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RESEARCH ARTICLE

THE RELATIONSHIP BETWEEN THE SOLUBLE AND EXCHANGEABLE MAGNESIUM IN NILE DELTA SOILS.

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Abstract

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Salt affected soils exist in several parts of Nile Delta of which are high-magnesium soils with improper properties. The identifying of rich-magnesium soils requires estimation ofthe exchangeable magnesium percentage (EMgP) and/or the exchangeable magnesium to exchangeable calcium ratio (EMg/ECa). The EMgP value and EMg/ECa ratio on soil surface are important statements that have an obvious equilibrium with the relative values of Mg and Ca in soil solution. Preliminary study was carried out to create proper relationship between the soluble magnesium in soil solution and exchangeable magnesium on the exchange complexes in Nile Delta soils.

To derive the relations between both soluble and exchangeable magnesium in soil, 90 soil samples were collected during winter season (2015/2016) from Kafre El-Sheikh, El-Hamoul, Borollus, Motobus and El-Mahalla Districts to represent non saline- , medium saline- and high saline- soils. The soluble cations in soil paste extract and the exchangeable cations on soil surface were determined. Chemical analysis of soil paste extract showed that the soluble magnesium percentage (SMgP) ranged from 9.0 to 36 and SMg/SCa ratio in soil solution ranged from 0.2 to 3.5. The determination of the exchangeable cations on soil surface indicated that EMgP value ranged from 8 to 29 and EMg/ECa ratio ranged from 0.12 to 2.0. Three empirical equations were derived to represent the relationships between:

1- **SMg/SCavs. EMg/ECa:**

$$EMg/ECa = -0.245 + 1.362\,(SMg/SCa) - 0.246\,(SMg/SCa)^2 \quad (R^2 = 0.858) \quad (1)$$

2- **SMgPvs. EMgP:**

$$EMgP = -9.298 + 2.191(SMgP) - 0.032(SMgP)^2 \quad (R^2 = 0.817) \quad (2)$$

3- **SMgP vs. EMgP after the suitable transformation:**

$$EMgP = -0.432 + 3.098(ASIN\,(SQRT\,(SMgP/100)) - 2.438(SQRT\,(SMgP/100))^2 \quad (3) \quad (R^2 = 0.830)$$

The coefficients of determination for the obtained relations aremost proper; consequently, EMg/ECa ratio and EMgP valueon soil surface can be safely predicted from their values in soil solution using these equations.

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Introduction:-

Salt affected soils exist in several parts of Nile Delta of which are high-magnesium soils with improper properties. To characterizethe rich-magnesium soils, the exchangeable magnesium percentage (EMgP) and/or the exchangeable magnesium to exchangeable calcium ratio (EMg/ECa) are required to be estimated. A possible reason for a specific Mg effect is that the hydration energy of Mg is greater than that of Ca, and the hydration radius is also greater ,0.47 vs. 0.42 nm **(Bohn et al., 1985)**, consequently lower electro static force with which a hydrated Mg ion is held at the clay surface**(Curtin et al., 1994)**.Therefore, when sodium's relative flocculating power is 1, potassium's is 1.7, magnesium's is 27, and calcium's is the highest, at 43(**Fisher, Madeline, 2011).**

There is a lack of information about the effects of Mg on soils properties, type and source of compounds responsible for the Mg enrichment and the way this accumulation occurs. However, **Dontsova and Norton (2002)** reported that Mg has a specific effect on soil clay dispersion and infiltrations due to its hydration behavior and it has greater aggregate destruction than Ca. **Agar (2012)** added that magnesium has a negative effect on soil physical properties when its concentration is relatively high compared to Ca. **Garcia-Ocampo (2003)** reported that the accumulations of Mg^{+2} on soil exchange complex to a very high saturation levels affect their physical, chemical and biological properties depending on its saturation in the exchange complex and high hydration energy. Although , Mg is a divalent cation , its elevated levels on soil exchange sites to more than 25 % result in severe structural degradation that leads to lower infiltration rate , hydraulic conductivity , structural instability **(Vyshpolskyetal ,2015)** , lower permeability and more clay dispersion **(Zhang** and **Norton ,2002)**. Also, the permeability tends to decrease with increasing EMgP**(Shainberg et al., 1988)** ,while the dispersion of clays from soils was increased while the hydraulic conductivity was significantly reduced when Ca/Mg ratios in the percolating solutions were below unity with an $SAR_{1:5}$ >3.It was observed that the saturated hydraulic conductivities were 0.17, 0.56 and 1.84 cm h^{-1} with Ca/Mg ratios of 1:2, 1.5:2 and 1:1 , respectively (**Bardhan et al.,2007)** while the productivity of soil was higher when Ca/Mg ratio on the soil exchange complex was 3.2:1**(Ansari et al.,2010)**.

