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Short Communication

Growth and phosphorus nutrition of rice exposed to sodic solutions at different calcium to magnesium ratios

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Abstract

Higher sodium adsorption ratio (SAR) of irrigation water severely hampers the growth of crop plants, mainly due to ionic imbalances. In present investigation, growth and phosphorus (P) nutrition of rice (Oryza sativa L., cv. IR-9) was studied in hydroponics at different sodicity levels [SAR = 5, 10, 25 and 50 (mmol$_c$ L^{-1})$^{1/2}$]. Each sodicity level was imposed at constant electrolyte concentration of 100 cmol$_c$ L^{-1}, with three calcium to magnesium (Ca:Mg) ratios (1:3, 1:1 and 3:1). Sodicity treatments and recommended P (2 mM) were applied to P starved seedlings. Increasing sodicity significantly ($P < 0.05$) retarded plant growth, while, increasing relative proportion of Ca over Mg in sodicity formulation restored root growth. Unlike root P concentration, shoot P concentration increased significantly ($P < 0.05$) by increasing sodicity or decreasing Ca:Mg ratio of nutrient solution. Sodium (Na) concentration positively correlated ($r > 0.90$, $n = 12$) with root-to-shoot P translocation and retarded plant growth. Conversely, Ca in plants improved growth by favoring P nutrition. Conclusively, the effect of sodicity on rice growth and P nutrition also depends upon relative proportions of Ca and Mg in sodicity formulation.

Keywords: *Phosphorus nutrition, sodicity, relative calcium, rice*

Rice (*Oryza sativa* L.) is an important cereal crop of the world. It is a medium salt tolerant crop which is mostly grown under submerged soil conditions. Saturated soil conditions are conducive to free leaching of ions. Rice, therefore, is a preferred crop for salt affected soils during their reclamation. Flooded rice generally does not respond to applied P because the availability of phosphorus (P) and soluble salts increases under flooded soil conditions (Mitsch and Gosselink, 2000).

Most of the research on salinity involved artificial salinization of nutrient solutions with sodium chloride (NaCl). Sodium chloride salinity affects transport and balance of ions in the plants (Läuchli and Epstein, 1990). High concentration of sodium in root media not only deteriorates soil properties but also injures plant (Qadir and Schubert, 2002). It inhibits the uptake and transport of P in many plant species (Martinez and Läuchli, 1991; 1994; Martinez *et al.*, 1996). However, NaCl salinity is reported to increase shoot P concentration (Kumar *et al.*, 2008) in rice plants. The interactive nature affecting availability, uptake and distribution of nutrients in plants is a complex mechanism (Marschner, 1995). Therefore, single salt (e.g. NaCl) salinization might not be true representative of salinity effect.

Based on source and geological area, irrigation water may conation varying amounts of sodium (Na), calcium (Ca) and magnesium (Mg). In differnat parts of the world, underground waters genrally contain 26–85 mg L^{-1} Ca and 2–48 mg L^{-1} Mg (Ong *et al.*,, 2009). This leads to varying ratios of Ca:Mg in irrigation water. Sodicity hazard in soil and irrigation water is generally expressed as sodium adsorption ratio; SAR (mmol$_c$ L^{-1})$^{1/2}$ = Na / [(Ca + Mg) / 2]$^{1/2}$, where concentrations of sodium (Na), calcium (Ca) and magnesium (Mg) are in mmol$_c$ L^{-1}. Influence of Ca and Mg on uptake and redistribution of P within plant is not similar (Marschner, 1995), although, their relative proportions is neglected in sodicity (SAR) formulation. Calcium decreases P uptake by rice (Maas, 1993) and Mg is known to have synergistic relationship with P uptake (Fageria, 2001). While, Grattan and Maas (1985) reported that shoot P accumulation is controlled by root P concentration and it is independent of salt composition in root medium. At the sametime, Ca and Mg are strong competiters at root binding sites (Marschner, 1995); as excess of one in root medium reduces the net uptake of other (Dibb and Thompson, 1985).

