THESIS

on

THE CHEMICAL CHANGES RESULTING FROM THE
APPLICATION OF SULFUR AND SULFATES ON
ALFALI SOILS

Submitted to the
OREGON STATE AGRICULTURAL COLLEGE

In partial fulfillment of
the requirements for the
Degree of
MASTER OF SCIENCE

by

Oscar FitzAllen Bartholomew

May 12, 1930
Redacted for Privacy

Professor of Soils Department
In Charge of Major

Redacted for Privacy

Chairman of Committee on Graduate Study
ACKNOWLEDGEMENT

The author takes this opportunity to thank Dr. W. L. Powers and Dr. W. B. Bollen for council during the execution of this work.
THE CHEMICAL CHANGES RESULTING FROM THE APPLICATION
OF SULFUR AND SULFATE ON ALKALI SOIL

INTRODUCTION

The world-wide occurrence of alkali soils makes their reclamation one of the major soil problems. As the addition of sulfur-bearing materials is often necessary for their reclamation, the chemical effect of such treatments on the soil is a fundamental problem. When only leaching is used in reclamation, the soils often "freeze up" and become very impermeable to water. Hilgard pointed out that this could be largely prevented by the use of certain chemicals such as gypsum to convert the carbonate to a neutral salt. Kelly and Arany (13) state that defloculation is due to the neutralizing effect or the lowering of the pH of the soil.

Base exchange reactions have been studied during the recent years and their relation to the physical and chemical properties of the soil is becoming more and more apparent. Their significance in alkali land reclamation has been recognized by investigators for
some time but their importance has not been fully realized until recently.

PURPOSE

There were available for this experiment ten tanks of soil from the experiment tract at Vale, Oregon, that had been treated with various alkali-remedying materials and left exposed to the climatic conditions of Corvallis for a period of five years. By using these soils, field variations could be avoided because the tanks were filled with representative samples and kept under partially controlled conditions. The various sulfur bearing treatments were studied as to their effect on the soil reaction and composition of exchangeable bases.

HISTORICAL

In 1850, Day (22) first called attention to the fact that the absorbing of odors by the soil was an exchange reaction between the various soil bases and that a soil having a high colloidal content had a higher absorbing capacity. The study of base exchange phenomena has been handicapped because adequate methods of analysis were not developed until recently.
Kelley (15), Burgess and Breazealle (5), and also Hiseink (8) have each devised methods and each method has certain advantages and disadvantages. Kelley (11) has revised his methods to meet certain criticisms regarding solubility.

Recently Thomas (21) has presented the relation of exchangeable bases to both the acidity and the alkalinity of the soil. He replaced all the bases with a single base and then studied the resultant soil. He found that alkali soils contain appreciable quantities of soluble silicates which were not present in soils from humid regions.

Kelley and his associates have studied the question of base exchange reactions in relation to alkali soils quite extensively. Their method has been to study replicate samples from the variously treated plots using their own ammonium-chloride method for the determination of exchangeable bases. In their earlier work (12) they call attention to the extreme variance of individual samples but minimize this difficulty by the use of replicate samples. Kelley and Brown (14) state that most of the water soluble salts must be leached from a soil and then calcium must replace the
sodium on the soil complex before reclamation will be successful. They add that drainage is the most important factor. In another publication (15) the same authors state that neutral soils are high in replaceable calcium; alkali soils are high in replaceable sodium; and acid soils are low in total replaceable bases but high in trivalent bases such as aluminum, iron, and manganese.

Kelley and Cummins (15) added chemical equivalents of chlorides, sulfates, and nitrates of a base and found that they produced equivalent chemical reactions in the soil. In their order of ease of being replaced the ions are calcium, sodium, ammonium, potassium, and magnesium. Neglecting (17) studied the exchange reactions of aluminum, iron, and manganese and found that iron and aluminum replaced the other bases and could not be replaced but that manganese replaced calcium and could be replaced by barium.

In recent years the relation between the physical properties of the soil and its content of exchangeable bases has been studied by various workers. Raver (1) and (2) leached soils with the acetate salt of calcium, magnesium, manganese, potassium, and sodium and then
studied the physical properties of these soils. He found that the moisture equivalent was increased by sodium acetate but unchanged by the others. The heat of wetting was lowered by sodium and potassium. He also found that calcium, magnesium, and manganese increased flocculation and that sodium and potassium decreased it.

