EFFECT OF Ca/Mg RATIO OF LEACHING

WATERS ON PROPERTIES

OF SOILS OF THE

JORDAN VALLEY

by

Arif Abdul-Rahim Arif

A Thesis Submitted to the Graduate Faculty

of the School of Agriculture in Partial

Fulfillment of the Requirements for

the Degree of

MASTER OF SCIENCE IN AGRICULTURE

Split Major: Soil Science - Irrigation

Minor: Chemistry

Approved _____

In charge of Major Work

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Chairman, Graduate Committee

American University of Beirut

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ACKNOWLEDGEMENT

ABSTRACT

An experiment was conducted in the laboratory to study the effect of different Ca/Mg ratio waters on the chemical and physical properties of soils in the Jordan Valley. Two soils, one virgin and the other cultivated were leached with three waters that differed only in Ca/Mg ratios (0.3, 0.6 and 0.9).

The soluble salts in both soils were leached to a great extent, and both soils became more or less similar in salt content at the end. Most of the salts were leached in the first two or three days as revealed from the conductivity of the leachate. The Ca/Mg ratio in the leachate decreased as more water was applied. Exchangeable calcium, magnesium and potassium increased in the soils while sodium was decreased. The exchangeable Ca/Mg ratio increased from top to bottom in the column, but was generally less than it was in the original soils. The pH of the saturated paste of the leached soils was increased as soluble salts were leached from the soil. Soil permeability decreased significantly as more water was applied. No significant difference was found between soils or waters regarding their effect on permeability. Waters differed significantly in their effect on aggregation, the more the Ca/Mg ratio in the water the more the aggregation. Sections of the columns differed significantly in the amount of aggregation with the top sections generally having greater aggregation. There was no significant correlation between exchangeable Ca/Mg ratio and permeability or aggregation, indicating that neither aggregation nor permeability were affected significantly by the Ca/Mg ratios on the clay. There was a low correlation

between aggregation and permeability indicating that low permeability was not caused mainly by low aggregation of particles less than 50 microns. Destruction of larger aggregates upon continuous wetting and leaching of soluble salts was probably the main factor that caused reduced permeability. Generally, magnesium levels at the rates used in this experiment had little effect in reducing permeability and aggregation of the soils used.

It was concluded that satisfactory crop production could be maintained in this section of the Jordan Valley provided that salt tolerant crops were grown and that sufficient leaching was done to prevent accumulation of soluble salts in the soils.

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INTRODUCTION

Salt-affected areas are common in the Middle East, especially in areas away from great bodies of water, where rainfall is scarce and the land is flat with poor natural drainage. Jordan has extensive areas of salt-affected soils in the Jordan valley near the Dead Sea. Some of these soils are not suitable for agricultural production and some of them are threatened by the salt problem. The productivity of land in this part of Jordan is very important for Jordanian agriculture. It is now supporting hundreds of farmers and thousands of people, and any threat to its productivity is a threat to the well being of all those people. The waters available for irrigation in most of these areas are of poor quality and contain considerable amounts of salts.

Much of the area of the Jordan Valley was once covered by the waters of the Dead Sea. This might be the cause of salt accumulation in that area. Moreover, the Jordan Valley is considerably below sea level and it is normal to have salt accumulation in such low areas. The high level of $MgCl_2$ in the Dead Sea water may be the main reason why there are high levels of magnesium in the soils and waters of the area. The soils and waters of the Jordan Valley have a high Mg/Ca ratio. This and the fact that the structure of many soils has deteriorated after irrigation with local waters indicate the possibility that this high Mg/Ca ratio in the waters might result in the deflocculation of soil particles.

The purpose of this experiment was to study the effect of leaching with waters of various Mg/Ca ratios on the exchangeable and soluble

cations in the soil, and on such soil physical properties as aggregation and hydraulic conductivity. Such information is needed to determine the cause of soil deterioration and thus help in designing remedial and managerial practices to keep these soils in production.

REVIEW OF LITERATURE

Some Physical and Chemical Properties of Soils and their Importance

Growth of plants in a soil is much affected by the physical and chemical properties of that soil. One of the most important physical properties of a soil is the aggregation of its mineral particles. Aggregation is important because it governs many important processes that are essential for plant growth, such as aeration, permeability, drainage and root penetration. Several specific interrelated factors seem to account for granule genesis. Of these, wetting and drying, freezing and thawing, the physical activity of roots and soil animals, the influence of decaying organic matter and the modifying effects of adsorbed bases are most important. The extent of interaction of these factors as well as the texture of soil governs the amount and size of granules. The stability of granules is important and is governed among other factors by the size of granule, kind of cementing agents and the kind and timing of tillage operations.

The amount and stability of aggregation are influenced by the kind and relative amounts of adsorbed as well as soluble cations and anions. It has been established that some cations such as Ca^{++} promote aggregation by being adsorbed to the clay particle and neutralizing its negative charge. Thus, the repulsive forces between the similarly charged clay particles are diminished and it becomes easier for the cementing agent to combine these particles to form an aggregate. On the contrary, sodium ions promote deflocculation and puddling of soil aggregates (12) because of the relatively large size of the hydrated ion and its rela-

tively smaller charge. The clay particle's negative charge will be less completely neutralized and the particle will be left with a net negative charge so that the particles will tend to repell each other with a resulting decreased aggregation.

The effect of a certain cation on aggregation is governed by the amount and kind of clay mineral as well as by the size and charge of the ion itself. The adverse effect of sodium ions on the physical properties of the soil varies according to the amount of clay in the soil and with the kind of clay present (10). 2:1 type clays adsorb sodium ions less strongly than 1:1 type, thus with the same Na saturation percentage it is expected that clays of 2:1 type will have a higher zeta potential and so more dispersion of particles. The effect of Mg^{++} on the physical properties of the soil also may vary with the kind of clay in a similar way, i.e. Mg^{++} is held more tightly to 2:1 type clays, so with 1:1 type clays it is more likely to cause dispersion. The adverse effect of Mg^{++} then should be more pronounced in soils having high levels of kaolinite and other 1:1 type clays.

The kind and amount of soluble salts in the soil solution of a saline soil affect aggregation (17). As the amount of soluble salts increases, the osmotic pressure of the soil solution becomes greater and adsorbed cations will be nearer to the clay particle and in turn will neutralize more of the negative charge of the particles thus promoting flocculation of the particles. On the contrary, if these soluble salts are leached out, some of the adsorbed cations will hydrolyse and the adsorbed cations as a whole will move further away from the clay

particle causing a higher net negative charge on the particle and thus
promote deflocculation (17).

One of the most important physico-chemical properties of a soil
is the cation exchange process. This process has a prominent effect
on the physical properties of the soil as well as on the availability
of soil nutrients to plants and microorganisms. The absorption of
nutrients by plant roots is partially an exchange process. The cation
exchange capacity as well as the relative proportions of adsorbed cations
is important in determining the fertility status of the soil. The ease
of exchange is determined by the kind of clay colloid, the proportion of
a certain adsorbed cation to the cation exchange capacity, the influence
of associated ions and the effect of the replacing cation (16).

The soluble salts in soil solution are also very important in soil
chemistry. They influence the cation exchange process by affecting the
relative amounts of adsorbed cations, thus affecting the physical proper-
ties of the soil and its fertility (17).

General Effect of Leaching

During the process of irrigation, water which has dissolved salts
in it is used. This water, especially under intensive irrigation, has
a considerable influence on the soil characteristics.