Some researchers think that the EMgP value and EMg/ECa ratio on soil surface are important statements that have an obvious equilibrium with the relative values of Mg and Ca in soil solution**.** For instance, **Dontsova and Norton (2001)** found highly significant linear relationship between Ca ion percentage on the clay surface and that in soil solution. Also, **Vyshpolskyetal(2008)** revealed that using irrigation water contains Mg^{2+} at levels higher than Ca^{2+} changed their exchangeable ratio on soil, resulting in its degradation and require adequate quantities of Ca^{2+} to be mitigated. The cation selectivity on soil exchange complexes has been influenced by ion size, valence and hydration radius **(Abdouetal, 2000)** and the amount of exchangeable Ca decreased while that of exchangeable Mg increased as the Ca/Mg ratio in the leaching water was decreased **(Abdul Ghafoor etal,1990)**. Also , **Karimovetal (2009)** reported that higher concentrations of Mg^{2+} in the irrigation water in comparison to Ca^{2+} led to replacement of Na^{+} by Mg^{2+} on the cation exchange complex resulting in poor soil physical and chemical properties.

There is a lack of studies on the relation between soluble Mg vs. exchangeable Mg in soils. The estimations of the soluble cationsare easier than that of the exchangeable cations.Therefore, this study aims to derive proper empirical equations represent the relationship between SMgP vs. EMgP and SMg/SCa vs. EMg/ECa to identify the Mg-soils directly from the soluble cations.

Materials and methods:-

Ninety soil samples from Kafr El-Sheikh, El-Hamoul, Borollus, Motobus and El-Mahalla El-kobraDistricts represent non saline- , medium saline- and high saline- soils werecollected during winter season (2015/2016) to be used for this study (Map, 1). The collected soil samples were air-dried, ground and sieved through a 2 mm sieve. The soluble ions, CEC and the exchangeable cations were determined using the methods described by **Richards (1954), Jackson (1973)** and **Page (1982)** as shown in Table (1).

SMgP (soluble Mg *100/total soluble cations), EMgP(exchangeable Mg*100/CEC), SMg/SCa and EMg/ECaratios were calculated.

Map (1): The area of study

Table 1:- Some physical and chemical properties of the selected soils.

Location	EC_e dS/m	Clay %	Silt %	Sand %	Texture	CEC(meq /100g)	SMgP	EMgP	SMg/ Ca	EMg/ Ca
Kafrelsheikh	2.5-12	38-58	19-24	22-31	Clayey	25-46	9-31	20-40	0.2-3.1	0.5-1.8
El-Hamoul	8.0-25	58-64	17-21	19-25	Clayey	29-50	15-36	38-50	0.6-3.5	0.6-2.4
Borollus	1.4-1.8	10-15	11-15	70-75	Sandy	5 - 8	11-30	10-29	0.4-0.7	0.2-0.5
Motobus	42-100	60-62	17-19	18-19	Clayey	29-40	10-33	44-59	1.2-2.3	1.6-2.5
El-Mahalla	6.5-11.5	53-55	25-29	20-25	Clayey	40-46	14-27	21-35	0.9-1.0	0.7-0.9

Least squares method was applied to derive proper relationships between SMgP vs. EMgP and SMg/SCa vs. EMg/ECa according to **Pindyck** and**Rubinfeld (1976)** and **Johnston (1972).** Also, the statistical comparison measurements with coefficient of determination (R^2), simple correlation coefficient (r) and t-test were used to compare the relationship between the predicted values calculated by these equations and their actual values.

Results:-

The characterization of rich-magnesium soils requires estimation of the exchangeable magnesium percentage (EMgP) and/or the exchangeable magnesium to exchangeable calcium ratio (EMg/ECa). Three empirical equations were derived to represent the relationship between SMg/SCa vs. EMg/ECa and SMgP vs. EMgP to identify the Mg-soils directly from the soluble cations.

