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Full Length Research Paper

Improvement of exchangeable Ca:Mg ratio by using gypsum and waste of sulfur in magnesium-affected soils

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The experiment was carried out under field conditions in order to improve exchangeable Ca:Mg ratio which depress on infiltration capacity and plant growth. The high amount of magnesium accumulation in soil exchangeable complex affects physical and chemical properties and productivity of soil. The affected land is about 1,000 ha and located in the south-west of Anatolia. The landscape units show that soils related to igneous Mg-materials. Mg bicarbonates were the dominant salts. Experiment was established using randomized block design with three replications in Acipayam Agricultural Enterprise. Treatments were prepared with 15, 30, 45 t ha^{-1} gypsum and 30, 60, 90 t ha^{-1} waste of sulfur, however, controls were without any chemical. To dissolve the amendments totally, 320 cm leaching water was applied for 4 years. The infiltration capacities of the soil increased in proportion to the amount of gypsum and waste of sulfur applied. Leaching of 70% of the exchangeable Mg from the soil profile required a depth of leaching water of approximately eleven or fifteen times the soil depth to be reclaimed. Relationships between theoretically calculated and required actual amendment could be described by linear equations. Waste of sulfur was more effective than gypsum for improving exchangeable Ca:Mg ratio in Acipayam Agricultural Enterprise soil.

Key words: Magnesium to calcium ratio, exchangeable magnesium percentage, magnesium-affected soils, gypsum, sulfur factory waste, infiltration ratio.

INTRODUCTION

It has been known that magnesium has a negative effect on soil physical properties when its concentration is relatively high compared to Calcium. However, soils that do not have sodic properties there is also a possibility for deterioration of soil structure due to high magnesium. High magnesium concentration in the soil solution can be natural or induced by input of dolomitic limestone.

The permeability of montmorillonitic clay soils is strongly dependent on the type of exchangeable cations and the salt concentration of the percolating solution. Permeability tends to decrease with increasing exchangeable sodium (ESP) and magnesium (EMP) percentage and decreasing salt concentration. Changes in hydraulic conductivity and clay dispersion in montmorillonitic clay soils are the function of exchangeable cations. Magnesium was less effective than calcium in stabilizing soil flocculation (Shainberg et al., 1988).

The Mg accumulation in the exchange complex of soils to a very high saturation levels affects their physical, chemical properties. Colombia has a large area of these soils, located mainly in the main rivers valleys and in the Caribbean Region (Borrero et al., 1998). Bardhan et al. (2007) reported that excess Mg in soil exchangeable complex affected hydraulic conductivity and various combinations of Ca:Mg (1:2, 1.5:2 and 1:1) were used to synthesis. Saturated hydraulic conductivity ranged from 0.02 to 0.32, 0.28 to 0.83 and 0.92 to 2.74 cm h^{-1} in clay, clay loam and sandy loam soils, respectively. Dontsova and Norton (2002) studied on flocculation behaviors of clay soils at different Ca:Mg ratios in a laboratory test. In soil that has various exchangeable Ca:Mg ratios, infiltrations were measured under simulated rainfall.

The result revealed that Mg has a specific effect on soil clay dispersion due to hydration behavior and had greater

Figure 1. General view of experimental location.

aggregate destruction than calcium.

Zhang and Norton (2002) reported that saturated hydraulic conductivity started to decline at higher concentrations of Mg than calcium, and the reduction was much greater in Mg than in calcium. Results indicated that high level of magnesium concentration in the exchange complex compared with calcium caused lower permeability and more clay dispersion. Vyshpolsky et al. (2008) conducted a field experiment to reclaim magnesium-affected soils in Central Asia. As a calcium source, phosphogypsum was applied, and increased calcium concentration in the soil triggered the replacement of excess magnesium from the cation exchange complex. Since the amendment was applied once at the beginning, exchangeable magnesium levels tended to increase for 4 years after its application, particularly in the treatment with 4.5 t ha^{-1} phosphogypsum. Thus, there would be a need for phosphogypsum application to such soils after every 4 to 5 years to optimize the ionic balance and sustain higher levels of cotton production. The economic benefits from the phosphogypsum treatments were almost twice those from the control. An investigation was carried out to know the effect of varying levels calcium and magnesium ratios on the yield of finger millet under pot culture condition. Finger millet was grown by applying calcium and magnesium at different levels using their chloride salts. The results revealed that plant height, number of fingers per pot, grain and straw yield were highest when calcium was much more than magnesium and magnesium level corresponding to Ca:Mg ratios of 3.2:1 on the soil exchange complex (Ansari et al., 2010).