The salt content of the water and that of the soil differs with
respect to each cation or anion. Soils irrigated continuously by a more
or less constant type of water reach an equilibrium with that water.
The time for this equilibrium to be attained varies with soils and waters
and the relative amount of water passing through the profile (3). The

chemical and physical properties of the soils at equilibrium are the most important because these are the ones that influence plant growth in the long run.

The general effect of leaching normal and saline soils with good water (conductivity less than 4 millimhos/cm.) is the washing of the salts from the soil especially from the upper layers. This washing process is very much enhanced by good permeability of the soil and adequate drainage (11). The more the water applied the more and deeper is the washing. The washed salts may accumulate at lower depths causing a more concentrated soil solution. Not all cations are leached with the same ease, e.g. it was found that sodium is leached more easily than magnesium and magnesium slightly easier than calcium (14, 19).

Saline sodic soils have relatively high exchangeable sodium. Yet, the physical condition of these soils is normally satisfactory, because of the high soluble salt content (10). Upon leaching, the soil solution becomes diluted and the equilibrium between exchangeable and soluble bases is disturbed, especially if there is no gypsum or calcium carbonate in the soil. Cations move towards soil solution to establish a new equilibrium, and deflocculation occurs (17).

When saline soils are leached with saline water the texture and structure of the soil play an important role in the kind and extent of the saline water effect on the soil (11). For example, when waters of high salt content are used, undesirable salt accumulations are most easily prevented if the soils are highly permeable. The salt content of soils might be decreased by leaching with saline water if the soils are permeable and if the water is applied in excess (11).

If the water used in leaching is rich with residual carbonate and bicarbonate — defined as $(CO_3^{--} + HCO_3^{-}) - (Ca^{++} + Mg^{++})$ —, calcium and magnesium in soil solution will be precipitated as carbonates (20, 7). The calcium in soil solution will decrease and some of the adsorbed calcium will move to soil solution to maintain the balance between adsorbed calcium and calcium in soil solution. The calcium leaving the colloid could be replaced by sodium, thus increasing the exchangeable sodium percentage and dispersion of the soil might occur, if the process was carried far enough.

Exchangeable Ca/Mg Ratio as Related to Chemical and Physical Properties of Soils

The cation exchange capacity characteristics and the ion saturations of soils are of interest from at least two points of view. One has to do with crop nutrition implications, while the other is concerned with magnitudes and sources of negative charge and with exchangeable cation populations as related to other physical and chemical characteristics of soils (6).

An appropriate balance between exchangeable bases is necessary for balanced uptake of nutrients by plants. An excess of one element may impair the uptake of another element. Adams and Henderson (1) found that in magnesium - deficient soils, high potassium helped to increase the availability of magnesium. On the contrary high potassium in soils having adequate magnesium level reduced the availability of magnesium. Soils having magnesium less than 4% of the exchangeable cations are considered to be deficient in magnesium. The optimum level of magnesium is about

10% of the exchangeable cations. On the other hand, calcium availability is influenced by the kind of clay minerals. 2:1 type clays require a calcium saturation of 70% or more before this element is released sufficiently rapidly to growing plants, while 1:1 type clays are able to satisfy the calcium requirements of most plants at saturation values of only 40 or 50 percent. From this, it is indicated that the optimum Ca/Mg ratio of the exchangeable soil cations for plant growth is in the range from 7 to 4.

The effect of the Ca/Mg ratio on growth of plants is modified by the amount of sodium present on the exchange complex. Joffe and Zimmerman (9) in an experiment on sudan grass concluded that at higher levels of exchangeable sodium (15 - 30%) the Ca/Mg ratio should be high (11:1) in order to insure a good plant growth and yield. However, this could be accomplished by low Ca/Mg ratios (2:1) if the exchangeable sodium is less than 5%.

Jacoby (8) reported an experiment to test the effect of Mg/Ca ratio on uptake of magnesium by citrus seedlings. Leaf analysis showed positive correlations between Mg/Ca ratios in the soil and magnesium contents, and Mg/Ca ratios in the leaves. Mg/Ca ratios below 0.05 impaired the uptake of magnesium by citrus. However, this was not due to low magnesium content in the soil but rather to an excess of calcium which antagonized the uptake of magnesium.

The negative charge on a clay particle is either a permanent one which is mainly due to isomorphous substitution in the clay mineral lattice, or a pH - dependent one which is due to ionization of H^+ ions from sites on the edges of the clay particle (6). The permanent charge is by far the most important one especially in 2:1 type clays. The

other is only pronounced at pH values higher than 7. These negative charges are the cause of cation adsorption to the clay particles. The total adsorbed cations determined at pH 8.2 is the maximum total for the two charges.

The strength of adsorption of a certain cation to a clay particle depends mainly upon the kind of clay particle and on the size and charge of the cation. Generally, 2:1 type clays adsorb divalent cations with more strength than 1:1 type clays, which adsorb monovalent cations with more strength than 2:1 type clays. The more the charge and the smaller the size of the hydrated ion of a cation the more strongly it is adsorbed to the clay particle.

Due to different sizes, charges, and percentage saturation on the exchange complex, cations differ very much in the extent of their effect on neutralizing the negative charge of clay particles and thus on soil aggregation. The effects of exchangeable sodium and calcium on the physical properties of soils are better understood than the effects of exchange able potassium and magnesium. A survey of the literature indicates that the roles of exchangeable potassium and especially magnesium are controversial.

Shawrygium as reported by Brooks et al.(2), Joffe and Zimmerman (9) and others have concluded that exchangeable magnesium has an effect similar to that of exchangeable sodium. Others believe that magnesium has an effect similar to that of calcium (10, 15). Few, if any, investigations have given satisfactory reasons for the poor soil physical conditions sometimes associated with high exchangeable magnesium. Brooks et al.(2)reported a paper by Baver and Hall pointing out that the low flocculating power of the magnesium ion with respect to organic matter suggests

a possible explanation of the formation of magnesium solonetz soils. Brooks et al. (2)also reported that Gill and Sherman have associated the poor physical properties of some Hawaiian soils with their high contents of exchangeable magnesium. They suspected that the reason for the low permeability and high plasticity was "that the hydration of the exchangeable magnesium ion is greater in the presence of certain humates and that this hydration results in dispersion of the clay and organic matter."

Brooks et al. (2) found that there was a slight increase in the permeability ratio - ratio of air permeability to water permeability - with increasing exchangeable magnesium. However, this increase was very small when compared with the effect of exchangeable sodium.

The modulus of rupture is related to the crusting characteristics of soils. Brooks et al. (2) found that the modulus of rupture was only slightly affected by increasing levels of exchangeable magnesium while it was increased substantially by increasing levels of sodium. He concluded that the effect of exchangeable magnesium on the dispersion and leaching of organic matter from the soil was similar to that of calcium but relatively smaller.

The occurrence of high Mg/Ca ratios in some soils such as hardspot soils and magnesium-solonetz soils is an interesting phenomenon. Hardspot soils are compact soils that are very poorly aggregated especially in the top soil. The chemical analysis of profiles of these soils (4) revealed that both exchangeable sodium and magnesium were high. Exchangeable magnesium was higher than exchangeable calcium in most clay loam soils of the hardspot type. Exchangeable magnesium was higher than

exchangeable calcium in some normal soils, but these soils were either sandy loam or sandy clay loam. So, it is possible that high exchangeable magnesium may be the cause of poor aggregation and compactness in some fine textured soils.

