MAGNESIAN SOILS OF NEW CALEDONIA: STUDIES ON THE RESTORATION OF THE BALANCE OF THE BASE EXCHANGE COMPLEX

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ABSTRACT

A range of soils in Western New Caledonia derived from magnesium rich parent materials show very high exchangeable magnesium contents. These high magnesium contents lead to an imbalance of cations in the exchange complex with very high exchangeable Mg/Ca ratios. These in turn lead to serious agronomic problems in areas where other factors are favourable for agricultural development (Boyer, 1978; Edmeades and Judd, 1980; Kanwar and Chaudhary, 1967). In order to study methods of reducing the Mg/Ca ratio samples of the soils have been treated in the laboratory with gypsum, lime and calcareous crust amendments (Clairon, 1969). Gypsum treatment lowers the Mg/Ca ratio but also leads to K displacement. Lime treatment causes the displacement of Mg from exchange sites but the displaced Mg remains in the soil. Calcium carbonate treatment causes an increase in exchangeable Ca but has little effect on the exchangeable Mg status of the soils studied.

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INTRODUCTION

The geological substratum of New Caledonia consists of diversified rocks, of which approximately one third is peridotite, very rich in magnesium. The alluvial plains which are associated with them are formed of soils of a different morphology, but which possess certain physico-chemical characteristics in common, especially very high contents of exchangeable magnesium. These soils are classified as vertisols (Typic Pellusterts), weakly developed soils of alluvial deposits (Mollic Ustifluvents), solonetz solnetz (Typic Natrustalfs) or fersiallitic soils (Typic Haplustalfs). From one group to another, or even within the same group, the quantities of exchangeable magnesium and the Mg/Ca ratios are very variable. According to the size of this ratio, we can distinguish magnesian soils ($1 < Mg/Ca < 5$) and hyper-magnesian soils ($Mg/Ca > 5$). However, recent surveys have revealed the presence of soils excessively rich in magnesium. The value of the Mg/Ca ratio can in these soils exceed 100. Such high Mg/Ca ratios are uncommon, but in New Caledonia values between 20 and 50 are common.

These plains occupy a relatively important part of the surface of agro-pastoral regions. Their extent is sufficient to consider cereal type cultivation. However, the physico-chemical nature of the soils presents a major constraint for which it is necessary to find a solution. This is particularly clear as far as the imbalance of the exchange complex is concerned. The aim of this initial study was to investigate possible methods of restoring the Mg/Ca balance of the exchange complex.

The principal types of magnesian and hypermagnesian soils

Several examples located on the west coast of New Caledonia are considered. In general, the rainfall is relatively low (1,000 to 1,200 mm); it can go down to 800 mm in the drier regions.

1. Vertisols (Typic Pellusterts)

These develop on old alluvial material which constitutes the major part of the plains of the west coast of New Caledonia. Vertisols are only slightly differentiated morphologically, especially in the upper horizons and are frequently characterized by the succession: HUMITE - HUMITE vertic (Beaudou et al., 1983a, b).

The upper horizons have thicknesses of between 30 and 60/80 cm. Below the upper horizons numerous differences exist. It is in the subsurface horizons that gypsum, calcium carbonate (crust-nodules), magnesium carbonate (nodules) and manganese (nodules, dendrites) can accumulate. All the morphological characteristics of vertisols are easily recognizable (structure, cracks, slickensides, colours...). The texture is always clayey. The pH is acid in the surface horizons but, at depth, it becomes near neutral, or even distinctly basic when there is an accumulation of carbonates. The percentages of organic matter are variable and sometimes rather high in certain surface horizons but in the subsurface horizons, organic matter is practically absent.

An examination of the data in Table 1 shows that the percentages of exchangeable magnesium are high. This cation largely dominates the exchange complex. The exchangeable calcium content is considerably lower and in some horizons it is very low. The percentages of exchangeable potassium are very low. Sodium can sometimes be abundant in the deeper and even the middle horizons. There are significant variations in the Mg/Ca ratio, which lies between 1.7 and 13.5 in the upper horizons and between 2 and 28.6, and between 2 and 152.7 for deeper horizons.

