

# Efficient Amendment Use in Sodic Soil Reclamation<sup>1</sup>

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## ABSTRACT

A laboratory column study of sodic soil reclamation was carried out using two soils high in exchangeable sodium percentage (ESP) and cation exchange capacity (CEC). Three amendments ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ,  $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ , and  $\text{H}_2\text{SO}_4$ ) were used singly and in combination to test their effectiveness and efficiencies with respect to amount of amendment, time, and leaching needed.

As a single amendment,  $\text{H}_2\text{SO}_4$  is more effective than  $\text{CaSO}_4$  and results in a more desirable ESP profile than  $\text{CaCl}_2$ . Combining either  $\text{CaCl}_2$  or  $\text{H}_2\text{SO}_4$  with  $\text{CaSO}_4$  (proportions of  $1/4$  and  $3/4$ , respectively) appreciably reduced the time and leaching needed to achieve reclamation as compared with  $\text{CaSO}_4$  alone. Certain soil conditions preclude or make undesirable the use of  $\text{CaSO}_4$  alone. Combining amendments results in effective reclamation and a potential savings in amendment costs.

**Additional Index Words:** calcium sulfate, gypsum, calcium chloride, sulfuric acid, alkali soils, exchangeable sodium.

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SODIC SOILS often have low hydraulic conductivities ( $k$ ) due to their high exchangeable sodium percentage (ESP) levels. For such soils the electrolyte concentration of the available irrigation or leaching water is often too low to promote flocculation (2). Reclamation of sodic soils requires that water pass through the profile to carry added divalent ions (usually Ca) into and flush exchanged Na ions out of the rootzone. The rate at which sodic soils can be reclaimed, therefore, depends on the rate of water flow through the profile and the concentration of Ca in solution. High electrolyte concentrations increase the  $k$  value but also waste amendments because a smaller proportion of it is exchanged (3). This effect is amplified as the ESP of the soil being reclaimed is reduced. Therefore, the use of concentrated solutions for reclamation of sodic soils of high ESP saves time and water. But as the ESP is lowered, use of concentrated solutions becomes increasingly less efficient.

The kind and amount of chemical amendment to be used for reclaiming sodic soils depend on the soil characteristics, the desired rate and extent of exchangeable Na replacement, and cost. Three of the most commonly used amendments are gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ), calcium chloride ( $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ ), and sulfuric acid ( $\text{H}_2\text{SO}_4$ ). In this study these amendments were compared and the concept of combining them was tested to increase effectiveness and efficiency. Amendments were applied once to the soil rather than in the water.

Gypsum is the most commonly used amendment for sodic soil reclamation, primarily because of its low cost.

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Because  $\text{CaSO}_4$  has relatively low solubility, more time and water are required than with other amendments (6). However, as the ESP is reduced, its low electrolyte concentration becomes increasingly more desirable in terms of reducing the amount of amendment needed.

Because  $\text{CaCl}_2$  is very soluble, it produces a leaching solution of high electrolyte concentration, which promotes increased water intake rates (1,4). It is expensive, however, unless available as a waste product. The high electrolyte concentration produced is efficient in replacing exchangeable Na only with high ESP. For such conditions, the overall time and water requirements of reclamation are dramatically less than for  $\text{CaSO}_4$ .

Sulfuric acid has been shown to be effective for reclaiming sodic calcareous soils (5,6). It reacts with soil calcium carbonates ( $\text{CaCO}_3$ ) to produce a soluble source of Ca and  $\text{CaSO}_4$ . Sulfuric acid promotes increased water intake rates in the soil (9); this is due primarily to the increased electrolyte concentration and its ability to solubilize aluminum and iron-hydroxy compounds, which promote flocculation and stabilization of soil structure. Its cost varies, depending upon availability and location, but it is becoming increasingly available as a byproduct of industry. It does require special handling and application equipment.