Magnesium-solonetz soils are characterized by the solonetz morphology with a B-horizon that contains greater equivalent amounts of exchangeable magnesium than of any other cation. Kelley (1) explained this situation by saying that these soils were submerged by sea waters, which contain one equivalent of magnesium to each 4.3 equivalents of sodium. Since the replacing power of magnesium is greater than that of sodium, then upon submerging soils with sea waters, magnesium will be adsorbed to clay particles in relatively greater amounts. Kelley (10) states that it is not necessarily true that exchangeable magnesium has been primarily responsible for the solonetz morphology, although magnesium might have contributed somewhat to that end. Several Russian workers questioned the causality of magnesium in the formation of solonetz morphology. Some of them (16) said that sodium may have been predominant in such soils before magnesium replaced it. Russell (19) stated that it is possible that during the leaching out of soluble salts that the exchange complex acquired a high proportion of exchangeable magnesium and the soils partially deflocculated and undersent a profile development similar to that of soils with a high proportion of exchangeable sodium.

However, a decisive answer as to whether the high level of magnesium contributes to the solonetz morphology or to the compact structure of hard spot soils has not yet been obtained.

The effect of a certain cation on aggregation is not a simple relationship. The literature reveals that the effect of an adsorbed cation is much affected by the other adsorbed cations as well as by the amount and kind of salts in the soil solution. Martin and Richards (12) found that increasing the exchangeable hydrogen increased the dispersing effect of sodium, potassium and ammonium ions. However, it could be possible that the resulting lower levels of calcium and magnesium were the cause of the intensified dispersing effect and not the presence of high exchangeable hydrogen. Joffe and Zimmerman (9) found that the Ca/Mg ratio on the exchange complex modified the dispersing effect of sodium. The wider the Ca/Mg ratio the more pronounced the sodium effect if sodium is present in high concentrations. Less dispersion was obtained when the ratio narrowed. On the other hand a high Ca/Mg ratio (11:1) was much more effective in reducing swelling caused by sodium than was a low Ca/Mg ratio (1:1.25). Either there was not enough calcium to antagonize the effect of sodium or the magnesium tended to act like sodium. The increased dispersion effect of sodium did not affect yield in this pot experiment because the soil was mixed with sand at a 1:2 ratio.

The distribution of cations in a soil profile is altered upon leaching. The ratios of cations to each other in the soil solution as well as on the clay complex change. Menchikowsky and Ravikovitch (14) stated that the distribution of cations of the water extract of soils in a certain degree reflects the distribution of the same cations present as replaceable on the colloid complex of the soil. However, some of the cations are leached more readily than others. Menchikowsky and Ravikovitch found that the exchangeable calcium percentage decreased with depth, but that of magnesium

and sodium increased with depth upon leaching some soils of Palestine.
Sodium and magnesium were leached downward, where they established a
new equilibrium between exchangeable and soluble cations. Menchikowsky
(13) found that Na/Ca ratio increased with depth in some profiles of
northern Jordan Valley.

In a 20-year lysimeter investigation, Pratt and Chapman (16) found
that the magnesium saturation decreased in the upper 24'' with increase
in application of calcium nitrate to the water applied. The sodium
saturation was also decreased.

Reeve and Bower (17) found that leaching with sea water increased
the exchangeable magnesium in soils. Nothing was found in the literature
about the effect of leaching with high Mg/Ca ratio waters on the chemical
and physical properties of soils.

MATERIALS AND METHODS

Soil samples for this experiment were taken from a farm which is
12 kilometers to the north of the Dead Sea. Cultivation on this farm
started about 10 years ago, and the cultivated part is irrigated by
deep well waters pumped from the same farm. Part of the farm is still
uncultivated (virgin).

Soil samples were taken from the upper foot of the virgin and of
the citrus orchard soils. Water samples from four wells on the farm
were also collected and analysed. The analyses of waters of nine other
wells from the same area were also available.[#] Waters for use in the
leaching study were synthesized in the laboratory in such a way that
the average ionic content was the same as the average for the thirteen
well waters except the proportion of calcium to magnesium which was
varied to provide the following Ca/Mg ratios: 0.3, 0.6 and 0.9. The
average Ca/Mg ratio of the well waters analysed was 0.6.

Soils were analysed (18) before leaching for the following:-

1) Soluble cations and anions, namely, Ca^{++}, Mg^{++}, Na^+, K^+, Cl^-,
$CO_3^=$ and HCO_3^- .

2) Exchangeable cations, namely, Ca^{++}, Mg^{++}, Na^+ and K^+.

3) Texture, $CaCO_3$ content, pH of saturated paste, 1/3 and 15
atmosphere moisture percentages and aggregation of particles less than
50 microns.

Soils were leached in columns prepared from 4 inch diameter steel
sections, (Fig. 1).

Analysis done by Soils Division, School of Agriculture, A.U.B., 1960.
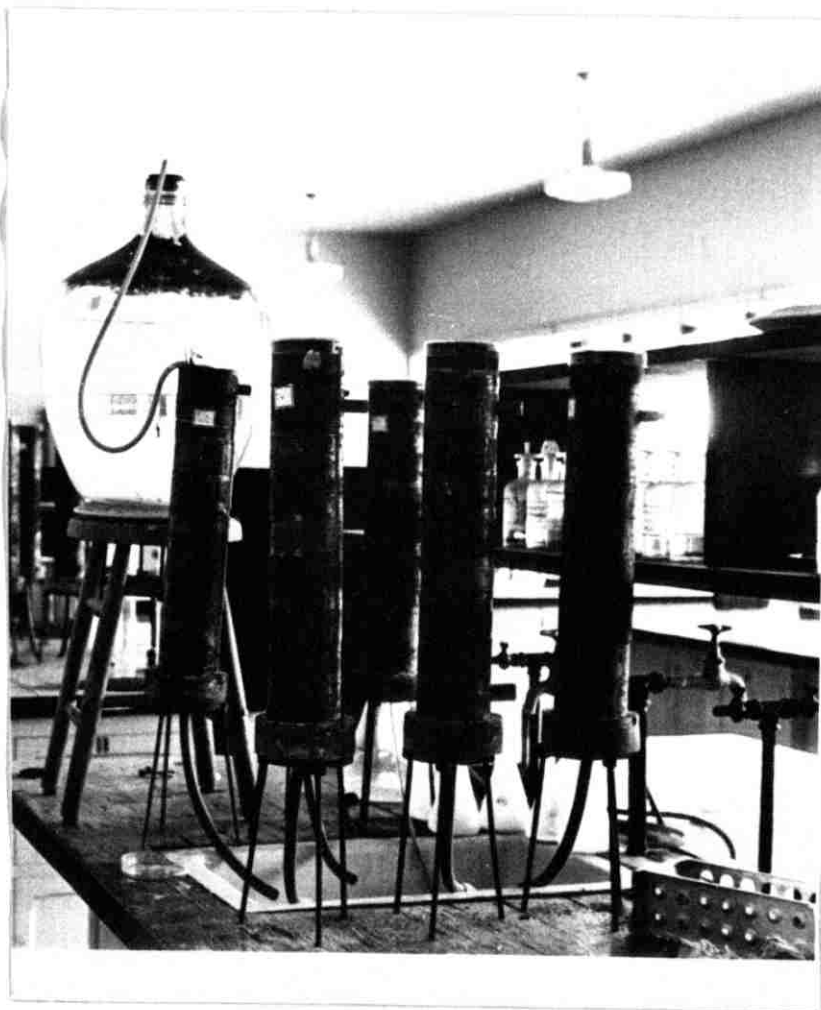
Figure 1. The apparatus for leaching soils.

