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EVOLUTION OF THE CHEMICAL CHARACTERISTICS OF AMODERATELY PODZOLIZED ALBIC LUVISOL UNDER THE INFLUENCE OF LIMING AND CULTIVATED AGRICULTURAL SPECIES

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ABSTRACT

In order to evaluate the nutrient supply status of amoderately podzolized albicluvic soil, and to assess the influence of liming on the chemical characteristics of the soil, an experimental field was established to test different agricultural species under both amended and unamended conditions.At the same time, the study aimed to identify and characterize agricultural species and varieties with high tolerance to soil acidity, capable of efficiently exploiting acidic lands, by assessing the agronomic performance and quality of new crops (buckwheat, chickpea, mustard, sweet sorghum, faba bean, lentil) alongside those of conventional crops cultivated in the area (red clover, lupine, triticale, wheat).The results demonstrated that liming of acidic soils has significant effects on the supply of macro- and microelements, reflected in an increased availability of essential nutrients and improved absorption by the ten plant species tested.

INTRODUCTION

The potential for multiplicative improvement of soil fertility characteristics to ensure adequate nutrient supply for crops arises from the relationships described by the law of the action of vegetation factors (Baule, 1918, cited by Bîlteanu and Motcă, 1989), as a consequence of the principle of equal importance or non-substitutability of vegetation factors. Interdisciplinary research conducted under the challenging conditions of northwestern Romania aims to maximize the use of natural soil and climatic resources and to optimize anthropogenic interventions to increase and diversify agricultural production.

Acidic soils represent a major constraint to agricultural productivity, the main limiting mechanism being aluminum toxicity and phosphorus deficiency at low pH values, due to the formation of insoluble aluminum and iron compounds (Zheng et al., 2010). The application of calcium-based amendments remains the most widespread method for correcting soil acidity, directly resulting in increased pH, reduced active Al^{3+} concentration, and improved availability of P, Ca, and Mg—

effects that contribute positively to root development and crop yield. However, the efficiency of liming depends strongly on the type of material used, particle fineness, application rate and method, as well as on the cultivated species and complementary agronomic practices (e.g., crop rotations with legumes or organic matter input). Therefore, comparative testing of various liming treatments at multiple rates and across different species (grasses vs. legumes) is necessary to develop locally adapted recommendations (Enesi et al., 2023; Li et al., 2018).

Since agronomic responses are not uniform: different varieties of the same species may react significantly differently to the same liming treatment, and yield performance depends on the interaction between amendment type and rate, and the specific tolerance to soil acidity (Bedassa et al., 2022; Grewal & Williams, 2001)—varietal screening (comparing multiple cultivars under limed vs. control conditions) becomes essential. Such screening helps identify genotypes that benefit most from soil improvement and provides a foundation for developing practical, site-specific recommendations (Etana, 2023; Holland, 2019).

Soil and plant chemical analyses play a crucial role in revealing the processes and phenomena occurring within the soil–plant system, closely related to plant nutrition and yield formation. They also help identify factors that may affect normal plant growth and development, providing the basis for establishing appropriate corrective measures.

MATERIAL AND METHOD

In order to achieve the proposed objectives, a soil sampling plan was developed and implemented after the experimental plots—cultivated with the studied crops (buckwheat, chickpea, mustard, sweet sorghum, faba bean, lentil, clover, lupine, triticale, and wheat)—were cleared.

From each plot, soil samples were collected from the 0–25 cm depth, with three partial samples taken for each level of the agrochemical amendment factor, which were then combined into a composite sample. The sampling points for the partial samples were established according to the field configuration to ensure uniform sample collection.

Figure 1. Soil sampling

Each partial sample weighed approximately 200–300g; the samples were mixed on-site, and from the well-homogenized mixture, a subsample of 800 g was taken to represent the composite sample. This sample was sent to the National Institute for Research and Development for Soil Science, Agrochemistry and Environment Protection (ICPA) Bucharest for laboratory analysis**.**

Before sampling, the soil surface was cleaned to a depth of 3–4 cm to remove plant residues and other organic debris. Sampling was performed using a soil auger designed for this purpose.