Greene (6) noted marked improvement in permeability of irrigation water by use of gypsum. Joseph and Oakley (10) conclude that physical properties are very closely correlated with exchangeable bases and that clay like properties are exhibited by lithium, sodium, and magnesium. Metzger (18) and (19) showed that the water content of the soil influenced exchangeable bases. He found that flooded soils decreased in exchangeable calcium and increased exchangeable magnesium. Optimum moisture content had very little, if any, effect on the exchangeable bases.
The Vale soil (Malheur silt loam) lies near but is not adjacent to the Snake River. It is quite alkaline having an initial reaction of pH 10.5 and is a typical "black alkali" soil, that is the alumina-silicate base holding complex holds very small amounts of any base except sodium. The soil has restricted drainage due to a silty, calcareous hardpan encountered at a depth of two or three feet. The water table fluctuates considerably but in general is about seven feet or more. Johnson and Powers (9) further describe this soil as to its chemical and physical properties. Black (3) sums up the results of the reclamation trials and finds that many tons of salts have been removed and that the rate of removal is decreasing. The original composition of this soil is given in Table I and II.

Samples from the most promising of the Vale plots were secured and analyzed for there content of exchangeable calcium, magnesium, and sodium using Breezeal-les barium chloride-soap titration method (5). The results secured are presented in Table III together with their treatment, reaction, and 1929 yield. This data, while not conclusive, shows that satisfactory crop yields can be secured without lowering the reaction
of the soil by use of sulfur bearing amendments. This is accomplished by the addition of organic matter which increases the fertility of the soil and thereby causes a lessening of the toxicity of the alkali salts present in the soil. The addition of sulfur aids a great deal. The reclamation, as measured by crop yields and reaction both, is secured at the expense of exchangeable sodium and at a gain in exchangeable calcium and magnesium and a decided increase in total exchangeable bases.
<table>
<thead>
<tr>
<th>Depth of Sample (feet)</th>
<th>Total Salts by distillation</th>
<th>Alkali Content per million</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Carbo-</td>
</tr>
<tr>
<td>0' - 1'</td>
<td>7359</td>
<td>1629</td>
</tr>
<tr>
<td>1' - 2'</td>
<td>7700</td>
<td>1563</td>
</tr>
<tr>
<td>2' - 3'</td>
<td>5205</td>
<td>1143</td>
</tr>
<tr>
<td>3' - 5'</td>
<td>4052</td>
<td>850</td>
</tr>
<tr>
<td>5' - 7'</td>
<td>1463</td>
<td>441</td>
</tr>
</tbody>
</table>

* Station data
TABLE II
CHEMICAL COMPOSITION OF SOIL

<table>
<thead>
<tr>
<th></th>
<th>April 1921 Sample</th>
<th>September 1921 Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_2O$</td>
<td>2.450</td>
<td>2.360</td>
</tr>
<tr>
<td>$CaO$</td>
<td>3.450</td>
<td>3.620</td>
</tr>
<tr>
<td>$MgO$</td>
<td>1.080</td>
<td>1.170</td>
</tr>
<tr>
<td>$P_2O_5$</td>
<td>0.242</td>
<td>0.237</td>
</tr>
<tr>
<td>$S$</td>
<td>0.041</td>
<td>0.028</td>
</tr>
<tr>
<td>$N$</td>
<td>0.040</td>
<td>0.074</td>
</tr>
</tbody>
</table>

Soluble Calcium, composite sample, 1921, 0.0147
Analysis by Station Chemist, J.S. Jones.
TABLE III