Relationship between *SMg/SCa vs. EMg/ECa*:-

The obtained analysis of soil samples under this study was used to create equation represent the relation between SMg/SCa ratio in soil solution and their exchangeable ratio (EMg/ECa) as shown in equation (1) and Fig (1).

$$EMg/ECa = -0.245+1.362\,(SMg/SCa) - 0.246\,(SMg/SCa)^2 \quad (R^2 = 0.858) \quad (1)$$

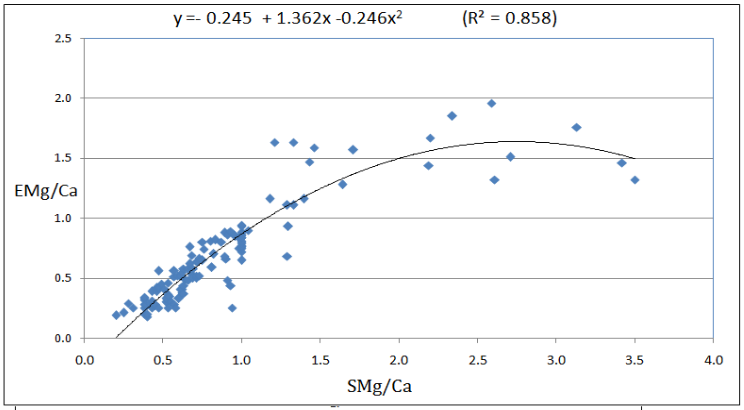

Fig 1:- Relationship between SMg/SCa in soil solution vs. EMg/ECa on soil surface.

The results showed an obvious positive quadratic relationship between the soluble Mg/Ca ratio in soil solution (SMg/SCa) and that on the exchange sites (EMg/ECa) in soil samples (R^2=0.858).The upward gradient of the relation's curve was higher with SMg/SCa in soil solution below unity.

Also, the basic data of soil analysis in this study indicated that Mg/Ca ratios in soil solution were higher than their exchangeable ratios (0.89 and 0.68, respectively). In the contrary, Ca/Mg ratio in soil solution was lower than that on the soil exchange complexes (1.54 and 2.08, respectively) for all Mg/Ca ratios in soil solution (Table, 2).

Table 2:- Effect of Mg/Ca and Ca/Mg ratios in soil solution on their exchangeable values.

Mg/Ca limits in soil solution	Mg/Ca ratio		Ca / Mg limits in soil solution	Ca/Mg ratio	
	Soluble	Exch.		Soluble	Exch.
< 1	0.60	0.46	< 1	0.58	0.75
1.0	1.00	0.82	1.0	1.00	1.23
>1	2.00	1.41	>1	1.90	2.60
0.2- 3.5(overall)	0.89	0.68	0.3- 5.0(overall)	1.54	2.08

Relationship between *SMgP vs. EMgP*:-

The data of soil analysis were used to derive equations represent the relation between soluble magnesium percentage in soil solution (SMgP) and its exchangeable percentage (EMgP) as shown in equation (2) and Fig (2).

$EMgP = -9.298 + 2.191(SMgP) -0.032(SMgP)^2$ (R^2 = 0.817)........(2)

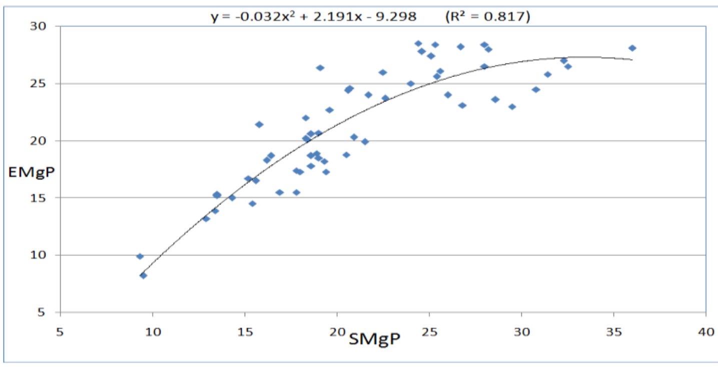

Fig2:- Relationship between *SMgP* in soil solution vs. *EMgP* on soil surface.

In this study, a highly significant positive quadratic relationship was observed between SMgP and EMgP, especially with the concentration of Mg in soil solution below 20 % as shown in Fig (2).Also, this relation showed that EMgP was slightly lower than SMgP, especially when SMgP value was above 20 %.

Relationship between *SMgP vs. EMgP* with arcsine transformation:-
The using of the arcsine transformation instead of the original values of soluble and exchangeable Mg gave a proper powerful relationship as shown in equation (3) and Fig (3). The determination coefficient (R^2) was increased from 0.817 in equation (2) to 0.830 in equation (3).