The laboratory analyses performed on the soil samples targeted the following parameters: soil reaction (pH); total nitrogen content (N); available phosphorus content (P_AL); available potassium content (K_AL); sum of exchangeable basecations (SB); hydrolytic acidity (Ah); total acidity (SH); total cation exchange capacity (T); base saturation degree (V_AH, % of T); exchangeable aluminum (Al); contents of trace elements (microelements) in mobile forms and magnesium soluble in $CaCl_2$.

RESULTS AND DISCUSSION

The determination of the actual soil acidity, carried out after the vegetation period specific toeach crop and using the aqueous suspension method with a soil/solution ratio of 1:2.5 (m/v), revealed clear differences between treatments. Thus, in the unlimed plots, the soil reaction was classified as *strongly acidic* for wheat, triticale, fababean, chickpea, lupine, lentil, buckwheat, and sorghum, and as *moderately acidic* for mustard and clover.

The application of TerraCalco at a rate of 1 t/ha(active substance 95% calcium), used as a maintenance or moderate corrective treatment, partially neutralized the acidity, increasing soil pH values by more than 0.5 units in most amended variants. This changes hifted soil classification from *strongly acidic* to *moderately acidic*, with the exception of the sorghum plots, which remained within the *strongly acidic* category (Figure 2).

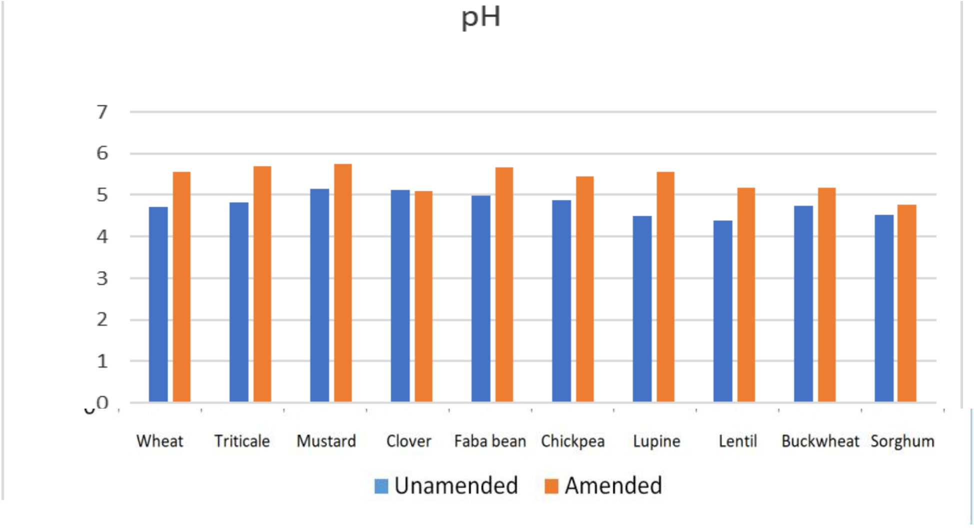

Figure 2. Changes in soil reaction values under the influence of amendments and the tested crops in the experimental field at SCDA Livada

The application of TerraCalco contributed to the increase in soil pH, which may reduce the solubility and mobility of aluminumions—particularly in acidic soils (Figure 3). This effect can mitigate Al-induced phytotoxicity, the rebyprotecting plant root systems and promoting better root development (Gillespie et al., 2021).

According to the classification table of exchangeable aluminum contents (Florea et al., 1987), the unamended variants presented *very low to low* levels of exchangeable Al, while the limed variants showed *extremely low* contents.

The influence of aluminum compounds on plants manifests both directly**,** by inhibiting root system development, and indirectly**,** by blocking nutrient ion uptake sites from the soil solution into plant tissues.

As shown in Figure 3**,** the values of exchangeable aluminum were higher in the unlimed variant. This can be explained by the fact that, although calcium amendments reduce aluminum toxicity by increasing soil pH, the presence of clover may temporarily increase exchangeable aluminum levels through the exudation of organic acids and subsequent alterations in rhizosphere chemistry.