EXCHANGEABLE BASES IN CERTAIN PLOTS
FROM THE VALE EXPERIMENT FIELD

<table>
<thead>
<tr>
<th>Plot</th>
<th>Treatment</th>
<th>Depth</th>
<th>Calcium</th>
<th>Magnesium</th>
<th>Sodium</th>
<th>Total Bases</th>
<th>pH</th>
<th>Yield 1929</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Inches</td>
<td>M.E.</td>
<td>M.E.</td>
<td>M.E.</td>
<td>Founds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Manure 19 T.year-</td>
<td>1t Sulfur 1 1/2 T.</td>
<td>0-5</td>
<td>10.97</td>
<td>2.70</td>
<td>13.67</td>
<td>27.34</td>
<td>8.47</td>
<td></td>
</tr>
<tr>
<td>B. Check</td>
<td></td>
<td>5-20</td>
<td>12.39</td>
<td>1.46</td>
<td>18.74</td>
<td>32.59</td>
<td>8.60</td>
<td>2160</td>
</tr>
<tr>
<td>C. Manure 10 T.year-</td>
<td>1t Sulfur 1/2 T.</td>
<td>1-5</td>
<td>7.46</td>
<td>1.00</td>
<td>12.32</td>
<td>20.78</td>
<td>9.28</td>
<td></td>
</tr>
<tr>
<td>F. Green Manure</td>
<td></td>
<td>5-20</td>
<td>6.20</td>
<td>1.00</td>
<td>14.5</td>
<td>20.71</td>
<td>9.64</td>
<td>1340</td>
</tr>
<tr>
<td>3 T. yearly</td>
<td></td>
<td>0-5</td>
<td>10.27</td>
<td>1.46</td>
<td>13.36</td>
<td>25.09</td>
<td>9.65</td>
<td></td>
</tr>
<tr>
<td>G. Sulfur 1 1/2 T</td>
<td></td>
<td>5-20</td>
<td>6.17</td>
<td>1.22</td>
<td>16.81</td>
<td>24.20</td>
<td>9.91</td>
<td>1900</td>
</tr>
<tr>
<td>J. Gypsum</td>
<td></td>
<td>0-5</td>
<td>13.81</td>
<td>2.91</td>
<td>6.67</td>
<td>23.39</td>
<td>9.11</td>
<td></td>
</tr>
<tr>
<td>20,400 Lb.</td>
<td></td>
<td>5-20</td>
<td>14.21</td>
<td>2.91</td>
<td>14.54</td>
<td>31.66</td>
<td>9.78</td>
<td>Seed</td>
</tr>
<tr>
<td>Virgin</td>
<td></td>
<td>0-5</td>
<td>8.28</td>
<td>4.84</td>
<td>17.95</td>
<td>31.07</td>
<td>9.28</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5-20</td>
<td>6.17</td>
<td>1.00</td>
<td>21.75</td>
<td>28.92</td>
<td>9.58</td>
<td>1040</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0-5</td>
<td>1.40</td>
<td>1.00</td>
<td>22.06</td>
<td>24.94</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5-20</td>
<td>0.84</td>
<td>0.973</td>
<td>29.31</td>
<td>30.94</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
In the fall of 1922 ten soil tanks, two feet in depth and eleven inches in diameter, were filled with soil shipped from the Vale Experiment field and placed in the greenhouse at Corvallis for the purpose of checking the field work and studying the effects of the various treatments on the amount and composition of the percolates resulting from heavy irrigations. The data secured from these studies was presented by Johnson and Powers (9) and agrees very well with the field data. The tanks were left exposed to the climate from the spring of 1924 until the spring of 1929 when they were analyzed as to their content of exchangeable sodium, calcium, and magnesium. This data is presented in Table IV. The treatments were then renewed and the exchangeable bases were determined again in October, 1929. These results are presented in Table V. The tanks were then removed to the greenhouse and the final analysis was made in April, 1930 and results presented in Table VI.

The data secured in this study is conclusive.

Field variations have been avoided entirely by the use of representative soil thoroughly mixed and kept under
partially controlled conditions. All water that has been added has been either distilled or added in the form of rain. The small amounts of sulfur added in the rain water are negligible.

The gain or loss in amounts of exchangeable bases is presented in Table VII. The results of these studies show that reclamation of alkali soils is accompanied by a loss of exchangeable magnesium. In no case could more than a slight trace of exchangeable magnesium be detected by the methods used.

