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Evaluation of Nutrient Status and Cation Balance in Wheat Cultivated on Serpentine-Derived Soils

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Abstract

Serpentine soils are derived from the serpentinization of ultramafic parent materials and are characterized by distinctive chemical and physical properties. The combined stress conditions imposed on plants growing in these soils are commonly known as the "serpentine problem." The present study was conducted to evaluate the nutritional status of wheat cultivated on serpentine-derived soils and to investigate soil–plant relations. A total of 15 soil and plant samples were collected from serpentine-origin agricultural fields located in the İslâhiye–Nurdağı region. Selected macro- and micronutrients together with several basic soil properties were determined in soil samples, whereas nutrient element analyses were performed in plant samples. The obtained data were further evaluated to assess the effects of soil–plant relationships and cation ratios on wheat nutrition. The soils of the study area were generally characterized as neutral to slightly alkaline, low in lime content, and non-saline. Soil analyses revealed high exchangeable Mg concentrations, whereas Ca levels were comparatively lower. In addition, available P and exchangeable K concentrations were determined to be above sufficiency levels. Mean concentrations were 37.2 mg kg^{-1} for P, 239.67 mg kg^{-1} for K, 558 mg kg^{-1} for Ca, and 2615 mg kg^{-1} for Mg. The average Fe, Zn, Cu, and Mn concentrations in soils were determined as 25.67, 0.95, 1.89, and 3.79 mg kg^{-1}, respectively. Soil Ni concentrations ranged between 14.88 and 112.06 mg kg^{-1}, confirming the characteristic accumulation of Mg and Ni in serpentine soils. Ni concentrations ranged between 14.88 and 112.06 mg kg^{-1}, confirming the characteristic accumulation of Mg and Ni in serpentine soils. Evaluation of cation ratios demonstrated that low Ca/Mg and high Mg/K ratios reflected a pronounced cation imbalance. Plant analyses indicated that the average N, P, and K concentrations in wheat were 4.38%, 0.37%, and 2.07%, respectively. In contrast, plant Ca concentrations were relatively low (0.02–0.13%), whereas the average Mg concentration was determined as 0.33%. Micronutrient concentrations were generally within sufficiency ranges. Evaluation of soil and plant data revealed a negative correlation between soil Mg/K ratio and plant K concentration, while elevated Mg levels were also associated with plant Ca and K nutrition. Overall, the findings demonstrated that Mg dominance in serpentine soils induces cation antagonism, thereby adversely affecting particularly Ca and K nutrition in wheat.

Keywords: *Serpentine soils, Wheat nutrition, Cation antagonism, Magnesium dominance*

Introduction

Serpentine soils are unique edaphic environments derived from the weathering of ultramafic rocks such as peridotite, dunite, and serpentinite. These soils possess distinctive physical and chemical characteristics that distinguish them from most agricultural soils. The mineralogical composition of serpentine parent materials typically results in elevated concentrations of magnesium (Mg), nickel (Ni), chromium (Cr), and cobalt (Co), whereas essential plant nutrients such as calcium (Ca), potassium (K), nitrogen (N), and phosphorus (P) generally occur at comparatively low levels (Brady et al., 2005; Oze et al., 2008).

The combined effects of nutrient deficiencies, nutrient imbalances, and potentially toxic metal levels create a stressful environment for plant growth, a condition commonly referred to as the serpentine syndrome or the serpentine problem. Among these constraints, the predominance of exchangeable magnesium (Mg) relative to calcium (Ca) is considered one of the most distinctive characteristics of serpentine soils. Low Ca/Mg ratios adversely affect root development, membrane stability, and nutrient uptake, thereby imposing significant limitations on plant growth and productivity (Proctor, 2003; Kazakou et al., 2008). Furthermore, elevated Mg concentrations may suppress Ca and K uptake through competitive interactions among cations at root uptake sites (White & Broadley, 2003).