2. Solodized Solonetz (Typic Natrustalfs)

These soils also derived from old alluvium are frequently found in the same geomorphologic sites as the vertisols.

They are characterized by the succession of horizons:
HUMITE - Leucitic HUMITE - Vertic STRUCTICHRON (Beaudou et al., 1983a, b).

Sample Depth (cm)		Texture					pH	Organic Matter			Exchangeable Cations (me %)					
		Clay	Fine Silt	Coarse Silt	Fine Sand	Coarse Sand		C%	N%	C/N	Ca	Mg	K	Na	CEC	Mg/Ca
Surface 0-30	1	55.2	22.9	11.2	4.8	5.9	5.6	22.3	1.4	15.9	12.6	21.0	0.1	1.8	47.5	1.7
	2	48.5	29.0	9.1	4.3	5.6	5.6	44.5	3.4	13.0	10.4	26.5	1.5	1.0	46.9	2.5
	3	52.2	22.7	10.5	6.4	8.2	6.1	38.0	3.0	12.6	3.1	41.8	0.3	0.6	52.1	13.5
30–60/80	1	68.4	18.4	7.4	2.5	3.3	5.7	8.7	0.7	12.4	13.6	26.7	0.07	3.8	44.5	2.0
	2	61.2	31.0	2.7	3.5	1.6	7.0	18.3	1.5	12.0	5.8	28.6	0.5	2.9	43.1	5.0
	3	63.3	18.5	9.6	5.7	2.9	6.4	13.4	1.3	10.5	1.7	48.6	0.1	1.1	53.2	28.6
Deep >60/80	1	62.4	21.6	7.1	7.3	1.6	7.3	–	–	–	15.9	31.0	0.07	4.3	48.3	2.0
	2	–	–	–	–	–	8.0	–	–	–	5.7	38.2	0.2	10.2	46.8	6.7
	3	69.7	13.6	7.8	6.1	2.8	7.6	3.1	0.4	8.4	0.4	61.1	0.1	2.1	57.5	152.7

TABLE 1 : Vertisols (C.P.C.S.) – Typic Pellusterts (Soil Taxonomy) – Pellic Vertisols (F.A.O.)

1 – Magnesian

2 – Hypermagnesian

3 – Hypermagnesian (exceptional)

ANALYTICAL DATA

Sample Depth (cm)	Texture					pH	Organic Matter			Exchangeable Cations (me %)					
	Clay	Fine Silt	Coarse Silt	Fine Sand	Coarse Sand		C%	N%	C/N	Ca	Mg	K	Na	CEC	Mg/Ca
Surface	19.6	34.0	20.7	7.0	18.7	5.8	26.4	1.9	13.8	2.3	4.6	0.6	0.01	21.1	2.0
Intermediate	27.5	34.2	22.6	6.8	8.9	5.1	13.7	1.1	12.6	1.4	7.2	0.1	0.4	12.7	5.1
Deep	54.4	26.1	14.2	3.5	1.8	6.3	3.3	0.5	6.1	0.4	17.4	0.04	4.0	28.8	43.5

TABLE 2 : Solonetz solodises (C.P.C.S.) - Typic Natrustalfs (Soil Taxonomy) - Ochric solonetz (F.A.O.)
(Soils deriving from old alluvial deposits)

The surface horizons are rather poor in clay; it is only in the argillic horizon that clay values become of consequence. The transition between leuahe (bleached) horizon and the vertic structichron (argillic) horizon is extremely abrupt. It is in structichron that sphenoclodic structures characteristic of vertic horizons associated with slickensides are observed. Accumulations of gypsum and calcium carbonate (crust, nodules) are sometimes found in these horizons. Typical analytical data are given in Table 2.

3. <u>Fersiallitic Soils</u> (Typic Haplustalfs)

They are derived from older alluvial formations than those from which the vertisols and solodized solonetz come. These soils show 3 major horizons - HUMITE (a surface organic rich layer), STRUCTICHRON (a well structured B horizon) overlying an ENTAFERON (weathered transported material).

