Studies in the Alkali Bee
(Nomia melanderi Ckll.)

I. Soil Physical Requirements for Bee Nesting
   W. P. Stephen
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II. Preliminary Investigations on the Effect of Soluble Salts on Alkali Bee Nesting Sites
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III. Management and Renovation of Native Soils for Alkali Bee Inhabitation
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Studies in the Alkali Bee
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I. Soil Physical Requirements for Bee Nesting

Introduction

The alkali bee, *Nomia melanderi* Cockerell, is one of the most efficient pollinators of alfalfa in Western America (Bohart 1950, Stephen 1959). Its rapidity in tripping alfalfa florets does not approach that of certain species of the leaf-cutting Megachile but its apparent fidelity to alfalfa, the tremendous numbers found in certain areas of Western America, and the capacity to construct up to twice the number of cells as most megachilids make the alkali bee by far the most important pollinator in this region.

The continual high yields of alfalfa seed recorded from Utah by Bohart (1950) and from Washington by Menke (1954), are attributed primarily to the high alkali bee population in close proximity to alfalfa seed fields. Similarly, high seed yields in the Pacific Northwest are very closely associated with the range and high populations of the alkali bee. It is generally accepted by students of alfalfa seed production that pollination, or tripping, is the principal factor restrictive to seed yielding in that crop. It is notable that the average yield of alfalfa seed per acre in the United States for the years 1957 and 1958 was approximately 180 pounds while in certain areas of Eastern Oregon and Washington yields of 1,500 and more pounds were not uncommon.

Since the future of the alfalfa seed industry in the Pacific Northwest rests largely on the ability to maintain or increase populations of the alkali bee, factors governing selection of nesting sites by the bee must be determined. Such information could assist seed producers in determining, with some accuracy, the possibility of establishing alkali bee populations in areas where seed production is contemplated. Observations made from 1955 to 1958 in Oregon, Nevada, and Washington indicate that two factors in particular restrict numerical expansion of the species. These are absence of sufficient pollen and nectar during active flight season, and absence of suitable nesting sites near food supply.

Numerous attempts have been made by the author since 1956 to transplant alkali bees. Care was exercised to select soil types closely resembling those of beds in which bees were active. Selection
of potential bee nesting sites was based solely on resemblance of soil appearance and texture to that of established nesting sites. In these admissibly crude comparisons only 33% of the transplants were at all successful and of these less than 10% survived over a period of two years. Emergence invariably proceeded from each soil transplant but most, if not all, of the renesting was limited to the soil of the transplant core. Many transplants dried out as the season progressed and were soon abandoned by the adult bees.

Other transplanted soil cores remained moist through much of the season but because of the desiccation of the soil around the transplant, renesting was confined to the core itself. In the successful transplants, bee nesting first began in the introduced soil of the core followed by expansion into the soil area immediately adjacent to it. Factors common to all successful transplant sites appeared to be the rather uniform moisture level and compactness of the soil surface throughout the season.

A high soil moisture level from the surface to the area of cell construction is common to each of the excellent natural sites examined in the Pacific Northwest. The soil water supplying occupied nesting sites, as well as any other permanently moist areas in the Great Basin area, is maintained by underground movement of water and its subsequent rise in restricted areas through capillarity. During spring or early summer (when transplanting should be done) when emerging bees generally begin seeking out new nesting sites, it is difficult to select satisfactory sites using the cursory soil comparison method. Apparently the bee herself experiences the same difficulty—many sites selected for expansion are abandoned as the season progresses.

The abundance of surface soil moisture from winter and early spring precipitation leaves many sites in a condition suitable for bee habitation. Most of these sites dry out rapidly as summer progresses, primarily because of changes in quantity or direction of flow of subsoil moisture. Cutting of drainage ditches near existing bee beds or changes in irrigation practices have left marked effects on present or potential nesting areas. In short, the variation in soil moisture essential to maintenance of an acceptable alkali bee nesting site is so great that long range prediction on suitability of a site is hazardous or impossible.

Investigations were undertaken in 1957 and 1958 to determine optimum soil conditions of bee beds of varying population densities throughout the Pacific Northwest. Attention was directed at a thorough soil texture, moisture, and chemical analysis with an attempt at distinguishing differences between excellent, good, and poor nesting sites. This is a report on soil texture and moisture optima as determined from these analyses.
Methods

A total of 88 alkali bee beds were sampled in Oregon, Washington, Idaho, Nevada, and Utah during 1957 and 1958 either by the author or through the generous cooperation of colleagues in these areas. Bee nesting sites that had been utilized for several consecutive years and in which the population of bees had been continuously high (above 20 nesting burrows per square foot) were designated as excellent; sites occupied for similar durations of time but in which nesting burrows ranged from 10 to 20 per square foot in areas of most concentrated activity were considered good; and those with less than 10 burrows per square foot were considered fair or poor depending on overall population. Soil samples were taken from beds representing each of the above conditions. Smaller bee beds that had been occupied for a single year and then apparently abandoned and other beds that were recently occupied were also sampled for soil texture and moisture analyses.

In considering selection of sites to be sampled, some consideration had to be given to the actual area of the occupied site and to the total bee population therein, for in certain areas in which bee population was high and suitable nesting area small the bees established themselves in adjacent situations not favorable for their survival even for a single season. Samples taken from this type of bee site were designated unacceptable or poor for continued bee activity.

The top 6 inches and the 6- to 12-inch level of each bed were sampled separately. Each sample consisted of a composite of three cores taken from that area of each bed in which bee population was most dense. The top 6 inches were thought to be most critical. This is the level in which the vast majority of cells are constructed and through which all bees must excavate. The 6- to 12-inch level contained cells in certain more populous beds and included the lowest levels to which the bee excavates in construction of her nest under natural conditions.

Additional soil samples were taken from the 12- to 18-inch level of several beds for analyses. This soil, while not in direct contact with the bees, often represents the soil conditions through which the entire nesting site is subirrigated. Information on its texture was desired as a possible indication of the optimum conditions for the rapid water rise necessary to maintain a suitable moisture level in the proximity of the bee cells and at the nest surface.

The hydrometer method (Bouyoucos 1951) was used throughout for determining particle size distribution of soils; however, pretreatment of samples differed. By method A, the samples were run without removal of organic matter or soluble salts. By method B,
organic matter was removed by hydrogen peroxide treatment but soluble salts were not removed. By method C, both organic matter and soluble salts were removed. Soluble salts were removed by intermittent dilution and filtration until 750 ml. of distilled water was used.

Method A did not remove the cementing and flocculation effects of organic matter and soluble salts, while method B removed organic matter effects but not soluble salt effects. These two methods do not give the true mechanical analysis of the soil, particularly for soils with high organic matter content or soluble salts concentration. Complete dispersion is not obtained and some finer particles are flocculated or aggregated into larger particles and are included in the silt and sand fractions. For this reason, methods A and B are called aggregate analyses. Samples were subjected to the usual mechanical stirring used in mechanical analysis. Throughout this paper results for these two methods are expressed as percent clay-, silt-, or sand-size particles.

All samples were analyzed by method B. It became obvious that complete dispersion was not being obtained for some soils so method C was used on some samples. As will be shown later, results by method B correlated better with the bee population than did results by method C. Removal of organic matter requires considerable time so method A was run on some samples for comparative purposes. Therefore, for certain soils, results were obtained by all three methods. All determinations were made in duplicate and results are expressed as a percentage of oven-dry sample weight.

Soil samples were taken from the 0- to 6-inch and 6- to 12-inch levels from four excellent beds at weekly intervals throughout 1957 and 1958 to determine soil moisture content during the year. Several beds were sampled to the 12- to 18-inch and 18- to 24-inch levels in an attempt to determine source of moisture for these particular areas. Additional samples were taken periodically from more than 20 beds classified as excellent, good, poor, and unacceptable to determine influence of soil moisture on acceptance of the site by the bee.

Soil moisture was determined by oven-drying the soil sample for 24 hours at 120° C. Soil moisture content is expressed as a percentage of dry weight. Special efforts were made to note and record presence of restrictive layers where they occurred, and to observe their effect on bee activity, soil moisture, and soil texture.

**Results**

Results of particle size analyses by method B, only organic matter removed, showed a striking feature in that all of the better bee
beds had a relatively low percentage of clay-size particles. Range of percentages was divided into 2% increments and the number of excellent, good, and poor beds determined for each increment. A graph of results is shown in Figure 1. All excellent beds had a percentage of clay-size particles of 12 or less and most excellent beds had a percentage of less than 7. Beds classified as good had a higher percentage of clay-size particles than did excellent beds, while poor beds covered a wide percentage range. Some poor beds had a low percentage of clay-size particles but upon examination it was apparent that other factors, such as moisture or restrictive layers, made the beds unacceptable to bees.

Representative data are presented in Table 1 to show particle size distribution for excellent, good, and poor beds. The high percentage of silt-size particles in these soils is no doubt significant since

FIGURE 1. Correlation of percent clay-size particles with condition of bee bed from which samples were taken.
a high silt soil tends to be more stable along a vertical soil-air interface than either a sandy or clayey soil.

Particle size analyses of soil samples were taken from six bee nesting sites using the hydrometer method cited above. Methods A, B, and C are cited in Table 2. In all samples, methods A and B gave comparable results. There are exceptions to this for in bed 1 the high concentration of organic matter at the 6- to 12-inch level influenced results of analytical methods. However, hydrometer analysis following removal of soluble salts and organic matter, method C yielded texture data sharply contrasting with the two methods cited above.