The soil was sieved through a $\frac{1}{4}$ inch sieve, and 2 kgm. of soil was placed in each column after filling the column with water. The average height of soil in each column was about 28 cm. Nine columns were prepared from each of the two soils. Each three columns were leached with a different water, so the total number of columns was eighteen.

Water was applied daily to the columns starting April 1st 1962 until

25 liters had been applied to each column. The soil in the columns was not allowed to dry. The total time of leaching varied from 58 to 90 days.

During the process of leaching, samples of the leachate were taken and the conductivity measured. Samples of the leachate were also taken after leaching with 5, 10, 15 and 25 liters and the samples were analysed for Ca^{++}, Mg^{++}, Na^+, K^+, Cl^-, $CO_3^=$ and HCO_3^- following procedures described in U.S.D.A. Handbook 60 (18).

Measurements of hydraulic conductivity were done after the application of 5, 10, 15, 20 and 25 liters of water. This was done by maintaining a constant head of water over the soil column and measuring the volume of the leachate in a fixed period of time. Darcy's equation (21) was used to calculate the coefficient of permeability.

At the end of the leaching operation, the columns were sectioned horizontally and the soil divided into three nearly equal portions. These samples were left to air dry then the following determinations were made according to U.S.D.A. Handbook 60 (18).

1) Moisture content, by drying in an oven at 105 C.

2) Soluble Ca^{++}, Mg^{++}, Na^+, K^+, Cl^-, $CO_3^=$ and HCO_3^- from the saturated extract.

3) Exchangeable cations by leaching with ammonium acetate.

4) Measuring the aggregation of particles less than 50 microns.

5) $CaCO_3$ content on a few samples (15).

Statistical analysis was done according to methods described by Cochran and Cox (5). The experimental design was a split-split plot design with soils as main plots and waters as subplots.

RESULTS AND DISCUSSION

Properties of Soils and Irrigation Waters

The two soils used in this experiment were sedimentary clay loam
soils as revealed from their mechanical analysis (Table 1). The dif-
ference in texture between these soils was not great, as they were from
the same area. The differences in chemical and physical properties result-
ed chiefly from the fact that one of them has been cultivated for a few
years while the other was still virgin. Both soils were calcareous with
a slightly higher calcium carbonate content in the cultivated soil. Both
soils were saline-sodic soils, but the virgin soil had much more soluble
salts than the cultivated soil, because most of the soluble salts of the
cultivated soil have been leached out during irrigation.

The high soluble salt content of the virgin soil caused that soil
to be better flocculated than the cultivated soil. The exchangeable
sodium percentage was greater in both soils than the 15% level which is
considered injurious to soil structure (18) but slightly less in the culti-
vated soil than in the virgin soil.

Plants would not grow normally in the virgin soil because of the high
salt content. The existance of some gypsum in the soil made its cultiva-
tion possible after leaching with a few inches of water. By leaching,
excess salts were removed from the soil and gypsum was dissolved giving
calcium ions that replaced the exchangeable sodium and thus alleviated
the hazard of soil structure deterioration, though this might be only
temporary and varies with the gypsum content and the quality and quantity
of water applied.

Table 1. Results of chemical and physical analyses of the
original soils used in the experiment.

Soil property	Value	
	Virgin soil	Cultivated soil
Moisture content of air dried soil, %.	3.00	2.56
Moisture content at 1/3 atmosphere pressure, %.	22.70	22.79
Moisture content at 15 atmosphere pressure, %	9.94	10.07
Saturation percentage.	25.90	32.90
Sand, %	25.75	39.47
Silt, %	40.42	28.58
Clay, %	33.83	31.95
Textural class.	clay loam	clay loam
pH of saturated paste.	7.15	7.50
Calcium carbonate, %	35.00	40.00
Aggregation of particles less than 50 microns, %	54.15	37.25
Cation exchange capacity, m.e./100 g.#	62.50	61.10
Exchangeable cations, m.e./100 g.		
Calcium	38.00	38.65
Magnesium	8.55	8.33
Sodium	14.19	12.20
Potassium	1.46	1.72
Exchangeable Ca/Mg ratio.	4.44	4.64
Exchangeable sodium saturation, %	22.70	20.00
Conductivity of saturation extract, millimhos/cm.	130.00	8.30
Gypsum content, m.e./100 g.	1.90	0.90

Calculated from sum of exchangeable cations

Assuming the two soils were more or less similar before cultivation started, some changes occurred in the soil properties as a result of the leaching process (Table 1). However, the quality and quantity of irrigation water used on the cultivated soil must also be considered.

The three waters used in the leaching process (Table 2), were synthesized in the laboratory in such a way that their composition resembled the average composition of waters found in the area. All cations and anions were the same in the three waters except for calcium and magnesium which had a fixed total in the three waters but the ratio of calcium to magnesium was varied within that total to give 0.3, 0.6 and 0.9 Ca/Mg ratio waters. The Ca/Mg ratio common in the waters of the area was 0.6, so one of the waters used in leaching had a higher ratio, one a similar ratio and the third a lower ratio. The sodium adsorption ratio of the waters was around 4 and their conductivity was 2.66 millimhos/cm., so they were classified as low sodium - very high salinity waters (18). Such waters, when used in irrigation, may require special managerial practices.

Table 2. Composition of the waters used in leaching

Water	Cations m.e./liter				Anions m.e./liter		
	Ca^{++}	Mg^{++}	Na^+	K^+	Cl^-	HCO_3^-	$SO_4^=$
0.3 Ca/Mg Water	3.40	11.32	10.33	1.55	15.58	7.72	3.30
0.6 Ca/Mg Water	5.52	9.20	10.33	1.55	15.58	7.72	3.30
0.9 Ca/Mg Water	6.97	7.75	10.33	1.55	15.58	7.72	3.30

Conductivity of leachate

At the beginning of the leaching process, the conductivity of the leachates was very high (Table 3), especially in the case of the virgin soil leachates. The conductivity dropped very rapidly as leaching went on. After eight days from the start of the experiment, that is, after application of about three liters of water, no substantial change in the conductivity of the leachate occurred. By that time, most of the soluble salts in the soils were leached. The greater fraction of the soluble salts was leached in the first two or three days. After that, the amount of salts removed by the leaching water decreased slowly until the conductivity of the leachate became more or less constant at about that of the original water indicating that no more salts were being leached.

Table 3. Conductivity of the leachate during the leaching process. Millimhos/cm. at 25°C.

Days from the start	0.3 Ca/Mg water		0.6 Ca/Mg water		0.9 Ca/Mg water	
	virgin	cultivated	virgin	cultivated	virgin	cultivated
1	96.47	6.79	95.87	7.47	83.84	6.94
4	6.21	3.79	4.76	2.90	5.63	2.85
6	3.27	2.93	2.97	2.80	3.01	2.75
8	2.65	2.73	2.66	2.68	2.61	2.68
10	2.61	2.68	2.61	2.63	2.58	2.66
16	2.70	2.73	2.66	2.65	2.64	2.64
23	2.70	2.72	2.67	2.65	2.71	2.66
31	2.58	2.57	2.62	2.62	2.58	2.60
41	2.64	2.62	2.59	2.58	2.55	2.61
56	2.63	2.61	2.58	2.63	2.55	2.61

Composition of leachate

Waters differed significantly (Table 5) among themselves in their effect on the Ca/Mg ratio of the leachate. The higher the Ca/Mg ratio in the original water, the higher it was in the leachate. This was more pronounced towards the end of the experiment, when the soluble salt content of the soils no longer affected the composition of the leachate (Table 4).

