Kirkuk University Journal for Agricultural Sciences
ISSN:2958-6585
https://kujas.uokirkuk.edu.iq

RESEARCH ARTICLE
https://doi.org. 10.58928/ku26.17303

Magnesium Fractionation and their Relationships with physiochemical Properties in Calcareous Soils of Duhok Governorate, Iraqi Kurdistan

Payezan Ihsan Ramadhan[1] **Lazkeen Ahmed Merween Mehmedany[1]**
[1]*Department of Soil and Water Sciences, College of Agriculture, Duhok University, Duhok, IRAQ.*
*Corresponding Author: Payezan.ramadhan@uod.ac

Received:25/10/2025 **Revised: 11/ 01/2026** **Accepted: 11/08/2026** **Published: 01/09/2026**

ABSTRACT

This study was conducted to evaluate the distribution of magnesium Fractions and their relationship with soil properties in ten representative calcareous soils from the Duhok governorate, Iraqi-Kurdistan region, including Baedra, Sulav, Rashank, Sarsing, Qadish, Heteet, Darhozan, Mahet, Girguran, and Zawita. Soil samples were air-dried, ground, and sieved to 2 mm to assess physical and chemical properties as well as magnesium forms, including organic, acid-soluble, exchangeable, mineral, and total magnesium. The studied soils exhibited slightly alkaline pH, calcareous characteristics, and textures ranging from clay to sandy clay loam, with non-saline conditions. Organic magnesium constituted a small portion of total magnesium (approximately 6-9%), showing a strong positive correlation with organic matter and moderate correlations with potassium and itself. Acid-soluble magnesium represented 35-52% of total magnesium and was positively correlated with organic matter and exchangeable magnesium. Exchangeable magnesium accounted for roughly 11-21% of total magnesium and correlated strongly with soil pH and active calcium carbonate content. Mineral magnesium comprised 21-56% of total magnesium and correlated significantly with exchangeable magnesium. Total magnesium showed significant positive relationships with organic matter, exchangeable magnesium, and acid-soluble magnesium, highlighting the interconnectedness of these fractions in calcareous soils. These findings indicate that exchangeable and acid-soluble magnesium are the most influential fractions, emphasizing the importance of managing soil organic matter and carbonate levels to optimize magnesium availability. This, in turn, has implications for soil fertility, crop nutrition, and sustainable management practices in calcareous soils of the Duhok. By focusing on essential findings and their practical relevance, this study provides a clear overview of magnesium fraction dynamics, offering guidance for improved soil management and agricultural productivity.

***Keywords*:** Total Mg, Mineral Mg, exchangeable Mg, acid-soluble Mg, organic Mg.

INTRODUCTION

Magnesium (Mg) is a necessary nutrient element for plant growth and reproduction [1]. The total magnesium content in soils varies widely, ranging from 0.05 to 0.5%, depending on the amount present in the parent material [2]. Although magnesium is the eighth most abundant mineral on Earth, making up approximately 2% of the crust, 90-98% of soil magnesium is bound within the crystal lattice of primary minerals and is largely unavailable for plant uptake. The release of plant-available magnesium from soils is influenced by weathering intensity, soil moisture, soil pH, and root-microbial interactions [3]. Primary silicate minerals such as hornblende, augite, olivine, talc, serpentine, chlorite, and biotite serve as magnesium sources, while dolomite ($CaCO3 \cdot MgCO_3$) remains the main source for soil fertility management [4, 5].

In plants, magnesium plays a key role in chlorophyll synthesis, enzyme activation, energy transfer, protein synthesis, and photosynthesis. Plants absorb magnesium as the Mg^{2+} ion, which is mobile within the plant and can move from older to younger tissues [6, 7, 8]. Adequate magnesium is essential for crops like maize and common bean to efficiently capture solar energy for growth and productivity [9]. Only about 20% of plant magnesium is bound to chlorophyll, while the remaining 80% exists in more mobile forms [10]. Soil magnesium exists in different fractions- exchangeable (adsorbed on mineral and organic colloids), non-exchangeable (structural within minerals), and dissolved in soil solution (5-50 mg L^{-1}) [12]. Thermodynamic equilibrium exists among these fractions, with most magnesium present in the non-exchangeable form derived from primary and secondary clay minerals [13]. The proportion of each fraction depends on soil parent material, degree of weathering, clay content, and mineralogy [11]. Exchangeable, organic-complexed, acid-soluble, mineral, and total magnesium in soils have been reported to range from 0.64 to 2.10, 0.12 to 0.63, 2.52 to 5.25, 2.94 to 5.04, and 7.35 to 12.60 cmol kg^{-1}, respectively [14]. Acid-soluble Mg contributed approximately 28.2% of total Mg, exchangeable Mg 14%, and mineral Mg the largest fraction.

The relative contributions of magnesium fractions generally follow the order: mineral > acid-soluble > exchangeable > water-soluble > organic-complexed. Exchangeable Mg represented 2.4–21%, organic Mg 0.12–6.6%, acid-soluble Mg 2–56%, and mineral Mg 23–82% of total soil Mg. These proportions demonstrate that most soil magnesium is bound in primary minerals, limiting immediate availability to crops [15]. Predicting magnesium availability to crops is complex due to interactions among environmental factors (rainfall timing and amount), site-specific conditions (soil type, nutrient interactions), and crop species [12]. Plant access to magnesium depends primarily on the exchangeable fraction and its saturation relative to other cations in the soil [16].