The purpose of this study was to investigate the effect of gypsum and the waste product of sulfur industry on the reclamation of exchangeable Mg in Mg-affected clay soil.

MATERIALS AND METHODS

The experiment was conducted in Acipayam Agriculture Enterprise. Site soils are physically and chemically degraded. The affected land is about 1,000 ha and located in the south-west of Anatolia (Figure 1). This area is situated on old lake basin and the landscape units showed that soils are related to igneous Mg-materials. Irrigation water was obtained from deep farm well. The area has surface drainage system, but it was not adequate. The region has a Mediterranean type climate with a mean annual precipitation of 530 mm, of which most precipitation falls in winter and spring seasons. Summer period is very hot and dry, while it is cold during the winter. Before setting up the experiment, soil samples were collected from different depths of whole area which are affected from excess magnesium and their physicochemical characteristics were analyzed. Soils of the study area are mostly fine textured (montmorillonitic clay) with a high amount of $MgHCO_3$ (magnesium bicarbonate) and magnesium was dominant in the cation exchange complex, salinity degree was low (1.2 to 1.4 dS m^{-1}), pH in the 0 to 60 cm depth averagely 8.5 (Table 1). Irrigation water was used for the purpose of dissolution of the amendments in the experiment, its salt concentration was about 0.52 dS m^{-1}, with 0.45 SAR value (Table 2).

Experimental setup

The experiment was designed as randomized blocks with three replications. Treatments were prepared with 15, 30, 45 t ha^{-1} gypsum (G) and 30, 60, 90 t ha^{-1} waste of sulfur (W), however, controls were without any chemical. Before application of amendments, all plots were spaded approximately 25 cm depth of soil and boundaries of the plots were sealed with plastic coating to prevent lateral flows. For appropriate drainage, the test plots were surrounded with an open drain of 2.0 m depth in order to maintain groundwater at deep level (Figure 2). Spacing of the drainage ditch was about 30 m. Fine powdered gypsum was obtained from a mine, purity level was more or less 98% and waste of sulfur pH 1.6, include Ca 10%, S 20%, Fe 10% and some very low concentration metal elements. Amendments doses were applied by spreading

Table 1. Physical and chemical properties of experimental plot, pretreatment.

Soil depth (cm)	pH	Saturation percentage (%)	EC_e (dS m^{-1})	Cations (meq l^{-1}) (saturation extract)					Anions (meq l^{-1}) (saturation extract)				$CaCO_3$ (%)
				Ca^{++}	Mg^{++}	Na^+	K^+	total	$CO_3^=$	HCO_3^-	Cl^-	$SO_4^{-\,a}$	
0-20	8.50	99.75	1.16	4.71	5.84	0.91	0.38	11.84	2.71	4.88	2.50	1.75	14.04
20-40	8.50	98.94	1.22	5.50	6.38	0.92	0.24	13.04	3.25	3.80	2.25	3.74	15.75
40-60	8.45	83.95	1.40	4.30	7.51	0.94	0.12	12.87	2.17	4.88	2.27	3.55	13.08

Soil depth (cm)	Exchangeable cations (%)				CEC (meq/100 g)	Bulk density (g cm^{-3})	Texture (%)				Gypsum (meq/100 g)
	Ca^{++}	Mg^{++}	Na^+	K^+			Sand	Silt	Clay	Class	
0-20	3.15	81.16	7.68	7.68	32.79	1.35	9.2	25.7	65.1	C	1.40
20-40	3.23	80.58	7.59	7.59	37.29	1.36	6.7	27.5	65.8	C	1.60
40-60	2.70	80.18	8.20	8.20	33.61	1.36	8.1	23.7	68.2	C	1.40

[a] Calculated values.

Table 2. Chemical properties of the leaching or irrigation water.

pH	EC(dS m^{-1})	Cations (meq l^{-1})					Anions (meq l^{-1})				SAR
		Ca^{++}	Mg^{++}	Na^+	K^+	Total	$CO_3^=$	HCO_3^-	Cl^-	$SO_4^{-\,a}$	
7.10	0.52	2.14	2.02	0.66	0.62	6.40	-	4.57	1.20	0.63	0.45

[a] Calculated values.