This does not indicate that the liming amendment is ineffective, but rather that crop-specific effects on soil chemistry can modulate the observed analytical results (Ma W. et al., 2022).

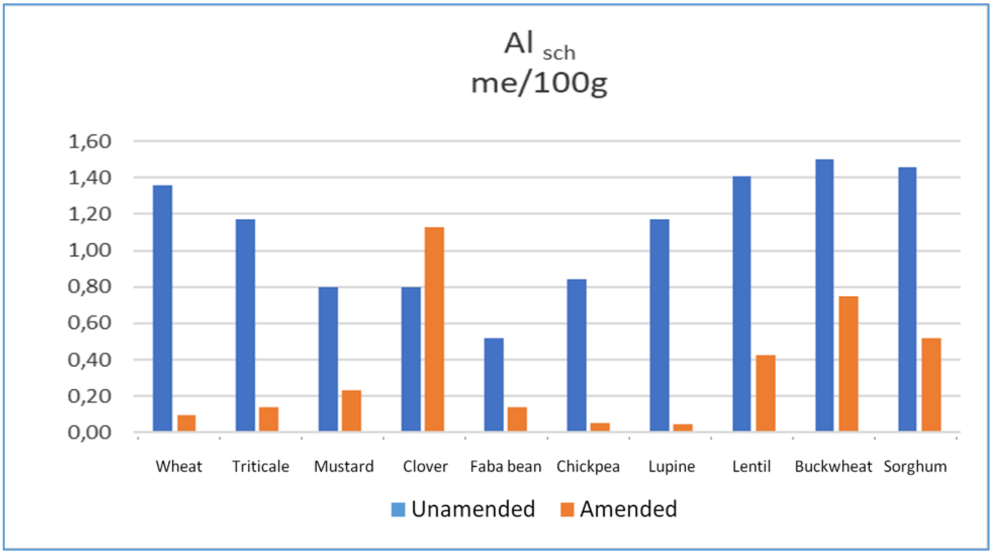

Figure 3. Exchangeable Al contents under the influence of amendments and the tested crops in the experimental field at SCDA Livada

As shown in Tables 1 and 2, in the variants treated with calcium amendment, the base saturation degree ($V_{8.3}$) exhibited higher values compared to the control variants. This increase results from the contribution of Ca^{2+} ions supplied by TerraCalco, which raises the sum of exchangeable bases (SB) and reduces exchangeable acidity (H^+, Al^{3+}), thereby improving the SB/TSH ratio.

The total cation exchange capacity ($T_{8.3}$) is obtained by summing the values of total exchangeable acidity (SH) and the sum of exchangeable base cations (SB), in order to determine the degree of soil base saturation ($V_{8.3}$).

Table 1.
Cation exchange properties of soils amples collected from the unlimed variants

No. Crt.	Identification	Solid efforts						
		SB	Ah	SH(A8.3)	TAh	T_{SH}(T8.3)	VAh	VSH(V8.3)
		me/100g ground					%	%
1	V1-Wheat	3.99	7.47	7.77	11.46	11.76	34.8	33.9
2	V2-Triticale	3.50	6.11	6.45	9.61	9.95	36.4	35.2
3	V3-Mustard	5.25	5.15	5.40	10.40	10.65	50.5	49.3
4	V4-Red clover	7.20	6.96	7.18	14.16	14.38	50.9	50.1
5	V5-Beans	7.59	5.89	5.96	13.48	13.55	56.3	56.0
6	V6-Chickpeas	5.35	4.89	4.91	10.25	10.26	52.2	52.1
7	V7-Lupins	3.70	5.94	6.13	9.63	9.83	38.4	37.6
8	V8-Lentils	3.60	7.17	7.45	10.77	11.05	33.4	32.6
9	V9-Buckwheat	5.35	7.53	7.94	12.88	13.29	41.5	40.3
10	V10-Sorghum	4.38	6.92	7.11	11.29	11.49	38.8	38.1

According to the classification of total acidity (SH), the values obtained for the control variants fall within the ranges characteristic of *low to medium acidity*.
Me/100g sol/ ground

