Role of Magnesium in Varying Quality Irrigation Waters in Influencing Soil Properties and Wheat Crop

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Ground water forms an important source of irrigation next to the surface water. In the arid and semi-arid regions as well as in the coastal areas of India, the underground waters are saline. In addition to the high concentration of the dissolved salts and higher SAR values, the proportion of Mg is often greater than that of Ca and generally increases with an increase in the salinity level of most ground waters. Owing to the scanty and erratic rainfall such waters constitute the major or even the only source of irrigation in the arid and semi-arid regions.

The continuous use of such poor quality ground waters having higher proportion of Mg influences the soil properties and plant growth. It is believed that magnesium can cause soil structure deterioration in the arid and semi-arid regions and can lead to the development of "magnesium solonetz" as described by ELLIS and COLDWELL [3]. QUIRK and SCHOFIELD [14] reported that the magnesium saturated soils show larger decreases in hydraulic conductivity than calcium saturated soils when leached with water. BAKKER and EMERSON [1], EMERSON and BAKKER [4] also observed that in the presence of Na and Mg the illitic soils are likely to disperse more than when Ca occurred as the dominant exchangeable ion. However, according to the USDA Handbook 60, calcium and magnesium are considered to behave as similar ions for the practical purposes of classifying the soils and irrigation waters.

Keeping in view the above diverse opinions regarding the behaviour of Mg, detailed investigations were undertaken to examine the effect of different quality waters having varying Mg:Ca ratios, electrolyte concentrations and SAR values on the soil properties and the yield of wheat crop. The relevant results obtained in these studies are presented in this paper.

Materials and methods

Separate laboratory and pot experiments were conducted to obtain information on the different aspects. In the laboratory, leaching trials were undertaken in specially designed permeameters to study the effect of different qualities of water having varying Mg : Ca ratios (2, 4, 8 and 16), SAR (10, 25 and 50) and electrolyte concentration (20 and 80 me/l) on the physico-chemical properties of soils. Two different alluvial soils (*A* from Karnal and *B* from Canning) dominated by illite clay mineral and two different black soils (*C* from Kota and *D* from Indore) dominated by montmorillonite clay mineral were collected for this investigation. However, for detailed studies on the composition of the leachates only two soils (one alluvial soil *A* and one black clay soil *C*) were used. The detailed initial physico-chemical properties of these soils have already been discussed by GIRDHAR and YADAV [5]. Two hundred g of each soil having 10 per cent moisture, were packed to a uniform bulk density in each permeameter. Leaching was continued with water of a given quality as per the treatment till a constant composition of the leachate was attained in each case.

The pot experiment was conducted in metallic pots (17.3 cm diam.; 20 cm length) using 8 kg each of sandy loam alluvial soil collected from Karnal and medium black clay soil collected from Indore. Fertilizer application was made according to the usual recommendation. Before sowing wheat, a pre-sowing irrigation was given with water having composition as per the treatments. Wheat (Var. *HD-2009)* was sown and only 4 plants were retained in each pot after proper establishment of germination. At each irrigation, 4 cm of water of desired quality was applied after every 5 cm of cumulative pan evaporation value, which led to a total application of 44 cm of water during the entire crop season in each treatment. The crop was protected from rain, though the amount of rainfall received during the growth period was very small. The observations on the dry matter production and grain yield of wheat were recorded at maturity.

The chloride salts of Ca, Mg and Na were used for preparing the irrigation waters of desired quality using deionized water in both experiments. In calculating SAR of the irrigation water, Mg was grouped with Ca as is widely done. The soil and plant samples were analysed for various properties, employing the standard procedures outlined by PIPER [13] and RICHARDS [16].

Results and discussion

Exchangeable cations

Four different soils, namely two black soils and two alluvial soils were used for the evaluation of the changes in the cationic composition of the exchange complex brought about as a result of leaching. The use of leaching water with varying Mg : Ca ratios and SAR values caused attainment of different cationic ratios in the exchange complex depending upon the texture, mineralogical composition and degree of calcareousness in the soil. In general, the concentration of Ca in the exchange complex decreased and that of Mg increased with an increase in the Mg : Ca ratio in leaching water of given SAR and electrolyte concentration. This differential adsorption of exchangeable Ca and Mg leads to an increase in Mg : Ca ratio on the exchange complex with an increase in the proportion of Mg over Ca in the leaching water, though the Mg: Ca ratio in the exchange complex remained lower than that of the leaching water in all soils (Fig. 1).