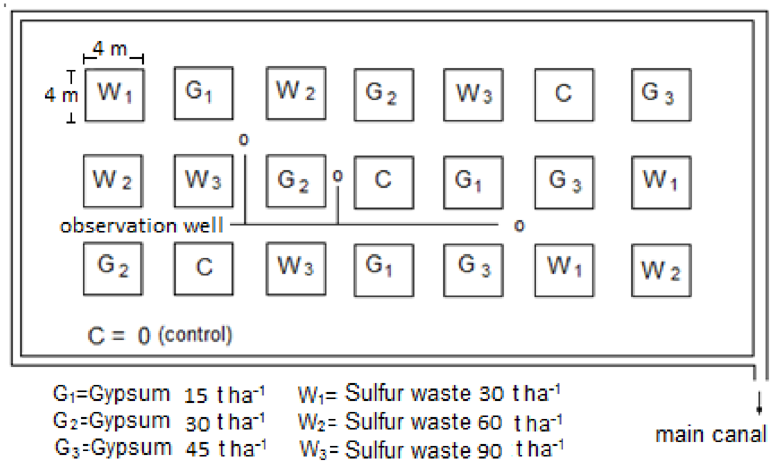

Figure 2. Layout of experimental site and treatments.

with hand on the soil surface and were mixed with spade within the 20 to 30 cm soil depth. Waters were applied as intermittent ponding method which increases dissolving and effectiveness of amendments. A mobile water tank and a water counter were used for water application. Soil samples were taken from all plots at 20, 40 and 60 cm depths at the beginning of tests and after applying 80, 120, 200, 240, 280 and 320 cm depth of water. The water table was monitored in test field where observation wells were located. These wells were made of PVC pipe, 5 cm in diameter and 2.0 m in length. Physical and chemical analyses of the soil and water were performed according to the methods described by U. S. Salinity Laboratory Staff (Tanji, 1990). After the samples were air dried and passed through a 2 mm sieve, particle size distributions of the soil samples were determined by the hydrometer method (Bouyoucos, 1951); carbonates by the calcimeter method, electrical conductivity (ECe) in soil saturation extract by a conductivity meter.

Cation exchange capacity (CEC) and exchangeable sodium were determined after ammonium acetate extraction and measured using a flame photometer.

Assessment of data

For all assessments, data were used as an arithmetical average of three plots. To determine infiltration capacities, infiltration time of 20 cm water depth being applied was recorded for each plot. Afterwards, the average of these values was calculated for each treatment. The infiltrated water depth (Z) and infiltration ratio (I) were determined using the averaged values and Kostiakov infiltration equations as follows:

$Z = KT^n$
$I = KT^n$

Where K = constant, T = time (h) and n = exponent.

Theoretical gypsum requirement equation (GR) was used for evaluation of amendments effectiveness. Gypsum requirement corresponding to the improvement being realized can be calculated by using the GR equation with initial and final EMgP values (Beyce, 1977). The amendment calibration curves were obtained between the theoretical and applied amendments for 320 cm leaching water levels and 60 cm soil depth. Gypsum requirement (GR) equation is given as:

$$GR = EW.10^{-5}.A.BD.D_s.\frac{EMgP_i - EMgP_f}{100}.CEC$$

$$EMgP = (MgX/CEC).100$$

In these equations, GR = gypsum requirement (meq/100 g dry weight), EW = equivalent weight of gypsum (meq/100 g dry weight), EMgP = exchangeable magnesium percentage (%), $EMgP_i$ = initial EMgP value (%), $EMgP_f$ = final EMgP value (%), CEC = cation exchange capacity (meq/100 g dry weight), BD = bulk density of the soil (t m^{-3} or g cm^{-3}), A = area (m^2) and Ds = soil depth (m), MgX = exchangeable magnesium (meq/100 g dry weight).

To assess exchangeable Ca:Mg ratio with amendments dosage at varying depth of water, ECaP:EMgP values were showed in a graphic. To comprehend the relation of variables regression and its correlation value were calculated in 60 cm depth of soil at 320 cm applied water. To assess removed exchangeable magnesium, remained exchangeable magnesium ($EMgP_f$) (after the leaching) was divided by the initial value ($EMgP_i$). Thus, $EMgP_f/EMgP_i$ values were calculated for each leaching water depth. The ratio of the leaching water (D_{lw})/the soil depth (D_s) was calculated separately. The depth of leaching water and removed EMgP were then made independent of the soil depth. The EMgP leaching curve and leaching function were obtained from the treatment between ($EMgP_f/EMgP_i$) and (D_{lw}/D_s) as reported by Boumans et al. (1963).