Despite the importance of magnesium in soil fertility and plant nutrition, there is limited information on its different fractions in calcareous and non-calcareous soils of the Duhok governorate, Iraqi Kurdistan. Therefore, this study aims to quantify magnesium fractions in ten representative soils and investigate how soil physicochemical properties influence magnesium availability, providing guidance for improved soil fertility management in the region.

Materials and methods

2.1. Determine physicochemical properties of Soils:

Soil particle size distribution was determined using the hydrometer method [17], soil pH was measured in a 1:2 soil-water suspension with a pH meter (HI 9023) [18], electrical conductivity (EC) was assessed in the same extract using a conductivity/TDS meter (HI-9635) and expressed as dS m^{-1} at 25°C [19], and soil organic carbon was quantified by the Walkley-Black method, in which organic matter is oxidized with potassium dichromate ($K_2Cr_2O_7$) in concentrated H_2SO_4 and the remaining $K_2Cr_2O_7$ is back-titrated with ferrous sulfate heptahydrate [20].

To estimate cations and anions, soil extract (1:2 soil: water) was utilized in the manner described below: Ammonium purpurate was employed as an indicator, and the pH of the solution was raised to 12 using (NH_4OH) for calcium determination. Eriochrom Black-T was then used to adjust the pH 10 for calcium + magnesium determination. The titration method was utilized to estimate soluble calcium and magnesium (Ca^{2+} and Mg^{2+}) with (EDTA-2Na) (*0.02 N*) [18]. Following calibration with standard solutions in accordance with [21], the Flame photometer equipment model (JENWAY/PFP7) was used to determine soluble sodium and potassium (Na^+ and K^+).

In a 1:2 soil-water extract, carbonate and bicarbonate (CO_3^{2-} + HCO_3^-) were determined by titration with 0.01 N sulfuric acid using phenolphthalein and methyl orange as indicators [21]. Chloride (Cl^-) was measured by titration with $AgNO_3$ using K_2CrO_4 as an indicator [21], and sulfate (SO_4^{2-}) was calculated from the difference between the total equivalents of dissolved cations and anions [22]. Total carbonate was determined by treating a known weight of soil with 1 N hydrochloric acid in a Calcimeter [23], while active carbonate was quantified by treating the soil with 0.2 M ammonium oxalate followed by titration with 0.2 M potassium permanganate [24].

The cation exchange capacity (CEC) was determined using a flame photometer (JENWAY FFP7). The procedure involved saturating the soil exchange sites with sodium ions using 1N sodium acetate (pH 8.2). Soluble sodium was then removed by washing with 95% ethanol, and the exchangeable sodium was subsequently displaced using 1N ammonium acetate (pH 7.0) [24]. Exchangeable Ca, Mg, K, and Na were extracted with ammonium acetate buffered at pH 7.0 [25]. Exchangeable Ca and Mg concentrations were measured by atomic absorption spectrophotometry, whereas K and Na were quantified using flame emission.

2.2. Determine Forms of Magnesium:

The sequential fractionation process described by [26], was used to identify the various fractions of calcium and magnesium in the soil samples. After being crushed, one gram of the sample was run through a 35 mesh sieve and put through a series of treatments. The organic complexed (Or-c) fraction was extracted by oxidizing the residue with a 10% H_2O_2 solution after the exchangeable fraction was extracted using *1N* neutral ammonium acetate. In order to eliminate the acid-soluble fraction, it was additionally treated with *1N* HNO_3. The Mineral fraction was then broken down by digesting the residue using a tri-acid mixture. The water soluble fraction was estimated using a modified [27], procedure and the total content was ascertained on a separate sample by digesting with 70% $HClO_4$ in accordance with [28], method.

2.3. Statistical Analysis:

Data analysis was performed using Minitab 19 statistical software. Pearson correlation coefficients were calculated to assess the relationships between soil physicochemical properties, exchangeable cations, soluble ions, and the different magnesium fractions (total, mineral, exchangeable, acid-soluble, and organic). Statistical significance was evaluated at the 0.05 and 0.01 probability levels.

Results and Discussions

3.1. Physico-chemical properties of soils

The characteristics of the soils are presented in Tables 1 and 2. Textures ranged from clay to sandy clay loam, with generally high clay contents across the sites. The dominant soluble cations followed the order Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}, while soluble anions followed HCO_3^- > SO_4^{2-} > Cl^-, with Heteet soil showing the highest levels of Ca^{2+} and HCO_3^-. All soils were non-saline, as indicated by their low electrical conductivity values (Table 3), and EC showed strong associations with the major ions listed in Table 4. Soil pH ranged from slightly neutral to mildly alkaline, with the lowest value recorded in Heteet soil, possibly due to its elevated sulfate content. Total and active calcium carbonate contents varied widely across locations, confirming the calcareous nature of the soils and reflecting differences in parent material. Cation exchange capacity (CEC) also differed among sites, with higher values generally occurring in soils containing more clay and organic matter, consistent with previous findings for Vertisols [29, 30, 31]. Organic matter levels were low overall, with the highest value occurring in Sarsing soil, likely due to slower mineralization and greater surface residue accumulation. Organic matter also showed a positive association with exchangeable potassium.

Table 1: Particle Size Distribution of Soil Samples ($g \cdot kg^{-1}$) of studied soils.