Table 2.
Cation exchange properties of soils amples collected from the limed variants

No. Crt.	Identification	Solid efforts						
		SB	Ah	SH(A8.3)	TAh	T_{SH}(T8.3)	VAh	VSH(V8.3)
		me/100g ground					%	%
1	V1-Wheat	10.90	3.94	5.23	14.83	16.13	73.5	67.6
2	V2-Triticale	7.30	3.09	4.45	10.38	11.74	70.3	62.1
3	V3-Mustard	8.17	2.81	3.64	10.98	11.84	74.4	69.0
4	V4-Red clover	9.44	6.28	7.48	15.71	16.91	60.1	55.8
5	V5-Beans	7.88	2.94	3.57	10.82	11.45	72.9	68.8
6	V6-Chickpeas	6.32	3.04	4.28	9.37	10.60	67.5	59.7
7	V7-Lupins	8.17	3.81	5.13	11.98	13.30	68.2	61.4
8	V8-Lentils	7.98	4.83	6.52	12.81	14.50	62.3	55.0
9	V9-Buckwheat	6.91	5.60	6.01	12.50	12.92	55.2	53.5
10	V10-Sorghum	7.39	5.30	6.08	12.69	13.48	58.3	54.9

For the calcium-amended variants, total acidity values ranged between 3.67 me/100 g soil for the mustard variant—classified as *very low total exchangeable acidity*—and 7.48 me/100 g soil for the clover variant, which falls within the *medium total acidity* class.

The lower total acidity values observed in soils cultivated with mustard can be explained by the fact that species belonging to the *Brassicaceae* family do not fix atmospheric nitrogen and therefore do not generate an additional input of protons (H^+) into the soil. Moreover, under conditions of calcium amendment, the neutralization effect of protons is more pronounced, maintaining acidity at low levels (Quintana-Esteras et al., 2025).

Conversely, the higher acidity values recorded in soils cultivated with clover are mainly due to the process of biological nitrogen fixation carried out by symbiotic *Rhizobium* bacteria. This process releases protons in the rhizosphere, leading to an increase in soil acidity (Zahran, 1999; Haynes, 1983). In addition, the mineralization of nitrogen-rich plant residues may further contribute to acidification (Hinsinger et al., 2003).

As shown in Figure 4**,** the influence of different crop types on the total nitrogen content of soil samples, with and without calcium amendment, is evident.

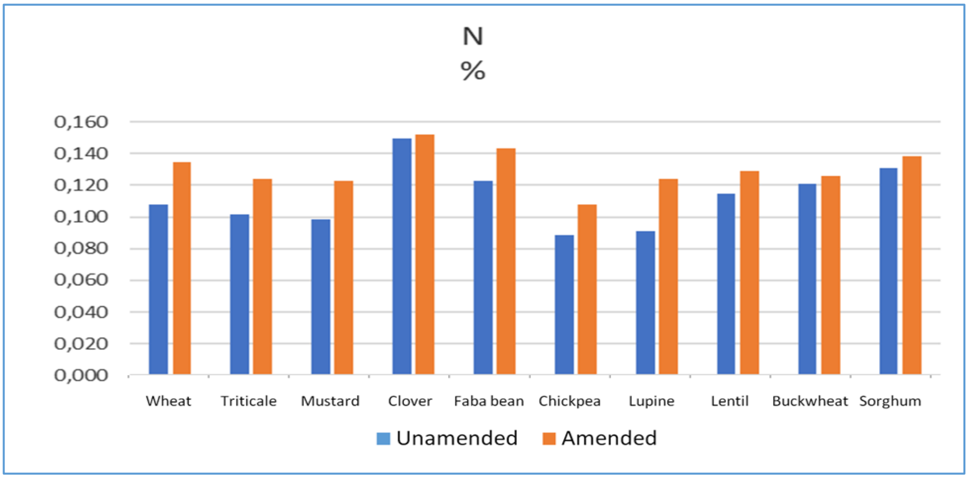

Figure 4. Comparison of total nitrogen content in soil after different crops, under limed and unlimed conditions

For leguminous crops such as clover, faba bean, chickpea, lupine and lentil, higher nitrogen contents were recorded—especially in the limed variants—due to the increased input of organic nitrogen in to the soil, mainly through root residues and nitrogen-fixing nodules. For grasses (wheat, triticale, sorghum), which are considered to have a deep root system, nitrogen mobilization and recycling occur, but the effects on total nitrogen increase are more modest compared to legumes (Ejigu et al., 2023). The nitrogen contents obtained for the tested grasses, ranging between 0.124–0.138 %, were lower than those measured in the clover and faba bean variants.