It was further observed that the build-up of Mg : Ca ratio in the exchange complex was relatively lower in calcareous soil as compared to non-calcareous soil, mainly because of the greater entry of Ca in the exchange complex as a result of increased release of Ca from the native $CaCO_3$ of the calcareous soil. Amongst the calcareous soils, the increase of Mg : Ca ratio in the exchange

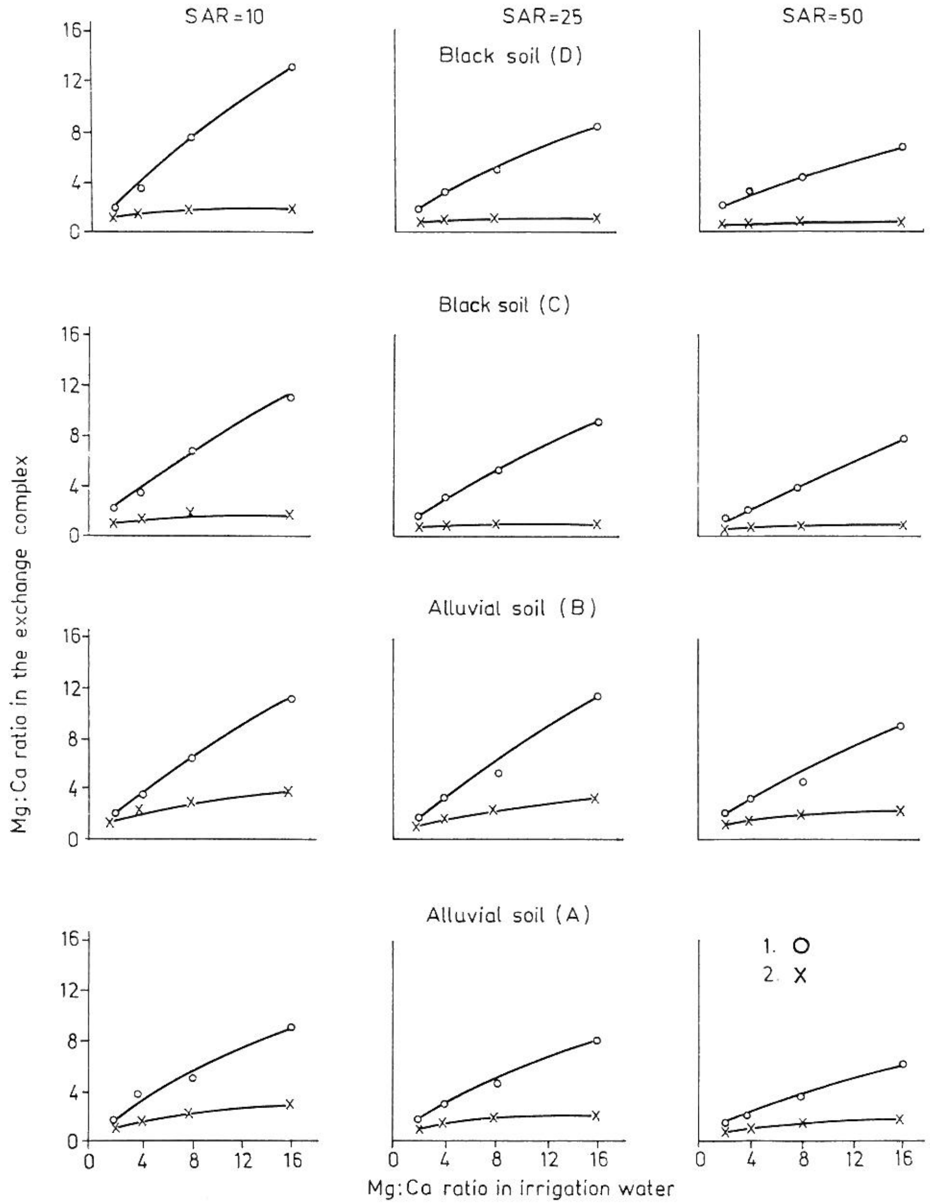

Fig. 1
Effect of varying quality irrigation waters (having 80 me/l electrolyte concentration) on the Mg : Ca ratio in the exchange complex of soils. 1. Non-calcareous soil; 2. Calcareous soil