RESULTS AND DISCUSION

High amount of Mg content in these soils has an adverse effect on soil structure, flocculation and infiltration ratio which is a rather sensitive indicator of soil physical conditions. It may be because of the greater hydration radius of Mg compared with Ca had a significant effect on clay dispersion for all soil clays. The leaching of the soil profiles indicated that the dispersed particles in layers were of very restricted permeability. The infiltration ratios were 3.0 mm h^{-1} at the beginning of the test. Dispersion of clay may be so intense as to block all pore spaces, rendering the soil impermeable to vertical drainage. The hydraulic gradient is always equal to or bigger than 1.0 in the unsaturated zone. The water table level remained below 1.65 m depths in the center of the plots during the test. Therefore, intermittent ponded water on the soil surface with amendments provided a rather good infiltration ratio and this resulted in rapid percolation from the plots. As shown in Table 3, gypsum and waste of sulfur application improve the infiltration. In control plots, 85 days were required for infiltration of 280 cm irrigation water while with G_3 and W_3, infiltration of 320 cm water required 15 and 8 days, respectively. Using data in Table 3 and the Kostiakov infiltration equation, exponential relationships were found between cumulative time and infiltration ratio for control, G_3 and W_3 (Figure 3). When these curves and equations were compared with control treatments, it was shown that both materials improved the soil physical properties and resulted in increase of the infiltration ratio. These increases were averagely 95 and 117% G_3 and W_3 treatment respectively.

The relationship between the variables, based on the correlation coefficient was found highly significant ($p<0.01$). Increased amendments dosage improved the soil physical properties and resulted in an increase in infiltration ratio. Dontsova and Norton (2002) studied infiltration of Mg-affected clay soils at different Ca:Mg ratios in a laboratory test. Infiltration was measured under simulated rainfall. The result revealed that increased Ca:Mg ratio in soil, enhanced infiltration rate up to 20 to - 100%. Bardhan et al. (2007) reported that hydraulic conductivity is low if soil has more exchangeable Mg than Ca in soil exchangeable complex. To increase hydraulic conductivities, calcium must be added. Vyshpolsky et al. (2008) reclaim Mg-affected soil in Central Asia and increase productivity of these soils used phospho-gypsum. Application of gypsum to the soil surface after tillage, or incorporation of gypsum into the surface of 10 cm was an effective method to improve infiltration ratios (Grattan and Grieve, 1999). To correlate real improving data and applied amount of amendments, theoretical gypsum requirement equation was used, and the calculated values

Table 3. Infiltration time of applied water for different treatments (h).

Infiltrated water (cm)	Control	(G_3)	(W_3)
20	86	6	2
40	201	18	9
60	329	30	16
80	472	43	25
100	617	57	33
120	776	73	43
140	936	93	54
160	1072	116	65
180	1220	141	76
200	1373	169	89
220	1531	195	102
240	1696	223	118
260	1864	253	133
280	2034	286	150
300		322	167
320		360	186
Control	$I = 0.472T^{-0.164}$	R2 = 0.989**	
(G_3) 45 t ha^{-1} gypsum	$I = 5.971T^{-0.316}$	R2 = 0.988**	
(W_3) 90 t ha^{-1} waste of sulfur	$I = 10.910T^{-0.357}$	R2 = 0.981**	