The most striking difference appears in the percentage of clay-size particles realized by each method, indicating that removal of salts, and organic matter to a lesser extent, from the sample prior to analysis had a marked effect on particle size distribution. For example, in bed 3, 28.84% of clay-size particles was recorded following removal of organic matter and salts, while the other two methods yielded from 4% to 5% clay-size particles. Results by method C did not correlate nearly as well with classification of the beds as did results by method B.

Total salts in parts per million are cited in Table 2. While there appears to be a direct correlation between total salts and soil aggregate structure, present indications are that location and concentration of the monovalent and divalent cations in various positions in the soil profile are of greatest consequence. Effect of soluble salts on soil aggregation and subsequent acceptance by the alkali bee are reported in Part II of this bulletin.

Table 1. Aggregate Analysis with Organic Matter Removed on Soils from Alkali Bee Beds.

<table>
<thead>
<tr>
<th>Bee bed</th>
<th>Condition of bed</th>
<th>Depth</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Excellent 0-6&quot;</td>
<td>26.2</td>
<td>65.6</td>
<td>8.2</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Excellent 0-6&quot;</td>
<td>37.2</td>
<td>55.58</td>
<td>7.20</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Excellent 0-6&quot;</td>
<td>25.6</td>
<td>66.4</td>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Excellent 0-6&quot;</td>
<td>20.81</td>
<td>74.53</td>
<td>4.67</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Excellent 0-6&quot;</td>
<td>68.51</td>
<td>27.79</td>
<td>3.71</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Excellent 0-6&quot;</td>
<td>31.50</td>
<td>62.20</td>
<td>6.30</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Excellent 0-6&quot;</td>
<td>32.66</td>
<td>66.01</td>
<td>1.34</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Excellent, deep brood</td>
<td>31.50</td>
<td>62.20</td>
<td>6.30</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Excellent, shallow brood</td>
<td>25.46</td>
<td>71.61</td>
<td>2.93</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Excellent, shallow brood</td>
<td>23.53</td>
<td>58.38</td>
<td>18.09</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Fair to good</td>
<td>27.24</td>
<td>61.18</td>
<td>11.58</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Poor</td>
<td>33.91</td>
<td>53.88</td>
<td>12.21</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Poor</td>
<td>23.46</td>
<td>61.78</td>
<td>14.76</td>
<td></td>
</tr>
</tbody>
</table>
Table 2. **Comparative Methods of Soil Analysis in Soil Texture Determination from Alkaline Bee Beds**

<table>
<thead>
<tr>
<th>Bee bed and sample depth</th>
<th>Aggregate analysis</th>
<th>Hydrometer analysis with organic matter removed</th>
<th>Hydrometer analysis with organic matter and salts removed</th>
<th>Total salts in ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sand</td>
<td>Silt</td>
<td>Clay</td>
<td>Sand</td>
</tr>
<tr>
<td>1 (0 – 6&quot;)</td>
<td>31.09</td>
<td>61.30</td>
<td>7.61</td>
<td>28.24</td>
</tr>
<tr>
<td>(6 – 12&quot;)</td>
<td>24.51</td>
<td>69.78</td>
<td>5.71</td>
<td>26.30</td>
</tr>
<tr>
<td>2 (0 – 6&quot;)</td>
<td>26.98</td>
<td>65.44</td>
<td>7.58</td>
<td>23.47</td>
</tr>
<tr>
<td>(6 – 12&quot;)</td>
<td>30.88</td>
<td>55.31</td>
<td>13.81</td>
<td>22.35</td>
</tr>
<tr>
<td>3 (0 – 6&quot;)</td>
<td>25.65</td>
<td>69.32</td>
<td>5.04</td>
<td>25.60</td>
</tr>
<tr>
<td>(6 – 12&quot;)</td>
<td>20.40</td>
<td>73.70</td>
<td>5.90</td>
<td>26.33</td>
</tr>
<tr>
<td>4 (0 – 6&quot;)</td>
<td>48.23</td>
<td>48.96</td>
<td>2.82</td>
<td>43.50</td>
</tr>
<tr>
<td>(6 – 12&quot;)</td>
<td>28.10</td>
<td>63.67</td>
<td>8.23</td>
<td>22.15</td>
</tr>
<tr>
<td>5 (0 – 6&quot;)</td>
<td>27.86</td>
<td>57.69</td>
<td>14.45</td>
<td>25.31</td>
</tr>
<tr>
<td>(6 – 12&quot;)</td>
<td>36.65</td>
<td>61.23</td>
<td>2.12</td>
<td>31.50</td>
</tr>
<tr>
<td>6 (0 – 6&quot;)</td>
<td>32.91</td>
<td>64.83</td>
<td>2.26</td>
<td>31.94</td>
</tr>
</tbody>
</table>
Soil moisture

The moisture percentages found for excellent, good, and poor beds are cited in Table 3. These percentages are based upon dry weight and are for either the 1956, 1957, or 1958 active bee season. Only biweekly data are cited.

It is immediately apparent that all excellent beds maintained a relative constant high moisture percentage throughout the period of measurement. Beds cited as good and poor were found to lose moisture rapidly during the season resulting in a drying and loosening of the soil surface. Soil was continually falling into the bee burrows and in extreme cases caused bees to abandon many such sites during the middle of the flight season.

Each of the excellent beds, except bed 3 and bed 5, had a high moisture percentage in upper levels and soil was relatively compact. The variation of soil moisture, from 7.85% in bed 3 to 27% in bed 2, appears to be highly significant. However, the difference is associated

<table>
<thead>
<tr>
<th>Bed</th>
<th>Condition of bed</th>
<th>Date</th>
<th>6 inches</th>
<th>12 inches</th>
<th>18 inches</th>
<th>24 inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Excellent, deep brood to 10 inches</td>
<td>6/16</td>
<td>26.30</td>
<td>31.22</td>
<td>31.46</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7/24</td>
<td>25.49</td>
<td>30.06</td>
<td>30.94</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8/15</td>
<td>24.72</td>
<td>28.49</td>
<td>27.73</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8/29</td>
<td>24.23</td>
<td>30.49</td>
<td>26.77</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Excellent, deep brood to 10 inches</td>
<td>6/27</td>
<td>22.09</td>
<td>23.62</td>
<td>21.30</td>
<td>23.69</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7/24</td>
<td>27.46</td>
<td>30.85</td>
<td>26.44</td>
<td>29.69</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8/15</td>
<td>25.39</td>
<td>32.62</td>
<td>32.69</td>
<td>33.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8/29</td>
<td>20.24</td>
<td>25.80</td>
<td>31.81</td>
<td>32.64</td>
</tr>
<tr>
<td>3</td>
<td>Excellent, shallow brood to 6 inches</td>
<td>7/1</td>
<td>7.83</td>
<td>10.27</td>
<td>11.29</td>
<td>12.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8/1</td>
<td>7.48</td>
<td>10.26</td>
<td>11.09</td>
<td>12.31</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8/29</td>
<td>6.18</td>
<td>8.63</td>
<td>10.13</td>
<td>11.20</td>
</tr>
<tr>
<td>4</td>
<td>Excellent, deep brood to 10 inches</td>
<td>7/1</td>
<td>16.66</td>
<td>18.70</td>
<td>33.69</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7/29</td>
<td>14.81</td>
<td>16.31</td>
<td>31.62</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8/29</td>
<td>13.20</td>
<td>18.45</td>
<td>27.10</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Excellent, deep brood to 12 inches</td>
<td>8/1</td>
<td>8.16</td>
<td>10.53</td>
<td>12.25</td>
<td>11.96</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8/29</td>
<td>7.18</td>
<td>10.44</td>
<td>12.77</td>
<td>12.69</td>
</tr>
<tr>
<td>6</td>
<td>Fair to good, shallow brood with drying surface in midsummer</td>
<td>6/17</td>
<td>13.93</td>
<td>15.16</td>
<td>14.63</td>
<td>18.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6/27</td>
<td>13.08</td>
<td>13.67</td>
<td>15.32</td>
<td>17.72</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7/24</td>
<td>9.96</td>
<td>19.95</td>
<td>13.76</td>
<td>16.41</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8/15</td>
<td>9.90</td>
<td>13.48</td>
<td>12.99</td>
<td>15.38</td>
</tr>
<tr>
<td>7</td>
<td>Poor, shallow brood, abandoned in early summer due to surface flocculation</td>
<td>6/27</td>
<td>19.83</td>
<td>24.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7/7</td>
<td>11.09</td>
<td>16.44</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8/7</td>
<td>8.41</td>
<td>14.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8/29</td>
<td>7.96</td>
<td>9.95</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
with a difference in texture between the beds. Although all beds had a low percentage of clay-size particles by method B, the actual amount of clay was quite different when measured by method C. Beds with higher moisture percentages had a much higher actual clay content but the clay was aggregated into larger secondary particles. Moisture in all excellent beds was at a low tension and near saturation, but the soil with the higher clay percentage merely held more water at these tensions, since water was held within aggregates as well as between aggregates. The end result and critical demand, that of a moist compact surface, was met in each of the above situations.