complex was greater in the alluvial soils (*A* and *B*) than in the black soils (*C* and *D*) because of higher degree of calcareousness in the latter soils. The Mg : Ca ratio in the exchange complex decreased with an increase in SAR of leaching water from 10 to 50.

The continuous use of Mg-rich water of given SAR and electrolyte concentration increases the Na hazard in the soil (Table 1.). The effect of a given Mg : Ca ratio in enhancing Na adsorption further increases with an increase in SAR of the leaching water. This can be explained by the lower binding energy of Mg as compared to Ca. KELLEY et al. [9] also reported that if the soil was saturated with Ca, less Na was adsorbed from a given solution than when the soil was saturated with Mg.

Due to increasing Mg : Ca ratio in the leaching water the adsorption of Na in the exchange complex was found to vary from soil to soil depending upon their characteristics. The quantity of Na adsorption was much larger in black soils (*C* and *D*) dominated by montmorillonite clay mineral than in alluvial soils (*A* and *D*) having illite type of clay mineral. Further, in these soils, Na adsorption was greater in the non-calcareous soil than in the calcareous soil.

Concentration of Ca and Mg in the leachate

For detailed studies on the leachates, only one alluvial soil (*A*) and one black soil (*C*), which represented the light textured illitic soil and heavy textured montmorillonitic soil, respectively, were employed. Data in Fig. 2 indicate that the concentration of Ca decreased and that of Mg increased with an increase in the cumulative volume of the successive leachates upto a certain limit and thereafter the concentration of Ca and Mg exhibited more or less a constant trend. This limit varies from soil to soil. At the same cumulative volume of the leachate, the concentration of Ca was found to be greater in the black soil than in the alluvial soil, thereby resulting in the attainment of lower Mg : Ca ratio in the case of the former soil which was more calcareous. Further, in a given volume of the leachate, the Mg : Ca ratio increased with an increase in the Mg : Ca ratio of the leaching water.

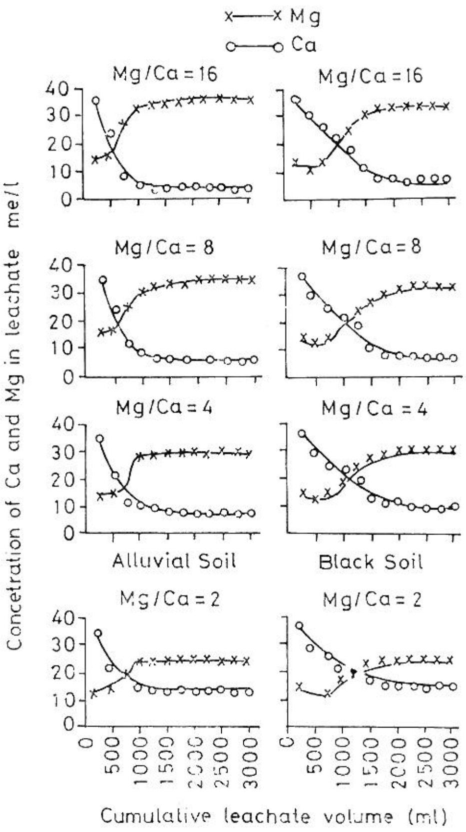

Fig. 2
Effect of leaching with waters of different Mg : Ca ratios, 80 me/l electrolyte concentration and SAR 10 on the concentration of Ca and Mg in successive leachates

Degree of dispersion

There was almost a proportionate increase in the degree of dispersion in the soil with an increase in Mg : Ca ratio of the leaching water of given SAR and electrolyte concentration (Fig. 3). The effect of increasing Mg : Ca ratio on the degree of dispersion became more pronounced at higher SAR and lower

