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Sometimes it seems as if the struggle to protect crops from debilitating diseases is hopeless. A prime weapon in our struggle to reverse that situation is research that produces results such as those reported in this issue of UTAH SCIENCE.
J. CLAIR THEURER, DEVON L. DONEY, and JOHN GALLIAN

FODDER BEET

FODDER BEET, a close relative of the sugar beet, has recently received significant publicity as a potential alcohol fuel crop. This beet is a member of the same species as sugar beet (Beta vulgaris L.) but has a lower sugar content and a higher root yield. Fodder beet has been grown as a forage crop for centuries in Europe, but it is a relatively new crop in the United States. The Europeans have given very little attention to using the beet for alcohol fuel production.

The large size of individual roots and the high root yield per acre are the factors that enhance the fodder beet's potential as a fuel crop. It has been hypothesized that even though its sugar content is lower than sugar beet, its greater root volumes would render a higher fermentable sugar yield (alcohol feedstock) than sugar beet. Sugar beet, however, is a good fuel crop in comparison with corn, sorghum, potatoes, or cereal grains (Doney and Theurer 1980). Data from European field trials show fresh root yields of fodder beet as high as 62 tons per acre, which is significantly greater than the root yield of their best adapted sugar beet hybrids. Doney (1980) estimated that fodder beets would produce 20 percent more fermentable sugar than sugar beet in the United States. New Zealand researchers have reported a superiority of over 100 percent for the fodder beet (Dunn 1980).

The term fodder beet has been applied to a specific type of beet as well as to any beet that is used as a livestock feed. In that sense, the term fodder beet could be used for sugar beets when fed to livestock. Fodder or “forage” beets have been categorized depending on sugar content (Table 1).

Root yields of beets are generally inversely related to their sugar contents; i.e., mangels have the highest and sugar beets the lowest root yields. Beets also exhibit a wide range of shapes and sizes. Sugar beets are largely cone-shaped and grow primarily below the soil surface. The mangels and fodder types (categories 1 and 2) may be round to oblong and grow largely above the soil surface. Figure 1 illustrates the relative size and root depth of a sugar beet hybrid, a high sugar content sugar beet hybrid, and two fodder beet varieties. The white line indicates the soil level. The fodder beets that have been considered by scientists as a potential fuel crop, and those that have been mentioned in recent news releases, consist mainly of categories 3 and 4 in Table 1. These categories generally are sugar beet X fodder beet hybrids and their shapes, sizes, and growth habits lie between those of the fodder beets and sugar beets (Figures 2 and 3).

During 1980, in cooperation with other sugar beet scientists throughout the United States, we conducted a rather extensive investigation to evaluate fodder beet as a fuel crop. The scope of these studies is summarized in Table 2.

Intermountain Test at Logan

Data on root weight, sucrose percentage, reducing sugar yield, and potential alcohol production for 14 fodder beet varieties and two commercial sugar beet hybrids are shown in Table 3. GWD2 and AH14 are the commercial sugar beet hybrid check varieties. The balance are fodder beet varieties from Europe.

The fresh root weight of the fodder beets ranged from 32 to almost 46 tons per acre. The root yields of Monoparte and Camobarres fodder beets were almost 60 percent greater than that of GWD2, the highest yield sugar beet. Conversely, the sugar percent of GWD2 was over 16 percent better than that for the best fodder beets. Two varieties of fodder beet, Meka Otofte and TCS/22-3, produced greater total sugar yields and had higher potential alcohol yields than GWD2. Similar results were observed in other field tests listed in Table 2.

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The large size and root yield of fodder beets can be misleading (Table 4). Ursus, Poly Blanche, and Peramono had almost double the root yield of the sugar beet hybrid GWD2; however, their sugar content averaged so low that their total fermentable sugar and potential alcohol yields were below those of the sugar beet hybrid. The fodder beet varieties TCS/45-9, Krake, and Monorosa are sugar beet X fodder beet hybrids. Their root yield averaged several tons per acre less than Ursus but their significantly improved sugar content resulted in significantly higher potential alcohol yields.

Non-sucrose sugars, which are also fermentable, have been reported to be high in fodder beets and thus should significantly improve their alcohol yield. In beets, these non-sucrose sugars are largely the reducing sugars glucose and fructose. These sugars were measured in all our tests. Most of the fodder beets had significantly higher reducing sugar contents than did the sugar beets (Tables 3 and 4). In no case, however, did the reducing sugar content exceed six-tenths of one percent (Table 4). Therefore, we concluded that the reducing sugars in the fodder beets added very little to the total potential alcohol yields.