No	Soil Samples	Sand	Silt	Clay	Texture
1	Baedra	8.0	518.0	474.0	Silty Clay
2	Sulav	367.0	284.0	349.0	Clay Loam
3	Rashank	451.0	209.0	340.0	Silty Clay Loam
4	Sarsing	442.0	284.0	274.0	Clay Loam
5	Qadish	251.0	309.0	440.0	Clay
6	Heteet	467.0	243.0	290.0	Silty Clay Loam
7	Darhozan	276.0	399.0	325.0	Clay Loam
8	Mahet	76.0	418.0	506.0	Silty Clay
9	Girguran	51.0	363.0	586.0	Clay
10	Zawita	301.0	355.5	343.5	Clay Loam

3.2 Forms of magnesium in soils

3.2.1 Organic magnesium

The organic magnesium in studied soils ranged between (6.00 – 13.62) mg. kg^{-1} soil (Table, 5), the low value found in Heteet soil and the high rate in Zawita soil, this consistent with the low and high organic matter content of the two soils (13.8 and 47.4 g. kg^{-1}) respectively. This range of organic Mg consist (5.96 – 8.86) % of the total Mg.

Table 2: Particle Size Distribution of Soil Samples of studied soils.

No	Soil Samples	Soluble Cation and Anion (Meq.L^{-1})						
		K	Mg	Ca	Na	Cl	HCO3	SO_4
1	Baedra	0.23	1.19	3.57	0.13	0.23	1.60	2.81
2	Sulav	0.13	1.80	1.08	0.21	0.22	1.70	0.94
3	Rashank	0.08	1.59	0.65	0.10	0.12	1.59	0.18
4	Sarsing	0.50	1.92	2.39	0.30	0.29	1.90	1.80
5	Qadish	0.50	2.52	2.60	0.23	0.18	2.50	1.90
6	Heteet	0.14	2.58	6.60	0.26	1.53	3.70	3.96
7	Darhozan	0.15	1.28	2.16	0.13	0.29	1.60	0.33
8	Mahet	0.19	3.29	2.89	0.67	1.12	3.2	0.68
9	Girguran	0.18	2.20	1.33	0.17	0.29	1.70	1.52
10	Zawita	0.14	1.80	0.90	0.10	0.23	2.00	0.37

Organic magnesium represented only a very small fraction of total soil magnesium, consistent with earlier findings that less than 5% of total Mg exists in organically complexed form in surface soils, this is supported by several studies: [26] reported that only a small portion of total Mg occurs in organic complexes, [32] noted that organic Mg rarely exceeds 5% of total Mg, and [13] observed that organic Mg averaged 0.33 cmol kg^{-1} (≈3.4% of total Mg). The present data agree with this pattern, as organic Mg showed generally weak correlations with most soil physicochemical properties (Table 6), including non-significant relationships with pH, EC, $CaCO_3$, texture fractions, and CEC. These findings confirm that organic Mg is a minor pool largely influenced by soil organic matter content rather than by mineralogical or physicochemical soil attributes.

Although organic Mg showed no significant correlation with most major soil variables, it was moderately and significantly associated with acid-soluble Mg ($r = 0.633^*$, $p < 0.05$), indicating that organic complexes contribute partly to the more labile Mg pool. Organic Mg also showed moderate but non-significant correlations with exchangeable Mg ($r = 0.497$), soluble Mg ($r = 0.510$), and soluble Ca ($r = 0.501$), suggesting that soils richer in organic Mg tend to have higher levels of readily available cations. This pattern highlights an important functional role: even though organic Mg is quantitatively small, it may influence Mg mobility and short-term nutrient cycling because organic matter can bind, protect, and gradually release Mg^{2+} into exchangeable or soluble forms. Thus, the relationships though not always statistically significant suggest that organic matter contributes indirectly to maintaining Mg availability and its interactions with competing cations such as Ca^{2+} in the soil solution.

Table 3: Some chemical properties of studied soils.

Soil No.	Soil Samples	pH	EC dS.m^{-1}	$CaCO_3$ g.kg^{-1}	Active $CaCO_3$ g.kg^{-1}	O.M g.kg^{-1}	CEC cmol.kg^{-1}
1	Baedra	7.63	0.47	90.9	8.64	43.9	32.68
2	Sulav	7.45	0.28	25.1	2.51	29.0	22.95
3	Rashank	7.26	0.15	15.7	0.79	18.0	20.42
4	Sarsing	7.47	0.43	28.2	1.97	49.0	26.39
5	Qadish	7.50	0.47	50.8	2.41	39.7	29.94
6	Heteet	7.16	1.02	3.8	0.10	13.8	16.96
7	Darhozan	7.57	0.25	66.7	4.17	20.6	24.37
8	Mahet	7.58	0.55	101.7	10.93	24.1	31.02
9	Girguran	7.68	0.32	37.8	2.46	24.8	33.56
10	Zawita	7.49	0.21	47.8	3.59	47.4	27.36

Table 4: Pearson Correlation Coefficients between Soil Physicochemical Properties and Cations and Anions.

Ions	pH	EC	$CaCO_3$	Active $CaCO_3$	O.M	CEC
K	0.208	0.144	0.077	0.040	0.620*	0.351
Mg	-0.104	0.544	0.079	0.179	-0.215	-0.097
Ca	-0.372	0.963**	-0.029	0.07	-0.241	-0.268
Na	0.105	0.420	0.415	0.556	-0.131	0.195
Cl	-0.412	0.867**	-0.030	0.130	-0.497	-0.330
HCO_3	-0.432	0.858**	-0.033	0.076	-0.325	-0.255
SO_4	-0.268	0.852**	-0.196	-0.140	0.007	-0.101

3.2.2 Acid-soluble Mg

The acid soluble fraction measures the potentially available/non-exchangeable forms present in the soil [34]. This fraction of magnesium ranged from 34.89 - 122.74 mg. kg^{-1} soil (Table, 5), noted in Heteet and Sarsing soils respectively. The alteration between these values due to the change of decomposition of organic matter and releases organic acid affect the minerals weathering in investigated soils. This range of acid–soluble magnesium accounted to (34.67 to 52.43) % of the total magnesium.