In Türkiye, particularly in the Eastern Mediterranean region, ultramafic and serpentine formations cover extensive areas. Despite their challenging chemical properties, some of these soils are widely used for agricultural production. However, information on soil nutrient availability, cation balance, and soil–plant nutrient relationships under serpentine conditions remains limited. A better understanding of these interactions is essential for developing effective nutrient management strategies and improving crop productivity on serpentine-derived agricultural soils. While previous studies on serpentine ecosystems have primarily focused on natural vegetation, metal tolerance, and ecological adaptation, comparatively little attention has been given to nutrient imbalances affecting agricultural crops such as wheat. Therefore, the present study was conducted to evaluate the nutritional status of wheat grown on serpentine-derived soils in the İslâhiye–Nurdağı region of southeastern Türkiye. Particular emphasis was placed on determining soil nutrient availability, exchangeable cation ratios, and plant nutrient concentrations.

Materials and Methods

Study area

The study was conducted in serpentine-derived agricultural fields located in the İslâhiye–Nurdağı region of southern Türkiye, within the Amanos Ophiolite Belt (Figure 1). The study area is underlain by widespread ophiolitic rocks, and the soils have predominantly developed from serpentinized ultramafic parent materials. The Amanos Belt consists of ophiolitic units emplaced during the closure of the Neo-Tethys Ocean and represents one of the most important ultramafic rock assemblages in southern Türkiye (Duman et al., 2017). Ultramafic rocks, including harzburgite, dunite, and serpentinite, are widely distributed throughout the region and have undergone extensive serpentinization. Consequently, the soils developed on these parent materials exhibit the characteristic physical and chemical properties of serpentine soils (Yapıcı et al., 2022).

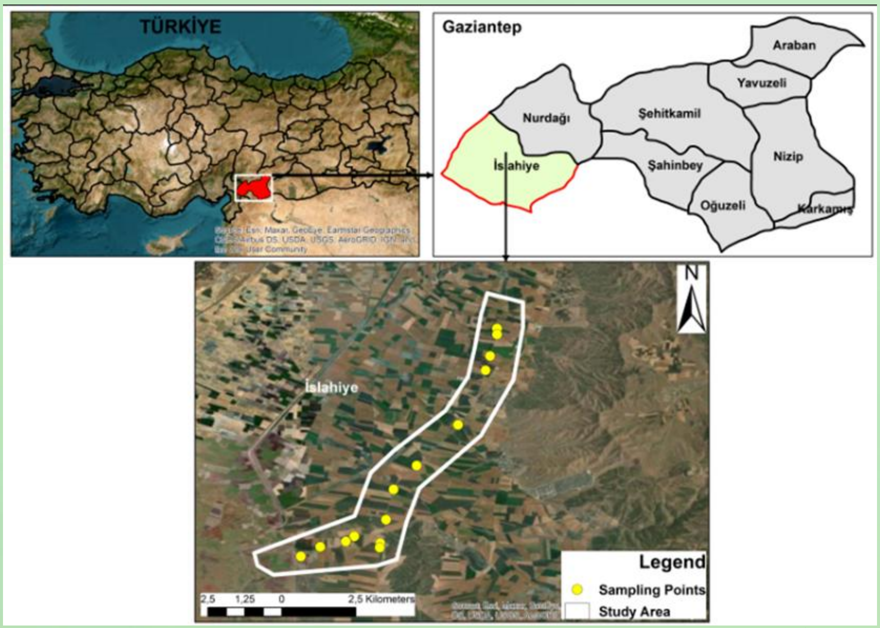

Figure 1. Map of the study area showing the distribution of soil sampling sites in the İslâhiye–Nurdağı region, southern Türkiye

Soil and Plant Analyses

Soil pH and electrical conductivity (EC) were measured in saturated soil paste extracts following the procedures of Black (1965) and Richards (1954), respectively. Calcium carbonate ($CaCO_3$) content was quantified using a Scheibler calcimeter (Klute, 1986). Particle-size distribution was determined by the hydrometer method (Bouyoucos, 1951), whereas soil organic matter was analyzed using the Walkley–Black method (Nelson & Sommers, 1996). Exchangeable K, Ca, and Mg were extracted with 1 N ammonium acetate (NH_4OAc) and subsequently quantified according to Helmke & Sparks (1996).

Plant samples were dried at 65°C, finely ground, and digested using the wet digestion procedure described by Jones & Case (1990). For each analysis, 0.50 g of ground plant material was treated with 5 mL HNO_3 and 4 mL $HClO_4$ and heated until complete digestion was achieved. The digest was then filtered and brought to the required volume with deionized water. Potassium, Ca, and Mg in both soil extracts and plant digests were quantified using an Agilent 240AA Atomic Absorption Spectrophotometer (AAS).