Potential Alcohol Yields

Data from the national, intermountain, and miscellaneous fodder beet field trials showed potential alcohol yields per acre (Tables 5, 6, and 7). These estimates are based on total sugar yield (sucrose plus reducing sugar) and a conversion factor of 14 pounds of sugar equalling one gallon of alcohol. The designations "S" and "F" in these tables refer to sugar beet and fodder beet, respectively. A line described as S X F is a sugarbeet X fodder beet hybrid, a S X S description is a sugar beet hybrid, a F X F description is a fodder beet hybrid, and a F description is an open-pollinated variety.

The potential alcohol yield of the hybrid variety of sugar beets GWD2 ranged from 635 to 768 gallons per acre (Tables 5, 6, and 7). Fodder beets and sugar beet X fodder beet hybrids showed wider variation than sugar beet and had a potential alcohol yield of 521 to 882 gallons per acre.

The sugar beet X fodder beet hybrids (S X F) generally promised greater potential yields than the sugar beet hybrid (S X S). The fodder beet hybrids (F X F) were generally lower in potential alcohol production than the sugar beet hybrid, and the open-pollinated varieties of fodder beet (F) were the lowest.

Sugar beet X fodder beet hybrids seem to have the best potential as an alcohol fuel crop. The superiority of the best current European varieties is in the range of 3 to 15 percent, however, and not the 20 to 100 percent as previously reported. This superiority must also be tempered with the fact that all the fodder beets tested were very susceptible to curly top and moderately susceptible to Cercospora leaf spot. In addition, the production costs of fodder beets will be slightly higher due to the handling of their higher tonnages. We estimate that a fodder beet or sugar beet X fodder beet hybrid must exceed sugar beet in total fermentable sugar production by at least 10 percent to be more economical than sugar beet as a fuel crop.

Nitrogen Fertilizer Effect

Four genetically diverse sugar beet hybrids, two sugar beet X fodder beet hybrids, and two fodder beet varieties definitely responded to nitrogen fertilizer when two times the normal rate of 175 pounds per acre was applied. In general, the higher nitrogen increased root yield but decreased sugar percentage. The end result was very little difference for the sugar beet hybrids in either total fermentable sugars or potential alcohol yield, between the normal and the high nitrogen levels. The two sugar beet X fodder beet hybrids resembled sugar beets in their responses. Additional nitrogen significantly increased root yields of the two open-pollinated fodder beet varieties, however, while not causing as extensive a drop in sugar percentage as occurred in sugar beets.

Breeding Program

Based on the 1980 field trials, it appears that the optimum "fuel beet" must be developed by breeding. That ideal would consist of a hybrid between U.S.-adapted, disease-resistant sugar beet crossed to a good fodder beet. We would anticipate a 15 to 20 percent increase in total fermentable sugar for this fuel beet over that of the best adapted sugar beet hybrids. A breeding program is under way at Logan to incorporate curly top resistance into fodder beet and to develop sugar beet X fodder beet hybrids for fuel production.
FIGURE 2. Sugar beet (SB), fodder beet (FB), and F₁ hybrid roots showing relative root shape and size.

FIGURE 3. Growth habit of open-pollinated fodder beet variety (a and c) compared with sugar beet X fodder beet hybrid where the open-pollinated fodder beet variety is a parent in the hybrid (b and c).
Conclusions

1. Both sugar beet and fodder beet can potentially produce high yields of alcohol fuel.

2. Open-pollinated fodder beets do not yield as much total fermentable sugar per acre as our best sugar beet hybrid.

3. Several sugar beet X fodder beet hybrids produced more total fermentable sugar per acre than did GWD2, our best sugar beet hybrid, with the best hybrids exceeding sugar beet by 8 to 12 percent.

4. Fodder beets or sugar beet X fodder beet hybrids must produce at least 10 percent more fermentable sugar per acre than sugar beets to make them more economical than sugar beet as a fuel crop because of the extra cost to handle and haul the larger tonnage.

5. All European fodder beet cultivars are highly susceptible to curly top and relatively susceptible to Cercospora leaf spot diseases.

6. Fodder beets respond more to nitrogen fertility than sugar beets to achieve their maximum production potential; however, the response of sugar beet X fodder beet hybrids react to nitrogen fertility was similar to that of sugar beet.