Moisture content of soil in poorer beds (6 and 7, Table 3) is equal to or greater than moisture found in two of the excellent beds (3 and 5) yet the bees abandoned both former sites by midseason. The 8% and 9% moisture levels recorded from the critical top 6 inches of beds 6 and 7 is insufficient to maintain compact soil surface and humid atmosphere in the proximity of the cells in these high clay soils. Conversely, the 7% and 8% moisture levels in sandy, unaggregated soils of beds 3 and 5 maintained suitable conditions for excellent bee activity. Soil aggregate analyses for beds 3, 6, and 7 of Table 3 are cited as beds 5, 11, and 13 respectively in Table 1. Moisture content of the highly aggregated soils recorded as beds 1 and 3 in Table 2 are cited as beds 1 and 2 respectively in Table 3.

Samplings of several beds for the source of the subirrigation water revealed, as expected, that there was no constant level at which moisture fed the bee beds. In bed 2 of Table 3, samples taken from 48 inches deep indicated that we had not yet reached a water table. In various other beds the source of moisture apparently was a perched water table above a hardpan. In bed 4 of Table 3, the hardpan fluctuated in depth from 20 inches to 6 inches and evidently the lateral movement of soil water followed the surface level of this hardpan very closely. Samples taken from below the hardpan indicated a very sharp reduction in amount of soil moisture.

In no instance did bees penetrate the hardpan. In certain areas where the undulating hardpan varied from 6 to 20 inches, depth of the nests fluctuated accordingly and larvae were found from 3 to 5 inches in shallow hardpan areas to 8 to 10 inches where the hardpan deepened. Apparently the high moisture immediately at the hardpan was a repellent to bee activity.

**Discussion**

On the basis of the particle size analysis with the removal of organic matter conducted in 1957, (Stephen 1959), it was concluded that nesting sites or potential nesting sites having less than 8% clay-
size particles would be suitable for bee habitation assuming an adequate level of moisture was maintained. However, data on texture gleaned from studies in 1958 and 1959 indicated that measurements of soil texture taken by this method were more measurements of aggregation of soil particles than an actual measurement of sand, silt, and clay.

From the 1958 and 1959 analyses it is obvious that organic matter, and particularly the amount of soluble salts, exert a tremendous influence on aggregation of the soil particles. As aggregation increases in a high clay soil, the number of particles acting physically as clay particles decreases, thus increasing rate of movement of moisture by capillarity. The measure of aggregation of a particular soil is perhaps more significant in determining acceptability of a nesting site than is a measure of the actual soil texture.

Consideration must also be given to the ratio of sand to silt to clay in any potential nesting site, for the purpose of the soil texture analysis is to determine water conducting and holding capacity. It can be appreciated that rate of water transportation through a soil having a high percentage of sand with a high percentage of clay-size particles (greater than those cited in Table 1) may be equivalent to the rate of water transportation through a soil having a low percentage of clay and a high percentage of small silt-size particles.

Thus, establishment of specific limits of sand, silt, and clay for optimal bee nesting activity is arbitrary and the composite of soil particle sizes must be considered in relation to its aggregation and to amount and location of the subsurface moisture source. Nevertheless, there are specific limits in the ultimate aggregation of the soil of the potential bee nesting site which must be reached and maintained. These optima appear to be closely linked to the percentage of clay-size aggregates or particles. Under natural conditions, any soil which is continually exposed to subirrigation by volumes of salty water will evolve to and beyond a condition deemed ideal for alkali bee utilization.

The problem then becomes one of arresting the change in the soil structure-soil moisture-soluble salt complex at a point where it can be used by the alkali bee for prolonged periods. Soil texture and structure will determine only the rate at which subsurface moisture is capable of moving. In other words, an adequate or abundant supply of subsurface moisture is of little significance if it is not able to move toward the surface at a rate which equals or exceeds the rate of evaporation from the soil surface. Conversely, even the most optimal soil structure is of little practical value if there is not an adequate subsoil moisture supply.

Rate of water replacement from the subsurface source is also
influenced by the depth at which subirrigating water is found. Several beds having a clay-size particle content of 8% to 10% have maintained an adequate surface moisture supply throughout the season while others with same clay content have had surface drying and flocculation by midsummer. In the former, the bed was being fed by an abundance of water above a shallow hardpan, while in the latter, the water had to rise over 24 inches to reach the surface. Thus, depth of water supply in the higher clay-size particle content bee beds can determine whether soils, marginal in clay content, may be utilized as efficient nesting sites.

A number of beds which were considered either fair or poor nesting sites were shown, upon analyses, to have an adequate and sometimes near-ideal soil texture for potential bee inhabitation. The restricting factor here appeared to be presence or absence of adequate subsurface moisture during warmer, more critical times of the season. These beds were classified fair to poor not on basis of soil texture, but rather because of insufficient moisture.

Although danger of excessive water is not as common as an insufficiency, it has been observed to be equally repelling to bee activity. Saturation of a nesting site during periods in which bees are not active has been noted to increase incidence of bacterial and fungal disease losses in larvae and overwintering prepupae. In two beds, excessive subsurface water had seeped into cells and prepupae were destroyed.

Adult alkali bees can tolerate but a very light amount of surface moisture during flight season, and heavy rainfall, flooding, or prolonged sprinkling of bee beds has had disastrous effects. A late evening rainfall of three-quarters of an inch during the spring of 1958 caused the death of every emergent bee in one of the observation plots. Accidental surface flooding eliminated the entire adult population from two nesting sites in 1958, and prolonged sprinkling on other sites has had similar effects.

Once adult activity ceases, burrows are rapidly sealed by wind and late rains. High salt concentration at the soil surface effectively seals the nesting site against water penetration, and heavy winter rains or even periodic flooding has little effect on overwintering prepupae. Tightness of the surface seal of each bed is related to amount and kinds of salt present as well as to structure of the soil. Those soils higher in silt and clay-size particles effect a much tighter deflocculated surface than those beds in which there is a greater proportion of sand; thus, under these conditions the latter is less desirable.

Conditions for nesting were simulated under greenhouse conditions in which soil texture of four small artificial nesting sites were all below 5% in total clay content. One of these sites was composed
of soil taken from an excellent existing bee bed while the others were composed of soil prepared for this specific purpose. Soluble salts were added to two prepared beds while the third was maintained free of salts. Moisture was added to each bed and so long as a compact and moist surface was maintained the bees readily accepted any of these experimental sites. Loss of moisture was extremely rapid in the salt-free bed and those with low salt concentrations. This would indicate that selection of a site by the alkali bee is perhaps most strongly influenced by the type of soil surface existing when nesting is initiated.

Optimum soil condition is one permitting rapid transport of subsurface moisture through the top 12 inches of soil, maintaining a moist and compact surface. Soil moisture is undoubtedly the most critical factor governing suitability of any site for bee inhabitation, while soil texture, the medium through which moisture must move, governs its rate of transportation. Since rate of moisture transportation is a function of soil texture, the two factors cannot be considered independently in evaluating existing or potential alkali bee nesting sites.

Since aggregation of soil particles rather than actual texture most strongly influences the physical nature of soil, use of this method of analysis is given precedence over the others cited above. Generally, soils having less than 8% of aggregated clay-size particles are suitable for establishment and maintenance of alkali bees.

References

II. Preliminary Investigations on the Effect Of Soluble Salts on Alkali Bee Nesting Sites

Introduction

Effectiveness of the alkali bee as an alfalfa pollinator is unequalled by any other bee in the area in which these studies were made. Their habits of nesting gregariously in sharply delineated sites having soils with moist, alkaline characteristics suggests that modification of soil conditions through management may be possible.

Since 1955 it has been observed that sites with stable bee populations have rather uniform compact and moist surfaces due to adequate subsurface moisture, and are composed of soils with a texture conducive to the rapid capillary rise of subsurface moisture from varying depths (Part I). Generally, the expansion of a given nesting site or its abandonment is primarily attributable to changes in flow or in source of soil water.

The name “alkali bee” implies that alkaline soils are preferred as nesting sites; yet in a series of greenhouse experiments it has been demonstrated that newly emergent bees will select any site displaying a moist, compact surface, whether alkaline or nonalkaline. Under field or greenhouse conditions the site is abandoned once the moisture level in upper reaches of soil falls below certain minimal standards, or more precisely, once flocculation or fluffiness of the surface proceeds to a point where there is continued drainage of fluff into the burrow.

Natural alkali bee nesting sites are found exclusively in soils of varying degrees of alkalinity, maintaining high populations for long periods of time where soil surface is dispersed or deflocculated. Although soils with high soluble salts having a compact, deflocculated surface are commonly referred to as “black-alkali” soils, such terminology is not necessarily accurate. Alkali bees will seldom frequent the soft, flocculated or encrusted surface of soils showing a “white-alkali” condition, even though both conditions have been created by high subsoil moisture. It becomes apparent that high-soluble salt concentrations at the surface are merely secondary expressions of suitable moisture conditions in the soil, and that flocculated or deflocculated surface is the property of the kind and ratio of cations carried up through the soil by capillarity.

As mentioned in Part I of this bulletin, soluble salts exert a marked effect on soil aggregation. Soils having over 20% clay-size particles were aggregated by the salt to give those soils capillary properties expressed by soils having less than 7% clay-size particles. This ability of salt to aggregate otherwise unsuitable soils so that
rapid capillary water rise is possible presents the possibility of re-
claiming many soils for suitable alkali bee domiciles. Effect of salt
on soil aggregation, plus the obvious fact that good or excellent bee
nesting sites have never been located on nonsaline soils in nature, has
prompted this investigation on the role of salts on alkali bee nesting
sites.