The nitrogen supply status of the soil in the experimental field places it in the category of low-nitrogen soils (0.100–0.140 %). This can be explained by the pH values, which did no treach the optimal interval of 5.5–7.5 required for mineralization processes. At pH values below 5.0, the proportion of mineralizable nitrogen may decrease to approximately 0.4 % of total nitrogen (Methodology for Agrochemical Soil Analysis, 1981).

As shown in Figure 5, for most tested crops, the organic carbon content of soil sincreased in the calcium-amended variants, corresponding to the category of soils with *moderate organic matter supply*. Liming increases pH, which stimulates microbial and enzymatic activity. Consequently, organic matter (e.g., plant residues, roots) decomposes more rapidly, leading to faster consumption of the organic carbon stored in thesoil—particularly the more labile fractions.

Therefore, after harvest, if the input of organic matter does not compensate for this enhanced mineralization, the net organic carbon content may be lower in limed soils (Tedone et al., 2023).

For clover and faba bean, if calcium amendment accelerates the decomposition of plant residues, the post-harvest soil organic carbon content may be lower than in the control variants. Conversely, in unamended soils, decomposition proceeds more slowly, allow inorganic carbon to accumulate more efficiently from crop residues.

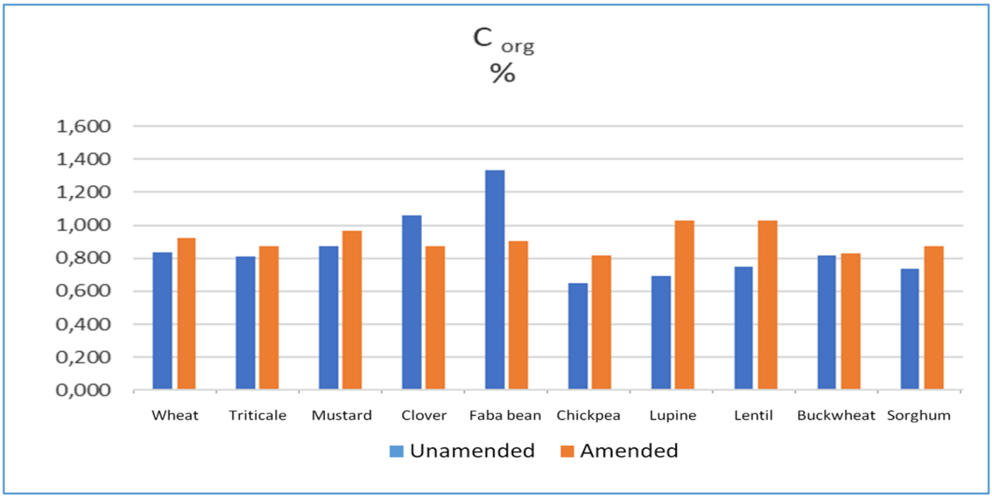

Figure 5. Comparison of soil organic carbon content afterdifferentcrops, underlimedandunlimedconditions

In Figure 6, the variations in the available phosphorus (P_{al}) content of soil sunderlimed and unlimed conditions are presented after the harvest of the tested plant species. In general, the values obtained for bothlimed and control variants indicate a good phosphorus supply status for plant nutrition