Statistical Analysis

The experimental data were evaluated using IBM SPSS Statistics 23.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics, including minimum, maximum, mean, and standard deviation values, were calculated for all soil and plant variables. Relationships among soil exchangeable cations (K, Ca, Mg), cation ratios (Ca/Mg, Ca/K, and Mg/K), and nutrient concentrations in wheat leaves were assessed by Pearson correlation analysis using JMP software (SAS Institute Inc., Cary, NC, USA). All figures were prepared using Microsoft Excel.

Results and Discussion

Physicochemical Characteristics of the Study Area Soils

The physicochemical properties of the study area soils are presented in Table 1. Soil pH ranged from 6.60 to 7.30, with a mean value of 7.11. Electrical conductivity (EC) ranged from 63.50 to 236.00 µS cm^{-1}, with an average of 121.96 µS cm^{-1}. Lime ($CaCO_3$) content varied between 1.09% and 15.15%, with a mean value of 2.75%, whereas soil organic matter content ranged from 2.01% to 3.49%, averaging 2.57%. Overall, the study area soils were characterized by neutral pH, non-saline conditions, low lime content, and moderate organic matter levels.

Table 1. Descriptive statistics of selected physicochemical properties of the study area soils

	pH	*EC*	*Lime*	*OM*
		(µS/cm)	%	
Min	6.60	63.50	1.09	2.01
Max	7.30	236.00	15.15	3.49
Mean	7.11	121.96	2.75	2.57

Macro-nutrient Status of the Study Area Soils

The concentrations of selected soil macronutrients are presented in Figure 2. The serpentine-derived soils of the study area were characterized by high Mg and low Ca contents. Among the exchangeable cations, Mg was the dominant element, with a mean concentration of 2615 mg kg^{-1}, whereas Ca averaged only 558 mg kg^{-1}. Exchangeable K ranged from 65 to 530 mg kg^{-1}, with a mean value of 240 mg kg^{-1}, while available P varied between 15.75 and 57.18 mg kg^{-1}, averaging 37.20 mg kg^{-1} (Figure 2).

According to the sufficiency criteria proposed by Kaiser et al. (2023), the mean exchangeable K concentration was above the critical level for wheat cultivation, whereas available P was also generally within the sufficient range. In contrast, exchangeable Ca was classified as deficient according to Kacar (1995), while exchangeable Mg was classified as very high based on the FAO (1980) guidelines. The pronounced imbalance between Ca and Mg resulted in a low Ca/Mg ratio, which is a characteristic feature of serpentine soils. The coexistence of low Ca availability and excessive Mg accumulation is considered one of the principal chemical constraints limiting plant nutrition in serpentine-derived soils (Kazakou et al., 2008). Accordingly, the application of lime in combination with gyttja, an organic matter-rich natural material that is abundant in the region, has been proposed as an effective strategy to alleviate Ca deficiency and improve cation balance in Mg-dominated soils (Saltalı and Korkmaz, 2015; Saltalı and Yıldırım, 2016; Demir et al., 2017).

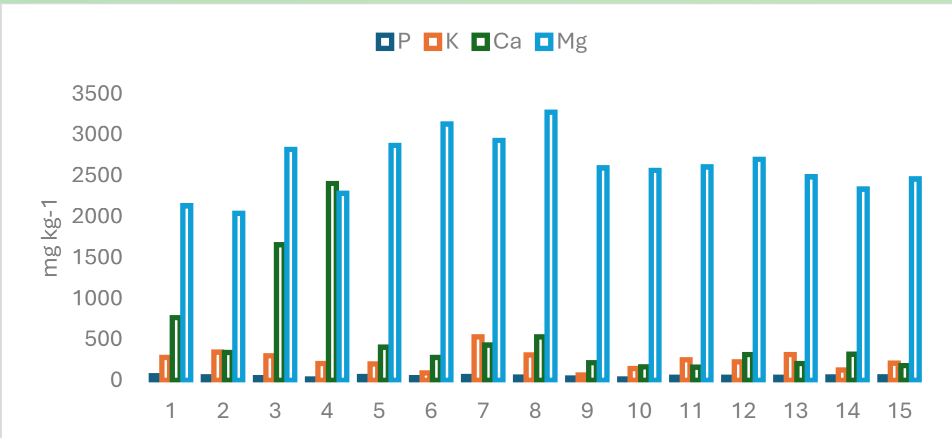

Figure 2. Distribution of available P and exchangeable cations in serpentine-derived soils