Methods

Eighty-nine beds were sampled in Oregon, Washington, Idaho,
Utah, and Nevada during 1957, 1958, and 1959. Classification of
these beds and methods used in sampling are outlined in Part I of this
bulletin.

Chemical analysis

Portions of each sample were taken for soil texture, soil moisture,
and chemical analyses. Soil moisture and texture data were reported
in Part I. Chemical analyses for the following constituents were con-
ducted by the Soil Testing Laboratory at Oregon State College: pH;
exchangeable potassium, calcium, magnesium, and sodium (ammon-
ium acetate extractable sodium minus saturated extract of sodium);
cation exchange capacity; conductivity in millimhos/cm. (total salts);
and an estimate of chloride, sulphate, and carbonate concentration.

The top 6 inches of the soil profile in each of the beds were con-
sidered to be the most critical for bee acceptance, and of this section
of the profile the surface inch or two is most important.

Methods used for chemical determination are those cited by

Effect of salts on soil aggregation and water conductivity

In a preceding paper, notation was made of the effect of soluble
salts on aggregation of various soil particles. It was apparent from
the texture analysis that an abundance of soluble salts resulted in the
aggregation of the majority of the clay-size and smaller silt-size
particles so that their activity in effecting capillary rise of subsoil
moisture was presumably that of larger silt-size particles. Preliminary
field and laboratory tests were conducted to determine effect of soluble
salts in their aggregating ability on various soils and effect of these
cations on rate of capillary water rise. This was accomplished by
leaching out soluble salts from the sample and subsequently per-
mitting the leached extract to rise through the salt-free soil by capil-
arity.

In this particular case the soil sample used was that from an
existing alkali bee bed in which texture and salt had been prede-
determined. Hydrometer analysis on this sample with and without removal of salts was reported in a previous paper (No. 3, Table 2, Stephen and Evans 1960). Through subirrigation of the salt-free sample and the subsequent hydrometer analysis of this sample when completed, it was possible to determine the aggregating effect of the solution.

Several 50- x 30-foot artificial alkali bee beds, details of which will be reported in a subsequent paper, were constructed to determine effect of the sodium on rate of capillary water rise when mixed with soils to depths of 24, 18, and 12 inches. All four beds were excavated to a depth of 30 inches and were backfilled with soil containing 6.3% clay-size particles on aggregate analysis. The soil had a high water permeability, contained less than 1,000 ppm of total salts, and it was thus assumed that the degree of soil particle aggregation was minimal. Any change in rate of capillarity could be attributed to the effect of the added sodium.

In bed 1, 1,500 pounds of No. 5 Hay and Stock Salt was intermixed with the upper 24 inches of the backfilled soil; in bed 2, 1,800 pounds of salt was intermixed with the top 18 inches of backfilled soil; in bed 3, 2,000 pounds was added to the upper 12 inches; and in bed 4, 1,800 pounds was added to the surface and rotovated in to a depth of 4 inches. Known quantities of water were added to the gravel underlying the backfilled soil at a depth of 30 inches, and since the surface beneath the gravel was effectively sealed, water rose through the salt-treated plots. Rate of water rise was recorded by auger sampling, but particular interest focused upon appearance and maintenance of high moisture conditions in the upper inch of soil surface.

Influence of salts on soil structure at the surface

All of the excellent natural bee sites examined during the last five years have been found to have a compact, deflocculated soil surface which retains a uniformly high moisture level throughout the active bee season. Conversely, in sites where bee activity is moderate to poor, soil surface is invariably flocculated and dry, even though a good supply of moisture is available at 2 inches.

Relying on the accepted soil concept that a high sodium concentration in a soil will result in a deflocculated or dispersed soil condition and that a high calcium or magnesium salt concentration will result in a flocculated state, several small plots were established to determine whether these highly flocculated white-alkali conditions could be renovated for alkali bee inhabitation. In these tests, four duplicated plots were set up in a highly flocculated white-alkali area, in which $\frac{1}{2}$, 1, 2, and 4 pounds of sodium chloride per square foot were rotovated in to a depth of 4 inches. Surface of the rotovated
areas was repacked by driving over the plots with a pickup truck, and the surface was examined weekly during the season.

In each analysis, an attempt was made to determine whether a relational balance existed between flocculum inducing divalent cations and deflocculating or dispersing monovalent cations in ultimate formation of a compact, water retaining soil surface which would be acceptable for prolonged alkali bee inhabitation.

Results and Discussion

Chemical analysis

Chemical analyses on four soil samples are cited in Table 1. These represent a small fraction of chemical analyses run on various soils from alkali bee beds throughout the Pacific Northwest during the past three years, but serve to indicate approximate range of cation concentration in the soils.

From the rather voluminous data, the following generalizations can be made on soil chemistry of excellent bee-nesting sites. Surprisingly, the pH of all soil samples was near neutral in spite of the very high total salt concentration. In none of the better beds was a pH higher than 7.8 recorded. The pH of the soils, although very high in salts, is near neutrality because of prevalence of sodium, potassium, calcium, and magnesium in the form of neutral salts. In other words, shortage of carbonates and bicarbonates is a primary reason for absence of high pH readings. Neutral salts, such as sodium chloride, calcium sulphate, and calcium chloride form the predominating soluble salts in all soils analyzed.

Analyses were conducted only for potassium and sodium among the monovalent cations, since it was felt that these two cations represented the vast majority of normal monovalent soil cations. In all samples concentration of potassium was exceedingly low, with the bulk of the monovalent cations represented by sodium. In analyses of the divalent cations, calcium was invariably present in excess of magnesium. However, as cited in sample 2, Table 1, there were certain beds in which magnesium made up the greater part of the divalent cation concentration.

Analyses were made on ammonium acetate extractable sodium and on a 1:1 water extract of sodium to compute the exchangeable sodium in each soil sample. It was thought that under soil conditions prevalent in alkali bee beds the 1:1 sodium extract, or even the ammonium acetate extractable sodium, would be a more accurate indication of the amount of immediately available sodium for ionic interchange than would exchangeable sodium. Sodium saturation percentage is cited for all samples even though the two samples listed in
Table 2 are obviously erroneous. On the basis of a number of samples, the methods of analyses developed for conventional soils apparently do not always yield the accuracy necessary for highly saline soils. For example, the two samples in Table 2 yield a calculated sodium saturation percentage of 203% and 908%, whereas a 100% maximum would represent the absolute upper limit. Also in sample 2, Table 1, the rather high sodium concentration has interfered with the accuracy of the magnesium determination, and it is strongly suspected that the high sodium as well as the magnesium concentration in this sample interferes with or prevents an accurate determination of each of the other cations under investigation.

The conductivity measurements in millimhos/cm. is the basis for computation of total salts in parts per million. This measurement is considered to be a more accurate indication of total salts in ppm than that achieved through summation of each of the individual cation and anion concentrations. Where analytical data are contradictory, conductivity measurements are given precedence.

Measurement of the anions chloride, sulphate, and carbonate are cited semiquantitatively. It was originally suspected that chloride and sulphate concentration would be high in those bee beds having a high degree of cation or salt solubility. However, upon analysis, there was no direct correlation between any specific anion, or anion radical, and the apparent solubility of salt in the soil. This does not imply that calcium in the form of calcium carbonate is as readily soluble as calcium chloride. However, it does indicate that there is probably a sufficient diversity of anions or anion radicals in each of the soils so that the degree of solubility necessary for the deflocculate or disperse surface can be effected through cation interchange.

Sodium in the upper few inches of soil was high in relation to the divalent cation concentration in all beds classified as good or excellent. Computations were made on 25 different beds, and for the most part, the ratio of divalent to monovalent cations, in parts per million, approximated 1 to 1.5. However, there are several exceptions in which the ratio went as high as 2 and 2.6. There is no method of ascertaining whether these specific instances are a result of an actual high ratio of the divalent to the monovalent cations, or whether the methodology used in analysis has prompted errors in computation.