If an increase in exchangeable calcium and a decrease in exchangeable sodium can be taken as a criteria of reclamation, this data shows conclusively that gypsum used at the rate of ten tons per acre is the best alkali amendment of any that were under study. It is followed by heavy applications of sulfur used alone. Gypsum used at the rate of five tons per acre is little better than aluminum sulfate and sulfur used in conjunction. Aluminum sulfate used alone is no better than manure and sulfur used together. Manure used alone does not change the content of exchangeable bases little more than can be expected from leaching with pure water. The increase in total exchangeable bases is not a fair criteria in alkali soil improvement.
<table>
<thead>
<tr>
<th>Treatment</th>
<th>Calcium</th>
<th>Sodium</th>
<th>Total Bases</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check</td>
<td>5.74</td>
<td>16.51</td>
<td>22.25</td>
<td>8.65</td>
</tr>
<tr>
<td>Aluminum sulfate</td>
<td>3.58</td>
<td>20.40</td>
<td>23.98</td>
<td>8.85</td>
</tr>
<tr>
<td>Sulfur Aluminum sulfate</td>
<td>4.30</td>
<td>20.77</td>
<td>25.07</td>
<td>8.53</td>
</tr>
<tr>
<td>Manure &amp; sulfur</td>
<td>3.53</td>
<td>19.40</td>
<td>22.93</td>
<td>8.80</td>
</tr>
<tr>
<td>Sulfur 2½ T.</td>
<td>5.74</td>
<td>18.47</td>
<td>24.21</td>
<td>8.53</td>
</tr>
<tr>
<td>Sulfur 1½ T.</td>
<td>6.89</td>
<td>17.40</td>
<td>24.29</td>
<td>8.57</td>
</tr>
<tr>
<td>Gypsum 10 T</td>
<td>5.02</td>
<td>17.14</td>
<td>22.16</td>
<td>8.53</td>
</tr>
<tr>
<td>Gypsum 5 T.</td>
<td>3.58</td>
<td>20.90</td>
<td>24.48</td>
<td>8.70</td>
</tr>
<tr>
<td>Manure 20 T.</td>
<td>4.30</td>
<td>18.77</td>
<td>23.07</td>
<td>8.77</td>
</tr>
<tr>
<td>Check</td>
<td>5.02</td>
<td>19.14</td>
<td>24.16</td>
<td>8.63</td>
</tr>
</tbody>
</table>


**TABLE V**  
Exchangable Bases in Vale Soil Tests  
September 1929

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Calcium</th>
<th>Sodium</th>
<th>Total Bases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check</td>
<td>6.94</td>
<td>17.79</td>
<td>24.73</td>
</tr>
<tr>
<td>Aluminum Sulfate</td>
<td>7.70</td>
<td>15.58</td>
<td>23.28</td>
</tr>
<tr>
<td>Aluminum Sulfate sulfur</td>
<td>23.11</td>
<td>4.85</td>
<td>27.96</td>
</tr>
<tr>
<td>Manure &amp; sulfur</td>
<td>7.07</td>
<td>17.58</td>
<td>24.65</td>
</tr>
<tr>
<td>Sulfur 2 T.</td>
<td>7.36</td>
<td>17.37</td>
<td>24.63</td>
</tr>
<tr>
<td>Sulfur 1 ½ T.</td>
<td>14.54</td>
<td>11.60</td>
<td>26.14</td>
</tr>
<tr>
<td>Gypsum 10 T.</td>
<td>9.95</td>
<td>15.53</td>
<td>25.53</td>
</tr>
<tr>
<td>Gypsum 5 T.</td>
<td>13.55</td>
<td>11.79</td>
<td>25.35</td>
</tr>
<tr>
<td>Manure 20 T.</td>
<td>6.05</td>
<td>18.24</td>
<td>24.29</td>
</tr>
<tr>
<td>Check</td>
<td>6.37</td>
<td>18.65</td>
<td>25.02</td>
</tr>
</tbody>
</table>
Table VI

EXCHANGEABLE BASES IN FALL SOIL TANKS

May 1930

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Calcium</th>
<th>Sodium</th>
<th>Total Bases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check</td>
<td>9.65</td>
<td>17.83</td>
<td>27.48</td>
</tr>
<tr>
<td>Aluminum Sulfate</td>
<td>11.71</td>
<td>15.02</td>
<td>26.73</td>
</tr>
<tr>
<td>Sulfur aluminum sulfate</td>
<td>13.84</td>
<td>19.77</td>
<td>33.61</td>
</tr>
<tr>
<td>Tronate &amp; Sulfur</td>
<td>8.58</td>
<td>21.16</td>
<td>29.74</td>
</tr>
<tr>
<td>Sulfur 2½ T.</td>
<td>12.76</td>
<td>15.41</td>
<td>28.15</td>
</tr>
<tr>
<td>Sulfur 1½ T.</td>
<td>15.79</td>
<td>12.45</td>
<td>28.24</td>
</tr>
<tr>
<td>Gypsum 10 T.</td>
<td>22.05</td>
<td>7.27</td>
<td>29.32</td>
</tr>
<tr>
<td>Gypsum 5 T.</td>
<td>14.77</td>
<td>13.75</td>
<td>28.52</td>
</tr>
<tr>
<td>Tronate 20 T.</td>
<td>9.34</td>
<td>17.15</td>
<td>26.49</td>
</tr>
<tr>
<td>Check</td>
<td>10.08</td>
<td>18.71</td>
<td>28.79</td>
</tr>
</tbody>
</table>
## TABLE VII