Micronutrient Status of the Study Area Soils

The concentrations of selected soil micronutrients are presented in Figure 3. Considerable variation was observed among the analyzed micronutrients. Iron (Fe), zinc (Zn), copper (Cu), and manganese (Mn) averaged 25.67, 0.95, 1.89, and 3.79 mg kg^{-1}, respectively. The most remarkable result was the wide range of Ni concentrations, varying from 14.88 to 112.06 mg kg^{-1}, with an average of 43.73 mg kg^{-1} (Figure 3). This elevated Ni level is characteristic of the nickel enrichment commonly associated with serpentine-derived soils. Based on the sufficiency criteria proposed by Lindsay & Norvell (1978), the analyzed micronutrients were generally within or above the recommended ranges. Furthermore, the elevated Fe and Ni levels are consistent with the geochemical signature of serpentine-derived soils.

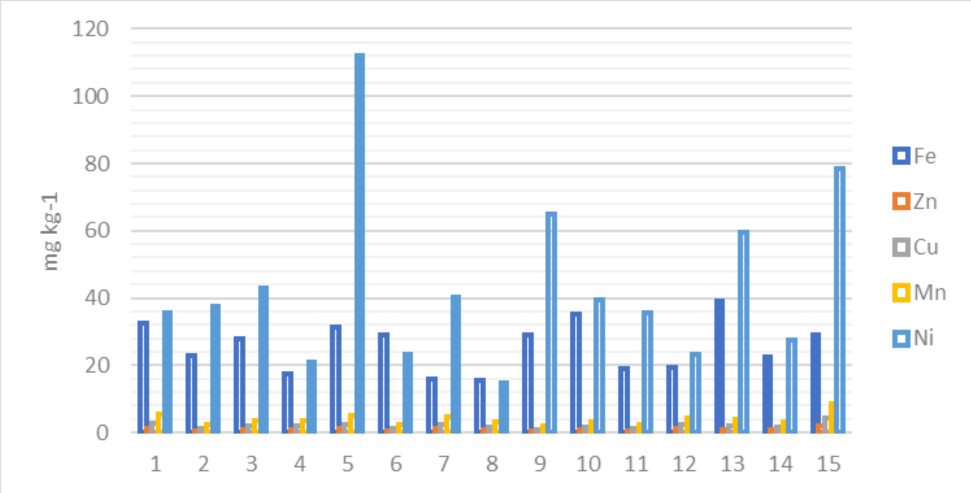

Figure 3. Distribution of DTPA-extractable Fe, Zn, Cu, Mn and Ni concentrations in serpentine-derived soils

Soil Cation Ratios

The mean Ca/K, Ca/Mg, and Mg/K ratios in the study area soils were 5.09, 0.13, and 47.15, respectively (Figure 4). Among the evaluated cation ratios, the lowest value was observed for Ca/Mg, whereas the highest was recorded for Mg/K. These results indicate a pronounced predominance of Mg relative to both Ca and K in the serpentine-derived soils.

The observed cation ratios differed markedly from the ideal values proposed by Albrecht (1975), indicating a pronounced cation imbalance in the study area soils. According to Albrecht, the optimum Ca/Mg, Ca/K, and Mg/K ratios for plant growth are approximately 6.5, 13, and 2, respectively. In contrast, the mean Ca/Mg ratio (0.13) was substantially lower than the recommended value, whereas the mean Mg/K ratio (47.15) greatly exceeded the optimum level. Likewise, the mean Ca/K ratio remained below the recommended value. These findings clearly demonstrate the characteristic Mg dominance and relative Ca deficiency of serpentine-derived soils, indicating that the cation balance is strongly shifted toward Mg. Such cation imbalance is considered a major chemical constraint that may restrict the uptake of Ca and K, thereby adversely affecting plant nutrition. Similar cation imbalance has been reported in previous studies, where low Ca/Mg and high Mg/K ratios were associated with reduced Ca and K uptake and impaired plant nutrition despite sufficient soil nutrient reserves (Aytop et al., 2026). Likewise, elevated Mg relative to Ca and K has been shown to negatively affect K nutrition under field conditions (Aytop et al., 2025). Similar responses have also been reported in peanut, highlighting that balanced Ca–Mg–K relationships are more critical for plant nutrition than the individual concentrations of these cations (Demir et al., 2026).