In perusal of analytical data collected for scores of samples over the past three years, it is immediately apparent that discrepancies exist between data procured and some of the tenets held in soil physics. The vast majority of observations and data recorded in this bulletin are taken from field observations and field tests. Unfortunately, only a few of these observations have been repeated under strictly controlled laboratory conditions. In the field it has been pos-


### Table 1. Chemical Analysis on Soils from Four Excellent Alkali Bee Nesting Sites

<table>
<thead>
<tr>
<th>Plot no.</th>
<th>Depth</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>NH₄ Ac Ext. Na</th>
<th>Sat. Exr. Na</th>
<th>Ex. Na</th>
<th>CEC</th>
<th>Na sat. percent</th>
<th>Conductivity mmhos/cm</th>
<th>Total salts ppm</th>
<th>pH</th>
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<td>66.8</td>
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<td>32.4</td>
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<td>7.02</td>
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<td>70.0</td>
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<td>35.31</td>
<td>18.93</td>
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<td>48,000</td>
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<td>3.86</td>
<td>9.2</td>
<td>29.8</td>
<td>22.6</td>
<td>14.10</td>
<td>8.50</td>
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<td>5,860</td>
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### Table 2. Chemical Analysis of a Dense Soil Flocculum in a Prerenovated State

<table>
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<tr>
<th>Plot no.</th>
<th>pH</th>
<th>NH₄Ac Ext. Na</th>
<th>Sat. Exr. Na</th>
<th>Ex. Na</th>
<th>CEC</th>
<th>Na sat. percent</th>
<th>CO₃²⁻ me/100 g</th>
<th>Cl⁻</th>
<th>SO₄²⁻</th>
<th>Conductivity mmhos/cm</th>
<th>Total salts ppm</th>
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<td>8.5</td>
<td>258.13</td>
<td>223.91</td>
<td>34.24</td>
<td>16.84</td>
<td>203.3</td>
<td>264</td>
<td>v. high</td>
<td>v. high</td>
<td>434.0</td>
<td>277,700</td>
</tr>
<tr>
<td>2</td>
<td>8.7</td>
<td>421.73</td>
<td>280.43</td>
<td>141.30</td>
<td>15.06</td>
<td>938.2</td>
<td>124</td>
<td>less than above</td>
<td>less than above</td>
<td>315.0</td>
<td>201,600</td>
</tr>
</tbody>
</table>
sible to duplicate soil nesting plots that are readily accepted by alkali bees and have been used by bees for the past three years. Two prime conditions for bee acceptance apparently have been met in each of these modified bee nesting sites. These are an adequate supply of soil moisture capable of rising to the soil surface and a deflocculated or relatively dispersed soil surface which remains compact throughout the period of bee activity.

There are still a number of very pertinent questions which remain unanswered, and a number of points on which our observations and conclusions differ from alkali soil characterizations as held by soil scientists.

In “Diagnosis and Improvement of Saline and Alkali Soils” (Richards 1954) saline-alkali soils are characterized as having a conductivity of the saturation extract greater than 4.0 mmhos/cm., and an exchangeable sodium percentage of over 15. These soils are usually recognized by the presence of white salt crusts on the surface. Nonsaline-alkali soils, on the other hand, have an exchangeable sodium percentage greater than 15, but conductivity of the saturation extract is less than 4 mmhos/cm. These soils are often referred to as “black alkali” or “slick spots,” and generally have a dispersed surface with a pH above 8.

It is apparent that soils with which we are dealing are in fact a composite of characteristics of each of the saline- and nonsaline-alkali soils. They are typical of saline-alkaline soils in that conductivity is always well above 4.0 mmhos/cm., exchangeable sodium percentage is greater than 15, and pH is near neutrality. Yet, their appearance is typical of nonsaline alkali soils in that they are dispersed or deflocculated at the surface (i.e. “slick-spots”) and, depending upon the organic matter content, are often black. The surface is, for all practical purposes, impermeable to water penetration and can be made increasingly so by the addition of sodium.

Further, it is generally considered that if the clay-size particle percentage of a soil changes only slightly when the salts are removed, the soil is considered to be deflocculated. If, on the other hand, the clay-size particle percentage undergoes a great change upon removal of salt, it is considered flocculated. Precisely opposite conditions have been found to exist in each of the soils taken from established alkali bee nesting sites. The upper 4 inches of each established nesting site is invariably deflocculated, and removal of the salts has resulted in a marked change in the calculated clay-size particle percentage.

Preliminary observations and estimations also indicate that the opinion that salts in themselves do not give a water binding capacity to soil appears to be in error.

Certain analyses support and supplement existing data which
would account for the favorable results achieved in construction and modification of alkali bee nesting sites. While these do not supply answers as to why chemical changes occur under certain manipulations, they indicate that certain effects of salts can be anticipated with soils of varying textures.

Manipulation of the soil through selection of a particular soil texture and addition of one or more soluble salts has permitted us to proceed with modification and construction of acceptable alkali bee beds. These particular sites conform with long established natural bee nesting areas in that they permit a rapid capillary rise of moisture through the flocculated soil from the water table to the increasingly dispersed upper few inches; they maintain a compact, deflocculated or dispersed surface which will permit alkali bees to burrow freely; and apparently, the dispersed surface exhibits a strong moisture retention capacity over that of nonmanipulated or nonsodium treated soils.

**Effect of salts on soil aggregation and water conductivity**

As indicated in Part I, removal of soluble salts from many soils classified as excellent bee nesting sites yielded unusually high clay-size particle percentages. Under laboratory conditions it was possible to leach salts from a soil sample taken from an excellent bee nesting site and "subirrigate" the desalted sample with a solution containing salts in the same proportion as that removed from it.

Once the subirrigated solution had reached the surface of these soils, and texture analysis had been repeated, they were found to have undergone considerable aggregation. Aggregate clay-size particle content fell from 28.8% in the desalted sample to 8.2% in salt permeated state, which is still slightly above the 5.04% aggregated clay-size particle content in its native condition (see Table 2, No. 3, Part I). The logical assumption is that divalent cations bind clay-size and smaller silt-size platelets into larger sized aggregates. Thus, each of these aggregated clay and silt particles responds as a large silt-size particle to yield a more rapid rate of capillary rise, maintaining a steady supply of moisture to the soil surface.

Investigations of effect of high sodium on rate of capillarity in the artificial bee beds yielded data that strongly supported the above flocculating tendency of the divalent cations. The rate of water rise in four beds having sodium chloride added to varying depths of the backfilled soil was inversely proportional to amount (and depth) of sodium added. In bed 1, with salt intermixed into the upper 24 inches of the backfilled soil, rate of capillarity was exceedingly slow. At the end of the first month following application of the subsurface moisture, there was no appreciable increase in moisture content of soil at
the 12-inch level. Ninety days after water application, over half the surface was dry and not accepted by searching alkali bees.

Bed 4, with salt rotovated to a depth of 4 inches, achieved a uniformly moist (13%) and compact surface by the end of the first week and was quickly accepted by bees. In bed 3, with salt added to the upper 12 inches, the rate of water rise was slower than in bed 4, but considerably more rapid than in bed 1. However, even after three weeks, there were still patches of the surface of this bed remaining dry and hard. This patchiness probably is attributable to an unequal distribution of salt at time of application.

A striking condition appeared in bed 2, in which 1,800 pounds of salt were added to upper 18 inches of backfilled soil. Rate of capillary water rise in this bed approximated that of bed 4, and the surface quickly assumed a condition optimal for bee activity. Upon chemical analysis of samples from the 6-, 12-, 18-, and 24-inch level, it was found that an unusually high amount of calcium was present among the soluble salts. Further checking revealed that gravel for this bed was taken from a pit with a high level of calcium sulphate. Addition of water to this gravel apparently had dissolved sufficient quantities of the calcium to counter-balance the dispersing effect of the sodium. The calcium is believed to have exerted an aggregating effect on the clay-size and small silt-size particles at lower levels of the bed and permitted a water rise through the soil sufficiently rapid to overcome rate of evaporation from the soil surface. An additional application of water to all beds 10 days after the first supports this assumption, for it apparently dissolved additional calcium sulphate and transported it only 6 inches above the gravel layer. Concentration of calcium in m-equiv/100 gms. is cited in Table 1, No. 4, for the various depths in this bed.

It would appear from conditions in these artificial beds that sodium had the effect of dispersing clays in the lower reaches, or in those areas in which it was prevalent. This dispersing effect restricted the rate of capillary water rise through the soils, with the result that surface evaporation proceeded at a rate in excess of water replacement from the subsurface water source. In all of these beds, surface sodium concentration was sufficiently high to disperse or deflocculate these soils, and the sealing effect prohibited loss of water through evaporation.

This aggregating tendency of the divalent cations and its subsequent effect on rate of water passage is a condition that must be met in reaches of the bed 2 or 3 inches below the surface. But this condition is undesirable at the soil surface where an excess of the divalent cations will result in soil flocculation and a more rapid water loss. Thus, a sealing effect must be achieved at the soil surface.
Under natural conditions this results from an excessive sodium deposition in the upper levels which produces a deflocculated or dispersed surface with a high water retention capacity. It would be possible, although relatively impractical, to reclaim a high clay soil (a clay over 25%) by addition and intermixing of vast amounts of a divalent soluble salt such as calcium chloride to the soil above the water table. This calcium would eventually effect a capillary water movement through the soil which would meet moisture requirements at the surface of a typical alkali bee nesting site. This, in association with a compensating application of sodium chloride to the bed surface to insure soil dispersion, could conceivably result in conditions favorable for establishment of alkali bees.

Concentration of salts in all natural alkali bee nesting sites is invariably much greater at the soil surface than at lower depths. This concentration results from continual capillary rise of water soluble salts from the water table through capillary action with the resulting deposit of salts at or near soil surface. Concentration of salts in the upper level, and continual decline in their concentration at the 4-, 6-, 8-, and 10-inch levels exerts a possible complementary action to rate of rise of subsurface moisture through creation of an osmotic differential between the solution at the soil surface, and that in the water table itself.

**Influence of salts on soil structure at surface**

Using these data on the deflocculating effect on the monovalent cations and the flocculating effect on the divalent cations, attempts to renovate natural and artificial bee nesting sites proved highly successful. The addition of ½, 1, 2, and 4 pounds of sodium chloride to the surface of eight different plots which were moderately to very highly flocculated resulted, upon compaction, in a deflocculated soil surface readily accepted by alkali bees.