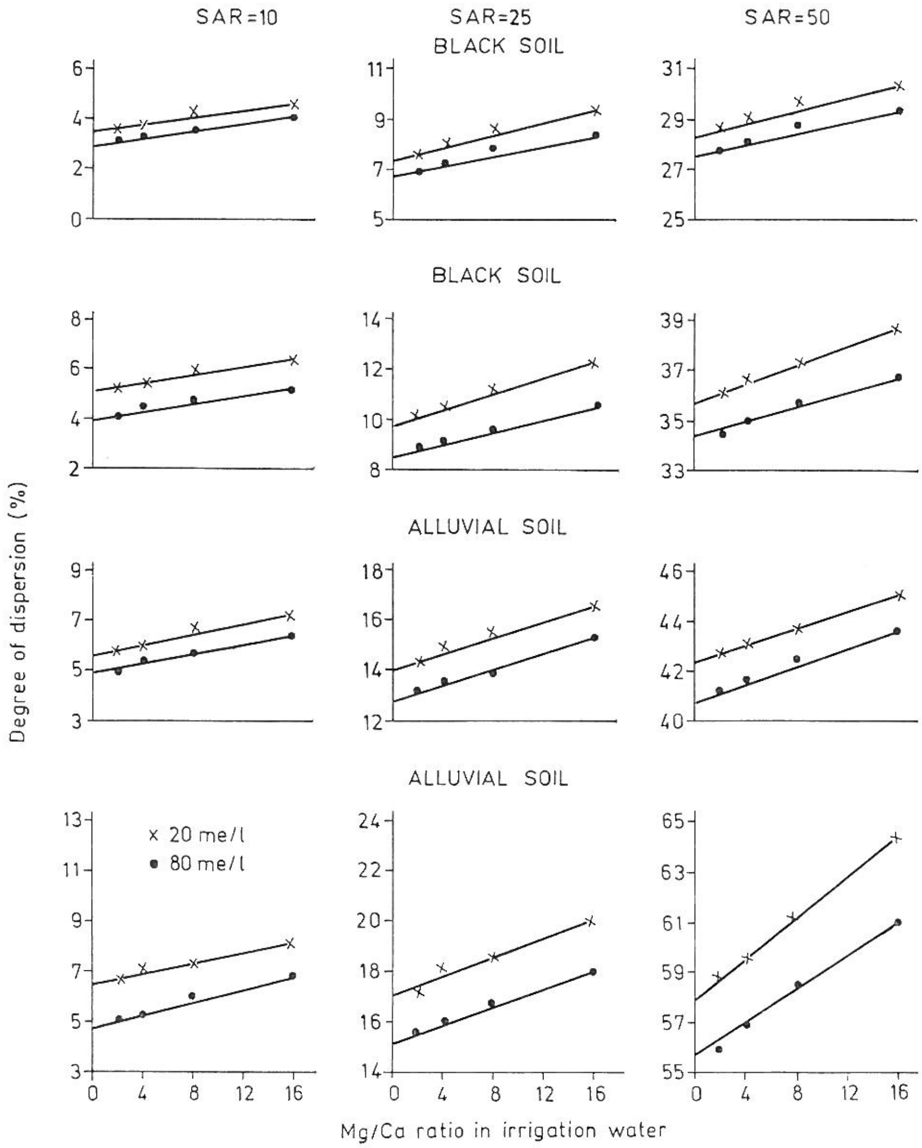

Fig. 3

Effect of leaching with waters of different electrolyte concentrations, SAR values and Mg : Ca ratios on the degree of dispersion of different soils

Table 1

Sodium adsorption (me/100 g) in calcareous and non-calcareous soils as affected by varying quality leaching waters