Table 5: Chemical forms of magnesium in studied soils.

Soil No.	Soil Samples	Magnesium (mg. kg^{-1})				
		Total	Mineral	Exchangeable	Acid. soluble	Organic
1	Baedra	178.29	64.13	30.07	77.94	6.15
2	Sulav	181.12	101.12	33.94	39.91	6.15
3	Rashank	117.59	36.13	13.48	61.80	6.19
4	Sarsing	234.09	65.43	32.88	122.74	13.04
5	Qadish	148.47	44.80	20.32	75.48	7.85
6	Heteet	100.64	46.16	13.59	34.89	6.00
7	Darhozan	161.49	57.13	23.85	71.01	9.51
8	Mahet	165.79	52.97	34.78	64.92	13.12
9	Girguran	144.13	50.06	25.67	60.77	7.63
10	Zawita	153.72	32.41	26.79	80.90	13.62

In Table (6) shown High positive significant relationship between acid-soluble Mg and organic matter (r= 0.756**) and positive significant correlation with potassium (r= 0.690*) and organic Mg form (r= 0.633*). Similarly, [14] reported that 2.02 to 56.12% of the total magnesium in different soils was present in the acid-soluble fraction. According to [13], the mean acid-soluble Mg content (cmol kg^{-1}) was 3.69±0.31, with a range of 2.52 to 5.25. Acid-soluble Mg made up 28.23% of the soils' total Mg content. In general, there was more acid-soluble Mg than magnesium exchangeable. With r = 0.487* and r = 0.532* ($P < 0.05$), respectively, acid-soluble Mg had a significant and positive correlation with mineral Mg and total Mg. It made up 40.04 % of the soils' magnesium total content. Additionally, strong correlations between organic matter (r=0.756*) and acid-soluble magnesium and soluble K^+ (r=0.690*) were discovered, suggesting that organic ligands with easily accessible nutrient pools influence magnesium bound to soluble fractions. According to [12], organic acids in the soil can increase the solubility of magnesium from mineral fractions, thereby increasing plant availability.

Table 6: Pearson Correlation Coefficients between Magnesium Fractions and Soil Physicochemical Properties and Soluble Ions

Soil properties		Total Mg	Mineral Mg	Exchangeable Mg	Acid-soluble Mg	Organic Mg
pH		0.509	0.193	0.666*	0.357	0.304
EC		-0.277	-0.046	-0.219	-0.289	-0.167
$CaCO_3$		0.314	0.016	0.547	0.237	0.358
Active $CaCO_3$		0.313	0.112	0.622*	0.135	0.346
Clay		-0.078	-0.073	0.258	-0.132	-0.083
Silt		0.319	0.100	0.537	0.202	0.194
Sand		-0.124	-0.010	-0.441	-0.029	-0.054
O.M		0.692*	0.077	0.511	0.756**	0.461
CEC		0.403	-0.013	0.559	0.399	0.293
Soluble Cations and Anions	K^+	0.553	0.046	0.216	0.690*	0.283
	Mg^{2+}	0.093	0.020	-0.183	-0.037	0.510
	Ca^{2+}	-0.083	-0.016	0.520	0.094	0.501
	Na^+	0.285	0.128	-0.330	-0.239	-0.221
	Cl^-	-0.025	0.004	-0.313	-0.239	-0.221
	HCO_3^-	-0.380	-0.263	-0.223	-0.273	0.091
	SO_4^{2-}	-0.152	0.061	-0.223	-0.151	-0.410
Total-Mg		1.000	0.558	0.826**	0.729**	0.491
Mineral-Mg		0.558	1.000	0.614*	-0.128	-0.231
Exchangeable-Mg		0.826**	0.614*	1.000	0.365	0.497
Acid-soluble-Mg		0.729**	-0.128	0.365	1.000	0.633*
Organic-Mg		0.491	-0.231	0.497	0.633*	1.000

*= significant at $p \leq 0.05$
**= significant at $p \leq 0.01$

3.2.3 Exchangeable Mg

Exchangeable magnesium, which includes Mg soluble in water and that retained on clay and organic soil particles (IPF, 2021), represented a minor fraction of the total magnesium in the studied soils. Rashank and Mahet soils exemplified the lower and higher exchangeable Mg content, respectively, reflecting site-specific differences in mineral and organic matter exchange sites (Table 5). Overall, exchangeable Mg showed significant positive correlations with soil pH and active $CaCO_3$, indicating that alkaline conditions and carbonate activity favor its retention on soil colloids. It also exhibited positive but non-significant associations with CEC, total $CaCO_3$, silt content, exchangeable Ca, organic matter, and organic Mg (Table 6). These patterns suggest that although exchangeable Mg is a small pool, it plays a key role in short-term magnesium availability and mobility in soils.

Only 45% of the variation in exchangeable magnesium could be accounted for by a combination of pH and clay content, according to [34], who also found that there was no significant ($P > 0.05$) correlation between exchangeable magnesium and organic carbon. The diffuse layer's cationic exchangeable magnesium particles, which are electrostatically adsorbed to negatively charged soil particles, make up the easily interchangeable magnesium forms [35]. According to [13], exchangeable magnesium had a mean of 1.36±0.17 cmol kg^{-1} and ranged from 0.64 to 2.10 cmol kg^{-1}. It was responsible for 3.38 to 38.78 percent of the soils' exchange capacity, and made up 13.99% of the soils' total magnesium content.