Effect of sodicity on P nutrition (concentration, uptake and translocation within plant) has rarely been investigated by scientists. Similarly, almost no consideration is given to varying Ca:Mg proportion in sodicity (SAR) formulation. Therefore a solution culture experiment was conducted at constant electrolyte concentration (ionic strength) to evaluate the effect of increasing sodicity (SAR) with varing Ca:Mg ratios on growth and P nutrition of rice (cv. IR-9).

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Growth response and P nutrition of rice (cv. IR-9) was studied in solution culture at four different levels of sodicity. Rice seeds were germinated in quartz sand taken in polyethylene lined iron trays. Optimum moisture for germination was maintained by using distilled water. Fourteen-day old rice seedlings were transplanted in foam-plugged holes (two seedlings $hole^{-1}$) of a thermopal sheet. Each thermopal sheet floated over 100 L of Johnson's nutrient solution (Johnson *et al.,* 1957) contained in plastic tubs. To check evaporation, foam in thermopal sheets was kept above the solution. For 25 days, rice seedlings were P starved by growing them in half strength Johnson's modified nutrient solution containing only 0.03 mM P. Twenty-five days after transplantation, four sodicity (SAR) levels [5, 10, 25, and 50 $(mmol_c\ L^{-1})^{1/2}$] were imposed and recommended P (0.2 mM P) was maintained. Sodicity levels were applied by using chloride and sulphate salts of Na, Ca and Mg at constant electrolyte concentration of 100 $cmol_c\ L^{-1}$. At each sodicity level, three Ca:Mg ratios (1:3, 1:1 and 3:1) were used by varying relative amounts of Ca and Mg in SAR ($SAR = Na / [(Ca + Mg) / 2]^{1/2}$) formulation (Haider and Ghafoor, 1992). The experiment was laid out in completely randomized design (CRD) for two factors and each treatment was replicated five times (Steel et al., 1997). During the experimental period, the average temperature in the green house was 35 ± 5˚C at day times and 25 ± 3˚C during the night hours. Light intensity varied between 300 to 1400 μmol photon $m^{-2}\ s^{-1}$ and relative humidity varied from 35% (midday) to 85% (midnight).

Table 1: Effect of increasing sodicity [SAR as $(mmol_c\ L^{-1})^{1/2}$] with varying Ca:Mg ratios of nutrient solution on rice (cv. IR-9) growth

Sodicity level	Shoot Dry Matter (g $plant^{-1}$)				Root Dry Matter (g $plant^{-1}$)			
	Ca:Mg ratio			Mean	Ca:Mg ratio			Mean
	1:3	1:1	3:1		1:3	1:1	3:1	
5	4.75	4.74	4.70	4.73	0.54	0.51	0.55	0.53
10	4.50	4.42	4.53	4.48	0.50	0.49	0.53	0.51
25	4.11	4.10	4.02	4.08	0.46	0.46	0.49	0.47
50	3.79	3.73	3.69	3.74	0.40	0.43	0.45	0.43
Mean	4.29	4.25	4.24	---	0.47	0.47	0.50	---
$LSD_{(0.05)}$	Sodicity 0.26				Sodicity 0.03; Ca:Mg ratio 0.02			

The plants were harvested seven days after the application of treatments and separated into shoots and roots. The shoot and root samples were washed with distilled water and blotted dry with tissue paper. These were air-dried and then oven dried at 65˚C in a forced air oven to constant weight. After recording dry matter yield, plant samples were finely ground with a Wiley mill fitted with stainless steel chamber and blades. A homogeneous portion of finely ground plant material was digested in di-acid (HNO_3:$HClO_4$ mixture of 2:1 ratio) for nutrient analysis (Jones and Case, 1990). Phosphorus concentration in the digest was estimated on spectrophotometer after developing yellow color by vanadate-molybdate method (Chapman and Pratt, 1961). Calcium and Mg concentration of plant tissues was determined on atomic absorption spectrophotometer. Sodium in shoot and root samples was determined by flame photometry. Statistical analysis were performed on a computer based software; MSATA-C (Russel and Eisensmith, 1983). Significantly ($P < 0.05$) different treatment means were separated by least significant difference (LSD) method (Steel *et al.*, 1997). Pearson correlation coefficients (r) were calculated to assess relationship among various plant response variables.