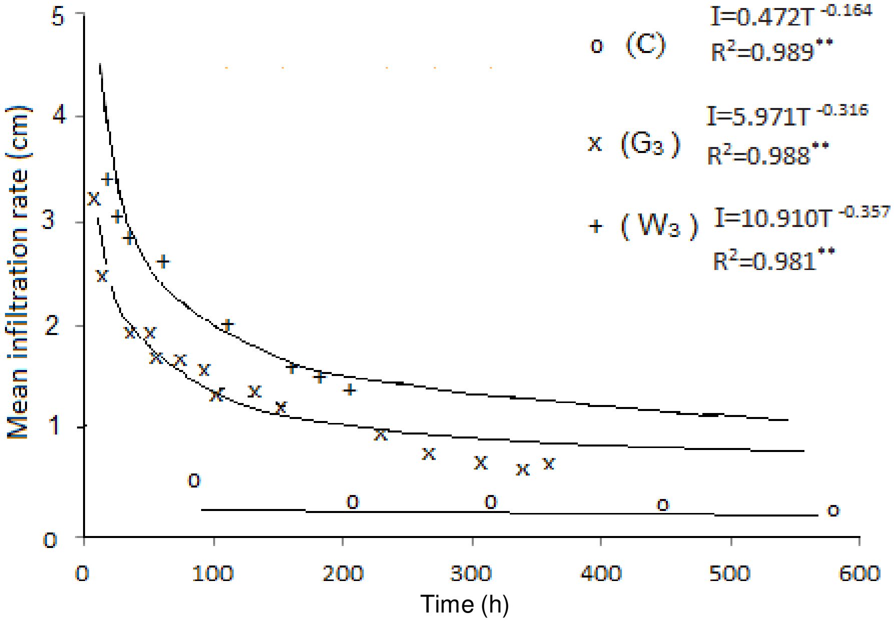

Figure 3. Infiltration rate curves (C, G_3, W_3) and observed data.

values for all treatments were given in Table 4. Exponential functions were fitted to describe the relationships between applied and theoretically gypsum requirement for G_3, W_3 and both exponential regressions were highly significant ($p<0.01$).

Figure 4 shows the amendments calibration curves obtained by treatment of amendment applied (Aap) to plots and theoretically calculated gypsum requirement (GR_T) at two different amendments of irrigation water applications (320 cm) for 60 cm soil depth which removed an equal amount of adsorbed Mg (t ha^{-1}):

(G_3) 45 t ha^{-1} gypsum, G_{ap}= 2E-04$(GR_T)^{2,931}$, $R^2 = 0.986^{**}$
(W_3) 90 t ha^{-1} waste of sulfur, G_{ap}= 2E-04$(GR_T)^{2,890}$, $R^2 = 0.922^{**}$

Table 4. Theoretical amounts of gypsum calculated for the replaced exchangeable Mg with various amendments in different doses in the Mg-affected soils in the Acipayam.

Applied amendments (t ha^{-1})	Theoretical gypsum calculated for removed exchangeable Mg (t ha^{-1})		
	Soil depth (cm)	Leaching water applied (cm) 280	320
Control	0-20	13.48	-
	0-40	18.37	-
	0-60	19.92	-
G1 =15	0-20	21.39	26.13
	0-40	33.52	44.42
	0-60	41.52	47.25
G2 =30	0-20	27.76	32.81
	0-40	39.89	53.9
	0-60	43.08	69.75
G3 =45	0-20	35.63	39.71
	0-40	52.05	62.06
	0-60	64.51	80.04
W1 =30	0-20	22.57	27.39
	0-40	28.7	38.59
	0-60	35.99	43.76
W2 =60	0-20	30.88	37.84
	0-40	43.7	61.73
	0-60	46.22	79.28
W3 =90	0-20	40	45.99
	0-40	66.5	78.39
	0-60	77.09	95.84

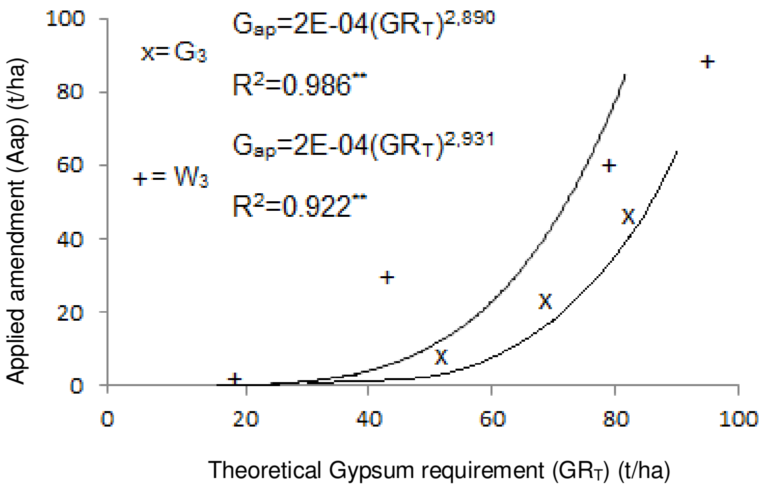

Figure 4. Gypsum calibration curves relating amendment amounts applied (Aap) to theoretical gypsum (GR_T) for the 320 m leaching water depth.

Table 5. Average ECaP:EMgP ratios at varying depth of applied water.