The amendment, water, and time requirements could be efficiently managed with a potential for minimizing amendments costs if the desirable attributes of each amendment are understood and the possibility of amendment combination is considered. Water intake and initial reclamation could be promoted by use of  $\text{CaCl}_2$  or  $\text{H}_2\text{SO}_4$ , and the subsequent reduction of ESP at lower levels could be achieved with the use of  $\text{CaSO}_4$ . The initial depth of reclamation can be extended while growing a crop, if additional water for leaching is supplied.

## MATERIALS AND METHODS

Both soils used in this study were sodic with rather high CEC (cation exchange capacity) and ESP (Tables 1 and 2). The Waukena soil member of the mixed, thermic Natrixeralf family and the Arlington is a mixed thermic haplic Durixeralf. The clay mineralogy of the Waukena soil is predominantly montmorillon-

Table 1—Some physical and chemical properties of the soils used.

Analysis	Arlington	Waukena
EC, mmho/cm (saturation extract)	31.5	29.2
Sodium adsorption ratio	170.0	210.0
Cation exchange capacity, meq/100 g	19.0	23.0
Exchangeable sodium percentage	72.0	75.0
Sand, %	42.0	8.0
Silt, %	45.0	51.0
Clay, %	13.0	41.0
Predominant clay type	V*	M†
$\text{CaCO}_3$ , %	0.5	0.8
Saturation paste, % water	34.0	43.0
pH of saturation extract	8.1	8.5

\* Vermiculite.

† Montmorillonite.

Table 2—Chemical analysis of soil saturation extract and leaching water.

	Ca	Mg	Na	K	Cl	SO <sub>4</sub>	NO <sub>3</sub>	HCO <sub>3</sub>	CO <sub>3</sub>	SAR*	EC†	pH
	meq/liter									mmho/cm		
Arlington	5.8	1.0	313	0.2	308	10	0.7	1.3	-	170	31.5	8.1
Waukena	3.0	1.7	322	0.4	253	64.5	1.2	3.8	2.2	210	29.2	8.5
Water	4.0	1.0	1.5	0.06	1.3	1.1	0.5	3.7	-	1.0	1.0	7.2

\* Sodium adsorption ratio =  $Na^+ / [(Ca^{2+} + Mg^{2+})^{1/2}]$ .

† Electrical conductivity.

tic, whereas that of the Arlington soil is vermiculitic. The Waukena soil was impermeable to the leaching water used (see Table 2); the Arlington was not.

Columns were formed by joining twelve 5-cm segments of plastic tubing (I.D. = 6.9 cm). Soil was packed to a depth of 55 cm and a bulk density of 1.5 g/cm<sup>3</sup>. Tap water (composition given in Table 2) was applied by constant head ponding. Solution outflow from the bottom of the columns was collected and analyzed. After leaching, the columns were segmented and analyzed for both water-soluble (saturation extract) ions and exchangeable Na (ammonium acetate extractable) (7).

Amendments were applied to the dry soil as follows: Gypsum and CaCl<sub>2</sub> were mixed uniformly with the soil to be packed in the top segment (upper 5 cm). Sulfuric acid was applied as a 10N solution to the soil surface. For combined amendment treatments, each individual amendment was applied as described above. The treatment identification number as used in the figures is given in Table 3.

Depth of wetting as a function of time was measured as an index of infiltration rate. Hydraulic conductivities were also determined.

Amendment application rate was equivalent to the total number of equivalents of exchangeable Na present in the entire soil column. Sulfuric acid rates were calculated assuming a 1 to 1 equivalent release of Ca for H. Combined amendments were portioned as 1/4 the total equivalence of Ca as CaCl<sub>2</sub> or H<sub>2</sub>SO<sub>4</sub>, with the remaining 3/4 as CaSO<sub>4</sub>. These amendment application rates, in meq of Ca or potential Ca produced and in Mg/ha, are listed in Table 3.