Exchangeable magnesium (Mg^{2+}) was significantly correlated with soil pH (r = 0.666*), silt content (r = 0.537*), and cation exchange capacity (CEC, r = 0.559*), suggesting that soils with higher pH and finer textures are more effective at retaining magnesium on exchange sites, as higher pH in calcareous soils reduces the risk of Mg leaching and enhances its availability to plants. In addition, the positive correlation between exchangeable Mg and soluble calcium (r = 0.520*) indicates that divalent cations may compete or cooperate at these exchange sites, a behavior commonly observed in calcareous systems. These findings align with previous research showing that higher pH and finer soil textures improve cation retention and magnesium availability [36, 37], and that interactions between calcium and magnesium at exchange sites can strongly influence divalent cation dynamics [38, 39].

3.2.4 Mineral Mg

The mineral fraction is linked to the more resilient primary minerals and clay lattice structure of the soils [36]. The majority of the total magnesium is found in the non-exchangeable fraction, which is made up of magnesium derived from primary minerals and secondary clay minerals [13]. In studied soils low and high amount of mineral Mg in studied soil are 32.41 to 101.12 mg. kg^{-1} demonstrated in Zawita and Sulav soils respectively (Table, 5). It may be the differences between soils of mineral Mg due to variation of quantity and quality clay minerals in soil structure. This number of mineral magnesium kinds up 21.08 to 55.83 out of a hundred of the total Mg**.** The statistical analysis showed positive significant relationship with exchangeable Mg (0.614*), while non-significant correlation noted between mineral Mg with the all properties of studied soils (Table, 6).

The minerals, from which the soil is formed, such as biotite, olivine, chlorite, and dolomite, as well as clay minerals like montmorillonite and vermiculite, contain the majority of the magnesium in the soil in non-exchangeable forms that are not directly accessible to plants [16]. According to [13], the average mineral Mg content (cmol kg^{-1}) of the soils was 3.86±0.33, with a range of 2.94 to 5.04. It comprised the largest portion of total Mg. There was a significant and positive correlation between mineral Mg and total Mg, with r = 0.834** ($P < 0.001$).

It has been shown that non-exchangeable magnesium can be released gradually under a range of circumstances, but the amount of magnesium dissolved in these minerals is frequently insignificant when compared to the amounts needed to maintain high crop yields for several years. Both the interlayer material and the octahedral clay layers may be the source of this non-exchangeable magnesium. This gradual release of magnesium might be enough to restore the soil solution and satisfy the nutritional needs of plants in low-productivity agriculture [40]. According to [41], the mineral magnesium and acid-soluble magnesium were the two main fractions found in south Indian lateritic soils.

3.2.5 Total Mg

The total magnesium in the soil can be separated into three fractions: (1) exchangeable, which is electrostatically adsorbed by soil mineral and organic colloids; (2) non-exchangeable, which is found in the mineral structure; and (3) free ions in the soil solution, which range in concentration from 5 to 50 mg. L^{-1} [42].

The total magnesium content of the investigated soils ranges from 100.64 mg kg^{-1} in the Heteet soil to 234.09 mg kg^{-1} in the Sarsing soil (Table 5). While there was a non-significant positive correlation between total magnesium with potassium K (r=0.553), pH (r=0.509) and CEC (r=0.403), whereas positive significant relation noted with organic matter (r= 0.692*) of the soils under study (Table, 6), the statistical analysis with Mg fractions revealed a high positive significant relationship with exchangeable magnesium (r=0.826**) and acid-soluble Mg (r=0.729**) however positive non-significant correlation noted to mineral Mg (r=0.558) and organic Mg(r=0.491).

The strong correlation with K further supports earlier findings that cations may compete for exchange sites, particularly in soils with high fertility potential [43]. The average total Mg content (cmol kg^{-1}) of the soils was 9.65±0.79, with a range of 7.35 to 12.60, and the total Mg influenced by parent materials. The amounts of Mg present in various chemical forms in the soils could be ranked in the following order: mineral Mg > acid Mg> exchange Mg> organic Mg. Mineral Mg made up the largest fraction of total Mg in the majority of the soils. This could suggest that the majority of magnesium is found in primary minerals, where it is a component of their fundamental structure. Positive significant correlation distinguished with acid-soluble Mg (r = 0.532*) and mineral Mg (r = 0.834**) and positive non-significant to exchangeable and organic Mg [13]. The combined impact of cation exchange and soil fertility on the total magnesium pool was demonstrated by the strong correlations between total Mg and exchangeable potassium (K^+) (r = 0.848**) and organic matter (r = 0.692**). This finding is consistent with that of [12], who found that organic matter increases magnesium's bioavailability and retention by forming stable complexes with it.

Overall, these results indicate that different magnesium fractions respond to specific soil properties and cation-anion interactions. Exchangeable magnesium is largely determined by soil texture and cation exchange capacity, while total magnesium is influenced by organic matter and exchangeable cations. Acid-soluble and organic magnesium fractions are shaped by the availability of other reactive soil components. Understanding these relationships is important for managing magnesium availability in calcareous soils, as it helps guide fertilization and soil amendment practices to optimize nutrient supply for crops [14, 12, 44].