Depth (cm)	Treatment	Applied water (cm)						
		0	80	120	200	240	280	320
0-20	C	0.11	0.15	0.17	0.26	0.31	0.43	-
20-40	C	0.13	0.14	0.17	0.19	0.21	0.33	-
40-60	C	0.14	0.15	0.16	0.17	0.19	0.28	-
0-20	G_1	0.11	0.20	0.26	0.39	0.46	0.71	0.95
20-40	G_1	0.13	0.18	0.24	0.34	0.40	0.57	0.80
40-60	G_1	0.14	0.14	0.21	0.31	0.34	0.49	0.55
0-20	G_2	0.11	0.28	0.48	0.66	0.84	1.05	1.42
20-40	G_2	0.13	0.24	0.31	0.39	0.42	0.69	1.05
40-60	G_2	0.14	0.20	0.28	0.30	0.35	0.50	0.88
0-20	G_3	0.11	0.33	0.61	0.89	1.33	1.69	2.21
20-40	G_3	0.13	0.24	0.36	0.48	0.73	1.00	1.35
40-60	G_3	0.14	0.18	0.31	0.43	0.46	0.79	1.07
0-20	W_1	0.11	0.19	0.27	0.41	0.53	0.77	1.02
20-40	W_1	0.13	0.16	0.21	0.33	0.36	0.48	0.67
40-60	W_1	0.14	0.15	0.19	0.25	0.28	0.43	0.51
0-20	W_2	0.11	0.27	0.45	0.71	0.90	1.26	1.95
20-40	W_2	0.13	0.22	0.35	0.36	0.47	0.78	1.33
40-60	W_2	0.14	0.17	0.21	0.24	0.31	0.54	1.06
0-20	W_3	0.11	0.56	0.65	0.84	1.67	2.25	3.58
20-40	W_3	0.13	0.33	0.58	0.63	1.10	1.54	2.28
40-60	W_3	0.14	0.20	0.31	0.48	0.74	1.01	1.48

Table 6. Average ECaP:EMgP values in 60 cm depth of soil layer in G_3 and W_3 treatment at varying depth of applied water.

Treatment	Applied water (cm)						
	0	80	120	180	240	280	320
Gypsum (G_3)	0.13	0.25	0.42	0.60	0.88	1.16	1.54
Wst of Slf (W_3)	0.13	0.36	0.51	0.65	1.17	1.60	2.45

When removed, exchangeable Mg was compared with the applied doses, improvement ensured was much more than the expected outcome. This can be explained by the dissolution of natural gypsum and $CaCO_3$ in soil. Dissolution was higher in treatments with waste of sulfur than that in gypsum. Because, the sulfur waste with low pH decreased pH value in soil, thus increased dissolution of natural gypsum and $CaCO_3$. Bahçeci (2009) used gypsum to reclaim soil of Eregli plain, when gypsum was applied at 17.5 t ha^{-1} to the soil with 360 cm of irrigation water, the exchangeable sodium removed would be equivalent to 40 t ha^{-1} gypsum for 100 cm soil depth. The basic purpose of this trial was to improve the ECaP:EMgP ratio in 60 cm soil layer. This ratio must be at least 1:1 or more (Tables 5 and 6). As shown in treatment of G_3 and W_3, exchangeable Ca/Mg rates were seen to be 1.5:1 and 2.4:1 in consecutive irrigation of 320 cm leaching water. The results indicated that for a satisfactory leaching of exchangeable magnesium in Acipayam Agricultural Enterprise, the waste of sulfur factory material is more suitable than gypsum. The G_3 and W_3 exchangeable Ca:Mg ratios were shown in Table 6 and Figure 5 for varying depth of leaching water and 0 to 60 cm soil layers. The relation between exchangeable Ca:Mg ratio and leaching water were found to be an exponential equation and its correlation coefficient was highly significant ($p<0.01$). The data show that applied water dissolved the amendments then Ca replaced Mg in exchangeable complex from up to downwards in consecutive process. Removing exchangeable magnesium; the gypsum that corresponds to removed magnesium was calculated by considering the initial and final EMgP values. The exchangeable Mg percentage values were given for all treatments before and after applications of gypsum, sulfur waste and leaching water (Table 7). The exchangeable magnesium was leached from topsoil to deeper layer and accumulated in lower soil layer.