Soluble and extractable cations were determined by atomic adsorption spectrophotometry. Chloride and sulfate were determined by potentiometric titration and turbimetric methods, respectively. Nitrate was determined by selective ion electrode, and carbonate and bicarbonate were measured by acid titration. Soil calcium carbonate was determined by measuring total pressure upon reaction of soil with acid in a closed container (8). Cation exchange capacity and exchangeable sodium were determined by standard methods (7).

## RESULTS

**Depth of Wetting**—Depths of wetting with time were determined to judge the relative effectiveness of the amendments in promoting water intake of these soils. The data were plotted in terms of wetting depth vs. square root of time. Table 4 gives the regression equation of the best fit linear lines for the data. The relative rates of wetting were similar for both soils and increased as follows: check, CaSO<sub>4</sub>, H<sub>2</sub>SO<sub>4</sub> and CaSO<sub>4</sub>, H<sub>2</sub>SO<sub>4</sub>, CaCl<sub>2</sub> and CaSO<sub>4</sub>, and CaCl<sub>2</sub>. This order is as expected, based on the effects of increasing electrolyte concentration of the initial infiltrating soil solution on soil permeability. The absolute rates for the treatments were similar for both soils, with the exception of the CaSO<sub>4</sub> treatment. This latter rate was slower for the Waukena soil than for the Arlington soil (i.e., CaSO<sub>4</sub> was relatively more effective in the Arlington soil).

**Hydraulic Conductivity**—Hydraulic conductivity,  $k$ ,

Table 3—Treatment number and amendment application rate.

Treatment no. amendment	Arlington		Waukena	
	meq Ca	Mg/ha†	meq Ca	Mg/ha†
<u>Single</u>				
5 CaSO <sub>4</sub>	450.0	100.7	495.0	110.7
2 CaCl <sub>2</sub>	450.0	86.0	374.0	71.5
1 H <sub>2</sub> SO <sub>4</sub>	450.0	59.8	495.0	65.7
<u>Combined</u>				
4 CaCl <sub>2</sub>	112.5	21.5	93.5	17.8
and CaCO <sub>3</sub>	338.0	75.5	371.4	83.1
3 H <sub>2</sub> SO <sub>4</sub>	112.5	14.9	124.0	16.4
and CaSO <sub>4</sub>	371.4	75.5	371.4	83.1

† Megagrams per hectare.

Table 4—Depth of wetting. Regression equation of best fit line for plots of accumulative time (hours) vs. square root infiltration (cm).

Treatment	Regression equation
<u>Arlington</u>	
Check	$Y = 1.047X + 1.084$
CaSO <sub>4</sub>	$Y = 4.866X + 8.727$
CaCl <sub>2</sub>	$Y = 13.096X + -1.556$
CaCl <sub>2</sub> and CaSO <sub>4</sub>	$Y = 11.119X + 0.109$
H <sub>2</sub> SO <sub>4</sub> and CaSO <sub>4</sub>	$Y = 7.144X + 5.088$
H <sub>2</sub> SO <sub>4</sub>	$Y = 10.472X + -6.772$
<u>Waukena</u>	
Check	-
CaSO <sub>4</sub>	$Y = 3.304X + 5.944$
CaCl <sub>2</sub>	$Y = 11.494X + -1.637$
CaCl <sub>2</sub> and CaSO <sub>4</sub>	$Y = 9.702X + -1.459$
H <sub>2</sub> SO <sub>4</sub> and CaSO <sub>4</sub>	$Y = 9.189X + -2.624$
H <sub>2</sub> SO <sub>4</sub>	$Y = 5.771X + 5.605$

(cm<sup>3</sup>/hr) vs. accumulative time,  $t$ , (hours) is given in Fig. 1 and 2. The initial  $k$  values obtained with the various treatments were in the same relative order as the results obtained in the depth of wetting test. Sulfuric acid and CaCl<sub>2</sub> applied singly produced dramatic increases in  $k$ . Note that the application rates were very high (Table 3). Once the high electrolyte concentration resulting from CaCl<sub>2</sub> and H<sub>2</sub>SO<sub>4</sub> treatments were leached from the columns, the  $k$  value decreased markedly. In general, the CaCl<sub>2</sub> and H<sub>2</sub>SO<sub>4</sub> treatments resulted in higher final  $k$  than the CaSO<sub>4</sub> treatment. The Waukena soil showed a greater residual response to CaCl<sub>2</sub> and H<sub>2</sub>SO<sub>4</sub> than did the Arlington soil.