7. Fodder beets and some fodder beet X sugar beet hybrids present some harvesting problems for existing sugar beet equipment. New fodder beet X sugar beet hybrids can be developed, however, that would be compatible with present harvesting equipment.

8. A 15 to 20 percent increase in fermentable sugar yields over that for adapted sugar beet varieties should be attainable from an effective, accelerated long-range breeding program.

9. At the present time, sugar beets appear to be more desirable than fodder beet as a fuel crop because of their disease resistance and high potential alcohol yield. An alcohol industry using sugar beet as a feedstock could easily incorporate new fuel type beets into their program as these new varieties are developed.

TABLE 1. Sugar content of forage type beets

<table>
<thead>
<tr>
<th>Type</th>
<th>% Sugar</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mangel</td>
<td>3-6</td>
</tr>
<tr>
<td>2. Fodder</td>
<td>6-9</td>
</tr>
<tr>
<td>3. Fodder-Sugar</td>
<td>10-12</td>
</tr>
<tr>
<td>4. Sugar-Fodder</td>
<td>13-15</td>
</tr>
<tr>
<td>5. Sugar beet</td>
<td>16-19</td>
</tr>
</tbody>
</table>

TABLE 2. 1980 fodder beet X sugar beet fuel crop studies

<table>
<thead>
<tr>
<th>Field Test</th>
<th>Number of Varieties</th>
<th>Locations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 sugar beet hybrids</td>
<td></td>
</tr>
<tr>
<td>Intermountain</td>
<td>14 fodder beet</td>
<td>Logan, Utah, Fillmore, Utah, Rexburg, Id., Prosser, Wash.</td>
</tr>
<tr>
<td></td>
<td>2 sugar beet hybrids</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous fodder beet</td>
<td>36 fodder beet</td>
<td>Logan, Utah, Aberdeen, Id.</td>
</tr>
<tr>
<td>Sugar beet X fodder beet hybrids</td>
<td>14 European sugar beet X fodder beet hybrids</td>
<td>Farmington, Ut., Logan, Ut.</td>
</tr>
<tr>
<td></td>
<td>20 USDA sugar beet X fodder beet hybrids</td>
<td></td>
</tr>
<tr>
<td>Fertilizer effect on variety</td>
<td>2 sugar beet hybrids</td>
<td>Kimberly, Id.</td>
</tr>
<tr>
<td></td>
<td>2 sugar beet hybrids</td>
<td></td>
</tr>
<tr>
<td>Disease resistance</td>
<td>68 fodder beet varieties</td>
<td>Logan, Ut. (curly top), Beltsville, Md. (Cercospora leaf spot)</td>
</tr>
</tbody>
</table>
### Table 3. Root weight, sugar percentages, total fermentable sugars, and potential alcohol yields, Intermountain Field Trial, Logan, Utah, 1980