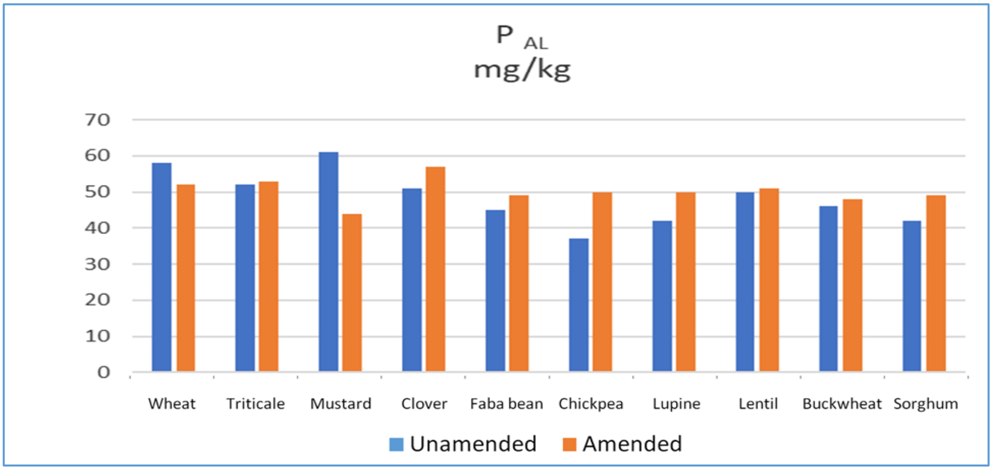

Figure 6. Comparison of available phosphorus content in soil after different crops, under limed and unlimed conditions

Calcium amendment is commonly applied to alleviate soil acidity and improve crop yields on acidic soils; however, its direct effect on mobile phosphorus content is often a slight reduction in measurable values. Conversely, liming enhances phosphorus bioavailability to crops by reducing fixation by Al and Fe compounds (Liao et al., 2020).

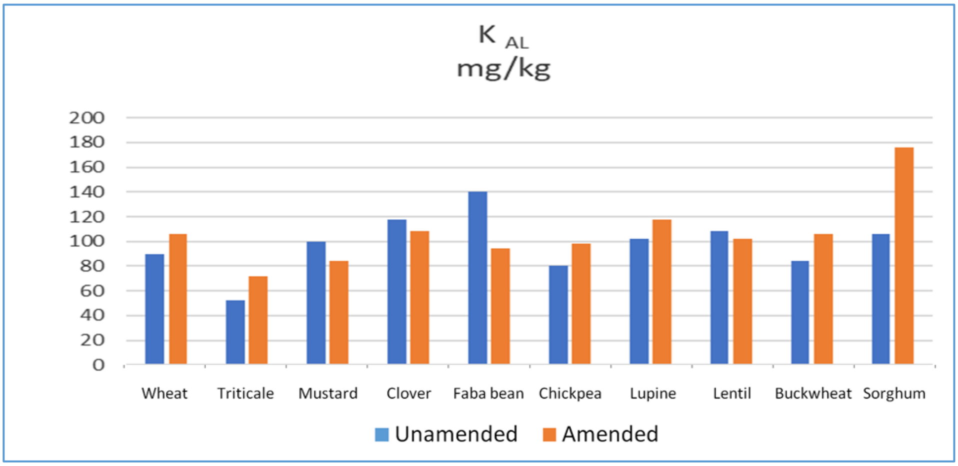

Figure 7. Comparison of available potassium content in soil after different crops, under limed and unlimed conditions

The available potassium (K_{al}) values (Figure 7) obtained for the analyzed variants fall within the category of moderately supplied soils for field crops. On the other hand, calcium amendment tends to slightly reduce the level of mobile K, as determined by ammonium acetate-lactate extraction at pH 3.75, due to Ca^{2+}–K^{+}competition and potential fixation within clay minerals. Never the less, in the long term, liming can prevent K leaching losses and contribute to main taining overall soil fertility (Kebede&Dereje, 2017).

An increase in soil pH follow ingliming directly affects the solubility and availability of micronutrients to plants. As shown in Tables 3 and 4, the content of each micronutrient varied across crops and between limed and unlimed treatments

Table 3.