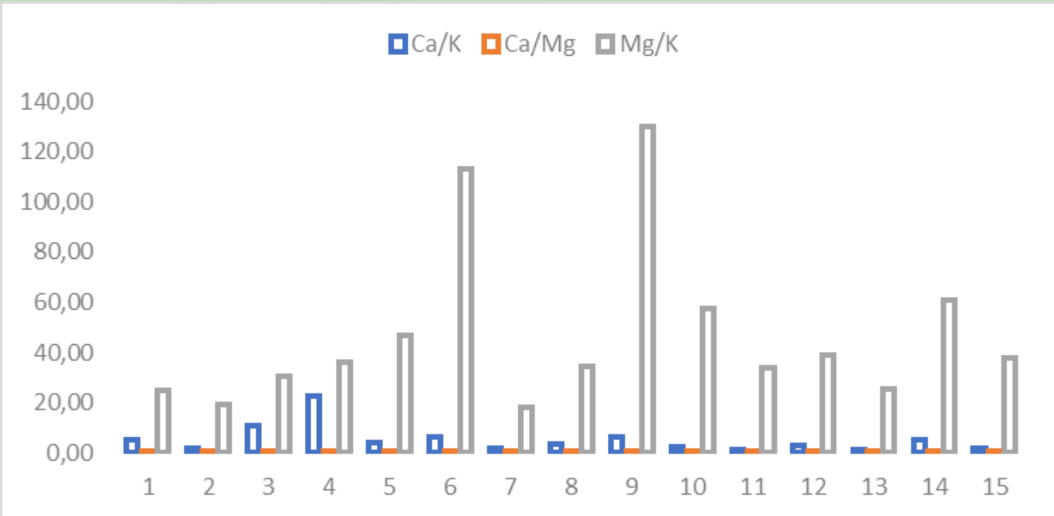

Figure 4. Variations in soil Ca/K, Ca/Mg, and Mg/K ratios among sampling sites

Foliar Macronutrient Concentrations in Wheat

The foliar macronutrient concentrations of wheat varied among the sampling sites (Figure 5). On average, N was the most abundant macronutrient in plant tissues (4.38%), followed by pot K (2.07%). Phosphorus, Ca and Mg averaged 0.31%, 0.06%, and 0.33%, respectively. Based on the sufficiency ranges proposed by Jones et al. (1991) and Reuter and Robinson (1997), the nutritional status of N, P, K, and Mg was generally adequate. In contrast, foliar Ca remained below the sufficiency range. This finding may be attributed to the combined effects of low soil Ca availability and the pronounced Mg/Ca imbalance characteristic of serpentine-derived soils, both of which may restrict Ca uptake by plants (O'Dell & Rajakaruna, 2011).

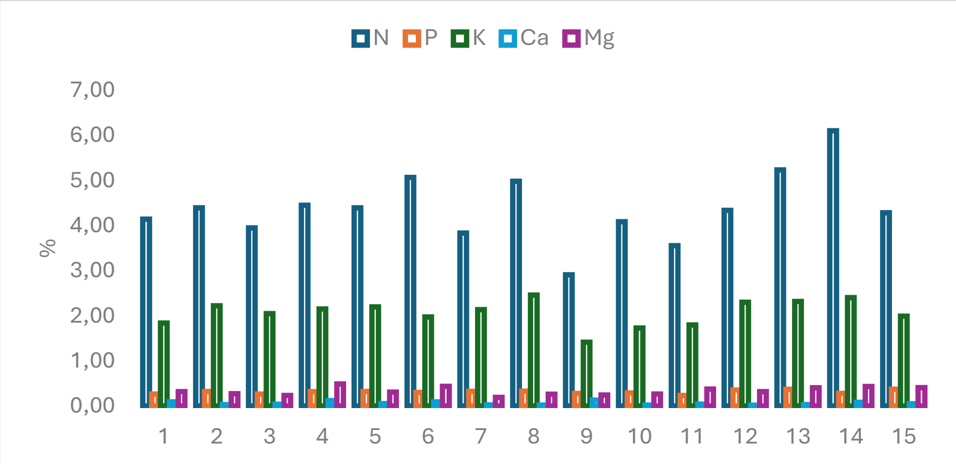

Figure 5. Foliar concentrations of macronutrients in wheat collected from serpentine-derived soils