**Leaching Time and Water Requirements**—Considerable differences in  $t$  and amount of leaching required to achieve maximum Na removal were observed for the different treatments (See Fig. 3, 4, 5, and 6). Such differences for completion of exchange resulted from the differences in the rate at which leaching water passed through the soil column

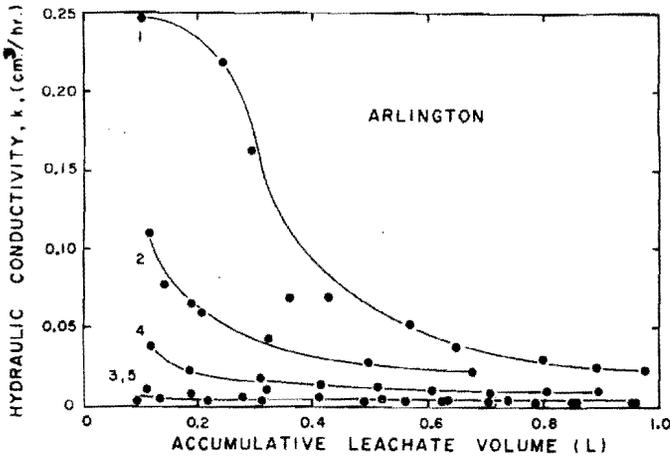


Fig. 1—Arlington soil. Plot of accumulative volume (liters) outflow vs. hydraulic conductivity ( $\text{cm}^3/\text{hr}$ ) for the five treatments. See Table 3 for treatment number identification.

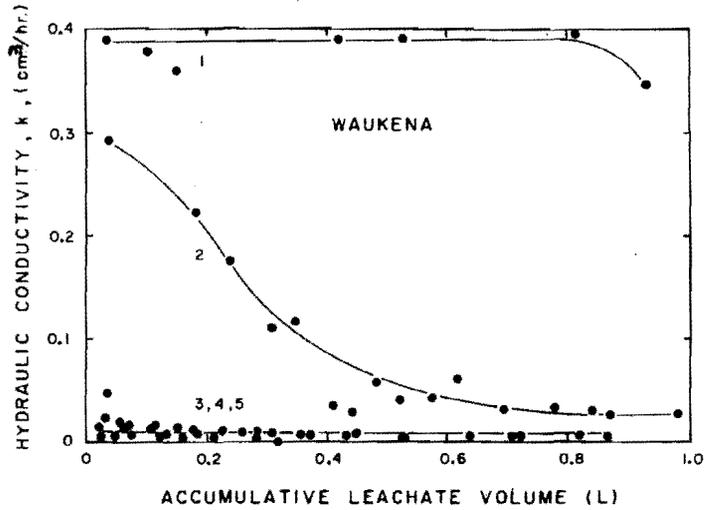


Fig. 2—Waukena soil. Plot of accumulative volume (liters) outflow vs. hydraulic conductivity ( $\text{cm}^3/\text{hr}$ ) for the five treatments.