<table>
<thead>
<tr>
<th>Variety</th>
<th>Root Weight Tons/Acre</th>
<th>Sucrose %</th>
<th>Reducing Sugar %</th>
<th>Total Fermentable Sugars Tons/Acre</th>
<th>Potential Alcohol Gallons/Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>GWD2</td>
<td>29.0</td>
<td>16.6</td>
<td>0.17</td>
<td>4.85</td>
<td>693</td>
</tr>
<tr>
<td>AH14</td>
<td>25.7</td>
<td>15.3</td>
<td>0.17</td>
<td>3.98</td>
<td>569</td>
</tr>
<tr>
<td>Meka Otofte</td>
<td>37.7</td>
<td>13.5</td>
<td>0.23</td>
<td>5.18</td>
<td>741</td>
</tr>
<tr>
<td>TC5/22-3</td>
<td>42.4</td>
<td>11.6</td>
<td>0.25</td>
<td>5.01</td>
<td>716</td>
</tr>
<tr>
<td>Monoparte</td>
<td>45.4</td>
<td>10.5</td>
<td>0.29</td>
<td>4.91</td>
<td>702</td>
</tr>
<tr>
<td>Monorosa</td>
<td>35.7</td>
<td>13.4</td>
<td>0.21</td>
<td>4.85</td>
<td>694</td>
</tr>
<tr>
<td>Monofix</td>
<td>34.7</td>
<td>13.7</td>
<td>0.15</td>
<td>4.81</td>
<td>686</td>
</tr>
<tr>
<td>Monoblanck</td>
<td>37.0</td>
<td>12.3</td>
<td>0.25</td>
<td>4.67</td>
<td>665</td>
</tr>
<tr>
<td>Barb 79-1</td>
<td>41.1</td>
<td>11.1</td>
<td>0.24</td>
<td>4.61</td>
<td>658</td>
</tr>
<tr>
<td>Cimarosa</td>
<td>32.2</td>
<td>13.8</td>
<td>0.16</td>
<td>4.48</td>
<td>640</td>
</tr>
<tr>
<td>Solanka</td>
<td>39.0</td>
<td>11.0</td>
<td>0.27</td>
<td>4.30</td>
<td>628</td>
</tr>
<tr>
<td>Camobarres</td>
<td>45.5</td>
<td>9.1</td>
<td>0.37</td>
<td>4.32</td>
<td>617</td>
</tr>
<tr>
<td>Zentaur</td>
<td>44.5</td>
<td>8.9</td>
<td>0.39</td>
<td>4.14</td>
<td>592</td>
</tr>
<tr>
<td>Monoborris</td>
<td>42.7</td>
<td>9.3</td>
<td>0.35</td>
<td>4.09</td>
<td>584</td>
</tr>
<tr>
<td>Mean</td>
<td>38.0</td>
<td>12.2</td>
<td>0.25</td>
<td>4.58</td>
<td>655</td>
</tr>
<tr>
<td>LSD .05</td>
<td>3.6</td>
<td>0.8</td>
<td>0.07</td>
<td>0.47</td>
<td>68</td>
</tr>
</tbody>
</table>

### Table 4. Selected entries from Aberdeen, Idaho test for root yield, percent sucrose, percent reducing sugars, total fermentable sugars, and potential alcohol yields

<table>
<thead>
<tr>
<th>Entry</th>
<th>Root Yield Tons/Acre</th>
<th>Sucrose %</th>
<th>Reducing Sugars %</th>
<th>Total Fermentable Sugars Tons/Acre</th>
<th>Potential Alcohol Gallons/Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>GWD2</td>
<td>35.3</td>
<td>16.6</td>
<td>0.19</td>
<td>5.92</td>
<td>845</td>
</tr>
<tr>
<td>TC5/45-9</td>
<td>59.2</td>
<td>11.9</td>
<td>0.24</td>
<td>7.15</td>
<td>1022</td>
</tr>
<tr>
<td>Krake</td>
<td>47.7</td>
<td>14.3</td>
<td>0.17</td>
<td>6.88</td>
<td>983</td>
</tr>
<tr>
<td>Monorosa</td>
<td>49.0</td>
<td>13.1</td>
<td>0.25</td>
<td>6.56</td>
<td>938</td>
</tr>
<tr>
<td>Ursus</td>
<td>68.0</td>
<td>8.1</td>
<td>0.30</td>
<td>5.68</td>
<td>812</td>
</tr>
<tr>
<td>Poly Blanche</td>
<td>65.3</td>
<td>7.4</td>
<td>0.62</td>
<td>5.09</td>
<td>728</td>
</tr>
<tr>
<td>Peramono</td>
<td>64.0</td>
<td>7.8</td>
<td>0.27</td>
<td>5.13</td>
<td>733</td>
</tr>
<tr>
<td>LSD .05</td>
<td>2.9</td>
<td>1.8</td>
<td>0.10</td>
<td>0.91</td>
<td>131</td>
</tr>
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</table>