Foliar Micronutrient Concentrations in Wheat

The foliar micronutrient concentrations of wheat are presented in Figure 6. Overall, the analyzed micronutrients were within the adequate ranges. Iron, Zn, Cu, and Mn averaged 115.80, 30.80, 2.42, and 60.48 mg kg^{-1}, respectively. These values indicate an adequate micronutrient status for wheat according to the sufficiency ranges reported by Jones et al. (1991). In contrast, Ni concentrations were below the detection limit in many samples. In the samples where Ni was detected, concentrations ranged from 0.50 to 7.00 mg kg^{-1}, with a mean value of 2.50 mg kg^{-1} (Figure 6). Despite the elevated Ni concentrations in the soils, the relatively low Ni concentrations in plant tissues suggest that Ni uptake and translocation are regulated by physiological mechanisms within the plant. Previous studies have demonstrated that a substantial proportion of absorbed Ni may be retained in root tissues, thereby limiting its translocation to the shoots through the xylem (Iqbal et al., 2026). Furthermore, despite the elevated Ni concentrations commonly observed in serpentine-derived soils, Ni uptake by plants is often restricted by species-specific physiological mechanisms and the relatively low bioavailability of Ni (Broadley et al., 2012; Brady et al., 2005).

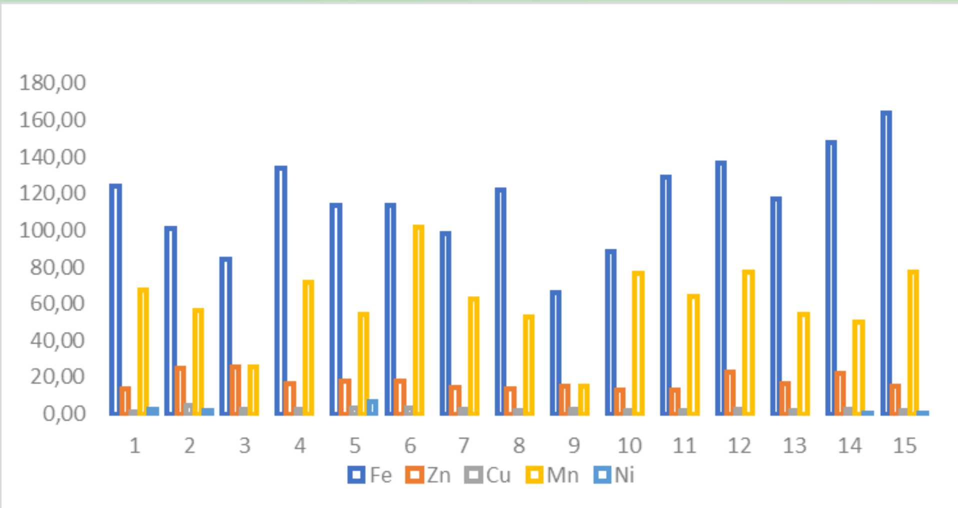

Figure 6. Foliar micronutrient concentrations in wheat grown on serpentine-derived soils

Conclusion

This study demonstrated that the serpentine-derived agricultural soils of the İslâhiye–Nurdağı region exhibit the characteristic features of serpentine soils, including high exchangeable Mg and Ni concentrations together with low Ca levels. Although soil P and K were generally within the sufficient range, the marked deviation of the cation ratios from the recommended values indicated a pronounced Mg-induced cation imbalance. This imbalance was associated with reduced Ca nutrition in wheat and suggests that elevated Mg levels may also restrict K uptake through cation antagonism. In contrast, foliar micronutrient concentrations were generally adequate, and Ni accumulation in plant tissues remained limited despite the elevated Ni concentrations in the soils. Overall, these findings demonstrate that the nutritional status of wheat grown on serpentine-derived soils should be evaluated not only in terms of nutrient concentrations but also by considering cation balance. Therefore, nutrient management strategies aimed at improving Ca and K nutrition while mitigating the effects of Mg dominance are essential for sustainable wheat production on serpentine-derived soils.