The texture is silty-clayey in surface layer, clayey in the well structured B horizons and clayey-silty in the deeper horizons. The pH is acid in the first two horizons becoming neutral or slightly basic at depth. As in the other soils, the exchangeable magnesium dominates the cation exchange complex (Table 3). The Mg/Ca ratio varies between 1.5 and 5.8. The percentages of exchangeable potassium are very small while sodium is sometimes quite abundant at depth.

4. <u>Weakly developed soils of alluvial deposits</u> (Mollic Ustifluvents)

These soils, formed on recent alluvial deposits, show little morphological development. In general, they are composed of an organic rich surface layer overlying on weathered transported material (HUMITE overlying an ENTAFERON (Denis and Mercky, 1979)).

The principal variations of physical characteristics are seen in the texture which can be sandy, silty or clayey. These textural variations are extremely rapid and there are associated important structural and water movement consequences. Analytical characteristics of two soils are presented in Table 4. The first is a hypermagnesian silty

ANALYTICAL DATA

Horizons	Texture					pH	Organic Matter			Exchangeable Cations (me %)					
	Clay	Fine Silt	Coarse Silt	Fine Sand	Coarse Sand		C%	N%	C/N	Ca	Mg	K	Na	CEC	Mg/Ca
Surface	32.6	24.9	26.9	4.9	10.7	6.2	31.3	2.8	11.2	5.9	9.5	0.4	0.2	21.7	1.6
Intermediate	55.4	24.0	15.3	2.6	2.7	6.3	10.6	1.3	8.2	2.8	13.2	0.1	1.7	21.8	4.7
Deep	41.5	31.7	21.5	3.1	2.2	7.5	-	-	-	3.2	18.4	0.1	5.2	25.4	5.8

TABLE 3 : Sols Fersiallitiques (C.P.C.S.) - Typic Haplustalfs (Soil Taxonomy) - Ferric Luvisols (F.A.O.)
(Soils derived from old alluvial deposits)

ANALYTICAL DATA

Horizons		Texture					pH	Organic Matter			Exchangeable Cations (me %)					
		Clay	Fine Silt	Coarse Silt	Fine Sand	Coarse Sand		C%	N%	C/N	Ca	Mg	K	Na	CEC	Mg/Ca
Surface	1	15.5	50.1	23.6	4.4	6.4	7.5	29.3	1.3	22.0	3.3	22.2	0.4	0.2	22.8	6.7
	2	41.0	41.3	11.7	1.4	4.6	6.7	21.3	2.4	8.9	8.3	21.3	0.3	0.3	32.9	2.6
Intermediate	1	14.6	46.4	25.0	10.0	4.0	8.3	9.3	0.9	10.8	0.5	22.2	0.7	1.6	26.2	44.4
	2	41.5	39.7	12.5	4.3	2.0	7.5	7.5	0.9	7.8	4.4	22.9	0.1	1.3	29.0	5.2
Deep	1	17.7	42.1	24.6	12.3	3.3	8.5	-	-	-	0.7	17.6	0.5	1.8	17.0	25.2
	2	26.1	27.8	19.2	22.5	4.4	8.5	3.8	0.6	6.7	3.2	15.3	0.1	4.9	20.4	4.8

<u>TABLE 4</u> : Sols peu évolués d'apport (C.P.C.S.) - Mollic Ustifluvents (Soil Taxonomy) -
Eutric Fluvisols (F.A.O.)
(Sols dérivés d'alluvions récentes).
1 - Hypermagnesian (Silty)
2 - Magnesian (Clayey-silty)

soil, the second is a magnesian silty-clayey soil. In both cases the pH is greater than 7, becoming very basic in the subsurface horizon. The percentages of exchangeable magnesium are high and practically identical, horizon by horizon. It is the variations of the levels of exchangeable calcium which permits differentiation of these two into magnesian and hypermagnesian soils (Table 4).

As with all these plain soils, the exchangeable potassium levels are very small particularly in the clayey-silty soil. The exchangeable sodium cannot be ignored, particularly in the subsurface horizon, where the percentages are sometimes quite high.