### Table 5. Summary of 1980 national fodder beet X sugar beet field trials

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Description</th>
<th>Potential Alcohol Gallons/Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kyros</td>
<td>SXF</td>
<td>655</td>
</tr>
<tr>
<td>Lamonol II</td>
<td>SXF</td>
<td>652</td>
</tr>
<tr>
<td>Monovigor</td>
<td>SXF</td>
<td>651</td>
</tr>
<tr>
<td>Barsein</td>
<td>SXF</td>
<td>649</td>
</tr>
<tr>
<td>Lamonol I</td>
<td>SXF</td>
<td>647</td>
</tr>
<tr>
<td>Monilac</td>
<td>SXF</td>
<td>640</td>
</tr>
<tr>
<td>GWD2</td>
<td>SXS</td>
<td>635</td>
</tr>
<tr>
<td>Monorosa</td>
<td>SXF</td>
<td>632</td>
</tr>
<tr>
<td>Monosorver</td>
<td>SXF</td>
<td>636</td>
</tr>
<tr>
<td>Monoblanck</td>
<td>SXF</td>
<td>590</td>
</tr>
<tr>
<td>Oscar</td>
<td>FXF</td>
<td>581</td>
</tr>
<tr>
<td>Beta Rose Sugar</td>
<td>SXF</td>
<td>567</td>
</tr>
<tr>
<td>Monara</td>
<td>FXF</td>
<td>552</td>
</tr>
<tr>
<td>Yellow Daeno</td>
<td>F</td>
<td>527</td>
</tr>
<tr>
<td>Eckdobarres</td>
<td>F</td>
<td>521</td>
</tr>
<tr>
<td><strong>LSD .05 = 36</strong></td>
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### Table 6. Summary of 1980 Intermountain Fodder Beet X Sugar Field Trials

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Description</th>
<th>Potential Alcohol Gallons/Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monofix</td>
<td>SXF</td>
<td>723</td>
</tr>
<tr>
<td>Meka Otofte</td>
<td>FXF</td>
<td>716</td>
</tr>
<tr>
<td>Monorosa</td>
<td>SXF</td>
<td>695</td>
</tr>
<tr>
<td>Barb 79-2</td>
<td>SXF</td>
<td>694</td>
</tr>
<tr>
<td>TC5/22-3</td>
<td>SXF</td>
<td>693</td>
</tr>
<tr>
<td>Cimarosa</td>
<td>SXF</td>
<td>685</td>
</tr>
<tr>
<td>GWD2</td>
<td>SXS</td>
<td>683</td>
</tr>
<tr>
<td>Monoblanck</td>
<td>SXF</td>
<td>680</td>
</tr>
<tr>
<td>Monoparte</td>
<td>FXF</td>
<td>674</td>
</tr>
<tr>
<td>Camobarres</td>
<td>FXF</td>
<td>654</td>
</tr>
<tr>
<td>Solanka</td>
<td>FXF</td>
<td>652</td>
</tr>
<tr>
<td>Zentaur</td>
<td>F</td>
<td>625</td>
</tr>
<tr>
<td>Monoborris</td>
<td>F</td>
<td>603</td>
</tr>
<tr>
<td><strong>LSD .05 = 50</strong></td>
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### Table 7. Summary of 1980 miscellaneous fodder beet and sugar beet field trials

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Description</th>
<th>Potential Alcohol Gallons/Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC/45-9</td>
<td>SXF</td>
<td>882</td>
</tr>
<tr>
<td>Hugin</td>
<td>SXF</td>
<td>834</td>
</tr>
<tr>
<td>Proto 2n Rose</td>
<td>SXF</td>
<td>825</td>
</tr>
<tr>
<td>Krake</td>
<td>SXF</td>
<td>808</td>
</tr>
<tr>
<td>Monorosa</td>
<td>SXF</td>
<td>799</td>
</tr>
<tr>
<td>TC2018</td>
<td>SXF</td>
<td>799</td>
</tr>
<tr>
<td>Monover</td>
<td>SXF</td>
<td>799</td>
</tr>
<tr>
<td>Barb 79-2</td>
<td>SXF</td>
<td>798</td>
</tr>
<tr>
<td>Proto 3n Blanche</td>
<td>SXF</td>
<td>794</td>
</tr>
<tr>
<td>Monovol</td>
<td>FXF</td>
<td>792</td>
</tr>
<tr>
<td>TC1157</td>
<td>SXF</td>
<td>787</td>
</tr>
<tr>
<td>Proto 3n Rose</td>
<td>SXF</td>
<td>781</td>
</tr>
<tr>
<td>TC201</td>
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<td>779</td>
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<tr>
<td>Peroba</td>
<td>FXF</td>
<td>776</td>
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<tr>
<td>Kimono</td>
<td>SXF</td>
<td>775</td>
</tr>
<tr>
<td>GWD2</td>
<td>SXS</td>
<td>768</td>
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<tr>
<td>Monobomba</td>
<td>SXF</td>
<td>768</td>
</tr>
<tr>
<td>Vital Daehnfieldt</td>
<td>FXF</td>
<td>758</td>
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<td>Barb 78-1</td>
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<td>756</td>
</tr>
<tr>
<td>TC5014</td>
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<td>752</td>
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<td>TC1148</td>
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<td>748</td>
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<td>Babalonal Yellow</td>
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<td>Yellow Eckendorfer</td>
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<td><strong>LSD .05 = 65</strong></td>
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Soil Minerals

If your teakettle is coated with minerals, you can blame the water you boil in it. When the water boils, some evaporates as steam, leaving minerals behind. Repeated adding and boiling of water eventually coats the kettle with minerals.