The amount of water applied also affected significantly the Ca/Mg ratio of the leachate (Table 5). The more the water that was applied - regardless of its kind - the lower was the Ca/Mg ratio of the leachate. This indicated that as leaching went on, more and more of the calcium of the water was adsorbed by the soil colloids or retained in the soil. The final Ca/Mg ratio in the leachate was lower than in the original waters. This indicated that equilibrium had not yet been attained between the soils and the waters. As soluble salts were leached, a new equilibrium had to be established between soluble and exchangeable cations in the soil. Some sodium, which is easily replaced by divatent cations, moved out from the exchange complex and was replaced mainly by calcium and magnesium coming from the leaching waters. The total calcium plus magnesium in the leachate at the beginning of the experiment was more than it was in the original waters (Table 4), because of the calcium and magnesium leached from the soil solution. At the end of the experiment the total calcium plus magnesium was lower than in the original waters indicating that some of this total was adsorbed by the soil in place of sodium or retained in the soil as the insoluble carbonates. Actually, calcium was the cation retained more by the soil, since its absolute amount in the leachate, at the end of the leaching process, was less than in the original waters (Table 4).

Table 4. Cations and Ca/Mg ratios in the leachate during the leaching process. m.e./liter

Cation	liters applied	0.3 Ca/Mg water		0.6 Ca/Mg water		0.9 Ca/Mg water	
		Virgin	Cultivated	Virgin	Cultivated	Virgin	Cultivated
Ca^{++} m.e./ liter	5	6.26	5.95	5.73	5.82	6.25	6.13
	10	5.16	4.80	4.58	5.05	5.10	5.45
	15	3.73	3.08	3.92	4.02	4.23	4.30
	25	2.22	2.15	3.05	3.22	3.60	3.67
Mg^{++} m.e./ liter	5	9.12	10.40	9.21	9.85	8.48	9.39
	10	9.32	9.29	9.05	8.03	8.49	7.68
	15	10.07	10.41	9.74	8.39	7.73	7.59
	25	12.03	11.26	10.96	9.19	9.19	7.93
Ca/Mg^{++} ratio	5	0.68	0.57	0.62	0.59	0.74	0.65
	10	0.55	0.52	0.51	0.63	0.60	0.70
	15	0.37	0.30	0.40	0.48	0.54	0.57
	25	0.19	0.19	0.28	0.35	0.39	0.47
Na^{+} m.e./ liter	5	10.78	11.71	11.39	10.69	11.30	10.49
	10	9.65	10.17	10.20	11.04	10.32	10.23
	15	10.43	11.04	11.04	10.22	9.22	10.78
	25	10.85	10.23	10.61	10.47	10.42	11.17
K^{+} m.e./ liter	5	1.16	1.22	1.15	1.18	1.17	1.18
	10	1.02	1.08	1.02	1.05	0.96	1.13
	15	0.98	1.30	1.09	1.13	1.01	1.31
	25	1.57	1.73	1.74	1.64	1.38	1.58

L.S.D. for comparison of Ca/Mg ratio of the leachate between different waters on the same soil after application of a certain amount of water is 0.041.

L.S.D. for comparison of Ca/Mg ratios in the leachates of a certain soil-water treatment as the amount of leaching water is increased is 0.033.

Table 5. Analysis of variance for Ca/Mg ratio in the leachate

Source	d.f.	s.s.	m.s.	Observed F.
Replicates	2	0.0071	0.0035	0.493
Soils	1	0.0028	0.0028	0.389
Replicates x soils error (a)	2	0.0144	0.0072	-
Waters	2	0.3167	0.1583	31.05[##]
Waters x soils	2	0.0416	0.0208	4.08
Error (b)	8	0.0409	0.0051	-
Amount of water	3	1.2241	0.4080	118.19[##]
Amount of water x soil	3	0.0680	0.0227	6.56[##]
Amount of water x water	6	0.0903	0.0150	4.36[#]
Amount of water x soils x water	6	0.0060	0.0010	0.29
Error (c)	36	0.1243	0.0035	
Total	71	1.9362		

Significant at 5 per cent level.

Significant at 1 per cent level.

A significant interaction was found between the amount of water applied and the kind of soil (Table 5). The gradiant in Ca/Mg ratio was greater in the virgin soil than in the cultivated soil (Table 4). That is, the decrease in Ca/Mg ratio from the beginning till the end of the experiment was more in the virgin than in the cultivated soil.

A significant interaction was also found between the amount and kind of water applied (Table 5). After leaching with 5 liters, all the Ca/Mg ratios were closer to each other than at the end of the leaching process when the difference between the Ca/Mg ratios of the leachates of different waters was more pronounced (Table 4).

Sodium concentration in the leachate (Table 4) was almost the same all through the experiment. But in the majority of cases, the concentrations were slightly higher than in the original waters indicating that some of the soil sodium was replaced by calcium and magnesium as mentioned above. This is also indicated by the reduction of exchangeable sodium after leaching of the soils (Table 10).

Potassium (Table 4) remained less in the leachate than in the original water for most of the leaching process, showing that it was being adsorbed or fixed by the soil. This is indicated by the increase of exchangeable potassium on the exchange complex of the leached soils. At the end of the experiment, potassium increased again in the leachate approaching that of the applied waters indicating that a state of equilibrium had been approximately attained.

Chloride (Table 6) was more in the leachate than in the original waters indicating that it has been leached from the soil. The total carbonates and bicarbonates was less in the leachate. The reduction of carbonates and bicarbonates in the leachate below that of the original

Table 6. Chloride, carbonates and bicarbonates in the leachate during the leaching process. m.e./liter

Anion	liters applied	0.3 Ca/Mg water		0.6 Ca/Mg water		0.9 Ca/Mg water	
		virgin	cultivated	virgin	cultivated	virgin	cultivated
Cl^- m.e./ liter	5	17.52	16.84	17.15	16.80	16.81	16.61
	10	17.02	16.54	16.83	16.53	16.74	16.49
	15	16.40	16.52	17.15	17.10	15.02	15.73
	25	18.43	18.01	18.01	17.13	17.60	16.51
$CO_3^=$ m.e./ liter	5	1.43	0.92	1.38	1.26	1.43	1.23
	10	1.48	1.35	1.23	1.03	1.03	1.15
	15	1.21	1.06	0.59	1.05	0.68	1.26
	25	1.52	1.06	1.21	0.98	1.13	1.02
HCO_3^- m.e./ liter	5	3.34	5.13	3.13	5.62	3.51	4.13
	10	3.56	4.64	3.67	3.76	3.57	3.55
	15	5.12	5.58	3.41	3.51	4.97	3.77
	25	4.61	4.12	4.23	3.40	4.45	3.19

level in the waters is explained by the formation of some insoluble carbonates which were retained in the soil. This explains the reduction of calcium in the leachate to some extent. The carbonates in the leachate came from the bicarbonates of the waters.

No significant difference was found between soils regarding their effect on the composition of the leachate (Table 5). The reason for this was that the virgin soil soon became similar to the cultivated soil after leaching with a few liters of water and the changes after that were similar in the two soils.

Soluble ions in the saturation extracts of the soils

Comparison between content of soluble cations and anions in the soils before (Table 8) and after (Table 7) leaching shows clearly the drastic changes that occurred in the soils due to the leaching process. All cations, in all soil-water combinations and all through the columns were much less in the leached soils than in the original soils. Calcium had a tendency to be greater at the bottom of the column, while magnesium had no such regular tendency. The reason for less calcium at the top of the column was that the bicarbonates and the carbonates derived from the bicarbonates in the leaching waters tended to precipitate as calcium carbonate. By the time the water reached the bottom of the columns, its carbonate content was reduced and less precipitation of calcium occurred. That was probably the reason that soluble calcium was greater at the bottom.