Summary of Soil Properties

Although rapid, this presentation of the principal types of magnesium soils allows one to establish a first appraisal of their morphological and principal physicochemical characteristics and thus, to bring out the major restraints which are connected with them. Good land improvement depends upon the control of these constraints which are

- On a physical level

a. Texture : very clayey in Vertisols
very variable in the weakly developed soils
very contrasted in solodized solonetz

b. Structure : evolutive in the vertichrons and in the vertic structichrons of vertisols and solodized solonetz. It depends strictly upon the conditions of soil moisture.

- On a chemical level

a. Large deficiencies in phosphorus and potassium

b. The imbalance of the exchange complex with regard to calcium-magnesium a situation that must be dealt with even before fertilizer practices are considered. In this paper the results of initial studies of the exchangeable Mg/Ca imbalance and its correction are presented. The studies were made on small samples in the laboratory.

ANALYSIS OF THE RELATIVE MOBILITY OF MAGNESIUM AND CALCIUM

The initial experiments were undertaken to study the relative mobility of calcium and magnesium after the addition of different amendments such as gypsum ($CaSO_4$), carbonate ($CaCO_3$) or lime ($Ca(OH)_2$), and to see if it is possible, by associating leaching and enrichment in calcium, to appreciably reduce the Mg/Ca ratio of the exchange complex and to bring it nearer to one.

Experimental

A series of percolation tests was devised to test two types of soils - vertisols and solodized solonetz. The samples used were taken from

(a) the surface horizon of a magnesium vertisol
(b) the surface horizon of a hypermagnesium vertisol and
(c) the argillic horizon of a solodized solonetz

Each sample was air dried, then crushed and sifted at 5 mm.

Next, for the magnesium vertisol material a series of samples were treated with additions of gypsum (3 rates) and a second series with additions of calcareous crust (4 rates). A series of hypermagnesian vertisol samples were treated with additions of gypsum (3 rates), and a second series with additions of lime (2 series). Solodized solonetz samples were treated with additions of gypsum (3 rates).

The different rates of the amendments added correspond to:

Rate 1	:	1.5 T/ha of CaO
Rate 2	:	3 T/ha of CaO
Rate 3	:	4.5 T/ha of CaO
Rate 4	:	6 T/ha of CaO

A control (no amendment added) was used in each experiment and all experiments were carried out in duplicate. The amendments and soils were thoroughly mixed.

The samples thus prepared were placed in percolation columns 20 cm high and with a diameter of 11 cm - such a volume allows the use of 1.5 kg of soil sample. The samples were wetted drop by drop, until the appearance of the first drops of percolate. The samples were left for 15 days at this constant moisture level (daily verification by weighing). On the 15th day, sufficient distilled water was then added to collect 200 ml of percolate in which the Ca, Mg, K, Na cations were determined. This percolation and the cation determinations were done every 15 days for 4 months*. The total addition of water during 4 months corresponded to the percolation of 150 mm of water. The soil samples were analysed in the beginning and at the end of the experiments.

Cations were determined using atomic absorption spectrophotometry.

1 - Magnesian and hypermagnesian vertisols : Gypsum ($CaSO_4$) treatment

The analytical results show that the cation concentrations in the percolated water increased very distinctly with gypsum treatment (Fig. 1). The amounts of calcium and magnesium rose from 25 mg/l to 200-250 mg/l, then to 350-400 mg/l in the first two months for treatments 1 and 2. Treatment 3 showed only a slight increase in this movement of magnesium out of the exchange complex of the soil. At the beginning of the experiment, the concentrations of sodium, close to 100 mg/l for the nil treatment, were increased by 3 and 4 times by the addition of gypsum. In contrast, the amounts of displaced potassium, although showing a slight increase, do not go over 10 mg/l. Therefore, gypsum facilitated the displacement of the Mg and Na cations in this type of soil. As a result one should

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* Eight percolater volumes for each soil sample were therefore collected and analysed. The results of the last quantity determinations being identical, we noted only one value, i.e. 7 in all, in the graphs of Figure 1. For Figures 2-5 samples were collected after 15 days for 2 months and then 1 sample was collected after 4 months.