There was no apparent difference in the amount of deflocculation among the different rates of sodium chloride application. However, these observations were made during a single season, and it is anticipated that continual flow of the soluble divalent cations from the subsoil water table to the surface will continually dilute the sodium and result in a gradual return of the flocculated white alkali condition during the next season. It is suspected that plots with lower rates of added sodium will be those which will undergo earliest reversion to the flocculated condition. Inadvertent packing of flocculated soil surface immediately about plots to which sodium was added resulted in an immediate compact surface. However, those areas lacking sodium chloride reverted to the rather deep, white flocculum of surrounding areas within a week.
Preliminary chemical analysis made on one of the latter areas is cited in Table 2, and although sodium concentration is high in parts per million, it is apparently not sufficiently high in relation to the amount of other salts present, particularly the flocculating divalent cations. Addition of 1 pound of sodium chloride per square foot to the upper 4 inches of soil increased total sodium and chlorine content by approximately 40,000 ppm of which half would be sodium. The 4-pound rate resulted in an increase of 80,000 ppm of sodium, and 80,000 ppm of chlorine.

It is conceivable that addition of salt resulted in an ionic interchange with carbonate or bicarbonate forms of the divalent cations, thus lowering the pH and causing them to return to solution. This is based on the accepted premise that "at high pH readings and in the presence of carbonate ions, calcium and magnesium are precipitated" (Richards 1954). Excessive sodium exerted additional dispersing effect on the soil to account for the temporary modification into a "slick spot" which was accepted by the adult bee.

Some relational balance must exist between the monovalent and divalent cations above which flocculation will proceed, and below which deflocculation or dispersion can be affected. In all analyses made, we have been unable to determine precisely what this relational balance might be. Comparisons of the divalent to the monovalent cations in parts per million or millequivalents per hundred grams has failed to yield any consistent static ratio which might prove to be an operating basis for determining quantities of sodium necessary to change a given soil from a flocculated to a deflocculated state. It is highly probable that various other factors influence such a relational balance.

Although we have not succeeded in determining what relational balance must exist between the monovalent and the divalent cations to result in a deflocculated soil surface, it has been established that flocculated conditions can be corrected through addition of excess sodium in the form of sodium chloride. Indications from the computation of the divalent and monovalent cations in parts per million give a tentative indication that a one to one balance invariably results in a near optimal working soil surface. It must be understood that this is a tentative conclusion, and that a multitude of factors other than the simple cation relational balance play some part in determining the degree of dispersion of any given soil. Among these, consideration must be given to the anion or anion radicals, amount of unaggregated clay, and type of clay, as well as prevalence and degree of decay of existing organic matter.

Granting the inconclusiveness of much of the chemical analyses conducted on these alkaline soils, sufficient pertinent data have been
accumulated to strengthen the validity of "reclamation" procedures used under field conditions. While salt in itself is not essential to the alkali bee or to soils in which the alkali bee will nest, it appears to give most soils an equilibrating tendency that minimizes texture and moisture fluctuations about an optimal mean. Without prevalence of soluble salts, soil texture as well as position of the existing water table would, of necessity, have to be so critical that suitable nesting sites would be extremely rare.

In three artificial beds constructed during 1958 there was no sodium added to backfilled soil. In these particular beds having an aggregated clay-size particle content of 3.15%, it was necessary to subirrigate the beds daily in order to maintain a sufficiently moist, compact surface for bee inhabitation. During winter of 1958 and spring of 1959, one of these beds was subirrigated with the equivalent of 1 pound of salt per square foot. Equivalent amounts of water were added to the other two beds which lacked the salt. In 1959, the two saltless beds required daily or minimal tri-weekly subirrigation with water to maintain the soil surface of the bed in an optimal condition. The bed to which salt had been added required little or no water after the early season subirrigation. This indicates that salts, in this case sodium, have an effect on water retention capacity of soil, either in a hygroscopic or in a binding capacity.

Data on soil texture and moisture (Part I) as well as data gleaned from these preliminary soil chemical analyses, will permit further investigation into the ecology of the alkali bee, as well as its propagation in modified, currently unoccupied nesting sites. Many problems of soil chemistry and soil physics remain, and their solution will undoubtedly permit a more critical determination of salt requirements for optimal soil conditions in alkali bee domiciles.

References

III. Management and Renovation of Native Soils for Alkali Bee Inhabitation

Introduction

Previous studies have indicated that specific soil conditions must be met before a site is effectively utilized by the alkali bee. Of particular significance is the presence of an adequate moisture level from the surface to a depth of at least six inches, in association with a soil having less than 7% aggregated clay-sized particles. (Part I, this bulletin.)

In Part II, this bulletin, it was concluded that certain relational balances must exist between and among the cations to result in precisely optimal conditions for maximum bee utility. These include a flocculated soil condition in the lower reaches of the soil to foster capillary action, which is in turn counterbalanced by an excess of the dispersing monovalent cations at the soil surface. These conditions are a transitory stage in development of a soil that will undergo drastic change upon removal of the water source, or upon a change in the ratio of soluble salts being carried in the water table. The primary problem in maintaining optimal soil conditions is, in reality, a problem in arresting the evolution of soil in this prescribed state.

All excellent bee nesting sites examined in the Pacific Northwest and Nevada appear to have the above cited features in common. Margins of nesting areas may be sharply delineated from adjacent soils or may blend imperceptibly into nearby areas, with the concentration of active burrows diminishing rapidly at the periphery. It is apparent that one or more of the desirable soil characteristics is missing from those areas not occupied by bees. These may include: a shortage of moisture at the soil surface, generally indicated by a dry powdery surface; an overabundance of flocculated or precipitated salts, forming a crust or flocculum at the surface, through which bees find it difficult to work; or an overgrowth of weeds or grass which repel bee activity in soils. Beds with a declining population are invariably characterized by gradual conversion of the soil surface from a dispersed black alkali to a highly flocculated saline-alkali. With this change the soil becomes more receptive to plant growth and the vegetative cover gradually increases in size and density, which in turn accelerates rate of water loss from the soil. The obvious indication of this condition is density of plant cover, principally the alkali weed, *Bassia hyssopifolia* and salt grass, *Distichlis*, in once heavily populated sites.

This section is a report on methods of soil maintenance in exist-
ing alkali bee beds, attempts to expand the bee into unoccupied areas through soil moisture manipulation and modification and effect of weed control on bee populations.

Methods

Eight different plots, ranging in size from 400 square feet to three acres were selected as areas for soil modification and renovation in 1957, 1958, and 1959. These plots represented a diversity of soil conditions in the area to which the alkali bee is endemic. They included: attempts at modification of submarginal soils immediately adjacent to large existing bee beds; a renovation of sites removed by some distance from established bee beds, in which it was thought a potential for alkali bee establishment existed; and an improvement of existing soil conditions so that density of the nesting population in the plot could be increased.

Throughout this paper the term “renovation” is used in contrast to “modification” to indicate the magnitude of soil modification necessary for bee acceptance. Renovation refers to the processes as they are applied to soils which appear to have a potential for bee inhabitation, but in which no nesting bees have been noted during the five years of the program. Modification is applied to soil manipulation in areas immediately adjacent to occupied nesting sites, in which bee encroachment and recession has been observed during the past five years, or to active nesting sites in which it was felt that nesting populations could be increased.

Necessary changes in the soils were accomplished by adding water through shallow ditches, and incorporation of dispersing salts into the upper few inches of soil surface.

Attempts were made to reclaim or improve several bee sites by removal and control of infringing alkali weed and salt grass. Trials on plant growth control were conducted on beds of sufficiently large size to permit plot randomization. Plots were delimited so they extended to the submarginal periphery of the beds, in order to determine whether further infringement could be arrested. As increase in plant cover in all of the better beds is preceded by an increase in amount of flocculation, an attempt was made to reverse this tendency by adding sodium. Effect of soil modification and weed control was determined by measuring increase or decrease in the reproductive and survival potential of the bee when compared with the field condition norm. Evaluation of population density has been simplified by recording the number of active female nesting burrows per square foot in better bee nesting sites or in the premodified conditions, and extrapolation against the number of burrows per square foot in experimental areas.
Since each plot represented a unique combination of soil texture, soil structure, and soil moisture, the specific methods employed differed from plot to plot and were largely determined by data secured from the previous year's studies. Thus, for clarity and continuity, the specific "methods and results" are reported chronologically.

**Soil Modification and Renovation**

**Methods and Results, 1957**

Three plots were selected in 1957. Plot I consisted of a small 25 foot by 20 foot area in which a nonanalytical examination of soils indicated by its texture that it held a potential for bee inhabitation. Surface was powder dry and there was no evidence of a water table in the upper three feet. The area was levelled and a 24-inch deep ditch dug the length of one side. The ditch was filled with water in an attempt to elevate the soil moisture in the surrounding area by lateral capillarity.

Plot II, 1957, was one-half acre in size, selected by the same method of nonanalytical soil comparison. Several shallow ditches, spaced 25 feet apart, were dug across the plot and water was permitted to flow continuously through them to raise the water table of intervening areas. Sodium chloride was introduced into the ditch water each week. It was anticipated that lateral and vertical water movement would carry the sodium chloride to the soil surface and yield the desired dispersed condition.

Plot III, 1957, consisted of 1.5 acres, and was immediately adjacent to a large existing alkali bee bed. The surface was weed covered and the upper two inches were powder dry. Weeds were scraped off and the area compacted by a wheeled vehicle. Ditches, 12 inches deep, were spaced 25 feet apart and water was permitted to stand continuously in these ditches throughout most of the spring and early summer.