**CHANGES IN EXCHANGEABLE BASES IN SOIL TANKS**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Calcium</th>
<th>Sodium</th>
<th>Total Bases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M.E.</td>
<td>M.E.</td>
<td>M.E.</td>
</tr>
<tr>
<td>1. Check</td>
<td>+4.94</td>
<td>+1.2</td>
<td>+6.15</td>
</tr>
<tr>
<td>2. Aluminum Sulfate</td>
<td>+7.63</td>
<td>-3.81</td>
<td>+2.83</td>
</tr>
<tr>
<td>3. Aluminum sulfate</td>
<td>+8.06</td>
<td>-1.22</td>
<td>+6.84</td>
</tr>
<tr>
<td>sulfur</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Manure + Sulfur</td>
<td>+7.53</td>
<td>-0.71</td>
<td>+6.82</td>
</tr>
<tr>
<td>5. Sulfur 2½ T.</td>
<td>+10.12</td>
<td>-8.31</td>
<td>+1.80</td>
</tr>
<tr>
<td>6. Sulfur 1½ T.</td>
<td>+9.25</td>
<td>-5.23</td>
<td>+4.02</td>
</tr>
<tr>
<td>7. Gypsum 10 T.</td>
<td>+12.61</td>
<td>-8.10</td>
<td>+4.51</td>
</tr>
<tr>
<td>8. Gypsum 5 T.</td>
<td>+8.97</td>
<td>-4.47</td>
<td>+4.01</td>
</tr>
<tr>
<td>9. Manure 20 T.</td>
<td>+5.04</td>
<td>+0.14</td>
<td>+4.9</td>
</tr>
<tr>
<td>10. Check</td>
<td>+4.79</td>
<td>+0.32</td>
<td>+4.47</td>
</tr>
</tbody>
</table>
DISCUSSION

The results secured in both the tanks and from the plot sample agree very well in general. They show that base exchange relations are of prime importance in the reclamation of alkali soils. Whenever the combined amounts of exchangeable calcium and magnesium exceed the amount of exchangeable sodium the soil is improved enough for the production of crops. If the exchangeable sodium exceeds the calcium and magnesium the soil will probably be still unproductive.

The data secured from the tanks shows that an increase in total exchangeable bases accompanies the exchange of bases. This fact is significant as it illustrates the build up of the soil complex as mentioned by Burgess (4) but does not strictly correlate with his work. The phenomenal increase in the total exchangeable bases in soil tank number one is due to the increase in exchangeable sodium. It is hard to attribute this increase to any one factor although the variation of the soil samples will partly account for it. As could be expected the heaviest application of gypsum has the greatest effect on exchangeable bases.
The beneficial effects of small amounts of sulfur used in conjunction with organic matter is demonstrated in both the tank experiment and in the field plots.

The effect of the various sulfur bearing materials on the physical properties of the soil is very marked. The two checks and manure-alone tanks are very hard, compact, and nearly impermeable to water. All of the others show marked improvement. They are very much more pervious to water and have fairly good granular open structure. No adequate method was available for measuring these properties so the results are merely observations, however, extreme care was used in securing these observations.

It will be noted that these observations as to the physical properties agrees very well with the ratio between the content exchangeable sodium and calcium. The three tanks with poor physical condition are low in exchangeable calcium and high in exchangeable sodium. The tanks that show improvement in physical condition also show a decided gain in exchangeable calcium and varying loss of exchangeable sodium.
A discussion of the reclamation of alkali lands is not complete without a brief mention of the microbiological population of the soil. Soil bacteriology has been studied by many workers and the literature is reviewed very well by Telegdy-Kovats (20). He cites practically all the American and European workers and gives a brief resume of their work.