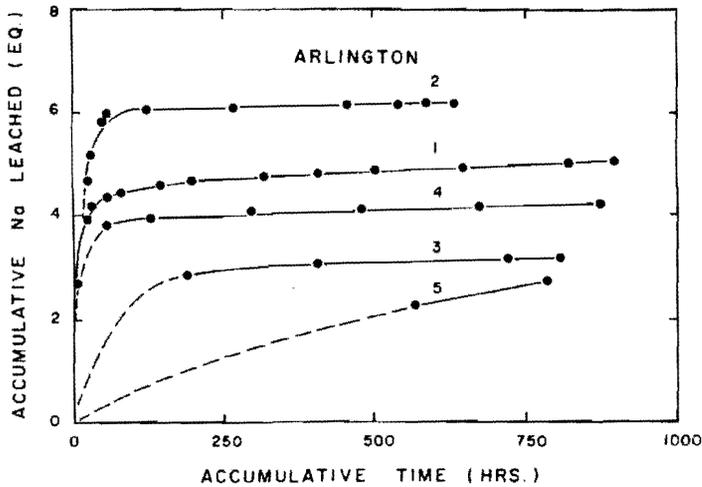


Fig. 3—Arlington soil. Plot of accumulative time (hours) vs. accumulative sodium leached (eq) for the five treatments.

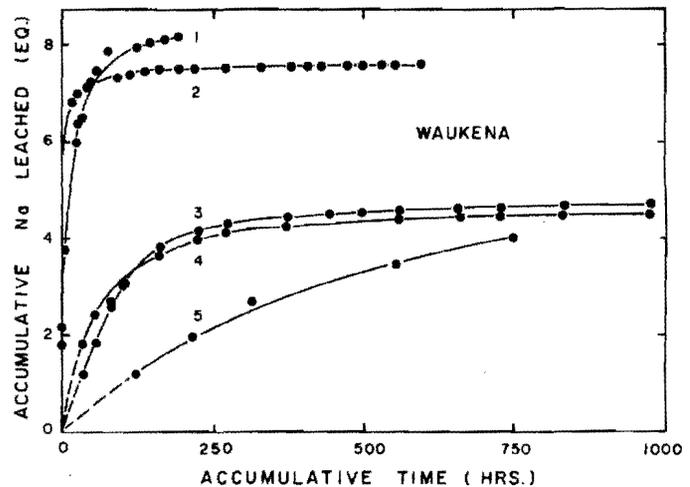


Fig. 4—Waukena soil. Plot of accumulative time (hours) vs. accumulative sodium leached (eq) for the five treatments. Note, the  $\text{CaCl}_2$  treatment received 120 meq less Ca than did the others.

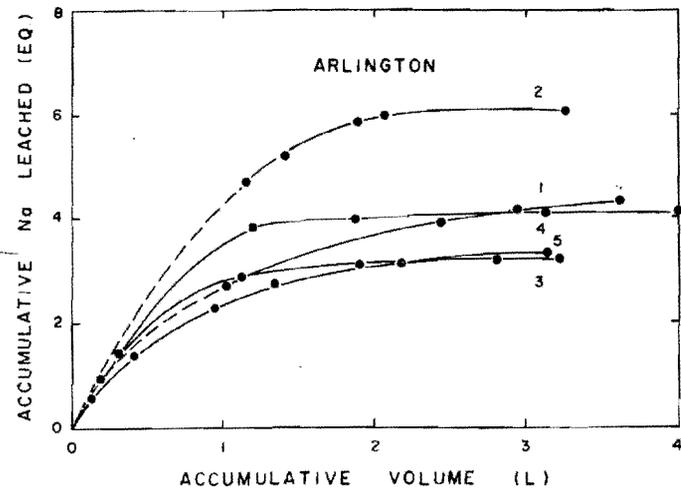


Fig. 5—Arlington soil. Plot of accumulative volume (liters) vs. accumulative sodium leached for the five treatments.