Conclusion

This study shows that magnesium in the investigated soils is predominantly present in the mineral and acid-soluble fractions, with smaller amounts in exchangeable and organic forms. The dominance of mineral Mg suggests that much of the soil magnesium is relatively unavailable for immediate plant uptake, highlighting the importance of soil

management practices that enhance the more labile fractions. Soil pH, calcium carbonate, and organic matter were key factors influencing magnesium distribution and mobility, and the observed positive correlations between exchangeable magnesium and these parameters indicate that modifying these properties can improve Mg bioavailability in calcareous soils. These findings provide practical guidance for farmers: incorporating organic amendments, optimizing cation exchange capacity, and carefully managing liming and fertilization can enhance nutrient retention and crop productivity.
However, this study was limited to a single sampling period and did not include measurements of plant uptake, so the seasonal dynamics and crop interactions with magnesium remain unexamined. Seasonal variations, crop growth stages, and soil moisture fluctuations could significantly alter the availability of magnesium and the relative contributions of each fraction. Future research should involve long-term trials across multiple seasons and cropping systems, monitoring both soil Mg fractions and plant uptake, to develop more precise management recommendations. Such studies would allow a clearer understanding of how soil properties and management interventions influence magnesium cycling and crop nutrition over time.

References

[1]. Koch, M., Busse, M., Naumann, M., Jákli, B., Smit, I., Cakmak, I., Hermans, C., & Pawelzik, E. (2018). Differential effects of varied potassium and magnesium nutrition on production and partitioning of photoassimilates in potato plants. Physiologia Plantarum, 166(4), 921–935. https://doi.org/10.1111/ppl.12846
[2]. Maguire, M. E., & Cowan, J. A. (2002). Magnesium chemistry and biochemistry. BioMetals, 15, 203–210. https://doi.org/10.1023/a:1016058229972
[3]. Senbayram, M., Gransee, A., Wahle, V., & Thiel, H. (2015). Role of magnesium fertilisers in agriculture: plant–soil continuum. Crop and Pasture Science, 66(12), 1219–1229. https://doi.org/10.1071/CP15104
[4]. de Sousa Ferreira, L., de Souza Oliveira, V., de Paula Marchiori, J. J., Ferreira, T. C., Bernabé, A. C. B., Boone, G. T. F., … & Carriço, E. (2023). The nutrient magnesium in soil and plant: a review. International Journal of Plant & Soil Science, 35(8), 136–144. https://doi.org/10.9734/IJPSS/2023/v35i82890
[5]. Siddique, M. S., Hashim, N. A., Junaidi, M. U. M., Ullah, A., Yusoff, R., & Rabuni, M. F. (2024). Recent advances in the application of dolomite in membrane separation and beyond: A review on an abundant and versatile mineral. Materials Today Sustainability, 28, 100951. https://doi.org/10.1016/j.mtsust.2024.100951
[6]. Ling, L. L., Huang, Y., Peng, L. Z., Wu, Y. T., Jiang, C. L., Cao, L., & Chun, C. P. (2014). Influence of magnesium deficiency and excess on chlorophyll fluorescence characteristics of Newhall navel orange leaves. Acta Ecologica Sinica, 34, 1672–1680. https://doi.org/10.5846/stxb201304250813
[7]. Dukic, E., Van Maldegem, K. A., Shaikh, K. M., Fukuda, K., Töpel, M., Solymosi, K., & Spetea, C. (2023). Chloroplast magnesium transporters play essential but differential roles in maintaining magnesium homeostasis. Frontiers in Plant Science, 14, 1221436. https://doi.org/10.3389/fpls.2023.1221436
[8]. Zhu, Z., Zhang, H., Tian, H., Chai, G., Muhammad, R., Wang, Q., … & Wu, X. (2025). Comprehensive analysis of the effects on photosynthesis and energy balance in tomato leaves under magnesium deficiency. Plant Physiology and Biochemistry, 222, 109671. https://doi.org/10.1016/j.plaphy.2025.109671
[9]. Canizella, B. T., Moreira, A., Moraes, L. A. C., & Fageria, N. K. (2015). Efficiency of magnesium use by common bean varieties regarding yield, physiological components, and nutritional status of plants. Communications in Soil Science and Plant Analysis, 46(11), 1376–1390. https://doi.org/10.1080/00103624.2015.1034133
[10]. Marschner, P. (2012). Rhizosphere biology. In P. Marschner (Ed.), Marschner's mineral nutrition of higher plants (3rd ed., pp. 369–388). Academic Press. https://doi.org/10.1016/B978-0-12-384905-2.00015-7
[11]. Gransee, A. and Führs, H. (2013). Magnesium mobility in soils as a challenge for soil and plant analysis, magnesium fertilization and root uptake under adverse growth conditions. Plant, 368:5–21. https://doi.10.1007/s11104-012-1567-y
[12]. Melo, V. F., Novais, R. F., Fontes, M. P. F., & Schaefer, C. E. G. R. (2000). Potássio e magnésio em minerais das frações areia e silte de diferentes solos. Revista Brasileira de Ciência do Solo, 24, 269–284. https://doi.org/10.1590/S0100-06832000000200004
[13]. Morrison, R. J., & Kubuabola, S. (2005). The magnesium status of some Fiji soils. Communications in soil science and plant analysis, 36(17-18), 2343-2358. https://doi.org/10.1080/00103620500251062.
[14]. Osemwota, I. O., Omueti, J. A. I., & Ogboghodo, A. I. (2009). Distribution of magnesium forms in surface soils of Central Southern Nigeria. South African Journal of Plant and Soil, 26(2), 59-63. https://doi.org/10.1080/02571862.2009.10639935
[15]. Bhindhu, P. S., & Sureshkumar, P. (2021). Availability indices of calcium and magnesium in soils of

Kerala. Journal of Tropical Agriculture, 59(1), 38–44. https://jtropag.kau.in/index.php/ojs2/article/view/1067