An attempt was made to measure the bacterial activities of alkali soils treated with various sulfur and sulfur bearing materials by measuring the evolution of carbon-dioxide by the methods of Heck (7). His apparatus was modified by the use of normal sodium hydroxide, saturated barium hydroxide, and 35% sulfuric acid for the air purification train instead of the soda-lime and pumice saturated with sulfuric acid that he used. His methods were changed slightly as the carbon-dioxide was titrated direct by the double titration method.
A fresh sample of the virgin Vale soil was secured for this study and one kilogram was used in each jar. The entire experiment was run in duplicate and the results were the average of the duplicate jars. The sulfur was furnished by the Western Sulfur Company of San Francisco. The fine sulfur is the same as used in the preparation of the Bac-ul but it does not carry the sulfur oxidizing organisms.

The four ton application of the sulfur and the twenty ton application of gypsum is enough to theoretically reduce the reaction of the soil to pH 8.0 and the heavier application should reduce it to pH 6.4. These figures were obtained from studies made by Black. (3)

The results are presented in Table VIII and Plate I and show little significance. This is due primarily to the low content of microorganisms found in the soil. The high production of carbon dioxide in all the sulfur treated samples can be attributed to the chemical oxidation and reaction of the sulfur with the soil constituents. It was assumed at the outset of the study that the carbon dioxide produced by the
microorganisms would greatly exceed that produced by the chemical action, but this was not substantiated. The heavy application of gypsum apparently has no effect on the production of carbon dioxide from the soil. The manure treated samples show a decided increase in carbon-dioxide production and this can probably be attributed to microbiological activities.

At the close of the experiment the soils were sampled and the number of bacteria, actinomycetes, and fungi was determined by the plate method. These results are given in Table IX and show no significant differences but the content of each is extremely low. It can be concluded from this that the soil is too alkaline to permit the growth of bacteria. The reaction was determined by the hydrogen electrode and shows that the effects of the treatments were not complete at the end of the five week period.
<table>
<thead>
<tr>
<th></th>
<th>CO₂ March 6 Mgs</th>
<th>CO₂ March 8 Mgs</th>
<th>CO₂ March 10 Mgs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Check</td>
<td>15.79</td>
<td>17.48</td>
<td>33.98</td>
</tr>
<tr>
<td>2. Sulfur 4 T.</td>
<td>11.66</td>
<td>30.24</td>
<td>59.64</td>
</tr>
<tr>
<td>4. Bac-Sulf 4 T.</td>
<td>13.96</td>
<td>21.42</td>
<td>63.26</td>
</tr>
<tr>
<td>5. Fine Sulf 4 T.</td>
<td>15.24</td>
<td>29.72</td>
<td>65.56</td>
</tr>
<tr>
<td>6. Gypsum 20 T.</td>
<td>15.18</td>
<td>23.16</td>
<td>53.42</td>
</tr>
<tr>
<td>7. Gypsum 57 T.</td>
<td>13.20</td>
<td>27.76</td>
<td>43.42</td>
</tr>
<tr>
<td>8. Manure 20 T.</td>
<td>12.82</td>
<td>23.76</td>
<td>44.46</td>
</tr>
<tr>
<td>9. Manure 20 T.</td>
<td>8.64</td>
<td>10.44</td>
<td>53.70</td>
</tr>
</tbody>
</table>