Plant Growth

Shoot and root dry matter of rice seedlings were significantly ($P < 0.05$) reduced at sodicity levels of 25 and 50 $(mmol_c\ L^{-1})^{1/2}$ (Table 1). Yasin and Rashid (2002) have also reported that rice growth is reduced by increasing sodicity (SAR) of nutrient solution. The deleterious effects of sodicity on crop plants are widely known (Qadir and Schubert, 2002). Threshold SAR level, at which yield is reduced by 50%, is > 15 for transplanted rice (Gupta and Sharma, 1989). Due to its high tolerance against sodicity, rice growth non-significantly differed at lower SAR levels. Even at higher sodicity levels, dry matter reduction was not more than 22%.

Only root growth was significantly ($P < 0.05$) influenced by established Ca:Mg ratios in root medium (Table 1). Lower Ca:Mg ratios (1:3 and 1:1) significantly reduced root dry matter compared to the higher ratio (3:1). Single salt salinity could not be interpreted as a general plant response to salt stress as increased proportion of Ca over Mg in sodicity (SAR) formulation restored root growth. Many researchers have already described higher external (Herrmann and Felle, 1995; Kinraide 1998) and internal requirements (Genc *et al.,* 2010) of Ca in plants under Na stress. Thus, crop growth is dependent on sodicity (SAR) and existing ionic ratios of nutrient solution (Guzman and Olave, 2006). Salt-affected soils contain cations in different proportions and relative proportion of Ca is important for better plant nutrition on salt-affected soils (Kinraide, 1999).

Concentration and Uptake of Phosphorus

Both sodicity (SAR) and Ca:Mg ratio had a significant ($P < 0.05$) main and interactive effect on shoot and root P concentrations (Table 2). Increasing sodicity (SAR) or decreasing Ca:Mg ratio significantly increased shoot P concentration. Phosphorus is widely recommended for calcareous and salt-affected soils of Pakistan (Sarfraz *et al.*, 2009; Rahim *et al.,* 2010). There is controversy in literature for influence of root medium Na on P concentration in plants. Mousavi *et al.* (2008) reported low shoot and root P concentration in olive under Na stress. While, Kumar *et al.* (2008) reported increased shoot and root P concentration in rice with increasing Na in root medium. The results of later study were confirmed in the present investigation on rice indicating that the response is genotype specific. Interaction of sodicity and Ca:Mg ratio showed maximum shoot P concentration (6.22 mg g^{-1}) at sodicity level of 50 ($(mmol_c\ L^{-1})^{1/2}$ when Ca:Mg ratio was 1:3.

Unlike shoot P concentration, root P concentration was suppressed by increasing sodicity (SAR) or decreasing Ca:Mg ratio of nutrient solution (Table 2). Maximum root P concentration (6.91 mg g^{-1}) was observed at sodicity level of 5 $(mmol_c\ L^{-1})^{1/2}$ when Ca:Mg ratio was 3:1. Increase in shoot P concentration with decrease in root P concentration under increasing sodicity levels was due to increased root-to-shoot P translocation under Na stress (Figure 1).

Main and interactive effects of sodicity and Ca:Mg ratio were significant ($P < 0.01$) for root-to-shoot P concentration ratio (Figure 1). Significant decrease in root-to-shoot P concentration ratio with increasing sodicity (SAR) was indicative of increased P translocation to shoots. Previous studies also revealed increased P translocation to shoots in response to Na stress (Kumar *et al.*, 2008; Grattan and Maas, 1985). Increased root-to-shoot P translocation might be due to higher xylem uploading with P and presence of high-affinity Na-depended P transport system in vascular plants (Rubio *et al.,* 2005; Rausch and Bucher, 2002). Nevertheless, Na effect can partially be modified by Ca:Mg ratio of nutrient solution. Increasing Ca:Mg ratio in sodicity formulation depressed the translocation of P to shoots.