Leaching water		Alluvial soil				Black soil			
		A		*B*		*C*		*D*	
SAR value	Mg : Ca ratio	I	II	I	II	I	II	I	II
10	2	1.45	1.60	1.81	2.10	2.51	3.14	4.32	6.13
	4	1.47	1.65	1.84	2.17	2.50	3.27	4.40	6.40
	8	1.51	1.73	1.89	2.26	2.63	3.37	4.47	6.57
	16	1.57	1.79	2.01	2.43	2.70	3.51	4.63	6.64
25	2	2.81	3.20	3.30	3.92	5.42	6.50	9.13	12.10
	4	2.87	3.36	3.42	4.20	5.47	6.79	9.23	12.45
	8	2.93	3.60	3.54	4.47	5.66	7.14	9.50	13.00
	16	3.20	3.82	3.75	4.64	5.98	7.52	9.89	13.65
50	2	4.76	5.50	5.62	6.78	9.57	11.23	15.56	18.10
	4	4.91	5.75	5.88	7.23	9.68	11.64	15.75	18.65
	8	5.23	6.25	6.21	7.75	9.95	12.25	16.22	19.65
	16	5.55	6.75	6.70	8.41	10.37	13.10	17.11	20.20

I = calcareous soil; II = non-calcareous soil

electrolyte concentration of the leaching water. Further, the deteriorating effect of a higher Mg : Ca ratio in causing dispersion was found to be of a greater magnitude in the alluvial soils (*A* and *B*) than in black soils (*C* and *D*), obviously because of attainment of a lower Mg : Ca ratio in the exchange complex of the black soils, which were more calcareous in nature. KLAGES [11] and PANOV and ADDA [12] also reported that soil dispersion increases with the increasing degree of Mg saturation.

Further, the percentage increase in the degree of dispersion became remarkably more pronounced at the SAR value of 50 than at the SAR value of 10 at a given electrolyte concentration and Mg : Ca ratio (Fig. 3). The effect of SAR 25 occupied somewhat intermediate position. The percentage increase in soil dispersion as a result of increasing Mg : Ca ratio and SAR was greater in the case of lower electrolyte concentration (10 me/l) than in the case of a higher electrolyte concentration (80 me/l). The high degree of dispersion at lower electrolyte concentration may be caused by the increase in the thickness of the diffuse double layer. ROWELL [15] and HAMIN and MUSTAFA [6] also reported similar results.

Hydraulic conductivity

The effect of varying Mg : Ca ratio, SAR and electrolyte concentration on the hydraulic conductivity of different soils showed a trend opposite to that of dispersion. The value of hydraulic conductivity recorded in the treatment of the leaching water having a Mg : Ca ratio of 2, SAR of 10 and electrolyte concentration of 80 me/l was the maximum, viz. 8.3, 2.1, 17.6 and 39.0 mm/hr in soil *A*, soil *B*, soil *C* and soil *D*, respectively. The percentage

Table 2

Percental decrease in the hydraulic conductivity of soils as affected by varying quality leaching waters

Leaching water		Alluvial soil				Black clay soil			
		A		*B*		*C*		*D*	
SAR value	Mg : Ca ratio	20*	80*	20	80	20	80	20	80
10	2	21.7	0	26.2	0	18.8	0	12.8	0
	4	26.5	7.2	28.6	4.8	19.9	2.3	13.8	2.6
	8	28.9	10.8	30.5	8.1	23.3	5.1	16.2	5.6
	16	32.5	14.5	33.3	12.4	25.6	9.1	17.9	7.4
25	2	38.6	19.3	47.6	23.8	35.2	16.5	25.6	10.3
	4	43.4	26.5	50.0	28.1	36.9	20.5	27.9	13.6
	8	45.8	30.1	53.3	34.3	40.3	24.4	31.5	17.9
	16	49.4	36.1	55.7	37.1	43.2	28.4	32.8	20.5
50	2	47.0	30.1	61.9	38.1	44.9	27.3	33.3	17.9
	4	51.8	36.1	63.8	41.9	51.7	31.8	35.1	21.8
	8	54.2	41.0	66.2	47.6	53.4	35.2	38.5	25.4
	16	60.2	45.8	69.0	51.0	55.7	40.3	40.0	27.4

* 20 and 80 denote electrolyte concentrations of leaching water in me/l.

decrease in hydraulic conductivity in other treatments in different soils is shown in Table 2. It was found that the hydraulic conductivity of soils decreased with an increase in Mg : Ca ratio in the leaching water of given SAR value and electrolyte concentration. The effect of increasing Mg : Ca ratio on the percentage decrease in the hydraulic conductivity was more pronounced at higher SAR and lower electrolyte concentration of leaching water. Further, the effect of increasing Mg : Ca ratio was more detrimental in the alluvial soils (*A* and *B*) than in the black clay soils (*C* and *D*), presumably due to the lower build-up of Mg : Ca ratio in the latter soils.