Sulfur ½T
<table>
<thead>
<tr>
<th>No. corresponding to those on p. 22</th>
<th>CO₂ March 12</th>
<th>CO₂ March 14</th>
<th>CO₂ March 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 1</td>
<td>43.30</td>
<td>99.78</td>
<td>64.52</td>
</tr>
<tr>
<td>2</td>
<td>93.78</td>
<td>131.68</td>
<td>176.30</td>
</tr>
<tr>
<td>3</td>
<td>116.76</td>
<td>154.04</td>
<td>198.24</td>
</tr>
<tr>
<td>4</td>
<td>76.19</td>
<td>126.96</td>
<td>264.28</td>
</tr>
<tr>
<td>5</td>
<td>139.80</td>
<td>162.76</td>
<td>187.22</td>
</tr>
<tr>
<td>6</td>
<td>59.54</td>
<td>84.84</td>
<td>60.50</td>
</tr>
<tr>
<td>7</td>
<td>47.46</td>
<td>85.02</td>
<td>59.56</td>
</tr>
<tr>
<td>8</td>
<td>52.00</td>
<td>80.44</td>
<td>93.50</td>
</tr>
<tr>
<td>9</td>
<td>86.44</td>
<td>141.80</td>
<td>146.10</td>
</tr>
<tr>
<td>No. Corresponding to those on p. 22</td>
<td>CO₂ March 18 Mgs</td>
<td>CO₂ March 20 Mgs</td>
<td>CO₂ March 23 Mgs</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>-----------------</td>
<td>-----------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>No. 1</td>
<td>70.84</td>
<td>76.56</td>
<td>123.42</td>
</tr>
<tr>
<td>2</td>
<td>177.76</td>
<td>121.22</td>
<td>160.83</td>
</tr>
<tr>
<td>3</td>
<td>364.54</td>
<td>151.04</td>
<td>195.90</td>
</tr>
<tr>
<td>4</td>
<td>190.08</td>
<td>160.38</td>
<td>101.73</td>
</tr>
<tr>
<td>5</td>
<td>184.36</td>
<td>138.82</td>
<td>144.42</td>
</tr>
<tr>
<td>6</td>
<td>82.06</td>
<td>50.36</td>
<td>81.39</td>
</tr>
<tr>
<td>7</td>
<td>85.80</td>
<td>39.60</td>
<td>72.50</td>
</tr>
<tr>
<td>8</td>
<td>127.60</td>
<td>71.72</td>
<td>124.74</td>
</tr>
<tr>
<td>9</td>
<td>193.80</td>
<td>130.46</td>
<td>83.76</td>
</tr>
</tbody>
</table>
### TABLE VIII CONCLUDED

<table>
<thead>
<tr>
<th>No. corresponding to No. p. 22</th>
<th>CO₂ March 26 Mgs</th>
<th>CO₂ March 21 Mgs</th>
<th>CO₂ April 6 Mgs</th>
<th>CO₂ Total Mgs</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 1</td>
<td>117.47</td>
<td>152.05</td>
<td>114.00</td>
<td>929.20</td>
</tr>
<tr>
<td>2</td>
<td>132.90</td>
<td>226.55</td>
<td>222.18</td>
<td>1544.64</td>
</tr>
<tr>
<td>3</td>
<td>177.69</td>
<td>335.25</td>
<td>328.80</td>
<td>2069.64</td>
</tr>
<tr>
<td>4</td>
<td>180.09</td>
<td>247.10</td>
<td>228.84</td>
<td>1669.12</td>
</tr>
<tr>
<td>5</td>
<td>172.92</td>
<td>272.80</td>
<td>201.00</td>
<td>1714.62</td>
</tr>
<tr>
<td>6</td>
<td>82.38</td>
<td>245.65</td>
<td>116.40</td>
<td>954.80</td>
</tr>
<tr>
<td>7</td>
<td>102.21</td>
<td>137.70</td>
<td>114.30</td>
<td>828.63</td>
</tr>
<tr>
<td>8</td>
<td>144.30</td>
<td>229.25</td>
<td>211.26</td>
<td>1235.49</td>
</tr>
<tr>
<td>9</td>
<td>73.26</td>
<td>235.60</td>
<td>180.72</td>
<td>1364.72</td>
</tr>
</tbody>
</table>
### TABLE IX

**MICROBIOLOGICAL POPULATION AND REACTION**

**OF VARIOUSLY TREATED ALKALI SOILS**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Bacteria</th>
<th>Actinomycetes</th>
<th>Fungi</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>1. Check</td>
<td>102</td>
<td>1</td>
<td>10</td>
<td>9.70</td>
</tr>
<tr>
<td>2. Sulfur 4 T.</td>
<td>154</td>
<td>1</td>
<td>14.4</td>
<td>8.90</td>
</tr>
<tr>
<td>3. Sulfur 12.5 T.</td>
<td>80</td>
<td>0</td>
<td>11.5</td>
<td>8.01</td>
</tr>
<tr>
<td>4. Bac-Sul 4 T.</td>
<td>120</td>
<td>1</td>
<td>7.2</td>
<td>8.82</td>
</tr>
<tr>
<td>5. Fine Sulfur 4 T.</td>
<td>162</td>
<td>1</td>
<td>8.9</td>
<td>8.75</td>
</tr>
<tr>
<td>6. Gypsum 20 T.</td>
<td>138</td>
<td>1</td>
<td>10</td>
<td>8.79</td>
</tr>
<tr>
<td>7. Gypsum 67 T.</td>
<td>66</td>
<td>1</td>
<td>10</td>
<td>8.26</td>
</tr>
<tr>
<td>8. Manure 20 T.</td>
<td>58</td>
<td>1</td>
<td>11.8</td>
<td>9.50</td>
</tr>
<tr>
<td>9. Manure plus S.</td>
<td>170</td>
<td>2</td>
<td>15</td>
<td>8.92</td>
</tr>
<tr>
<td>10. Original</td>
<td>5</td>
<td>0</td>
<td>2</td>
<td>9.65</td>
</tr>
</tbody>
</table>
CONCLUSIONS