Both main effects of sodicity (SAR) and Ca:Mg ratios were also significant ($P < 0.05$) for shoot and root P uptake (μg P $plant^{-1}$) by rice plants (Table 2). On an average, increasing sodicity (SAR) also significantly increased P uptake by rice. Phosphorus uptake increased in roots and

Table 2: Effect of increasing sodicity [SAR as $(mmol_c\ L^{-1})^{1/2}$] with varying Ca:Mg ratios of nutrient solution on concentration and uptake of phosphorus (P) by rice (cv. IR-9)

Sodicity level	Shoot P				Root P			
	Ca:Mg ratio			Mean	Ca:Mg ratio			Mean
	1:3	1:1	3:1		1:3	1:1	3:1	
Concentration (mg P g^{-1})								
5	5.03	5.06	4.99	5.03	6.40	6.89	6.91	6.73
10	5.82	5.80	4.67	5.43	4.61	6.19	6.50	5.76
25	5.66	5.47	4.86	5.33	4.12	4.23	4.55	4.30
50	6.22	5.42	5.28	5.64	3.87	4.26	3.89	4.01
Mean	5.68	5.44	4.95	---	4.75	5.39	5.46	---
$LSD_{(0.05)}$	Sodicity 0.21; Ca:Mg ratio 0.18; Interaction 0.36				Sodicity 0.26; Ca:Mg ratio 0.22; Interaction 0.45			
Uptake (mg P $plant^{-1}$)								
5	23.84	23.99	23.47	23.76	3.47	3.48	3.79	3.58
10	26.14	25.61	21.15	24.30	2.28	3.06	3.42	2.92
25	23.26	22.39	19.58	21.74	1.88	1.93	2.25	2.02
50	23.57	20.22	19.42	21.07	1.56	1.82	1.75	1.71
Mean	24.20	23.05	20.90	---	2.30	2.57	2.80	---
$LSD_{(0.05)}$	Sodicity 1.63; Ca:Mg ratio 2.83				Sodicity 0.13; Ca:Mg ratio 0.16; Interaction 0.32			

decreased in shoots with increasing Ca:Mg ratio of nutrient solution. It is known that Mg enhances (Fageria, 2001) and Ca suppresses P uptake (Maas, 1993).

Sodium concentration in shoot and root of rice plants increased with increasing sodicity. Increasing relative Ca over Mg in sodicity formulation decreased tissue Na concentration. Both Ca and Mg concentrations decreased significantly with increasing sodicity of nutrient solution. Increasing relative proportion of Ca or Mg in sodicity formulation significantly increased the concentration of respective element in rice plants.

Table 3: Pearson correlation coefficients among plant growth and ionic relations in rice (cv. IR-9) grown at different sodicity levels with varying Ca:Mg ratios of nutrient solution

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1. Shoot DM	1											
2. Root DM	0.89	1										
3. Shoot Na	−0.93	−0.96	1									
4. Root Na	−0.94	−0.90	0.95	1								
5. Shoot Ca	0.72	0.82	−0.86	−0.71	1							
6. Root Ca	0.51	0.75	−0.75	−0.55	0.83	1						
7. Shoot Mg	0.70	0.41	−0.41	−0.55	0.16	−0.21	1					
8. Root Mg	0.88	0.62	−0.68	−0.77	0.45	0.13	0.89	1				
9. Shoot P	−0.40	−0.67	0.62	0.55	−0.63	−0.76	0.14	0.01	1			
10. Root P	0.89	0.85	−0.94	−0.94	0.75	0.67	0.39	0.68	−0.55	1		
11. Shoot P uptake	0.60	0.27	−0.36	−0.41	0.16	−0.16	0.79	0.85	0.49	0.36	1	
12. Root P uptake	0.91	0.91	−0.97	−0.96	0.77	0.70	0.39	0.67	−0.60	0.99	0.34	1
13. Root:Shoot P	0.84	0.88	−0.94	−0.92	0.77	0.75	0.28	0.55	−0.73	0.97	0.16	0.98

