Efficient Amendment Use in Sodic Soil Reclamation

R. J. Prather, J. O. Goertzen, J. D. Rhoades, and H. Frenkel

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 (CaSO₄·2H₂O, CaCl₂·2H₂O, and H₂SO₄) 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, H₂SO₄ is more effective than CaSO₄ and results in a more desirable ESP profile than CaCl₂. Combining either CaCl₂ or H₂SO₄ with CaSO₄ (proportions of 1/4 and 3/4, respectively) appreciably reduced the time and leaching needed to achieve reclamation compared to CaSO₄ alone. Certain soil conditions preclude or make undesirable the use of CaSO₄ 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.


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 (CaSO₄·2H₂O), calcium chloride (CaCl₂·2H₂O), and sulfuric acid (H₂SO₄). 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. Because CaSO₄ 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 CaCl₂ 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 CaSO₄.

Sulfuric acid has been shown to be effective for reclaiming sodic calcareous soils (5,6). It reacts with soil calcium carbonates (CaCO₃) to produce a soluble source of Ca and CaSO₄. Sulfuric acid promotes increased water intake rates in the soil (9); thus it 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 amendment 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 CaCl₂ or H₂SO₄, and the subsequent reduction of ESP at lower levels could be achieved with the use of CaSO₄. 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 Natuxeralf family and the Arlington is a mixed thermic haplic Durixeralf. The clay mineralogy of the Waukena soil is predominantly montmorillonite.

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

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Arlington</th>
<th>Waukena</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC, mmho/cm (saturation extract)</td>
<td>31.5</td>
<td>29.2</td>
</tr>
<tr>
<td>Sodium adsorption ratio</td>
<td>170.0</td>
<td>210.0</td>
</tr>
<tr>
<td>Cation exchange capacity, meq/100 g</td>
<td>19.0</td>
<td>23.0</td>
</tr>
<tr>
<td>Exchangeable sodium percentage</td>
<td>72.0</td>
<td>75.0</td>
</tr>
<tr>
<td>Sand, %</td>
<td>42.0</td>
<td>8.0</td>
</tr>
<tr>
<td>Silt, %</td>
<td>45.0</td>
<td>51.0</td>
</tr>
<tr>
<td>Clay, %</td>
<td>13.0</td>
<td>41.0</td>
</tr>
<tr>
<td>Predominant clay type</td>
<td>V*</td>
<td>M†</td>
</tr>
<tr>
<td>CaCO₃, %</td>
<td>0.5</td>
<td>0.8</td>
</tr>
<tr>
<td>Saturation paste, % water</td>
<td>34.0</td>
<td>43.0</td>
</tr>
<tr>
<td>pH of saturation extract</td>
<td>8.1</td>
<td>8.5</td>
</tr>
</tbody>
</table>

* Vermiculite.
† Montmorillonite.
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/cm³. 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 CaCl₂ were mixed uniformly with the soil to be packed in the top segment (upper 5 cm). Sulfuric acid was applied as a 10% 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 ¼ the total equivalence of Ca as CaCl₂ or H₂SO₄, with the remaining ¾ as CaSO₄. These amendment application rates, in meq of Ca or potential Ca produced and in Mg/ha, are listed in Table 3.

Soluble and exchangeable 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, CaSO₄, H₂SO₄ and CaSO₄, H₂SO₄, CaCl₂ and CaSO₄, H₂SO₄, CaCl₂. 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 CaSO₄ treatment. This latter rate was slower for the Waukena soil than for the Arlington soil (i.e., CaSO₄ was relatively more effective in the Arlington soil).

**Hydraulic Conductivity**—Hydraulic conductivity, k, (cm³/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 CaCl₂ applied singly produced dramatic increases in k. Note that the application rates were very high (Table 3). Once the high electrolyte concentration resulting from CaCl₂ and H₂SO₄ treatments were leached from the columns, the k value decreased markedly. In general, the CaCl₂ and H₂SO₄ treatments resulted in higher final k than the CaSO₄ treatment. The Waukena soil showed a greater residual response to CaCl₂ and H₂SO₄ 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 (cm/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 (cm/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 CaCl₂ 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 CaCl₂ 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, CaCl₂ required the least amount of time for Na removal and produced the greatest amount of exchangeable Na removal². Sulfuric acid was the next most effective amendment with respect to time. In comparing CaCl₂ with H₂SO₄ treatments, the Arlington soil responded relatively more favorably to CaCl₂ than did the Waukena soil. The time to achieve peak Na removal was considerably shorter with the combined amendment treatments than with CaSO₄ only.

²Note that due to error, the CaCl₂ of the Waukena soil received 120 meq less Ca than did the other treatments (Table 3). Hence, conclusions made with respect to Na removal were 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 CaCl₂ 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 CaCl₂: possibly this response was most striking for the CaCl₂ and CaSO₄ treatment as compared with the H₂SO₄ and CaSO₄ treatment.

The H₂SO₄ treatment for both soils showed an initial Na elution curve similar to that of the CaSO₄ treatment but eventually eluted greater quantities of Na at equivalent leachate volumes.

Reclamation—Extent of Sodium Removal—For the va-

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

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Arlington</th>
<th>Waukena</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W.S. †</td>
<td>Exch. †</td>
</tr>
<tr>
<td>Check</td>
<td>227</td>
<td>-13</td>
</tr>
<tr>
<td>CaSO₄</td>
<td>278</td>
<td>102</td>
</tr>
<tr>
<td>CaCl₂</td>
<td>303</td>
<td>256</td>
</tr>
<tr>
<td>CaCl₂ and CaSO₄</td>
<td>286</td>
<td>177</td>
</tr>
<tr>
<td>H₂SO₄ and CaSO₄</td>
<td>290</td>
<td>111</td>
</tr>
<tr>
<td>H₂SO₄</td>
<td>300</td>
<td>223</td>
</tr>
</tbody>
</table>

† 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.
 Balls Volume of leachate collected; pore volume = 892 cm³.
†† 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$_2$SO$_4$ might be expected to be similar to CaSO$_4$ for a calcareous soil, inasmuch as CaSO$_4$ is the reaction product of H$_2$SO$_4$ with CaCO$_3$. However, these results and those of Overstreet et al. (6), indicate that H$_2$SO$_4$ 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. 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. 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$_2$SO$_4$ and CaCl$_2$ treatments. The exchange fronts were similar to that for H$_2$SO$_4$, though the H$_2$SO$_4$ 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$_2$SO$_4$ 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$_2$SO$_4$ and CaSO$_4$ for the Arlington soil.

**DISCUSSIONS AND CONCLUSIONS**

Results of these studies show that overall, as a single amendment, H$_2$SO$_4$ is superior to either CaCl$_2$ or CaSO$_4$. 2H$_2$O 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$_2$SO$_4$ is as effective in reducing the near-surface ESP as is CaSO$_4$.

Combining either CaCl$_2$ or H$_2$SO$_4$ 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$_2$SO$_4$ 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.

**LITERATURE CITED**