No regular trend as to the distribution of sodium and potassium in the columns was observed.

Chloride was leached to a very great extent in both soils. The

final chloride content is more or less the same in both soils except a small tendency of chloride to be more in the bottom sections of the virgin soil columns. This is probably associated with the higher total cations in the basal sections of the virgin soil columns.

Leaching did not change appreciably the calcium carbonate content of the soils, but dissolved almost all the gypsum in the soils. Leached soils failed to give a positive result with a qualitative gypsum test.

When the general effect of leaching on the two soils was compared with regard to the soluble cations and anions (Table 7), it was indicated that the final salt content of the soil solution in both soils was the same. Since the virgin soil contained originally a much higher soluble salt content than cultivated soil and was brought finally to a more or less similar condition, it was suggested that the soluble salt content of these soils was approaching equilibrium with the leaching water and represented about the minimum that could be attained under these conditions.

pH of saturated paste

The high soluble salt content of the original virgin soil masked the basic effect on the soil pH of high exchangeable sodium percentage and high calcium carbonate content of the soil. That is probably the reason that the pH of the saturated paste of this soil was only slightly alkaline (Table 1). The same effect was found, but to a lesser degree, in the original cultivated soil, because of its lower content of soluble salts compared to the virgin soil.

Table 7. Soluble cations and anions[#] in the soils after the leaching process. m.e./100 g.

Ion	Section of the column	0.3 Ca/Mg water		0.6 Ca/Mg water		0.9 Ca/Mg water	
		virgin	cultivated	virgin	cultivated	virgin	cultivated
Ca^{++}	Top	0.09	0.16	0.14	0.17	0.16	0.16
	Middle	0.14	0.13	0.17	0.16	0.19	0.21
	Base	0.23	0.16	0.23	0.21	0.29	0.26
Mg^{++}	Top	0.34	0.39	0.33	0.33	0.40	0.26
	Middle	0.46	0.28	0.38	0.27	0.35	0.24
	Base	0.52	0.27	0.31	0.23	0.38	0.25
Na^{+}	Top	0.43	0.36	0.38	0.33	0.37	0.23
	Middle	0.38	0.34	0.39	0.41	0.42	0.28
	Base	0.33	0.44	0.35	0.29	0.32	0.20
K^{+}	Top	0.10	0.08	0.11	0.11	0.11	0.10
	Middle	0.11	0.09	0.13	0.10	0.13	0.11
	Base	0.13	0.09	0.14	0.10	0.13	0.09
Cl^{-}	Top	0.48	0.59	0.59	0.50	0.70	0.56
	Middle	0.68	0.42	0.71	0.46	0.74	0.50
	Base	0.81	0.58	0.76	0.51	0.82	0.48
HCO_3^{-}	Top	0.09	0.07	0.14	0.11	0.14	0.12
	Middle	0.07	0.07	0.12	0.11	0.14	0.11
	Base	0.06	0.05	0.12	0.11	0.11	0.09

No soluble carbonates were present in the soils.

Table 8. Soluble cations and anions in saturated extracts
of the original soils.

Soil	Soluble Cations m.e./100 g.				Soluble anions m.e./100 g.	
	Ca^{++}	Mg^{++}	Na^+	K^+	Cl^-	HCO_3^-
Virgin	15.33	15.45	17.17	0.45	49.32	0.04
Cultivated	1.68	1.34	0.63	0.07	3.43	0.07

Table 9. pH of saturated paste of soils after leaching.[#]

Section of column	0.3 Ca/Mg water		0.6 Ca/Mg water		0.9 Ca/Mg water	
	Virgin	cultivated	virgin	cultivated	virgin	cultivated
Top	8.10	8.09	8.16	8.06	8.12	8.00
Middle	8.12	8.08	8.06	8.00	8.00	8.02
Base	8.15	8.02	8.12	7.92	8.15	7.95

Each number is the average of three readings.

After leaching these soils, soluble salts were reduced very much as well as the exchangeable sodium (Table 10), but the pH of the saturated paste of the two soils increased (Table 9) probably due to the high calcium carbonate content of these soils. Both soils, and all through the columns had almost the same pH at the end of the leaching process.

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Exchangeable cations

Examination of the exchangeable cations in the original soils (Table 1) as compared with those in the leached soils (Table 10) indicated that all cations had increased upon leaching except sodium which had decreased. Since soluble salts, and especially sodium salts were leached from the soil solution, more of the exchangeable sodium moved out to the soil solution and was leached. This exchangeable sodium was replaced by calcium, magnesium and potassium. Exchangeable calcium tended to increase with depth in the column while exchangeable magnesium tended to decrease with depth. The probable reason was that when the waters - which were generally rich in magnesium relative to calcium - were passed through the column, the top section took a greater proportion of magnesium than the basal section which received the water after its magnesium content had been reduced relatively more than its calcium content. This was probably the cause of the significant difference between sections of a column with respect to Ca/Mg ratio (Table 11). The increase in Ca/Mg ratio with depth indicated that equilibrium had not been attained and that continued leaching would have affected further changes.

Table 10. Exchangeable cations in the soils after the
leaching process m.e./100 g.

Cation	Section of the column	0.3 Ca/Mg water		0.6 Ca/Mg water		0.9 Ca/Mg water	
		virgin	cultivated	virgin	cultivated	virgin	cultivated
Ca^{++}	Top	41.02	42.61	42.19	42.72	42.73	41.62
	Middle	42.41	41.98	43.94	42.62	42.37	42.79
	Base	43.66	43.50	44.54	46.45	44.71	44.52
Mg^{++}	Top	14.44	13.96	15.34	13.00	12.04	12.63
	Middle	14.31	12.72	13.95	11.39	12.42	12.76
	Base	11.81	11.39	11.74	9.99	12.40	10.30
Ca/Mg^{++}	Top	2.91	3.05	2.75	3.29	3.55	3.30
	Middle	2.96	3.30	3.15	3.74	3.41	3.35
	Base	3.70	3.82	3.79	4.65	3.61	4.32
Na^{+}	Top	2.90	1.60	4.02	2.07	2.94	3.43
	Middle	3.24	1.78	4.02	2.50	4.51	3.44
	Base	2.13	1.41	2.67	1.56	2.97	2.96
K^{+}	Top	2.55	2.70	2.70	2.41	1.97	2.71
	Middle	2.32	3.13	2.82	2.88	2.59	2.70
	Base	2.05	2.67	2.24	2.08	1.87	2.02

L.S.D. for comparison of exchangeable Ca/Mg ratios in sections of
a column is 0.23.

L.S.D. for comparison of exchangeable sodium in sections of a column
is 0.54.

L.S.D. for comparison of exchangeable sodium in sections of a soil
leached with different waters is 0.17.

Table 11. Analysis of variance for exchangeable Ca/Mg ratio
in the leached soils.

Source	d.f.	s.s.	m.s.	Observed F.
Replicates	2	2.0433	1.0216	2.14
Soils	1	2.1060	2.1060	4.41
Replicates x soils error (a)	2	0.9540	0.4770	-
Waters	2	1.3475	0.6737	0.89
Waters x soils	2	1.3278	0.6639	0.87
Error (b)	8	6.0865	0.7608	-
Sections	2	7.9233	3.9616	21.98[##]
Sections x soils	2	0.3277	0.1636	0.91
Sections x waters	4	0.8164	0.2041	1.13
Sections x soils x waters	4	0.4818	0.1204	0.67
Error (c)	24	4.3260	0.1802	-
Total	53	27.7403		

Significant at 1 per cent level.