$$EMgP = -0.432+3.098(ASIN (SQRT (SMgP/100))-2.438(SQRT (SMgP/100))^2 (R^2 = 0.830)....(3)$$

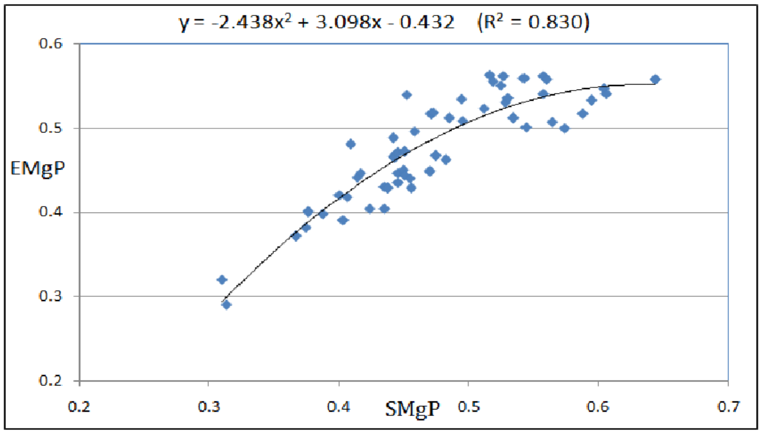

Fig 3:- Relationship between *ASIN (SQRT (SMgP)/100))* in soil solution vs. *(SQRT (EMgP)/100))* on soil surface.

In addition, the statistical comparison measurements with coefficient of determination (R^2), simple correlation coefficient (r) and t-test were used to compare the relationship between the predicted values calculated by these equations and their actual values.

The statistical comparison measurements indicated that the quadratic equation (1) is strongly satisfied since the predicted EMg/ECa ratios that calculated by this equation are strongly correlated to the actual values (r>0.92) with insignificant difference between them according to t-test. However, the statistical analysis revealed that equation (3) with the transformed data is relatively proper than equation (2) since the predicted EMgP values that calculated by this equation are strongly correlated to the corresponding actual values *(r>0.91)* with insignificant difference between them according to t-test.as shown in Table (3).

Table 3:- Statistical measurements to compare the actual values with the predicted values using the empirical equations.

Equation	R^2	r	t-test	
	value	value	t-value	Significance
1-SMg/SCa vs. EMg/ECa	0.85.5	0.927	0.076	0.991
2-SMgP vs. EMgP	0.817	0.904	1.342	0.676
3-SMgP vs. EMgP (Trans.)	0.830	0.911	0.070	0.998

Discussions:-

The results showed that the upward gradient of the relation's curve between SMg/SCa and EMg/ECa was higher with SMg/SCa in soil solution below unity, indicating that Ca is more preferable than Mg over this limit. Also, the SMg/SCa ratios were higher than EMg/ECa ratios (0.89 and 0.68, respectively). In the contrary, SCa/SMg ratio was lower than SCa/SMg (1.54 and 2.08, respectively) for all Mg/Ca ratios in soil solution. This indicated a preference for Ca in all studied soil samples. **Curtin et al. (1994)** explained the difference in behavior between Ca and Mg as due to that the hydrated radius of the Mg^{++} ion is slightly greater than that of Ca^{++} ion (0.47 vs. 0.42 nm, respectively) and consequently lower electrostatic force with which a hydrated Mg^{++} ion is held at the clay surface.

The trend test results showed highly significant positive relation was observed between SMgP and EMgP, especially with SMgP below 20 %, while, EMgP was slightly lower than SMgP, especially when SMgP value was above 20 %. **Fisher, Madeline (2011)** explained the slight difference between soluble and exchangeable Mg as due to the ability of different cations to held at the soil surface can be arranged as: *Ca > Mg > K > Na* with relative holding power of

43 ,27 ,1.7 and 1 ,respectively**.** This indicates that the ratio of the exchangeable portion comparing to the soluble portion is strongly higher with Ca, slightly lower with Mg and strongly lower with both K and Na.

The using of the arcsine transformation of soluble and exchangeable Mg gave a proper powerful relationship. The *SMgP vs. EMgP* were used after arcsinetransformation to give a gaussiandistribution and develop the relation according to**Isaaks and Srivastava (1989)**, so, the determination coefficient (R^2) was increased from 0.817 to 0.830.

The statistical comparison measurements indicated that the quadratic equation using the original data is strongly satisfied since the predicted EMg/ECa ratios that calculated by this equation are strongly correlated to the actual values (r>0.927) with insignificant difference between them according to t-test. Also, the statistical analysis revealed that the arcsinetransformed data is relatively proper since the predicted EMgP values that calculated by this equation are strongly correlated to the corresponding actual values more than that with the untransformed data (r =0.911 and 0.904, respectively) with lower t value.

Conclusion:-

It could be concluded that the exchangeable Mg^{++} as well as its relation to Ca^{++} on soil surface can be easily predicted using their corresponding values in soil solution. However, additional studies have to be in our interesting tostrengthen these relations to be safely used in identifying the rich-Mg soils.

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