n=12; $r_{(0.01)} = 0.71$; $r_{(0.05)} = 0.53$; DM = dry matter

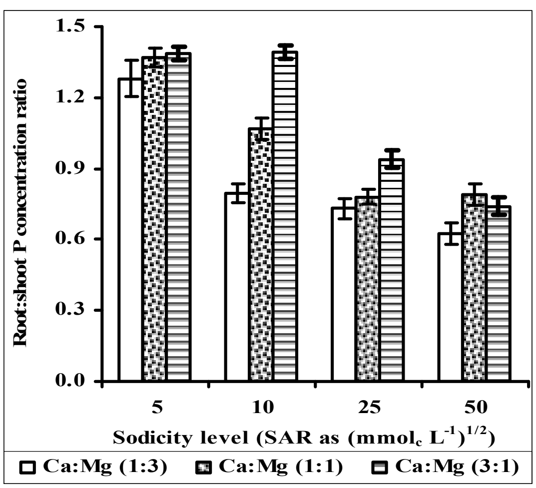

Figure 1: Effect of increasing sodicity (SAR) with varying Ca:Mg ratios of nutrient solution on root-to-shoot phosphorus (P) concentration ratio

Concentration of Sodium, Calcium and Magnesium

Various sodicity (SAR) treatments and Ca:Mg ratios of nutrient solution significantly ($P < 0.05$) influenced concentration of Na, Ca and Mg in plant organs (Figure 2).

High Na in root medium disturbed ionic balance in the shoot and root tissues of many plant species including rice (Kumar *et al.,* 2008). But, Sodium ions are known to compete with and decrease Ca in plant tissues (Dashti *et al.,* 2009). Ca is required for selective ion uptake (Kirkby and Pilbeam, 1984).

Ionic Interactions and Plant Growth

Sodium, Ca and Mg concentrations in plant tissues related with their external concentrations (Figure 2). However, the interrelationship was antagonistic that differentially affected plant growth and P nutrition (Table 3). Shoot and root Na concentrations had a strong negative ($r \leq -0.90$, n = 12) influence on plant growth. However, increased Ca concentration in plant organs had a positive relationship with biomass production. Excessive Na and Mg in root medium are toxic for plant growth. Calcium had a strong remedial effect against both the cations (Kinraide, 1998; Maas, 1993).

Shoot (r = 0.62, n = 12) and root (r = 0.55, n = 12) Na concentration positively associated with shoot P concentration. Root P concentration was negatively related