More exchangeable magnesium was leached when more

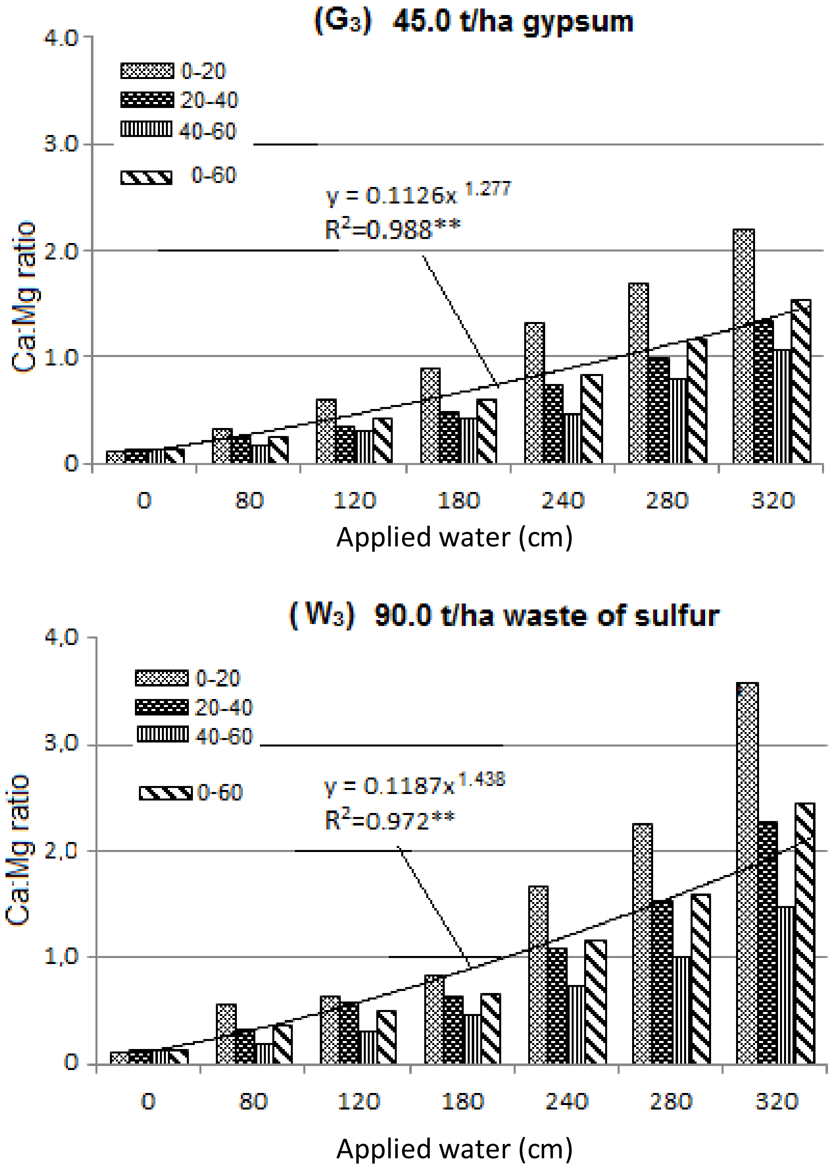

Figure 5. ECaP:EMgP values in different depths of soil layer in G_3 and W_3 at varying depth of applied water.

amendments were dissolved per area. After applying amendments and leaching water, the EMgP values decrease especially in the topsoil (20 cm depth) for 320 cm leaching waters. However, this decrease in deeper layers was not the same. The waste of sulfur was more successful than gypsum for removing EMgP. Significant differences in the Mg leaching could be observed between gypsum and waste of sulfur applications. Small doses were not capable enough to leach excess exchangeable magnesium. Therefore, the average exchangeable magnesium percentage values of G_3 and W_3 treatments were used to obtain exchangeable magnesium leaching curves and exponential equations (Figure 6). Logarithmic functions were fitted to describe the relationships between D_{lw}/D_s and remained EMgP for G_3, W_3, and both correlation were highly significant ($p<0.01$). The curves in Figure 6 show required water depth in order to leach exchangeable magnesium. The required leaching water depth to remove 70% exchangeable magnesium was eleven and fifteen times the soil depth in W_3 and G_3 respectively.

CONCLUSIONS AND RECOMMENDATIONS

The research results show that chemical amendment materials were needed to remove the exchangeable magnesium from soil profiles. Because of this requirement,

Table 7. Average remaining exchangeable magnesium percentage (EMgP) for varying leaching water.