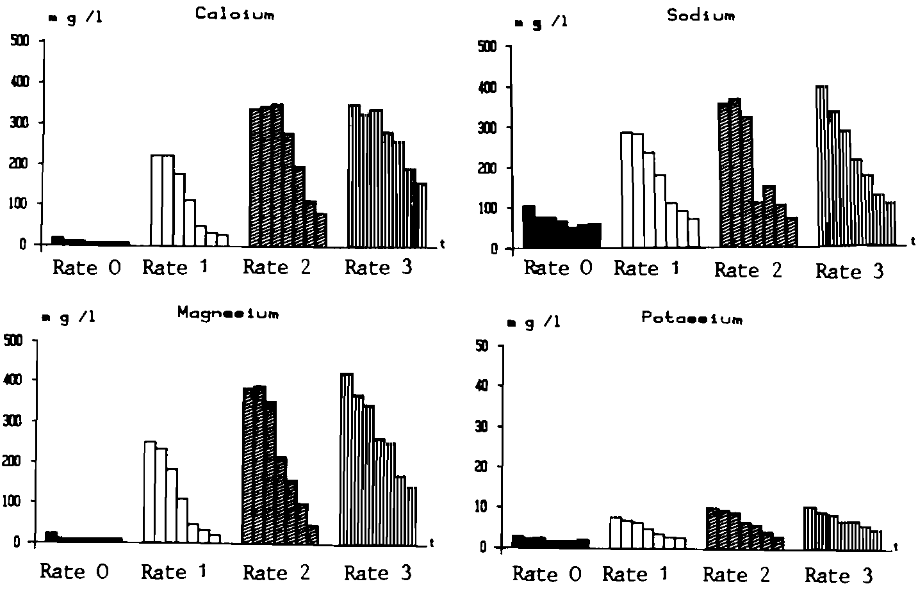

Fig.1 : Variations of cation concentrations in percolated waters through the surface horizon of a magnesian vertisol enriched with gypsum

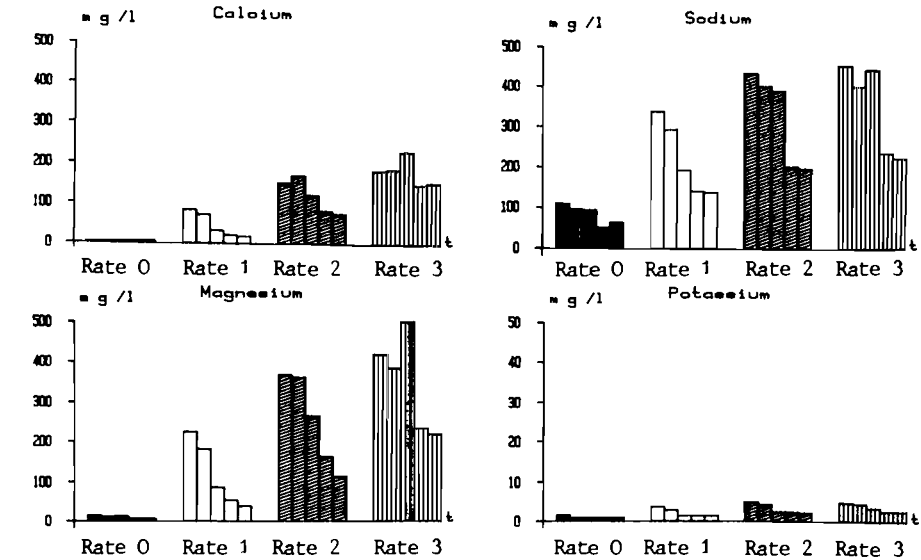

Fig.2 : Variations of cation concentrations in percolated waters through the surface horizon of a hypermagnesian vertisol enriched with gypsum