[16]. de Castro, C., de Oliveira Junior, A., de Oliveira, F. A., Firmano, R. F., Zancanaro, L., Klepker, D., … & Benites, V. D. M. (2021). Magnesium: management for nutritional balance in soybean. Embrapa Infoteca. https://www.infoteca.c.embrapa.br/infoteca/handle/doc/1125328

[17]. Ryan, J., & Rashid, A. A. (2001). Soil and plant analysis laboratory manual (2nd ed., pp. 139-140). ICARDA and NARC

[18]. Rowell, D. L. (1996). Soil science: Methods and applications. University of Reading. https://doi.org/10.1017/S0021859600070519

[19]. Robbins, C. W., & Wiegand, C. L. (1990). Field and laboratory measurements. In Agricultural salinity assessment and management. https://doi.org/10.1061/9780784411698.ch10

[20]. Nelson, D. W., & Sommer, L. E. (1986). Total carbon, organic carbon, and organic matter. https://doi.org/10.2134/agronmonogr9.2.2ed.c29

[21]. Estefan, G., Sommer, R., & Ryan, J. (2013). Methods of soil, plant, and water analysis: A manual for the West Asia and North Africa region (3rd ed., 2nd rev., pp. 65–119)

[22]. Sparks, D. L., Page, A. L., Helmke, P. A., & Loeppert, R. H. (Eds.). (2020). Methods of soil analysis, Part 3: Chemical methods. John Wiley & Sons

[23]. Loeppert, R. H., & Suarez, D. L. (1996). Carbonate and gypsum. In D. L. Sparks (Ed.), Methods of Soil Analysis (pp. 251–271). https://doi.org/10.2136/sssabookser5.3.c15

[24]. Summer, M.e., & Miller, W.P. (1996). Methods of soil analysis, part 3: Chemical methods. SSSA Book Series, 5. Soil Scince Society of America. https://doi.org/10.2136/sssabookser5.3.c40

[25]. Thomas, G. W. (1982). Exchangeable cations. In A. L. Page (Ed.), Methods of Soil Analysis, Part 2 (2nd ed., pp. 159–165). ASA and SSSA. https://doi.org/10.2134/agronmonogr9.2.2ed.c9

[26]. Mokwunye, A. U., & Melsted, S. W. (1972). Magnesium forms in selected temperate and tropical soils. Soil Science Society of America Journal, 36(5), 762–764. https://doi.org/10.2136/sssaj1972.03615995003600050023x

[27]. Baruah, B. K., Das, B., Haque, A., Medhi, C., & Misra, A. K. (2011). Sequential extraction of common metals (Na, K, Ca and Mg) from surface soil. Journal of Chemical and Pharmaceutical Research, 3(5), 565–573. https://www.researchgate.net/publication/279585787

[28]. Jackson, M. L. (1958). Soil chemical analysis. Prentice Hall, Englewood Cliffs, NJ. https://doi.org/10.2136/sssaj1958.03615995002200030025x

[29]. Aydinalp, C., & Cresser, M. S. (2003). The background levels of heavy metals in Vertisols under Mediterranean type of climate in the Region of Turkey. Journal of Central European Agriculture, 4(4), 289–296. https://hrcak.srce.hr/en/file/25064

[30]. Hailu, H., Mamo, T., Keskinen, R., Karltun, E., Gebrekidan, H., & Bekele, T. (2015). Soil fertility status and wheat nutrient content in Vertisol cropping systems of central highlands of Ethiopia. Agriculture & Food Security, 4(1), 19. https://doi.org/10.1186/s40066-015-0038-0

[31]. Gurav, P. P., Ray, S. K., Datta, S. C., Choudhari, P. L., & Hartmann, C. (2024). Role of clay cation exchange capacity, location of charge, and clay mineralogy on potassium availability in Indian Vertisols. Clays and Clay Minerals, 72, e3. https://doi.org/10.1017/cmn.2024.6

[32]. Salmon, R. C. (1963). Magnesium relationships in soils and plants. Journal of the Science of Food and Agriculture, 6, 421–442. https://doi.org/10.1002/jsfa.2740140901

[33]. Hermans, C., & Verbruggen, N. (2005). Physiological characterization of Mg deficiency in Arabidopsis thaliana. Journal of Experimental Botany, 56(418), 2153–2161. https://doi.org/10.1093/jxb/eri215

[34]. Hailes, K. J., Aitken, R. L., & Menzies, N. W. (1997). Magnesium in tropical and subtropical soils from north-eastern Australia. I. Magnesium fractions and interrelationships with soil properties. Australian Journal of Soil Research, 35, 615–627. https://doi.org/10.1071/S96081

[35]. [Vona, V., Centeri, C., Giczi, Z., Kalocsai, R., Biró, Z., Jakab, G., … & Kovács, A. J. (2020). Comparison of magnesium determination methods on Hungarian soils. Soil & Water Research, 15(3). https://doi.org/10.17221/92/2019-SWR

[36]. Solly, A., Berisha, E., Cotella, G., & Janin Rivolin, U. (2020). How sustainable are land use tools? A Europe-wide typological investigation. Sustainability, 12(3), 1257. https://doi.org/10.3390/su12031257

[37]. Dash, S. K., Chakraborty, S., & Elangovan, D. (2023). A brief review of hydrogen production methods and their challenges. Energies, 16(3), 1141. https://doi.org/10.3390/en16031141