This same kind of chemical process goes on in soil, whether on an irrigated farm or around a house plant. Irrigation water contains salts and minerals, the plants use or evaporate the water, and the salts and minerals remain behind in the soil. Fortunately, such soil salinity can be controlled through good management of soil and water.

Two Kinds of Salts

Salts in irrigation water can be roughly classified as either slightly or highly soluble. The slightly soluble salts (gypsum and lime) are not especially harmful to plants. The highly soluble salts (sodium-containing), can not only harm plants but can damage the soil. Soluble salts are the most detrimental, but they are also the easiest to remove.

Salt Removal

If you empty and refill your teakettle every day and never let it boil dry, the minerals will not accumulate or will do so only at a slow rate. To protect your soil from salinity, you must regularly pass enough water through the soil to safely carry away the salts. The water that must pass through the soil to carry away excess salt is called the leaching fraction. That fraction (whether for a flower pot or a farm) should equal from 3 to 20 percent of the applied irrigation water. The leaching process (movement of water and salt out of the root zone) can be accomplished every irrigation or on an average of once a year. The important thing is to carry the concentrated salt out of the plant root zone so that it will not accumulate in harmful amounts. That removal requires applications of water beyond the quantity needed for plant growth.

Excess Leaching

Unfortunately, too much water can be as destructive as too little. Excessive leaching may wash out soluble plant nutrients and cause drainage and aeration problems, thereby interfering with plant growth. On an irrigated farm, excessive leaching may also dissolve slightly soluble residual and geologic salt from the deep soil profile. This process can reduce downstream water quality as the seepage water reenters the water supply. If all the salts in the soil and water are highly soluble, the amount of salt leached will be equal to the amount applied in the irrigation water and will be independent of the amount of either drainage water or leaching fraction. The concentration of salt in the drainage water, however, will depend on the leaching fraction.

Irrigation Uniformity

Water management is one of the most difficult tasks for any irrigation farmer. Not only must decisions be made about when to irrigate and how much water to apply, there is also the problem of uniformly distributing the water. Unless the irrigation is reasonably uniform, parts of the field may experience excess leaching while others may be under-irrigated. Salts will accumulate in the under-irrigated parts of the field, and in addition, the plants will be short of water.
The irrigation water might be measured by the crop, the total water supplied to the crop that was consumed by the crop. The total water supplied could come from irrigation, stored soil moisture, or rainfall during the season. The irrigation water might be measured as it leaves a reservoir or upon delivery to the farm field. The latter measurement would eliminate any leakage or losses in canals or ditches that occur before the water is delivered to the crop.

It is sometimes assumed that an efficient irrigation is the best management. By definition, an irrigation that loses no water would be considered efficient. Such an irrigation, however, might not refill the root zone and could result in a salt buildup in the soil or a water deficit for the crop before the next irrigation.

The "best" irrigation management may be one that has several goals: to fill at least part of the root zone so that adequate water is available for plant use; to provide the required extra amount of water for leaching; and to lose a minimum amount of water to runoff and poor distribution. Water not used by the crop because of poor distribution and over-irrigation seeps into the ground and under certain conditions may pick up additional salt. Thus, when it is reused elsewhere, it may contain more salt than initially. If the amount of water applied was designed to impose a certain leaching fraction, however, the removal of salts from the plant root zone would represent good management. Over-land runoff water, on the other hand, remains relatively unchanged in salinity but may pick up suspended solids. Irrigation management is optimized when it is designed to remove soil salts as needed and accomplishes that purpose.