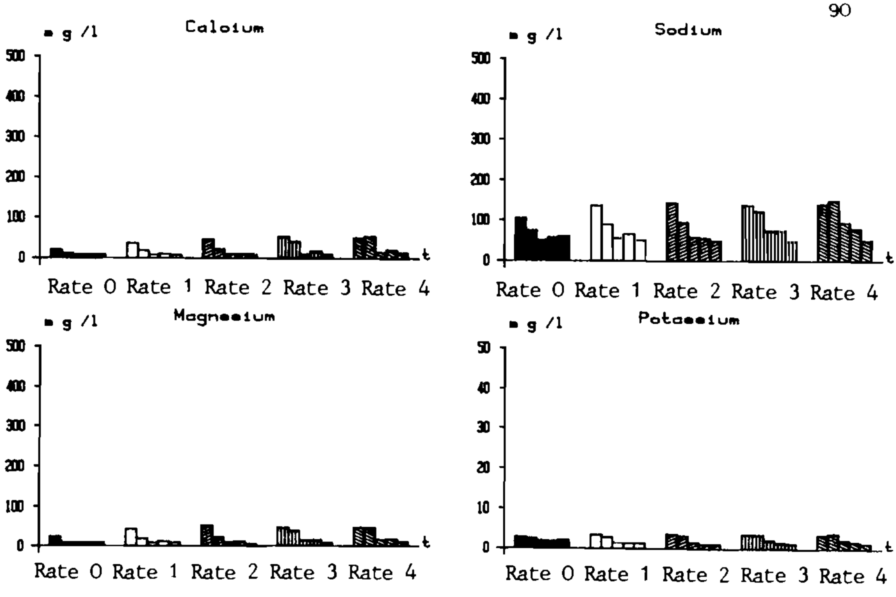

Fig.3 : Variations of cation concentrations in percolated waters through the surface horizon of a magnesian vertisol enriched with calcareous crust

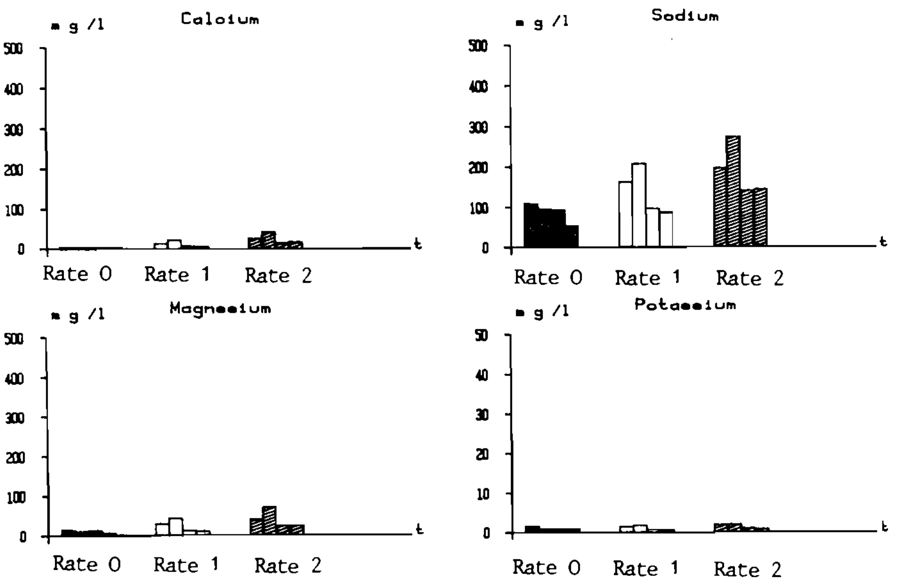

Fig.4 : Variations of cation concentrations in percolated waters through the surface horizon of a hypermagnesian vertisol enriched with hydrated lime

be able to eliminate a part of the exchangeable magnesium and sodium in the soil by using a system involving downward water percolation and the addition of a displacing cation source. The soil analyses confirm these results (Table 5). For the hypermagnesian vertisol similar results were observed (Fig. 2).

The effects of gypsum on the desorption of magnesium and sodium were spectacular. A significant increase in concentration in the percolated water was observed for these two elements. In the percolated water, the most involved cation was magnesium (Fig. 2). The quantities collected were greater than those of calcium; thus it is hoped to equilibriate the magnesium/calcium ratio after several months of processing or at least, be removed from the highly unfavourable values. The soil analyses showed that the magnesium/calcium ratio progressively decreased from 5.48 to 2.32 with the additions of gypsum (Table 6). Close of 3 meq/100 g of magnesium and sodium can be removed from the exchange sites and in part, eliminated from the soil.