According to Klages [11], exchangeable magnesium and sodium at the high levels found in the solonetz samples are capable of increasing dispersion and decreasing permeability. Khan [10] also reported that the permeability decreased with the increasing amount of exchangeable magnesium. According to him, magnesium — like sodium — also possibly initiates swelling and dispersion of clay, which in turn decreases the permeability of the soil.

Grain and dry matter yield

In the pot experiment conducted with wheat crop using one alluvial soil and one black clay soil, it was found that the average grain yield of wheat at Mg : Ca ratios of 2 and 16 of the irrigation water was 9.65 and 8.52 g/pot in the alluvial soil and 8.89 and 7.04 g/pot in the black clay soil, respectively (Table 3). The effects of Mg : Ca ratios of 4 and 8 on the grain yield occupied an intermediate position between those of Mg : Ca ratios of 2 and 16 in irrigation water. Almost similar trend was observed in the case of dry matter production. The magnitude of the relative decrease in the grain and dry matter yields — taking control as 100 — was greater at the higher electrolyte concentration than at the lower electrolyte concentration (Fig. 4). JOFFE and ZIMMERMAN [7] also reported that low Ca : Mg ratio had the same effect as that of Na on plant growth. According to KANWAR and KANWAR [8] the grain yield of wheat was

Table 3

Effect of different Mg : Ca ratios in irrigation water on grain and dry matter yields (g/pot) in different soils

Mg : Ca ratio in irrigation water	Grain yield		Dry matter yield	
	Alluvial soil *A*	Black soil *D*	Alluvial soil *A*	Black soil *D*
2	9.65	8.89	28.75	24.55
4	9.37	8.38	28.19	23.83
8	9.02	7.92	27.08	21.88
16	8.52	7.04	26.37	20.11
C. D. 5%	0.47	0.47	0.89	0.89