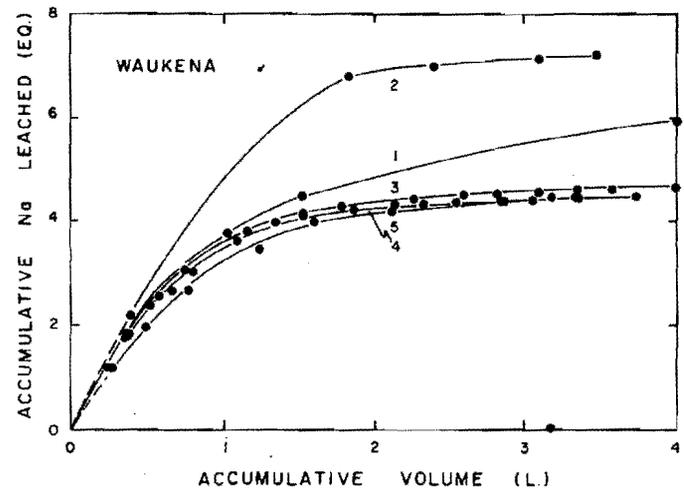


Fig. 6—Waukena soil. Plot of accumulative volume (liters) vs. accumulative sodium leached for the five treatments. Note, the  $\text{CaCl}_2$  treatments received 120 meq less Ca than did the others.

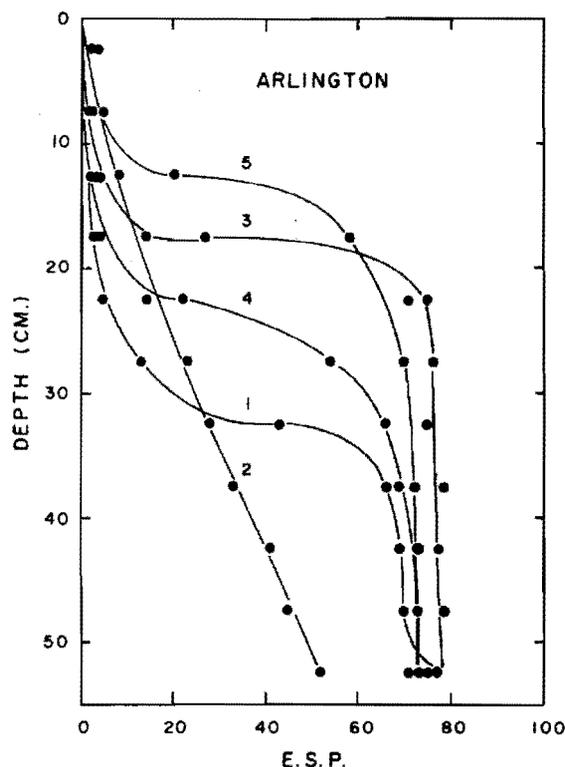


Fig. 7—Arlington soil. Plot of exchangeable sodium percentage vs. column depth (cm) for the five treatments following reclamation.

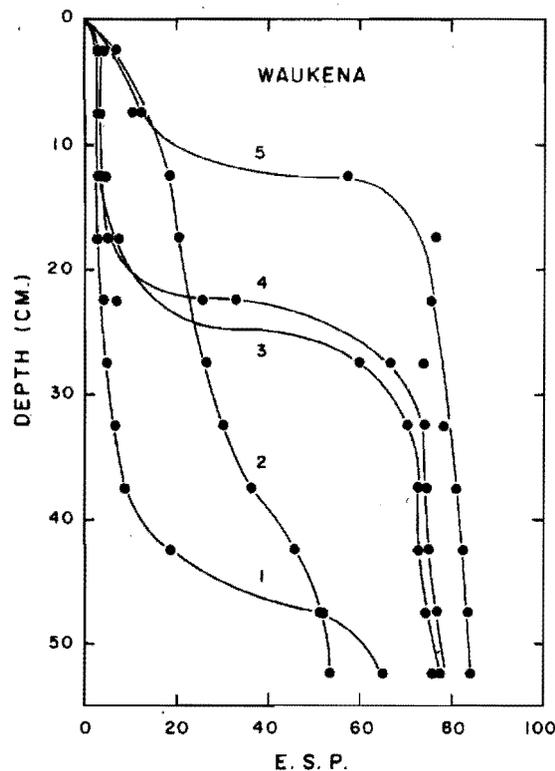


Fig. 8—Waukena soil. Plot of exchangeable sodium percentage vs. column depth (cm) for the five treatments following reclamation. Note, the CaCl<sub>2</sub> treatments received 120 meq less Ca than did the others.

and the amount of Ca made available for exchange per unit volume of leachate.