2 - Magnesian vertisol : Calcium carbonate treatment (carbonate crust)

After this treatment, the analysis of the percolated waters showed only a slight rise in the concentrations of sodium. This displacement of sodium, obtained as early as rate 1, is quite small and is virtually unaffected by higher rates (Fig. 3).

The pH (in water and in potassium chloride) rose regularly with the rate of $CaCO_3$ addition; the Ca^{++} ions of calcium carbonate enter the exchange complex (+ 7 meq/100 g for treatment 4) with a very small displacement of sodium (0.2 meq/100 g at the most)(Table 7).

3 - Hypermagnesian vertisol : Lime $Ca(OH)_2$ treatment

From the results obtained, it seems that the effect of this treatment on the mobility of Mg and Ca is minimal. Only sodium was found in a rather large concentration in the percolated waters (Fig. 4). On the 30th day, calcium barely reached 50 mg/l and magnesium 100 mg/l, then these values decreased and stabilized below 25 mg/l.

Gypsum Treatment	Exchangeable Cations (me %)				Mg/Ca
	Ca	Mg	K	Na	
0	10.2	15.9	0.56	1.6	1.6
1	11.7	15.7	0.58	0.9	1.3
2	13.2	14.5	0.49	0.9	1.1
3	18.2	14.2	0.49	0.8	0.8

TABLE 5 : Analytical results of vertisol after the addition of different amounts of gypsum.

Gypsum Treatment	Exchangeable Cations (me %)				Mg/Ca
	Ca	Mg	K	Na	
0	4.8	26.3	0.16	2.7	5.5
1	5.4	25.6	0.25	1.9	4.7
2	8.3	23.8	0.19	1.5	2.9
3	10.00	23.4	0.5	1.3	2.3

TABLE 6 : Analytical results for the hypermagnesian vertisol samples after the addition of different treatments of gypsum.

$CaCO_3$ Treatment	Exchangeable Cations (me %)				Mg/Ca
	Ca	Mg	K	Na	
0	10.9	15.1	0.58	1.6	1.4
1	13.7	14.8	0.57	1.5	1.1
2	14.1	15.0	0.58	1.5	1.1
3	17.1	15.3	0.57	1.4	0.9
4	18.0	15.1	0.58	1.4	0.8

TABLE 7 : Analytical results of the magnesian vertisol samples after the addition of calcium carbonate.

Lime Treatment	Exchangeable Cations				Mg/Ca
	Ca	Mg	K	Na	
0	6.2	25.8	0.38	2.7	4.2
1	11.3	19.1	0.27	1.6	1.7
2	12.1	18.1	0.25	1.5	1.5

TABLE 8 : Analytical results for the hypermagnesian vertisol samples after lime processing.

On the other hand, the soil analyses (Table 8) showed an important modification of amounts of calcium, magnesium (6 to 7 meq/100 g of soil) and sodium (1.1 meq) of the exchange complex. For rate 1, the calcium of $Ca(OH)_2$ was almost totally incorporated into the exchange complex; the exchangeable magnesium was displaced, but did not appear in the percolated water; it must therefore have formed a precipitate in the soil.

The value of the Mg/Ca ratio of 4.2 in the untreated sample went down again to 1.7 for rate 1 and 1.5 for rate 2. This modification was due in part to the incorporation of Ca into the exchange complex but also to a large displacement of exchangeable magnesium. The small difference in the effects of rates 1 and 2 on the exchange complex tends to indicate that rate 1 would be sufficient.

4 - Hypermagnesian argillic horizon of a solodized solonetz : Gypsum treatment

Increasing the gypsum rate resulted in a rise of Mg and Na concentrations in percolated waters. The mobilization of these elements operated quickly; in fact, maximal concentrations were observed from the 15th day. After four months of experimentation, during which 1,500 l of water were percolated, the values are still above 100 mg/l (Fig. 5).

The leaching of magnesium and the settling of calcium on the exchange complex modified the Mg/Ca ratio which went from 7.3 for the zero treatment to 3.9, 2.7 and 1.5 for treatments 1, 2 and 3 (Table 9). For the rate 3 treatment, 4.7 meq/100 g of exchangeable calcium settled on the complex and 3.7 meq/100 g of Mg were displaced and for the greater part leached.