No significant difference was found between waters regarding their effect on exchangeable Ca/Mg ratio. This would also indicate that the amount of water used in leaching was not enough for the soils to reach a state of equilibrium with the waters. No significant difference was found between the two soils regarding their exchangeable Ca/Mg ratio. However, the Ca/Mg ratio as a whole decreased in both soils with increased amounts of leaching, because the increase in exchangeable magnesium constituted a bigger fraction of the final total exchangeable magnesium than the increase in exchangeable calcium relative to total calcium.

Statistical analysis (Table 12) indicated that the amounts of sodium replaced, differed significantly between the three waters. The more the Ca/Mg ratio in the water the less the sodium replaced. Significant interaction was found between soils and waters regarding the amount of sodium replaced. As the Ca/Mg ratio of the water increased, the increase in exchangeable sodium was more in the cultivated soil than in the virgin soil. However, exchangeable sodium was generally less in the leached cultivated soil than in the leached virgin soil. That was probably because the virgin soil originally had a higher level of exchangeable sodium. The exchangeable sodium remained greater in the middle sections of the columns. The reason for this was not clear.

Soil permeability

Analysis of variance (Table 13) showed that permeability of the soil decreased significantly in all soil-water treatments as the amount of water applied was increased. No significant difference was found

Table 12. Analysis of variance for exchangeable sodium in
the leached soils.

Source	d.f.	s.s.	m.s.	Observed F.
Replicates	2	4.8925	2.4462	2.3424
Soils	1	12.4224	12.4224	11.8954
Replicates x soils				
Error (a)	2	2.0886	1.0443	-
Waters	2	12.9473	6.4736	71.2167[##]
Waters x soils	2	4.2660	2.1330	23.4653[##]
Error (b)	8	0.7268	0.0909	-
Sections	2	8.4323	4.2161	4.4905[#]
Sections x soils	2	1.2290	0.6145	0.6545
Sections x waters	4	1.0841	0.2710	0.2886
Sections x soils x waters	4	1.6543	0.4136	0.4405
Error (c)	24	22.5331	0.9389	-
Total	53	72.2764		

Significant at 5 per cent level.
Significant at 1 per cent level.

between the two soils or between the three waters or between combinations of both regarding their effect on permeability. This indicates that leaching was chiefly responsible for the decrease in permeability.

By the end of the experiment, the permeability coefficient was reduced to almost one half of what it was at the beginning of the experiment (Table 14). This reduction was caused by application of a total depth of 5 meters of water to the soil. Normally, if the soil passes 0.25 cm. or more of water per hour, then its infiltration rate is considered to be adequate (18). The rates (Table 14) at the beginning of the experiment, when converted from ml/min. to cm/hr. give values around 0.25 cm/hr., so the permeability of the soils was not bad at that time. At the end of the experiment, when the rates were reduced to about one half, the permeability was impaired and infiltration of water might become a serious problem. However, under natural irrigation, this much reduction in permeability would probably not occur, because wetting and drying, and plant growth would tend to maintain the permeability. Further work is needed to clarify the effect of natural irrigation on permeability of the soil.

Aggregation of particles less than 50 microns

Analysis of variance (Table 15) showed that waters differed significantly among themselves in their effect on aggregation. Generally, the more the Ca/Mg ratio in the water the more the aggregation. Interaction between waters and soils was also significant on aggregation. The higher the Ca/Mg ratio in the water the more the aggregation in

Table 13. Analysis of variance for coefficient of permeability of soils during the leaching process.

Source	d.f.	s.s.	m.s.	Observed F.
Replicates	2	0.0250	0.0125	2.69
Soils	1	0.0003	0.0003	0.06
Replicates x soils	2	0.0093	0.0046	-
Error (a)				
Waters	2	0.0225	0.0112	0.87
Waters x soils	2	0.0585	0.0292	2.29
Error (b)	8	0.1023	0.0128	-
Amount of water	4	0.0609	0.0152	5.86[##]
Amount of water x soil	4	0.0167	0.0042	1.61
Amount of water x water	8	0.0306	0.0038	1.47
Amount of water x soil x water	8	0.0369	0.0046	1.77
Error (c)	48	0.1248	0.0026	-
Total	89	0.4878		

Significant at 1 per cent level.

Table 14. Coefficient of permeability of the soils during
the leaching process, ml/minute.

Water applied	0.3 Ca/Mg water		0.6 Ca/Mg water		0.9 Ca/Mg water	
	virgin	cultivated	virgin	cultivated	virgin	cultivated
5 liters	0.1829	0.2552	0.2040	0.1802	0.1662	0.2786
10 liters	0.1639	0.2072	0.1682	0.1818	0.1409	0.2371
15 liters	0.1549	0.2215	0.1670	0.1877	0.1364	0.1695
20 liters	0.1618	0.1007	0.1706	0.1151	0.1463	0.1354
25 liters	0.0942	0.0916	0.1234	0.1227	0.1188	0.1410

L.S.D. for comparison of coefficients of permeability between
two increments of leaching water in one soil-water treat-
ment is 0.0283.

Table 15. Analysis of variance for per cent aggregation of particles less than 50 microns in the leached soils.

Source	d.f.	s.s.	m.s.	Observed F.
Replicates	2	49.93	24.96	0.188
Soils	1	137.41	137.41	1.034
Replicates x soils				
Error (a)	2	265.85	132.92	-
Waters	2	765.04	382.52	11.948[##]
Waters x soils	2	1183.13	591.56	18.478[##]
Error (b)	8	256.12	32.02	-
Sections	2	830.06	415.03	9.978[##]
Sections x soils	2	138.51	69.25	1.665
Sections x waters	4	702.44	175.61	4.222[##]
Sections x soils x waters	4	387.78	96.94	2.331
Error (c)	24	998.22	41.593	-
Total	53	5714.49		

Significant at 1 per cent level.

the cultivated soil. There was no such trend in the virgin soil.
The sections of one column were significantly different in per cent
aggregation from each other. Interaction between sections of the
column and kind of water was also significant. With 0.6 Ca/Mg ratio
water, soils showed a definite decrease in aggregation, while with
0.3 and 0.9 Ca/Mg waters there was no such a trend. This also ex-
plains the significant difference between sections.

The fact that there was a high exchangeable Ca/Mg ratio in some
sections having poor aggregation, and low exchangeable Ca/Mg ratio in
places of good aggregation (Table 16), suggests that the effect of
magnesium at levels present in the soils was probably not the main
reason for poor aggregation. This is verified by the low correlation
coefficient (r = 0.164) between aggregation and Ca/Mg ratio. However,
the existance of such a positive correlation, although it was not sig-
nificant, indicated the tendency for low Ca/Mg ratio on the exchange
complex to result in reduced aggregation.

Statistical analysis gave a low correlation coefficient (r =0.024)
between aggregation and permeability, suggesting that differences in
aggregation of particles less than 50 microns were not mainly respon-
sible for low permeability in this study. The aggregates measured
were very small, and their effect was probably not as important as
the effect of larger aggregates which were destroyed upon continuous
leaching for almost three months without a chance to dry and reform.

Upon leaching, two main processes went on in the soil that might
have caused poor permeability. One of these was the leaching from the
soil of soluble salts which had exerted a considerable flocculating

Table 16. Per cent aggregation of particles less than 50 microns in soils after the leaching process.