**Time**—For both soils, CaCl<sub>2</sub> required the least amount of time for Na removal and produced the greatest amount of exchangeable Na removal<sup>3</sup>. Sulfuric acid was the next most effective amendment with respect to time. In comparing CaCl<sub>2</sub> with H<sub>2</sub>SO<sub>4</sub> treatments, the Arlington soil responded relatively more favorably to CaCl<sub>2</sub> than did the Waukena soil. The time to achieve peak Na removal was considerably shorter with the combined amendment treatments than with CaSO<sub>4</sub> only.

<sup>3</sup>Note that due to error, the CaCl<sub>2</sub> of the Waukena soil received 120 meq less Ca than did the other treatments (Table 3). Hence, conclusions made with respect to CaCl<sub>2</sub> treatment for this soil are based on projected values had the correct amount been applied.

**Volume**—Plots of effluent volume vs. accumulative Na leached for the amendment treatments are shown in Fig. 5 and 6. The CaCl<sub>2</sub> treatment removed the greatest amount of Na per unit volume of leachate. The Na elution curves were similar for the other treatments. The Arlington soil responded relatively more favorably to CaCl<sub>2</sub>,<sup>31</sup> this response was most striking for the CaCl<sub>2</sub> and CaSO<sub>4</sub> treatment as compared with the H<sub>2</sub>SO<sub>4</sub> and CaSO<sub>4</sub> treatment.

The H<sub>2</sub>SO<sub>4</sub> treatment for both soils showed an initial Na elution curve similar to that of the CaSO<sub>4</sub> treatment but eventually eluted greater quantities of Na at equivalent leachate volumes.

**Reclamation—Extent of Sodium Removal**—For the va-

Table 5—Sodium and water movement data for the columns.

Treatment	Arlington					Waukena						
	W.S.†	Exch.‡	Σ§	Leach.¶	Σ Vol.#	Final k††	W.S.	Exch.	Σ	Leach.	Σ Vol.	Final k
	meq			ml			meq			ml		cm <sup>3</sup> /hr
Check	227	-13	214	232	229	0.0014	--	--	--	--	--	--
CaSO <sub>4</sub>	278	102	380	395	1,197	0.003	342	92	434	452	334	0.002
CaCl <sub>2</sub>	303	256	568	636	2,172	0.007	380	310	690	760	1,140	0.027
CaCl <sub>2</sub> and CaSO <sub>4</sub>	286	177	463	474	1,665	0.009	373	215	588	486	974	0.005
H <sub>2</sub> SO <sub>4</sub> and CaSO <sub>4</sub>	280	111	391	382	1,215	0.004	364	194	558	526	1,087	0.006
H <sub>2</sub> SO <sub>4</sub>	300	223	523	530	1,836	0.004	380	396	776	816	2,000	0.120

† Difference in meq of water-soluble Na found in the initial and final saturation extract.  
 ‡ Difference in meq of exchangeable Na found between the initial and final determination.  
 § Sum of columns W.S. and Exch.  
 ¶ Sodium found in the leachate.  
 # Total volume of leachate collected; pore volume = 892 cm<sup>3</sup>.  
 †† Hydraulic conductivity at termination.

rious amendment treatments the amount of water-soluble Na removed was similar for each soil. The different treatments resulted in a considerable range in extent of exchangeable Na replacement as can be seen in Table 5 and Fig. 7 and 8.

With respect to Na exchange and reclamation,  $H_2SO_4$  might be expected to be similar to  $CaSO_4$  for a calcareous soil, inasmuch as  $CaSO_4$  is the reaction product of  $H_2SO_4$  with  $CaCO_3$ . However, these results and those of Overstreet et al. (6), indicate that  $H_2SO_4$  is far more effective than  $CaSO_4$ . This difference can be accounted for by considering the depth of distribution of the  $CaSO_4$ . Placement of  $CaSO_4$  to deeper depths results in increased dissolution and exchange. This idea was verified using a computer model to simulate reclamation with  $CaSO_4$  (J. D. Oster, personal communication).