1957 attempts to renovate and create conditions which would be adequate for nesting were successful only in Plot III. Soil texture was not known to be consequential at the time of initiation of these trials and soil analysis was made simply by cursory comparison. Subsequent analysis showed that soils of Plots I and II were composed of more than 15% clay-sized aggregates, which effectively restricted rate of water movement from the ditches into intervening areas. In Plot I the clay-sized aggregates were 15.1% and, even though the ditch was full of water throughout the season, lateral capillarity was evident only one foot on either side. A very narrow zone in this area of lateral water transport was acceptable for alkali bee activity and a few burrows were recorded from it. Result of trials in Plots
I and II indicated, because of high clay content, the eight inches immediately adjacent to the ditch were saturated beyond a point of bee acceptibility, while the two or three inches making up the extremes of water transport were not moist enough. This resulted in a very narrow band between eight and ten inches which could be, and was, utilized sparingly during the first year.

Sodium chloride was added to the ditch water in Plot II, 1957. On this one-half acre, water movement from the ditch was less extensive than in Plot I. Sodium in solution had a soil dispersing effect on the aggregates at lower levels of the bed. This dispersing effect retarded, rather than increased, the rate of lateral capillarity and restricted the distance of water movement.

Plot II, 1957, was the only successful attempt at renovation during the first year of the trials. This plot was located immediately adjacent to a large active nesting site. The ditches, constructed at 25 foot intervals, lay on a very gentle slope, and soil texture (4.8% aggregated clay-size particles) permitted a very rapid lateral capillary movement of the moisture from them (Figure 2). Further investigations revealed that the entire area, including the original large nesting site, lay on a shallow undulating hardpan that fluctuated from 6 to 16 inches below the surface. The ditch water, to a large extent, moved laterally over the hardpan and gave a uniform distribution of moisture through much of the intervening areas. Those areas within this plot which displayed sufficient surface moisture and in which the surface was sufficiently compact were readily occupied by overflow populations from the adjacent natural bed during the first year. Some of the renovated area became flocculated or dry later in the season and was not accepted by the bees or was abandoned when the soil reached this condition. During the peak of 1957 flight season, approximately 15% of the renovated area has a nesting population of 18-24 per square foot, 45% of the area had from 5 to 18 burrowing bees per square foot, and 40% was unoccupied. Population expansion continued in 1958, and by the end of the 1959 flight season 30% of the area had a nesting population of over 20 per square foot. Approximately 15% of the area was unoccupied.

Methods and Results, 1958

In 1958, three plots ranging in size from 400 square feet to three acres were selected for further trial. However, consistent with the newly available data on soil texture (Part I, this bulletin) only those soils having an aggregated clay content of less than 7% were considered suitable for renovation. Plot I, an acre in size, consisted of a long narrow strip of soil, having a rather uniform texture to the depth of five feet. Shallow ditches were dug along either
side of the 40 foot strip and these were filled every two weeks during the active bee season. As much of the surface between the ditches showed a tendency to light flocculation, two 20 foot square plots were covered with a pound of sodium chloride per square foot, and the surface of these plots compacted by a wheeled vehicle to assist in its solubility. Comparisons in the surface conditions of the salted and unsalted areas were made throughout the season. Plot II, 1958, 25 by 16 feet in size, was located on a gentle slope. The surface was scraped free of a light grass cover and a single ditch, 24 inches deep, was run along the upper edge. Sodium chloride at the rate of one-half pound per square foot was applied to the area below the ditch and salt was raked into the soil surface. Because of inaccessibility of the area, compaction by a wheeled vehicle was impossible. Water was permitted to stand in the ditch until the surface of the soil beneath it assumed a compact, dispersed appearance.

Plot III, 1958, over three acres adjacent to two small alkali bee beds, was burned clean of weeds by a butane burner. Sodium chloride at the rate of one-half and one-quarter pound per square foot was then scattered over the surface and the entire plot compacted with a wheeled vehicle. The higher rate of salt was applied to those areas showing some surface flocculation, and the lower rate to the nonsaline areas in which rapid water loss was evident. Additional water was permitted to stand in shallow ditches located about the periphery of the trials area.

Renovation trials conducted in 1958 were considered successful in that each site was accepted by numbers of bees and utilized throughout the season. This was attributed in part to the use of only
those soils having less than 7% clay-size particles. Rate of lateral and vertical capillarity increased as the proportion of clay-size particles decreased, thus much more effective water distribution was achieved from the ditching technique.

Plot I had a water table evident one and one-half inches below the surface, and biweekly addition of water to the ditches was sufficient to raise the water level of the intervening area to the surface. Probings in the area of renovation indicated that there was soil saturation three feet below the surface and that this level of saturation fluctuated with the addition of water. It appears as if there were a continual drainage from the area which prevented the water table from reaching the surface under normal conditions. This drainage was, therefore, overcompensated through additional water. The two sections of this plot treated with one pound of sodium chloride per square foot underwent very slight change in soil moisture content throughout the active bee season. Bee activity proceeded in these salt covered areas while flocculation and surface drying was prevalent in the adjacent untreated areas. The salt appeared to convey a stabilizing effect in rate of water rise and in the water retention of these soils. Nesting population averaged 9.2 burrows per square foot in salted areas, and 6.33 per square foot in unsalted at the peak of the 1958 flight season. A large area, outside of the plot to which water was added, had a nesting population of 12-18 bees per square foot in 1956. With a drop in the general water table in 1957, the bee population declined rapidly and by early 1958, the plot was abandoned.

In Plot II, 1958, the single ditch at the upper edge of the slope provided sufficient moisture to elevate the water table below it to a point at which it was readily accepted by the bees (Figure 3). The first inflight to this bed was noted in mid-June and by mid-July the burrowing population reached 5.8 per square foot. Application of salt to the surface of this bed arrested its flocculating tendencies, but the surface scattering lacked uniformity, for patches of the bed dried rapidly soon after water application.

Removal of the dense weed cover from Plot III, 1958, appeared to reduce the rate of water loss attributable to transpiration to an insignificant level. Reduction in water loss associated with surface application of salt resulted in maintenance of an optimal working surface over much of the area treated. Bees began expanding into the new area during 1958 and during mid-season a massive inflight of bees from adjacent sites spread over much of the renovated area. Bee population in the new area ranged from 0 to 22 burrows per square foot by the end of the season, and it was estimated that 35 to 40% of the renovated area had been occupied. In 1959 additional salt was added to problem areas showing some flocculation and most
of the bed was recompacted. Expansion from the existing population as well as the inflight from other nesting sites exploded during 1959, and by mid-season well over 80% of the renovated area contained over 15 nesting burrows per square foot (Figures 4a, 4b). This represented the most significant expansion of any nesting sites during the three years of trials. It is particularly impressive since the original population of bees was restricted to two small areas, each slightly over 25 feet square with neither having a population greater than 16 per square foot.

**Methods and Results, 1959**

Plot I, an acre in size, well removed from any established bee nesting site, was scraped free of weeds, and salt at the rate of ½, ⅓, and 2 pounds per surface square foot was applied to three portions of equivalent size. Salt was rotovated into the surface to a depth of 2 to 4 inches and the area compacted. The water table in this plot was approximately an inch below the surface and the surface tended to show a moderate degree of flocculation. Salt was applied to overcome precipitated flocculum on the soil surface and to retard rate of water loss through evaporation. Plot II, 1959, an acre and a half in size, was treated in a manner identical with that of Plot III, 1958, under somewhat similar soil conditions. Salt at the rate of ½ and 1 pound per square foot was rotovated into the upper two inches to determine effect of different salt rates on deflocculation at the surface. Fifteen transplant cores were moved into each plot.

All three areas in Plot I, 1959, assumed a compact deflocculated
surface during the first season, and there was no apparent difference in effect of the three different salt rates. Bees began to move into each of the three plots at random shortly after emergence began in the area. The burrowing populations ranged from 0 to 15 per square foot by midseason with no significant population difference in any of the plots. Apparently the lower rate of sodium chloride was sufficient to effect an adequate surface dispersion, changing the plot character from an unacceptable to an acceptable condition.

In Plot II, 1959, the renovated area assumed a compact, moist surface shortly after renovation. Moisture moved well over 100 feet from the ditches by lateral capillarity (Figures 5a, 5b). At first bees from the transplants nested in close proximity to the cores from which they emerged, but as the season progressed they began toexpand into the adjacent renovated areas. The plot was three miles from the nearest large bed, and as a result the new population was derived from those introduced bees, or from the meager population found in submarginal conditions nearby. Burrowing populations at the peak of the 1959 season ranged from 0 to 14 per square foot, the more dense populations found in close proximity to the transplanted cores.

Rotovation resulted in a more uniform distribution of salt in the upper few inches of soil, which in turn yielded better dispersion and soil water retention. Both 1959 plots contained less than 6.8% aggregated clay-sized particles, and because of thorough distribution of the salt it was necessary to apply supplementary ditch moisture only once during the season, prior to bee emergence. The surface moisture level was maintained in a condition suitable for bee occupancy and bees moved into both areas on emergence. No difference in soil surface appearance or bee acceptance was noted among the plots in which different rates of salt were applied. The erratic response in surface dispersion found in all 1958 plots was lacking in the 1959 beds, and this was attributed to the more effective sodium distribution through rotovation.