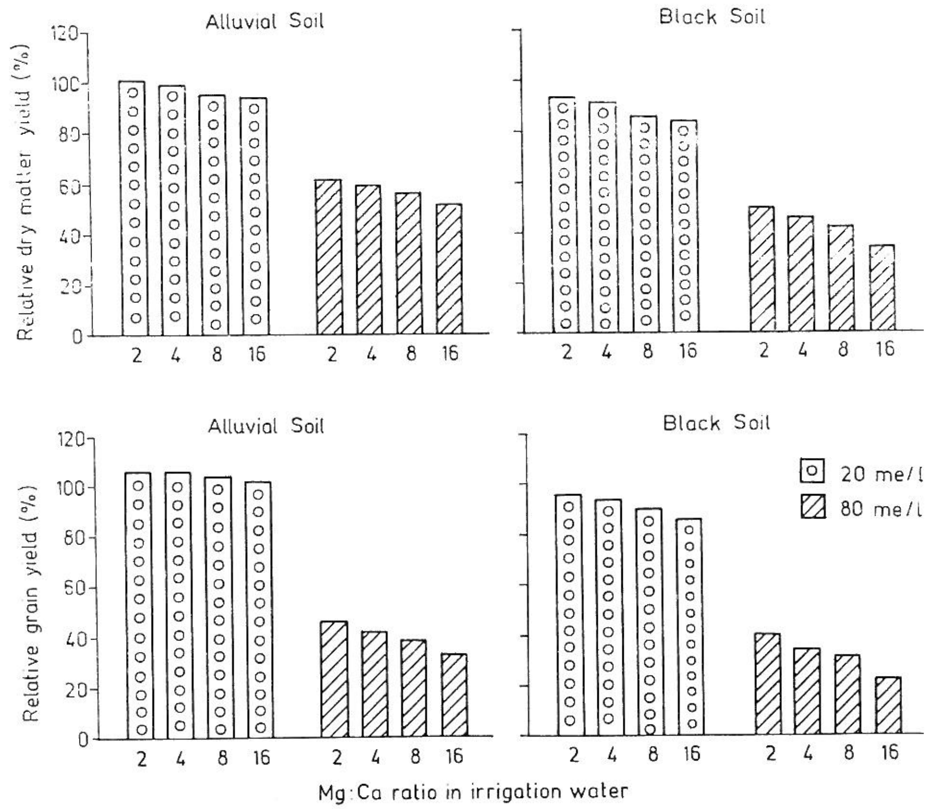

Fig. 4
Effect of different Mg : Ca ratios and electrolyte concentrations of irrigation water on relative dry matter and grain yield of wheat

much lower in the soil treated with Mg dominated water than in the soil treated with Ca dominated water. CARTER et al. [2] also made similar observations.

In the case of sandy loam alluvial soil, the yield levels of wheat at different Mg : Ca ratios of irrigation water at 20 me/l electrolyte concentration were almost at par and a substantial reduction was noticed only at 80 me/l electrolyte concentration (Fig. 4). On the other hand, in the case of black clay soil, a reduction in the yield due to the increase in the Mg : Ca ratio of irrigation water was observed even at 20 me/l electrolyte concentration. The crop yield also declined with an increase in the absolute quantity of Mg and Na in the exchange complex of the black clay soil with the use of high Mg : Ca ratio in the irrigation water.

It was further observed that the mean yield of grain and dry matter production decreased significantly with an increase in the electrolyte concentration in both the soils, but the adverse effect was more pronounced in the black clay soil because of greater accumulation of the soluble salts. These results are in accordance with the observations of YADAV [17].

In conclusion, it can be inferred from the results of the investigations that the effect of Mg is different from that of Ca. Therefore, grouping of Mg with Ca in the estimation of SAR may not be desirable for practical purposes and the SAR concept proposed by U.S. Salinity Staff needs modification. Further, while judging the quality of irrigation water, the Mg : Ca ratio and the soil type should also be taken into consideration. These results are of great relevance for most of the arid and semi-arid irrigated regions and coastal areas where underground waters used for irrigation have higher Mg : Ca ratio.

Summary

Laboratory and pot experiments were conducted to study the effect of different Mg : Ca ratios (2, 4, 8 and 16), SAR values (10, 25 and 50) and electrolyte concentrations (20 and 80 me/l) of irrigation water on the soil properties and wheat crop, using four soils of different texture, clay mineralogy and degree of calcareousness. The Mg : Ca ratio in the exchange complex increased with an increase in Mg : Ca ratio of the leaching water, and the build-up of Mg : Ca ratio was much lower in the calcareous soil as compared to the non-calcareous soil. Further, increasing Mg : Ca ratio in the leaching water at given SAR and electrolyte concentration increased the sodicity of the soil.

Increase in Mg : Ca ratio and SAR and decrease in electrolyte concentration of the leaching water increased the degree of dispersion and decreased the relative hydraulic conductivity of soils. The adverse effect of increasing Mg : Ca ratio was more pronounced at higher SAR than at lower SAR of leaching water. A significant reduction was noticed in the grain and dry matter yields of wheat with an increase in Mg : Ca ratio and electrolyte concentration of the irrigation water. The effects were more detrimental in heavy black clay soil than in alluvial soil.

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Discussion

RÉDLY, M.
When analysing the effect of different Mg : Ca ratios on the exchangeable Na, which method and how many replicates were used? Have you analysed the significance between the parallels — because the changes seem to be within the error of analysis in many cases.
GIRDHAR, I. K.
Na was extracted with 1 N ammonium acetate adjusted to pH 7.0 and the analyses were made by flame photometer. The determination of Na was replicated three times and the values of Na among the three replications were almost the same. Therefore there is no question of error in the determination.
DARAB, K.
Your data indicate that the increase in exchangeable Mg^{2+} is directly connected with the toxic effect of magnesium on the plants. Did you analyse the plants?
GIRGHAR, I. K.
We carried out the plant analyses. The data are available and they show increased ratio of Mg content with the increased ratio of exchangeable Mg.