References

Albrecht, W. A. (1975). The Albrecht papers. Vol. 1: Foundation concepts. Acres USA, Kansas City, MO.

Aytop, H., Demir, Ö. F., & Yılmaz, C. H. (2026). Assessment of Ca, Mg, and K nutrition in cotton through the base cation saturation ratio approach in southern Turkey. *Journal of Elementology*, 31(2), 377-399. https://doi.org/10.5601/jelem.2026.31.1.3769

Aytop, H., Yılmaz, C. H., & Demir, Ö. F. (2025). Spatial variability of cotton potassium nutrition in relation to soil cations in agricultural fields. Eurasian Journal of Soil Science, 14(4), 398-406. https://doi.org/10.18393/ejss.1759801

Black, C. A. (1965). Methods of Soil Analysis, Agron., No: 9, *American Society of Agronomy*, Madison, Wisconsin. USA.

Bouyocous, G. L. (1951). A recalibration of hydrometer method for making mechanical analysis of soils. *Agronomy Journal*, 43, 434–438.

Brady, K. U., Kruckeberg, A. R., & Bradshaw Jr. H. D. (2005). Evolutionary ecology of plant adaptation to serpentine soils. *Annual Review of Ecology, Evolution, and Systematics*, *36*(1),243-266. https://doi.org/10.1146/annurev.ecolsys.35.021103.105730

Broadley, M., Brown, P., Cakmak, I., Rengel, Z., & Zhao, F. (2012). Function of nutrients: micronutrients. In Marschner's mineral nutrition of higher plants (pp. 191-248). *Academic Press*. https://doi.org/10.1016/B978-0-12-384905-2.00007-8

Demir, Ö. F., & Dikici, H. (2025). Determination of plant nutrition status of corn in serpentine soils with different diagnosing methods. *Communications in Soil Science and Plant Analysis*, 56(19), 2785-2801. https://doi.org/10.1080/00103624.2025.2526785

Demir, O. F., Dikici, H., & Yilmaz, K. (2017). Effect of gyttja and nitrogen applications on plant growth of red pepper (Capsicum annum L.) in the soils formed on the different parent materials. *Turkish Journal of Agriculture-Food Science and Technology*, 5, 807-813.

Demir, Ö.F., Beycioğlu, T., Özcan, O.B., Özkiliç, D., & Yilmaz, C.H. (2026). Calcium, Magnesium and Potassium Nutrition of Peanut as Influenced by Soil Cation Ratios. *Legume Research-An International Journal*, 1, 11. https://doi.org/10.18805/LRF-938.

Duman, T. Y., Robertson, A. H., Elmacı, H., & Kara, M. (2017). Palaeozoic-Recent geological development and uplift of the Amanos Mountains (S Turkey) in the critically located northwesternmost corner of the Arabian continent. *Geodinamica Acta*, 29(1), 103-138. https://doi.org/10.1080/09853111.2017.1323428

FAO (1980). Soil and plant testing as a basis of fertilizer recommendations (FAO Soils Bulletin No. 38), Food and Agriculture Organization of the United Nations, Rome.

Helmke, P. A., & Sparks, D. L. (1996). Lithium, Sodium, Potassium, Rubidium, and Cesium. In Methods of Soil Analysis (eds D.L. Sparks, A.L. Page, P.A. Helmke, R.H. Loeppert, P.N. Soltanpour, M.A. Tabatabai, C.T. Johnston and M.E. Sumner). https://doi.org/10.2136/sssabookser5.3.c19

Iqbal, M., Mukhtiar, A., Mahmood, A., Javed, W., Khan, S. A., Qari, S. H., & Ullah, S. (2026). Nickel bioaccumulation, physio-biochemical responses, phytotoxicity, and its mitigation strategies in plants. *Discover Plants*, 3(1), 59. https://doi.org/10.1007/s44372-026-00551-x

Jones, J. B. Jr., & Case, V. W. (1990). Sampling, Handling, and analyzing plant tissue samples, chapter 15. In R.L. Westerman (ed) *Soil Testing and Plant Analysis*, Third Edition, SSSA, Madison, Wisconsin, USA, pp. 390-420.