Section of the column	0.3 Ca/Mg water		0.6 Ca/Mg water		0.9 Ca/Mg water	
	virgin	cultivated	virgin	cultivated	virgin	cultivated
Top	38.88	28.87	58.74	52.05	38.37	52.49
Middle	29.38	34.46	59.75	31.10	46.60	41.91
Base	44.70	30.43	29.77	25.65	40.43	50.89

L.S.D. for comparison of per cent aggregation in sections of a
soil leached with different waters is 3.26.
L.S.D. for comparison of per cent aggregation in sections of a
column is 3.61.

Table 17. Clay distribution in the soil columns after the leaching process. per cent.

Section of the column	0.3 Ca/Mg water		0.6 Ca/Mg water		0.9 Ca/Mg water	
	virgin	cultivated	virgin	cultivated	virgin	cultivated
Top	37.62	34.35	39.25	33.33	38.78	29.03
Middle	36.58	32.17	34.14	29.43	37.76	28.89
Base	38.08	27.79	36.02	25.88	35.66	23.40

effect on soil particles. The other process was the swelling and collapse of water unstable aggregates which might have blocked the macropores of the soil and thus reduced permeability. This explanation was supported by the fact that the correlation coefficient between permeability and exchangeable Ca/Mg ratio was very low (r =0.075), indicating that the exchangeable Ca/Mg ratio had little influence, if any, on permeability.

No definite conclusion regarding the effect of exchangeable magnesium on soil structure could be reached due to conflicting trends. The removal of salts and the effect of continued wetting tended to be deteriorating to soil structure, while the reduction in exchangeable sodium from greater than 20% to less than 5% of the exchangeable cations would be beneficial.

Distribution of clay

The clay fraction of the soil was not evenly distributed in the columns (Table 17), because of the way the soil was packed. In packing the soil, the column was first filled with water then the dry sieved soil was poured in. Some of the fine clay remained in suspension and settled later. This, contributed to a generally higher clay content in the top sections. The difference in clay content between top and bottom sections was less in the virgin soil than in the cultivated soil because the high salt content of the virgin soil kept it more flocculated and the aggregates settled more uniformly leaving less clay to settle later. Thus, some of the differences within the soil columns may be due to differences in the clay content. However, such measurements as the exchangeable Ca/Mg ratio would be affected very little.

SUMMARY AND CONCLUSIONS

The objective of this experiment was to study the effect of different Ca/Mg ratio waters on the chemical and physical properties of a virgin and of a recently cultivated saline sodic soil from the Jordan Valley. 0.3, 0.6 and 0.9 Ca/Mg ratio waters were used, the second being the average for well waters of the area. Soils were packed in columns prepared from 4 inch diameter steel sections, and 25 liters of water was applied continuously to each column. Permeability was measured after addition of each 5 liters. At the same time, samples of the leachates were collected and analysed. At the end of the experiment, columns were sectioned horizontally into three sections and soils were analysed for soluble cations and anions, exchangeable cations, pH of saturated paste, and aggregation of particles less than 50 microns.

The soils were calcareous clay loams with more than 20% exchangeable sodium. The virgin soil was very high in soluble salts while the cultivated soil was medium in salt content. The average conductivity of the well waters used for irrigation in the area was greater than 2.6 millimhos/cm. which is considered to be very high salinity water according to the U.S.D.A. Salinity Laboratory (18).

The conductivity of the leachate decreased sharply in the first few days of the experiment and then became more or less constant and similar to that of the original waters. This indicated that most of the soluble salts were leached in the first week of the leaching process.i.e. after application of about 3 liters of water. The Ca/Mg

ratio in the leachate decreased significantly as more water was applied indicating that relatively more calcium than magnesium was retained in the soil. The final Ca/Mg ratio in the leachate was less than in the original waters indicating that a state of equilibrium between soils and waters had not yet been attained.

Exchangeable calcium, magnesium and potassium increased in the leached soils and exchangeable sodium was reduced from more than 20% to less than 5% of the exchangeable cations. Therefore, accumulation of sodium would not be a problem with the soils and waters used in this experiment. The exchangeable Ca/Mg ratio was less in the leached soils than in the original soils, because the increase in adsorbed magnesium was a larger fraction of the total adsorbed magnesium than was the increase in adsorbed calcium of the total adsorbed calcium. The exchangeable Ca/Mg ratio increased significantly from top to bottom in the columns, because adsorbed calcium increased while adsorbed magnesium decreased with depth in the column. More sodium was replaced in soils leached with high magnesium waters. No significant difference was found between soils regarding their exchangeable cations.

The calcium carbonate content of the soil was not appreciably increased by the precipitation of some calcium carbonate during the leaching process. The pH of the saturated paste of the leached soils had increased to slightly more than 8.

Soil permeability decreased significantly as the amount of leaching water was increased. No significant difference was found between soils or waters regarding their effect on permeability indicating that leaching was chiefly responsible for the decrease in permeability.

Permeability was on the borderline for practical irrigation at the beginning of the experiment, but at the end of the experiment it was reduced to about one half of its value after leaching with 5 liters. This much reduction in permeability might be a serious problem, but probably it would not be reduced to this extent under natural conditions of irrigation and crop growth.

Waters differed significantly in their effect on aggregation of particles less than 50 microns. The higher the Ca/Mg ratio in the water the more the aggregation especially in the cultivated soil. The fact that there was a high exchangeable Ca/Mg ratio in some sections having low aggregation and in other sections having relatively high aggregation suggested that the effect of magnesium at levels present in the soils was probably not the main reason for poor aggregation. This was supported by the low correlation coefficient ($r = 0.164$) between exchangeable Ca/Mg ratio and aggregation. However, the presence of such a positive correlation indicated the tendency of low exchangeable Ca/Mg ratio to be correlated with reduced aggregation.

Permeability had a very low correlation ($r = 0.075$) with exchangeable Ca/Mg ratio indicating that the Ca/Mg ratio on the exchange complex had very little influence on permeability. The correlation coefficient between aggregation and permeability was also very low ($r = 0.024$) indicating that aggregation of particles less than 50 microns did not affect significantly the soil permeability. The destruction of larger water-unstable aggregates upon continuous wetting was probably the main reason for the reduced permeability.

The effect of magnesium on soil physical properties was not clear in this study because it was either masked by the effect of

other drastic changes such as the leaching of most of the soluble salts and the destruction of water-unstable aggregates, or counter-acted by the effect of reduced exchangeable sodium on the clay complex.

The salt content of the original cultivated soil is relatively high for citrus which are relatively sensitive to salt in the soil. In order to grow salt sensitive crops the conductivity of the satu-rated paste of the soil should be less than 4 millimhos/cm. To main-tain the salt content in the soil at less than 4 millimhos/cm., with the waters used in this experiment, the leaching requirement would be 2.6/4 = 65%. This means that 65% of the irrigation water applied should pass through the root zone. Assuming the consumptive use for citrus in the Jordan Valley to be 25 inches per year, and again assum-ing the water application efficiency to be 50%, and that the rainfall in the area is negligible, then the total depth of water to be used per year would be $Diw = 100\ Dcw/50\ (1-L.R.) = 25 \times 100/50\ (0.35) = 143$ inches or about 12 ft. of water, where Diw is the depth of irrigation water per year, Dcw is the depth of water for consumptive use and L.R. is leaching requirement. Since the amount of irrigation water in the area is limited, it would probably be better to grow more salt tolerant crops such as tomatoes, sugarbeets, barley, etc. where the salt content might be allowed to approach 8 millimhos/cm. without seriously limiting crop yields. The leaching requirement would then be reduced to less than 33%.

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