**Weed control**

A series of experiments were begun in 1958 to improve soil conditions of some existing bee nesting sites in which endemic populations were less than 10 burrowing females per square foot. Only established nesting sites which appeared to be becoming less populous were selected for modification.

Four methods of weed control were tried in 1958 and 1959. These included: (1) scraping the upper two inches of soil from the surface and repacking by a wheeled vehicle; (2) passing over the area twice at 10-day intervals with a field butane burner; (3) and
the application of the chemicals, 2, 4, 5 T at three pounds per acre, the soil sterilant, diuron at four pounds per acre, sodium chlorate at 300 pounds per acre, and sodium chloride at 3, 4, and 1 pound per square foot. In addition, salt at the rate of 3 pound per square foot was applied to the more flocculated areas immediately following scraping and burning. Effectiveness of weed control in the reclaimed areas was measured by the number of burrowing females per square foot in the treated as compared with the untreated areas in the same plot.

Trials conducted during the past three years on effect of vegetative cover on population density of burrowing bees have confirmed the need for its eradication.

Scraping the upper two inches of soil from the surface of the marginal areas proved successful only in those areas where soil was sufficiently dispersed and the water table sufficiently high to yield a surface adequate for bee acceptance. 1957 and 1958 trials, in which scraping was initiated on a flocculated soil surface with a dense plant cover, failed except in cases where the soil moisture condition and/or the degree of flocculation could be corrected. Observations made on the trial plots immediately following scraping indicated that the site often appeared suitable for bee occupancy. However, moisture loss from the surface was very rapid and flocculation usually began immediately. Scraping of the surface in one bed which showed a considerable amount of dispersion removed the major portion of the soluble salts. The result was detrimental to the site expansion because it resulted in exposure of a weakly saline surface to the flocculating tendencies of the high divalent cation concentration of the subsoil water table. This condition was rectified in 1959 by addition of 3 pound of sodium chlorite per square foot to the surface, and subsequent compaction.

It is possible that scraping of the soil surface in a marginal site may be desirable if the surface is a highly flocculated saline alkali. This would remove surplus divalent cations, and the amount of sodium chloride necessary to counterbalance the flocculating effect of the remaining cations would be minimal.

Butane burning of trial areas immediately prior to bee emergence proved successful in controlling plant cover during most of one alkali bee flight season. Occasional seeds germinated in mid or late summer but these were sufficiently late maturing so as not to impede general bee activity. Application of chemicals for weed control was conducted in plots having a good native bee population (10 to 15 burrows per square foot). Use of 2, 4, 5 T and diuron, resulted in effective weed control during the single flight season. However, because of high soil salinity and high moisture content, their effec-
ing females per square foot was recorded. Most significant increase in population density occurred in those sodium treated plots in which addition of sodium had resulted in a sharp increase in the dispersion of the soil surface. In one plot, which was unoccupied prior to treatment, the population rose from an absence of bees to a burrowing population of 23 females per square foot. All sodium treated plots were occupied to the same or greater extent during the following year, while the diuron and 2, 4, 5 T plots maintained partial Bassia cover (Figure 5b). Under the test conditions, the sodium application appeared to give effective control for at least two years.

Discussion

These investigations demonstrated that renovation and modification of existing sites is possible and practical for the maintenance of continual high alkali bee populations. The type of management practice to be instituted in modification of an existing site, or the renovation of a site that holds a potential for bee inhabitation, must be determined by the properties of a given soil and its chemical composition. The principal restricting factor for the establishment of new nesting areas is the presence of a soil having a texture with an aggregated clay-size particle content below 7%. This does not mean that soils with clay-size aggregates over 7% cannot be modified for bee accep-
tance, but that the problems associated with their modification become much more involved and require greater effort and longer periods of time for solution. If the soil texture conditions can be met, then further renovation can proceed through removal of existing vegetation, addition of necessary water, and application of one or more cations to the surface or subsurface.

Striking changes in the condition of natural bee beds have been seen to occur very rapidly. This is most evident when associated with an increase or decrease of subsurface moisture. Heavy late winter and early spring precipitation has been observed to raise the water table in some bee beds to such a level as to cause a high prepupal mortality and the abandonment of the site in a single year. Similar effects have been noted with increase in irrigation on crops immediately adjacent to the bed. Other beds have been abandoned in three months due to an insufficiency of subsoil water. Drop in the water table and loss of a nesting site was mused by cutting a drainage ditch near one bed, draining a pond which supplied the moisture to a second, and a sharp decrease in winter and spring precipitation for two consecutive years, which nearly destroyed four more.

Increase in incidence of flocculation in some older beds is most likely attributable to a change in the soluble salts being carried by subsurface water. If proportion of divalent cations in the water table increases, tendency towards surface flocculation will also increase.

FIGURE 5a (left). Native bee site to which sodium chloride and sodium chlorate had been added for weed control. Wooden stakes in center background mark plots. Extent of weed cover prior to control is indicated by growth immediately beyond staked plots.

FIGURE 5b (right). The weed-free area of the alkali bee bed (center background) has been kept clear of ground cover for two years with the single application of sodium chloride. The overgrown area to the left shows the extent of plant growth (Cressa) during the year following application of 2,4,5 T. The plot in the immediate foreground indicates the second year growth on the diuron plot.
Under such circumstances addition of sodium chloride to the surface to bring the divalent-monovalent cation balance up to a 1:1 ratio normally causes a return to the deflocculated or dispersed state. These changes in salts may occur rapidly and corresponding changes in management will have to be made to maintain an optimal surface.

It is difficult to evaluate or compare the degree of acceptability of each of the renovated plots, particularly when some plots were situated in areas where bee populations were sparse. Inflight of bees to these isolated plots would depend on nearness of the native bee population and degree of crowding exerted on the endemic site. Thus, rate of occupancy of the newly constructed sites must be considered in a relative manner and over a period of several years. In all areas where the renovated or modified plot was adjacent to an existing alkali bee bed, population expansion was immediate. However, total population varied with the type of treatment accorded the different trial plots within each area. One particular fact is significant—all renovated plots, with the exception of Plots I and II, 1957, were occupied in some degree during the first season of bee activity. Each of these plots has continued to increase in population density at a rate greater than can be accounted for by the natural reproductive potential of the resident population. This would indicate that there is a continual inflight of bees from surrounding areas and, on the basis of previous work, the inflight should continue so long as the renovated site remains more desirable than other accessible nesting areas.

Effect of weeds or vegetative cover on alkali bee nesting sites has been considered alternately as an asset and a detriment to the maintenance of maximum bee populations. The alkali bee often will be found in areas considered to be submarginal for inhabitation, burrowing into the soil immediately under existing vegetation, or near the base of a large alkali weed plant. This has led to the postulate that the bee may prefer a light vegetative cover in the initial inhabitation of a new area. Another factor that has prompted speculation of the desirable feature of cover is associated with the habit of its principal parasite, the bombyliid, *Heterostylum robustum* (O. S.). The fly hovers directly over an open hole and throws its egg into the exposed burrow orifice (Bohart, Stephen, & Eppley, 1960). Presence of vegetation is thought to restrict the incidence of parasitism by offering physical protection to the burrow openings and making it necessary for the fly to deposit its eggs from an altitude that would reduce the accuracy of its aim. However, there are compensating features which weigh heavily in favor of removal of vegetation to insure maximum bee inhabitation. Plant removal is most important in areas where the water table is suboptimal and in which the surface tends to dryness or flocculation. Vegetation, in any quantity, causes
a further reduction in amount of water available to the soil surface, and makes the site less acceptable. It is generally agreed that the rate of water loss through a vegetative cover of the denseness often seen on many of the submarginal soils could result in a 100-fold increase over the rate of loss through soil surface evaporation. Thus, surface evaporation is inconsequential compared to the water loss that will proceed through plant transpiration.

In addition, presence of a light to moderately dense plant cover restricts the area available to occupancy by the bee. Observations made since 1956, indicate that in many instances bees will accept the surface area immediately beneath a plant, because the surface, in being protected from the direct sun rays and prevailing winds, maintains a more desirable and uniform moisture level. Further, in all of the beds examined during the past five years, none of the beds having even a light plant cover has had a burrowing female population, or a wintering prepupal population that approached that of the weed free sites.

Where a light to moderate vegetative cover is found on a soil having a texture suitable for a potential bee bed, the salinity condition is one that must be modified before maximum bee utility can be achieved. If the monovalent salt concentration is high enough to effect a dispersion of soil surface, even alkali tolerant plants cannot survive. Increasing plant cover is thus an indication that the soil surface is becoming less desirable for bee activity.

Removal of vegetation in all trials conducted during the past three years has resulted in an increase in total burrowing population per square foot over the treated areas. Populations in endemic sites have been increased by as much as 300% merely by removing ground cover and adding ¼ to ½ pound of sodium chloride per square foot of bed surface. Vegetation can be effectively removed in several ways: through the use of a weedicide, a soil sterilant, by burning, or shallowly scraping the area to be renovated. Burning, scraping, or the application of nonsodium weedicide usually become an annual duty in each bed. Addition of excess sodium—sodium chloride or sodium chlorate—increases dispersion at the soil surface and appears to exert vegetative control for at least two years. Effective period will depend on total salt concentration in the soil, as well as the amount of surface leaching and runoff that may occur because of winter rains or periodic flooding.

Reference Cited