[38]. Yang, M., Zhou, D., Hang, H., Chen, S., Liu, H., Su, J., Lv, H., Jia, H., & Zhao, G. (2024). Effects of balancing exchangeable cations Ca, Mg, and K on the growth of tomato seedlings (Solanum lycopersicum

L.) based on increased soil cation exchange capacity. Agronomy, 14(3), 629. https://doi.org/10.3390/agronomy14030629

[39]. Goda, D. A., El-Gamal, E. H., Rashad, M., & Abdel-Fattah, Y. R. (2025). The optimization of calcareous soil cation exchange capacity via the feather hydrolysate and NP fertilizers integration. Scientific Reports, 15(1), 4676. https://doi.org/10.1038/s41598-025-86941-9

[40]. Wang, Z., Hassan, M. U., Nadeem, F., Wu, L., Zhang, F., & Li, X. (2020). Magnesium fertilization improves crop yield in most production systems: A meta-analysis. Frontiers in Plant Science, 10, 495191. https://doi.org/10.3389/fpls.2019.01727

[41]. Jayaganesh, S., Venkatesan, S., & Senthurpandian, V. K. (2011). Impact of different sources and doses of magnesium fertilizer on biochemical constituents and quality parameters of black tea. Asian Journal of Botany, 3, 273–281. https://doi.org/10.3923/ajb.2011.273.281

[42]. Roy, R. N., Finck, A., Blair, G. J., & Tandon, H. L. S. (2006). Plant nutrition for food security: A guide for integrated nutrient management. FAO Fertilizer and Plant Nutrition Bulletin, 16, 201–214.

[43]. Rengel, Z., & Marschner, P. (2005). Nutrient availability and management in the rhizosphere: exploiting genotypic differences. New Phytologist, 168(2), 305–312. https://doi.org/10.1111/j.1469-8137.2005.01558.x

[44]. Hermans, C., & Verbruggen, N. (2005). Physiological characterization of Mg deficiency in Arabidopsis thaliana. Journal of Experimental Botany, 56(418), 2153–2161. https://doi.org/10.1093/jxb/eri215

تجزئة المغنيسيوم وعلاقتها بالخصائص الفيزيائية والكيميائية في التربة الكلسية بمحافظة دهوك، كردستان ،العراق

بائيزان احسان رمضان[1] لزكين احمد ميروين المهمدانى[1]

[1]قسم علوم التربة والمياه، كلية الزراعة، جامعة دهوك، دهوك، العراق.

الخلاصة

أُجريت هذه الدراسة لتقييم توزيع كسور المغنيسيوم وعلاقتها بخصائص التربة في عشرة تربة كلسية تمثيلية من محافظة دهوك، إقليم كردستان العراق، بما في ذلك بيدرا، سولاف، رشنك، سارسينغ، قادش، حتيت، دارحزان، ماهت، جيرغوران، وزويتا. تم تجفيف عينات التربة بالهواء، وطحنها، ونخلها حتى حجم ٢ ملم لتقييم الخصائص الفيزيائية والكيميائية بالإضافة إلى أشكال المغنيسيوم، بما في ذلك المغنيسيوم العضوي، القابل للذوبان في الأحماض، القابل للتبادل، المعدني، وإجمالي المغنيسيوم. أظهرت الترب المدروسة درجة حموضة قلوية خفيفة، وخصائص كلسية، وملمسًا يتراوح بين الطين والطمي الطيني الرملي، مع ظروف غير مالحة. شكل المغنيسيوم العضوي شكل جزءًا صغيرًا من إجمالي المغنيسيوم (حوالي ٦–٩٪)، وظهر ارتباط إيجابي قوي مع المادة العضوية وارتباط متوسط مع البوتاسيوم والمغنيسيوم نفسه. شكل المغنيسيوم القابل للذوبان في الأحماض مثل ٣٥–٥٢٪ من إجمالي المغنيسيوم وارتبط إيجابيًا بالمادة العضوية والمغنيسيوم القابل للتبادل. شكل المغنيسيوم القابل للتبادل شكل حوالي ١١–٢١٪ من إجمالي المغنيسيوم وارتبط ارتباطًا قويًا بدرجة حموضة التربة ومحتوى كربونات الكالسيوم النشطة. شكل المغنيسيوم المعدني مثل ٢١–٥٦٪ من إجمالي المغنيسيوم وارتبط ارتباطًا مهمًا بالمغنيسيوم القابل للتبادل. أظهر إجمالي المغنيسيوم علاقات إيجابية مهمة مع المادة العضوية، والمغنيسيوم القابل للتبادل، والمغنيسيوم القابل للذوبان في الأحماض، مما يبرز الترابط بين هذه الأشكال في الترب الكلسية. تشير هذه النتائج إلى أن المغنيسيوم القابل للتبادل والمغنيسيوم القابل للذوبان في الأحماض هما الأكثر تأثيرًا، مما يؤكد أهمية إدارة المادة العضوية ومستويات الكربونات في التربة لتحسين توفر المغنيسيوم. بدوره، له ذلك تأثير على خصوبة التربة، وتغذية المحاصيل، وممارسات الإدارة المستدامة في الترب الكلسية في دهوك. من خلال التركيز على النتائج الأساسية وأهميتها العملية، تقدم هذه الدراسة لمحة واضحة عن ديناميكيات أشكال المغنيسيوم، مما يوفر إرشادات لتحسين إدارة التربة وزيادة الإنتاجية الزراعية.

الكلمات المفتاحية: المغنيسيوم الكلي، المغنيسيوم المعدني، المغنيسيوم المتبادل، المغنيسيوم القابل للذوبان في الأحماض، المغنيسيوم العضوي.