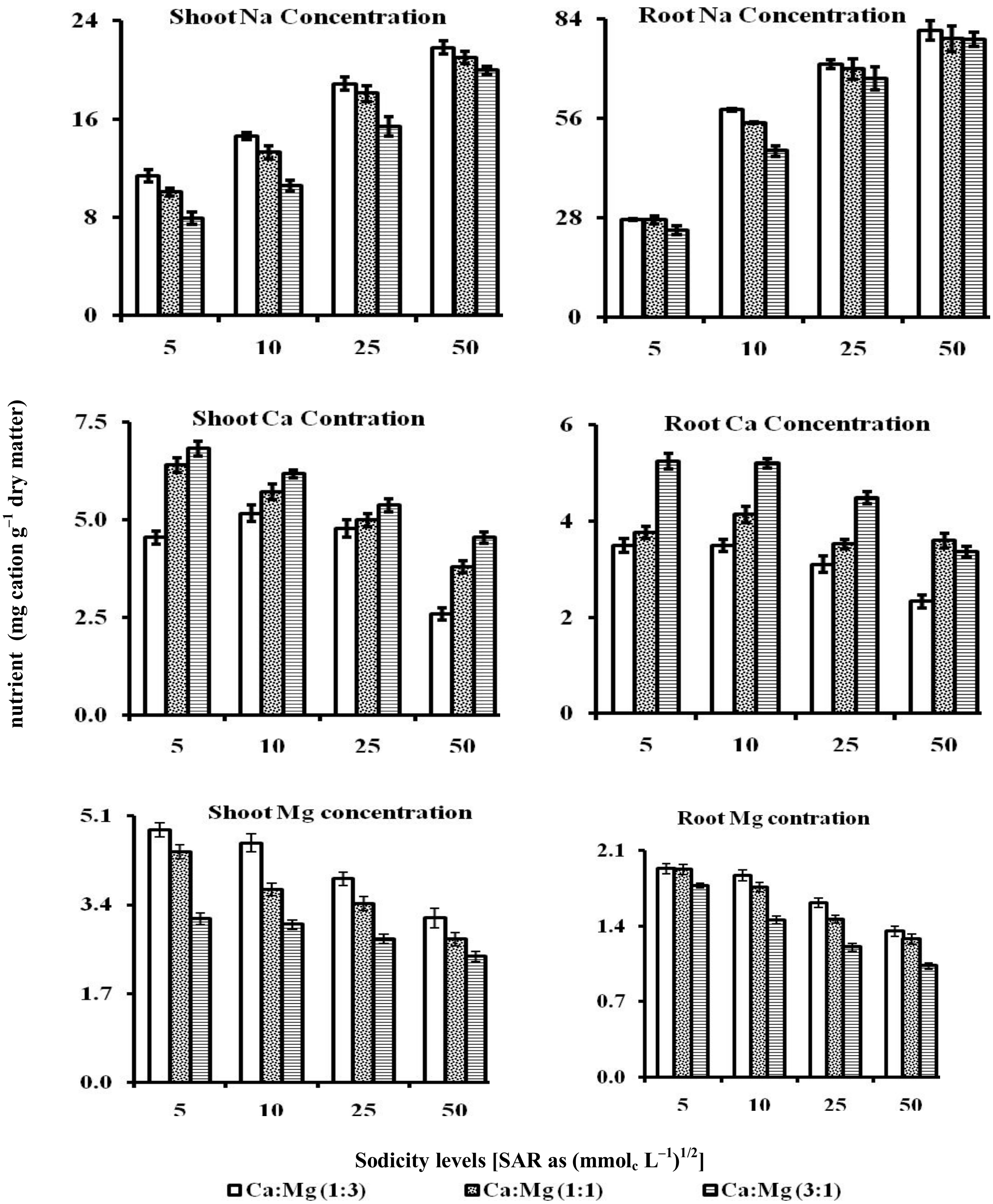

Figure 2: Effect of increasing sodicity [SAR as $(mmol_c\ L^{-1})^{1/2}$] with varying Ca:Mg ratios of nutrient solution on concentrations of Na, Ca and Mg in rice (cv. IR-9)

(r = −0.94, n = 12) with shoot and root Na concentrations. Calcium in plant improved root growth by increasing root P (r = 0.66, n = 12). At the same time, root growth strongly correlated (r = 0.89, n = 12) with shoot growth. Root-to-shoot P translocation was positively correlated with Na concentration in shoot (r = 0.94, n = 12) and root (r = 0.92, n = 12). Results of present study indicated that increased P translocation to shoot disturbed root P nutrition as increased root P was desirable for better root (r = 0.85, n = 12) and shoot (r = 0.89, n = 12) growth.

Conclusively, the effect of sodicity on growth and P nutrition of rice also depends upon relative proportions of Ca and Mg in sodicity (SAR) formulation. Therefore, Ca:Mg ratio in different sources of irrigation waters in Pakistan should be mapped and considered for crop nutrition. However, these results warrant further investigation under field conditions.

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