Treatment (t ha^{-1})	Soil depth (cm)	Leaching water (cm)						
		0	80	120	200	240	280	320
	0-20	74.7	72.1	70.9	66.1	63.5	58.1	
	0-40	74.1	72.6	70.9	67.8	66.2	60.2	
Control	0-60	73.7	72.4	71.1	68.8	67.4	61.7	
	0-20	74.7	69.2	66.0	59.6	56.8	48.4	42.6
	0-40	74.1	69.7	66.6	60.7	58.1	50.7	44.4
G_1 = 15	0-60	73.7	70.6	67.2	61.5	59.5	52.4	47.4
	0-20	74.7	64.8	56.0	50.0	45.0	40.6	34.4
	0-40	74.1	66.0	59.7	54.9	51.8	44.8	37.4
G_2 = 30	0-60	73.7	67.1	61.5	57.9	55.0	48.3	39.7
	0-20	74.7	62.5	51.6	43.9	35.7	30.9	25.9
	0-40	74.1	64.6	56.4	49.9	41.8	36.2	30.6
G_3 = 45	0-60	73.7	66.4	58.7	52.6	46.8	39.6	33.8
	0-20	74.7	70.0	65.3	59.0	54.2	47.0	41.0
	0-40	74.1	70.7	66.9	60.8	57.5	51.4	45.4
W_1 = 30	0-60	73.7	71.3	67.8	62.7	59.9	53.6	48.6
	0-20	74.7	65.6	57.4	48.5	43.6	36.7	28.2
	0-40	74.1	66.9	59.3	54.7	50.0	41.7	31.9
W_2 = 60	0-60	73.7	68.2	62.5	58.8	54.4	45.8	34.7
	0-20	74.7	53.4	50.4	45.0	31.1	25.5	20.1
W_3 = 90	0-40	74.1	57.8	51.5	47.9	35.4	29.1	23.7
	0-60	73.7	61.7	55.4	50.7	39.5	33.1	27.7

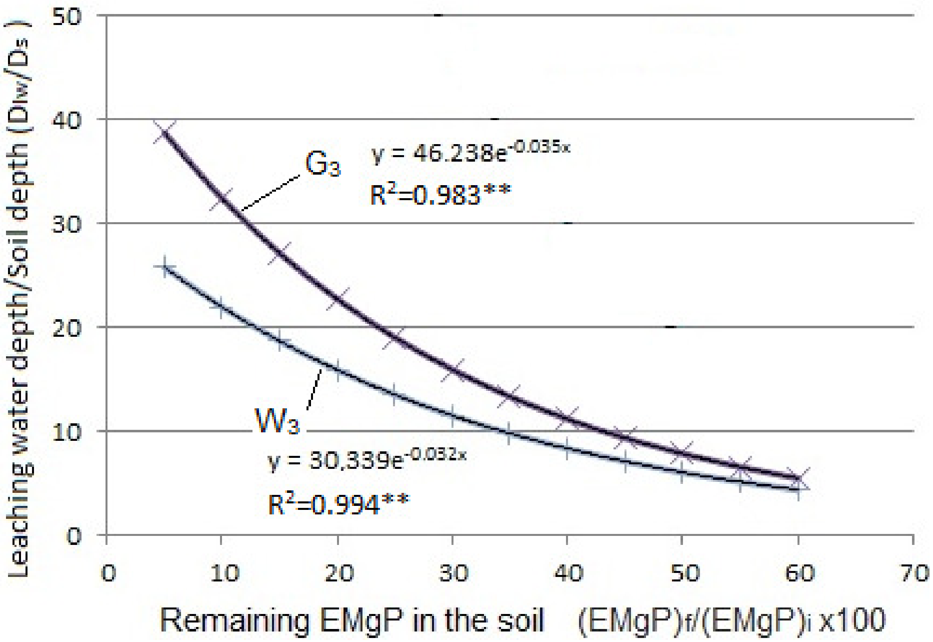

Figure 6. Remaining exchangeable magnesium percentage (EmgP) for G_3 and W_3 treatment of Dlw per unit depth of soil (D_S).

it is suggested that reclamation should be performed in stages instead of in one treatment. In this experiment, both materials were found to be effective. The ratios of exchangeable Ca:Mg and infiltration rates at the depth of 60 cm were generally better in sulfur waste-applied treatments than gypsum. The reason was that sulfur waste which has notably lower pH of 1.6, dissolving natural gypsum and calcium carbonate in soil than gypsum. Results also show that the application of 90 t ha^{-1} sulfur waste treatments along with 320 cm irrigation water would remove an amount of exchangeable magnesium equivalent of 96 t ha^{-1} and improve the infiltration rate satisfactorily.

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