Calcium chloride resulted in the greatest removal of exchangeable Na for both soils.<sup>3</sup> But the ESP values were not reduced as much as the shallow depths with  $CaCl_2$  as with other amendments. The exchange front was diffuse and broad for  $CaCl_2$  compared to the other treatments.

Gypsum resulted in the least and shallowest removal of exchangeable Na of all the amendment treatments, but it resulted in low ESP levels in the reclaimed portion. The reclamation front was relatively sharp. A direct comparison as to quantities of exchangeable Na removed does not indicate actual "per equivalent" efficiency of amendment. This is because all the  $CaSO_4$  applied was not necessarily brought into solution.<sup>4</sup> However, a direct comparison is valid for assessment of efficiency of time and leaching.

Sulfuric acid effectively reduced the ESP of both soils, though the extent of reclamation was greater for the Waukena soil. The ESP profiles displayed a sharp exchange front between the reclaimed top portion and the not-yet-reclaimed lower part of the profile. The ESP profiles were similar in shape and character to the  $CaSO_4$  treatments, except they are far more extensive. The amounts of exchangeable Na removed were approximately equal to those removed with the  $CaCl_2$  treatment.

The combined amendment treatments resulted in higher amounts of exchangeable Na removed than by the  $CaSO_4$  treatment, but less than by the  $H_2SO_4$  and  $CaCl_2$  treatments. The exchange fronts were similar to that for  $H_2SO_4$ , though the  $H_2SO_4$  and  $CaSO_4$  treatments produced a sharper break in the exchange front than did the  $CaCl_2$  and  $CaSO_4$  treatment. These treatments also demonstrated that  $H_2SO_4$  was relatively more effective for the Waukena soil. The ESP curves for the two combined treatments were similar for Waukena, but  $CaCl_2$  and  $CaSO_4$  was more effective than  $H_2SO_4$  and  $CaSO_4$  for the Arlington soil.

## DISCUSSIONS AND CONCLUSIONS

Results of these studies show that overall, as a single amendment,  $H_2SO_4$  is superior to either  $CaCl_2$  or  $CaSO_4$ .

$2H_2O$  in reclaiming the soils tested. It is nearly as effective as  $CaCl_2$  in increasing soil permeability and speed of reclamation. Unlike  $CaCl_2$ ,  $H_2SO_4$  is as effective in reducing the near-surface ESP as is  $CaSO_4$ .

Combining either  $CaCl_2$  or  $H_2SO_4$  with  $CaSO_4$  as an amendment can appreciably improve the time and water efficiency as compared to  $CaSO_4$  alone. Certain soil conditions, such as when sufficient water intake cannot be achieved, will preclude using  $CaSO_4$  singly. Amendment combinations are attractive in that they produce the benefits of either  $CaCl_2$  or  $H_2SO_4$  at a potential savings in amendment.

Amendments should be chosen considering such factors as:

- 1) Physical and chemical properties of the soil to be reclaimed,
- 2) Time available for reclamation,
- 3) Amount of water available for leaching and drainage capacity of the soil,
- 4) Extent of reclamation needed,
- 5) Costs for amendments, water and application.

Among the combinations of conditions, situations will occur where the combined amendment approach will be preferred. These data demonstrate the promise and feasibility of this approach.

This report addressed the questions of efficiencies with respect to time, water, and amendment. The comparisons of time and water efficiencies for the amendment treatments tested are readily discernible. But the comparison of amendment efficiency is incomplete due to the uncertainty of the extent of  $CaSO_4$  dissolution. However, even if amendment efficiencies were determined, their value is highly dependent on initial soil ESP and the desired extent of reclamation.

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<sup>4</sup>Because of its slow water intake rate, the Waukena  $CaSO_4$  treatment received much less leaching than did the Arlington soil (Table 5).