with the appearance of exchangeable aluminum, indicates early signs of acidification pressure, which may partly explain the reduced phosphorus availability observed in 2024.

Overall, the combined agrochemical and physicochemical data suggest that the two soils maintained fertility through different mechanisms: Fluvisol mainly through larger organic matter and nutrient reserves, and Luvic Chernozem through a more developed exchange complex and stronger cation-buffering capacity. The corrected humus interpretation further refines this contrast: Fluvisol remained humus-rich on average, whereas Luvic Chernozem shifted toward low humus status during the experimental period. These contrasting mechanisms may explain the soil-specific responses to biological products, but they should be interpreted descriptively because replicated analytical values were not available for formal significance testing.

Conclusion

The initial soil status was the main framework for interpreting the results. Fluvisol started with near-neutral pH and higher available phosphorus, potassium and humus content, whereas Luvic Chernozem had lower nutrient reserves and slightly acidic pH.

After the first year, mean mineral nitrogen, available phosphorus and available potassium increased in both soils. After the second year, the most consistent change was the decline in available phosphorus in both soils, accompanied by a moderate decrease in

potassium. Mineral nitrogen remained above the initial level on average, indicating that nutrient dynamics were indicator-specific and year-dependent.

Exchange-complex characteristics and the exploratory PCA helped explain part of the soil-specific response. Luvic Chernozem maintained higher T8.2, TCA, exchangeable Ca and Mg, and high base saturation, but the second-year pH decrease and appearance of exchangeable Al indicated early acidification pressure. Fluvisol maintained near-neutral pH, no exchangeable Al and higher humus status, but its available phosphorus reserves decreased markedly in the second year.

The humus results should be interpreted carefully. Luvic Chernozem showed a shift from medium to low humus status according to Penkov (1986), whereas Fluvisol remained humus-rich on average and showed only moderate interannual variation in measured total humus. The corrected data therefore do not support a conclusion of organic matter depletion in Fluvisol. The available data do not allow the mechanism of humus variation to be assigned to biological products alone.

Treatment responses were soil-specific and no product consistently improved all indicators in both soils. Naturalis + Softgard showed favorable second-year values for available phosphorus and potassium in Fluvisol, while strain 730 showed the highest positive difference for mineral nitrogen. In Luvic Chernozem, Softgard showed the largest positive difference for mineral nitrogen, but phosphorus and potassium differences were smaller. Overall, biological products may be considered as part of integrated nutrient management, provided that nutrient replenishment and pH control are monitored according to soil type.

The study supports the potential of biological products as part of integrated nutrient management, but the interpretation should remain descriptive unless plot-level replicate analytical data and yield data become available for formal statistical testing. For long-term use, biological products should be combined with monitoring of pH, hydrolytic acidity, exchangeable Al and base saturation, especially in soils showing early acidification pressure.

Acknowledgements

The authors acknowledge funding of research activities received from the Bulgarian National Science Fund under grant agreement KP-06-M66/5, project “Influence of biological products on plant and soil parameters in cultivation of beans (*Phaseolus vulgaris L.*)”.

References

Brady, N. C., & Weil, R. R. (2017). The nature and properties of soils (15th ed.). Pearson.

Chen, Z. R., Wang, Y., & Jiang, R. (2026). Functional biofertilizer with microbial and enzyme complex improves nutrients, microbial characteristics, and crop yield in Albic soil of Heilongjiang Province, China. Agronomy.

Filcheva, E., & Tsadilas, C. (2002). Influence of clinoptilolite and compost on soil properties. Communications in Soil Science and Plant Analysis, 33, 595-607.

Filcheva, E., Hristova, M., Nikolova, P., Popova, T., Chakalov, K., & Savov, V. (2018). Quantitative and qualitative characteristics of soil organic matter in Bulgarian soils. Bulgarian Journal of Agricultural Science, 24, 957-962.

Ganev, S., & Arsova, A. (1980). Methods for determining strongly acid and weakly acid cation exchange in soils. Soil Science and Agrochemistry, 15(3), 22-33.

Grzebisz, W., Zielewicz, W., & Przygocka-Cyna, K. (2023). Deficiencies of secondary nutrients in crop plants - a real challenge to improve nitrogen management. Agronomy, 13, 66. https://doi.org/10.3390/agronomy13010066.

Hinsinger, P. (2001). Bioavailability of soil inorganic P in the rhizosphere as affected by root-induced chemical changes: A review. Plant and Soil, 237(2), 173-195. https://doi.org/10.1023/A:1013351617532.

ISO 10390:2010. Soil quality - Determination of pH. International Organization for Standardization, Geneva, Switzerland.

Ivanov, P. (1984). A new acetate-lactate method for determination of available phosphorus and potassium in soils. Soil Science and Agrochemistry, 19(4), 88-98. (In Bulgarian).

Keeney, D. R., & Bremner, J. M. (1966). Comparison and evaluation of laboratory methods of obtaining an index of soil nitrogen availability. Agronomy Journal, 58, 498-503.

Kononova, M. M. (1966). Soil Organic Matter: Its Nature, Its Role in Soil Formation and in Soil Fertility. Pergamon Press, Oxford.

Kumar, N. V., Patil, M. B., & Beerge, R. (2026). Synergistic effects of different composts and microbial inoculants on crop yield, soil fertility, and microbial populations. Compost Science & Utilization.

Medendorp, J., DeYoung, D., Thiagarajan, D. G., Duckworth, R., & Pittendrigh, B. (2022). A systems perspective of the role of dry beans and pulses in the future of global food security. In Dry Beans and Pulses: Production, Processing, and Nutrition (pp. 531-550). https://doi.org/10.1002/9781119776802.ch21.

Ntatsi, G., Karkanis, A., Tran, F., Savvas, D., & Iannetta, P. P. M. (2020). Which agronomic practices increase the yield and quality of common bean (*Phaseolus vulgaris L.*)? A systematic review protocol. Agronomy, 10(7), 1008. https://doi.org/10.3390/agronomy10071008.

Penkov, M. (1986). Assessment and classification of soil organic matter status in Bulgarian soils. Sofia, Bulgaria. (In Bulgarian).

Raghothama, K. G. (2005). Phosphorus and plant nutrition: an overview. Phosphorus: Agriculture and the environment, 46, 353-378.

Tian, J., Wang, J., Dippold, M. A., Gao, Y., & Kuzyakov, Y. (2020). Microbial community-mediated soil acidification and pH buffering. Geoderma, 368, 114284. https://doi.org/10.1016/j.geoderma.2020.114284.

Von Uexküll, H. R., & Mutert, E. (1995). Global extent, development and economic impact of acid soils. Plant and Soil, 171(1), 1-15. https://doi.org/10.1007/BF00009558.

Wabela, R., Abera, G., & Gobena, A. (2024). Effects of integrated fertilizer application on selected soil properties and yield attributes of common bean (*Phaseolus vulgaris L.*) on different soil types. Heliyon.

Wang, Y., Chen, Y. F., & Wu, W. H. (2021). Potassium and phosphorus transport and signaling in plants. Journal of Integrative Plant Biology, 63, 34-52.

Zörb, C., Senbayram, M., & Peiter, E. (2014). Potassium in agriculture - Status and perspectives. Journal of Plant Physiology, 171(9), 656-669. https://doi.org/10.1016/j.jplph.2013.08.008.