CONCLUSIONS

After percolation tests conducted on three chemically imbalanced (in magnesium or in sodium and magnesium) soils treated with gypsum, agricultural lime and/or a calcareous amendment, several facts are clearly apparent.

Gypsum Treatment	Exchangeable Cations (me %)				Mg/Ca
	Ca	Mg	K	Na	
0	1.9	13.9	0.13	1.8	7.3
1	3.6	14.0	0.12	1.3	3.9
2	5.1	13.5	0.10	1.1	2.6
3	6.6	10.2	0.12	0.87	1.5

TABLE 9 : Analytical results of hypermagnesian argillic horizon of the solodized solonetz after gypsum processing.

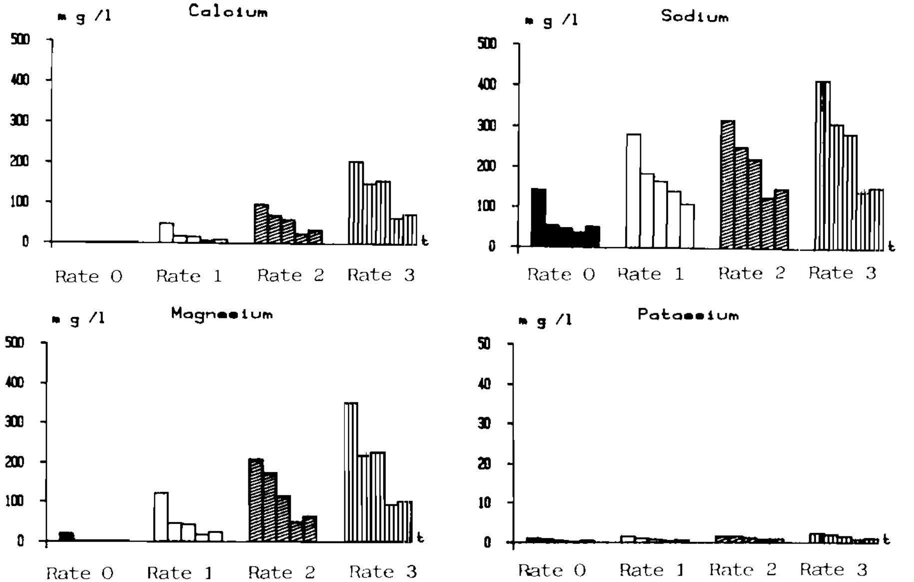

Fig.5 : Variations of cation concentrations in percolated waters through the argillic horizon of a solodized solonetz treated with gypsum

- Gypsum contributes to the lowering of the exchangeable magnesium/calcium ratio. Magnesium and sodium are in part desorbed, then removed in the percolated water; calcium settles on the sites thus freed, and on those occupied by hydrogen ions (Hogg, 1962; Hunsaker and Pratt, 1971). On the other hand, the use of gypsum presents one inconvenience - it also facilitates the leaching of potassium.

- Agricultural lime also facilitates the modification of the exchangeable magnesium/calcium ratios. If an exchange of magnesium and of sodium by calcium is indicated by soil analyses, it seems, however, that there is little elimination of magnesium from the soil; in fact, the percolated water is only charged with sodium, regardless of the amount of $Ca(OH)_2$ added to the soil. The limited number of samples processed did not show any influence of agricultural lime on the exchangeable potassium of the soil.

- Calcium carbonate treatment leads to an increase in the amounts of exchangeable calcium and contributes to an increase in the pH (Bussieres, 1978). In the magnesian vertisol studied, it seems that there is no calcium, magnesium or sodium displacement and that the migration of these cations is practically nil. The percolated water contains little magnesium, sodium or potassium and the amounts of these ions on the exchange complex varies little.

These findings are supported by other studes on the mobility of calcium which varies with the nature of the "associated" anion. Thus, sulphate facilitates the leaching of calcium, magnesium, sodium and potassium ions, whereas, carbonate retards the process.

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