Microelement contents, mobile forms, and$CaCl_2$-soluble Mg in soil samples collected from the unlimed variants

No. Crt.	Identification	Tests performed				
		Zn	Cu	Fe	Mn	Mg in CaCl
		mg/kg	mg/kg	mg/kg	mg/kg	mg/10g soil
1	V1-Wheat	1.47	2.09	221	75.9	4.48
2	V2-Triticale	1.27	1.41	174	66.7	3.84
3	V3-Mustard	1.81	1.3	154	58.2	6.85
4	V4-Red clover	1.72	3.02	214	66.3	8.59
5	V5-Beans	0.9	1.56	192	59.6	7.05
6	V6-Chickpeas	0.69	1.21	133	64.7	5.22
7	V7-Lupins	1.31	1.52	163	81.9	4.25
8	V8-Lentils	1.59	1.75	199	86.3	5.33
9	V9-Buckwheat	1.42	1.94	216	80.7	6.52
10	V10-Sorghum	1.62	1.95	200	82.6	8.01

Generally, calcium amendment reduces the availability of these micronutrients, posing potential deficiency risks, especially for Zn, Mn, and Fe (Lindsay, 1979; Marschner, 2012).

Table 4.

Microelement contents, mobile forms, and $CaCl_2$-soluble Mg in soil samples collected from the limed variants

No. Crt.	Identification	Tests performed				
		Zn	Cu	Fe	Mn	Mg in CaCl
		mg/kg	mg/kg	mg/kg	mg/kg	mg/10g soil
1	V1-Wheat	1.25	2.77	151	58.2	6.22
2	V2-Triticale	1.38	2.25	138	59.0	6.62
3	V3-Mustard	0.84	1.56	103	36.8	9.96
4	V4-Red clover	1.36	2.56	207	53.5	10.40
5	V5-Beans	1.80	1.71	121	52.2	10.90
6	V6-Chickpeas	0.99	1.97	109	55.7	7.26
7	V7-Lupins	1.52	2.48	176	66.0	8.01
8	V8-Lentils	1.52	2.04	191	54.8	7.23
9	V9-Buckwheat	1.19	2.08	171	64.2	6.83
10	V10-Sorghum	1.23	1.77	123	51.5	8.19

An increase in Cu content after liming represents an intermediate effect resulting from the transition of soil from a strongly acidic to a more “optimal” pH range. Additionally, different crops leave residues with varying compositions of organic ligands (humic and fulvic acids) that can complex Cu, rendering it more “soluble,” which explains the slightly higher values observed in limed variants.

According to the interpretation limits for soil supply status with zinc, copper, and manganese soluble in ammonium acetate–EDTA solution at pH 7.0, the results indicate that the soils fall into the category of low supply for zinc and high supply for copper and manganese.

The increase in extractable Mg ($CaCl_2$-soluble) content after calcium amendment can be explained by several mechanisms. First, the reduction of soil acidity and the alleviation of Al^{3+}-induced sorption favor the release and availability of Mg^{2+} (Lindsay, 1979). Second, if the amendment material had a dolomitic component, it could serve as a direct source of Mg^{2+} (Fageria et al., 2010).

Furthermore, plant residues, particularly from legumes or crops with deep root systems, contribute to Mg recycling and mobilization in the soil through decomposition and root exudation (Marschner, 2012). Finally, the increase in Ca^{2+} concentration following liming can enhance cation exchange processes, promoting Mg^{2+} desorption and transfer into the soluble fraction (Kabata-Pendias, 2011).

In this context, current research focuses on establishing optimal liming rates, optimizing soil management practices, and selecting plant species less sensitive to acidity, capable of ensuring high and stable yields under varying soil conditions.

CONCLUSIONS

The application of TerraCalco improved soil reaction, thereby reducing the phytotoxicity of exchangeable aluminum and increasing the availability of essential nutrients required for plant growth and development.

The amelioration of acidic soils through TerraCalco application demonstrated significant effects on the soil's supply of macro- and micronutrients, reflected in higher nutrient availability and improved uptake in all ten tested plant species.

The results provide a solid scientific foundation for technological recommendations aimed at enhancing resource-use efficiency, improving soil fertility, and supporting sustainable agricultural practices.

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