Jones, Jr. J.B, Wolf, B., & Mills H. A. (1991). Plant Analysis Handbook. Micro-Macro *Publishing Inc. Georgia*, U.S.A. 213 pp.

Kacar, B. (1995). Toprak Analizleri. Bitki ve Toprağın Kimyasal Analizleri: III. *Ankara Üniversitesi Ziraat Fakültesi Eğitim Araştırma ve Geliştirme Vakfi Yayınları*, No: 3, Ankara, pp. 705.

Kaiser, D. E., Fernandez, F., Wilson, M., Coulter, J. A., & Piotrowski, K. (2023). Fertilizer guidelines for agronomic crops in Minnesota, USA

Kazakou, E., Adamidis, G. C., Baker A. J., Reeves, R. D., Godino, M., & Dimitrakopoulos, P. G. (2010). Species adaptation in serpentine soils in Lesbos Island (Greece): metal hyperaccumulation and tolerance. *Plant and Soil*, 332:369-385. https://doi.org/10.1007/s11104-010-0302-9

Klute, A., (1986). Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods (2nd Edition), A. Klute, Ed., 1986, *American Society of Agronomy*, Agronomy Monographs 9(1), Madison, Wisconsin, 1188 pp.

Turkish Science and Technology Publishing (TURSTEP)
www.turstep.com.tr

Lindsay, W. L., & Norvell, W. A. (1978). Development of A DTPA Soil Test for Zinc, Iron, Manganese and Copper. *Soil Science Society of American Journal*, 42, 421-428. https://doi.org/10.2136/sssaj1978.03615995004200030009x

Nelson, D.W., & Sommers, L.E. (1996). Total Carbon, Organic Carbon, and Organic Matter. In D.L. Sparks (Ed) Methods of Soil Analysis, Part 3, 961-1011.Chemical Methods, *SSSA Book Series*, Number 5, SSSA., Madison, WI, 1390. https://doi.org/10.2136/sssabookser5.3.c34

O'Dell, R. E., & Rajakaruna, N. (2011). Intraspecific variation, adaptation, and evolution. In Serpentine: The Evolution and Ecology of a Model System (pp. 97–137). *University of California Press*. https://www.jstor.org/stable/10.1525/j.ctt1pnqkb.10

Oze, C., Fendorf, S., Bird, D. K., & Coleman, R. G. (2008). Chromium geochemistry and bio accessibility in serpentinized ultramafic rocks and soils from the Franciscan Complex, California. *American Journal of Science*, 308(6), 739–761.

Proctor, J., & Woodell, S. R. J. (1975). The ecology of serpentine soils. *Advances in Ecological Research*, 9, 255–366. https://doi.org/10.1016/S0065-2504(08)60291-3

Richard, L.A. (1954). Diagnosis and Improvement of Saline and Alkali Soils. Agriculture Handbook, No:60, U.S. *Department of Agriculture. U.S. Government Printing Office*, Washington D.C., 166.

Saltalı, K., & Korkmaz, K. (2015). Gidya organomineral toprak düzenleyicisi olarak değerlendirilebilir mi? In 4. Uluslararası Katılımlı Toprak ve Su Kaynakları Kongresi Bildiri Özet Kitabı (p. 15). Kahramanmaraş, Türkiye. 1–4 September 2015.

Saltalı, K., & Yıldırım, Ö. F. (2016). Kuru koşullarda çerezlik ayçiçeği (*Helianthus annuus* L.) yetiştiriciliğinde gidya uygulamasının bazı toprak ve bitki özelliklerine etkisi. *KSÜ Doğa Bilimleri Dergisi*, 19(1), 84-90.

White, P. J., & Broadley, M. R. (2003). Calcium in plants. *Annals of botany*, 92(4), 487-511. https://doi.org/10.1093/aob/mcg164

Yapici, N., sinda Ngbangandimbo, G. C., & Nurlu, N. (2022). Geodynamic significance and genesis of chromitites from the Islahiye ophiolite (Gaziantep, SE Anatolia) as constrained by platinum group element (PGE) compositions and mineral chemistry characteristics. *Acta Geochimica*, 41(5), 741-752. https://doi.org/10.1007/s11631-022-00541-2