1. The reclamation of alkali soils is accompanied by a loss of exchangeable sodium and a gain in exchangeable calcium and sometimes by a total disappearance of exchangeable magnesium.

2. Expressed in chemical equivalents, there is more calcium gained than sodium lost.

3. A small amount of sulfur used in conjunction with manure will give maximum returns per unit invested.

4. The evolution of carbon-dioxide is not a satisfactory measure of microbiological activities in alkali soils.

5. Tank experiments are superior to field trials in the study of the reclamation of alkali soils.
REFERENCES

1. Bever, L. D.
1930 Relation of the amount and nature of exchangeable cations to the structure of colloidal clay. Soil Sci. 29: 291-310

2. Bever, L. D.
1928 Relation of Exchangeable cations to the physical properties of soils.
Jour. Am. Soc. Agro. 20: 921-942

3. Black, Walter V.

4. Burgess, P. S.
1929 The so-called "build-up" and "break-down" of soil sediments as influenced by reaction. Ariz. Agri. Exp. Sta. Tech. Bul. 28

5. Burgess, P. S. and Breazeale, J. F.
1928 Methods for determining the replaceable bases of soils, either in the presence or absence of alkali salts.
Ariz. Agri. Exp. Sta. Tech Bul. 9

6. Greene, H.
1928 Soil permeability in the Eastern Gadsden Jour. of Agri. Soc. 18: 531-543

7. Heck, A. Floyd
1929 A method for determination of total carbon and also for the estimation of carbon-dioxide evolved from soils
Soil Sci. 28: 225-234

8. Hiscock, A. J.
1927 Report on Soil Adsorption
Proc. 1st Int. Soils Conf.

9. Johnson, W. L. and Powers, W. L.
1924 A progress report of alkali land reclamation investigations in Eastern Oregon
1929 The properties of heavy alkaline soils containing different exchangeable bases.
Jour. Agric. Sci. 9: 121-131

11. Kelley, W. P.
1929 The determination of base-exchange capacity of soils and a brief discussion of the underlying principles.

12. Kelley, W. P.
1922 Variability of alkali soil
Soil Science 14: 177-190

1928 The chemical effects of gypsum, sulfur, iron sulfate, and alum on alkali soils.
Hilgardia Vol. 3 no. 14

14. Kelley, W. P. and Brown, S. M.
1925 Base exchange in relation to alkali soils
Soil Sci. 20: 477-495

15. Kelley, W. P. and Brown, S. M.
1924 Replaceable bases in soils.
Cal. Tech. Bul. 15

1921 Chemical effects of salts on soils.
Soil Sci. 11: 139-156

17. Magistrad, C. C.
1928 The action of aluminum, ferrous and ferric iron, and manganese in base exchange reactions.

18. Metzger, F. H.
1929 The effect of moisture content and cropping on exchangeable calcium and magnesium.
Soil Sci. 27: 305-318
19. Metzger, H. H.  
1930  Replaceable bases in irrigated soils.  
Soil Sci. 29: 251-263

20. Telegdy-Kovats, von L.  
1929  Referat über die Ergebnisse der  
mikrobiologie der al-altboden.  Sonder-  
abdruck aus den Verhandlungen der  
Alkali-Subkommission der Internationa-  
alen Bodenkundlichen Gesellschaft.  
Budapest A.

21. Thomas, Mayer D.  
1928  Replaceable bases in some soils from  
arid and humid region soil.  
Soil Sci. 25: 379-392

22. Fay, J. Thomas  
1850  On power of soils to absorb manure  
Jour. of the Agri. Soc. Vol. 11:313-79
PLATE I

CURVE SHOWING

CO₂ EVOLUTION BY PERIODS

Date - March 6 to April 6

Milligrams of CO₂