**Salt Management—Highly Soluble Salts**

Irrigation with water containing only highly soluble salts, results in relatively little storage of salt in the soil if there is any leaching at all. To illustrate, assume a farm where 100 units of water having only highly soluble salts are diverted onto a field (Figure 1). The water contains 1.0 part of salt per 100 units of water (a concentration of 0.01). If 10 units of water run off the field, the remaining 90 units of water will go into the soil, carrying with it 0.9 parts of salt. If the soil can store 75 units of water for consumption by plants, 15 units will seep downward beyond the root zone. Consumption of water by plants is a distilling process in which pure water is returned to the atmosphere while salts are left in the soil. With perfect water distribution over the field, the average leaching percent would be 15 units of deep seepage divided by the 90 units of water that entered the soil, or 17 percent. With an ideal salt balance, the same amount of salt is leached as is added. With 0.9 parts of salt in the 15 units of drainage water, the drainage return flow would then have a concentration of 0.06. No salt has been added to the drainage water, but the concentration is higher than in the irrigation water. Since the 75 parts of water stored in the root zone were used by the plants, the total amount of salt added with the irrigation water would be carried out of the root zone by the 15 units of subsurface drainage water.

Under actual irrigation conditions, difficulties arise because of imperfect water distribution over the field. Surface irrigation, sprinkler irrigation, and trickle irrigation all have uniformity problems. Perhaps unexpectedly, the three irrigation methods achieve a similar distribution uniformity when each is well designed and well managed.

Because no irrigation is totally uniform, some water will almost always be lost to seepage beyond the root zone. For example, if the best available sprinkler system were used to apply the average amount of water required to fill the root zone, 10 percent of the water would still be lost to crop use because of application non-uniformity (Figure 2). Approximately half of the field would be over-irrigated and half the field would be under-irrigated. To be sure that none of the field was under-irrigated, at least 15 percent extra water is often advised (Figure 3).

In the preceding irrigation example, 90 X 1.15 or 103.5 units of water would have to enter the soil. Because of runoff with the surface irrigation system, only 90 percent of the water applied to the field actually infiltrates. A total irrigation amount of 103.5/0.90 or 115 units of water would have to be applied.

Since only 75 units of the 115 units diverted were stored, it appears that the irrigation was only 65 percent efficient (75/115). In practical terms, however, the irrigation management was very good. As shown in Figure 4, 11.4 units of water went to runoff, 103.5 units of water entered the soil, 75 units of water were stored in the soil for the plants, and 28.5 units of water went to deep drainage because of leaching and non-uniformity. The drainage water carried 1.035 parts of salt in 28.5 units of water at a concentration of 0.036.

Changing to a sprinkler system would, at most, eliminate the runoff (Figure 5). The amount of water applied for required infiltration would still be 103.5 units. The same 75 units would be stored in the root zone. The same 28.5 units of water would go to deep drainage carrying 1.035 parts of salt at a concentration of 0.036. The irrigation efficiency would be calculated as 103.5 or 72 percent (75/103.5).

As far as the plants and soil salinity are concerned, the two different irrigation methods produced identical results. Salt management with both irrigation systems (a surface system...
Surface irrigation can result in salt buildup on seedbeds, resulting in poor stands and reduced yields.

Excess levels of soil salts, even in the presence of good quality irrigation water, will reduce yields if the water is not properly managed.

showing an apparent efficiency of 65 percent, and a sprinkler system showing an apparent efficiency of 72 percent) would be identical. Increasing irrigation efficiency did not change the amount of salt leached from the soil, but it did decrease the total amount of irrigation water applied.

Salt Management—Slightly Soluble Salts

Slightly soluble salts produce a more complicated situation than when the salts are highly soluble. Slightly soluble salts can be stored in the soil despite leaching. Also, salts previously stored in the soil can be dissolved into the drainage water if other conditions are right.

To manage this situation, it is important to minimize the amount of water leached through the soil. This will minimize the dissolution of salts already in the soil. With such a minimum leaching scheme, less salt will leave the soil than enters it. A net removal of salt from the soil solution will occur, by chemical precipitation of the salts to a solid phase. If the salts entering the soil with the irrigation water were all of the slightly soluble type, it would be theoretically possible to irrigate without leaching at all for many years. However, the amount of salt that can be stored in the soil decreases with time.

Salt Management—Mixture of Highly and Slightly Soluble Salts

Almost all real field situations fall under this category. Irrigation water in the Upper Colorado River Basin tends to be high in slightly soluble salts (i.e., gypsum) and relatively low in highly soluble salts (i.e., sodium chloride). Effective management thus demands some leaching to keep the soil levels of sodium chloride low. This can be accomplished with a very small amount of leaching. The amount of leaching water applied will influence the proportions of calcium and sulfate leached and causes the ratio of sodium to calcium to increase downstream. Downstream water is progressively composed of more and more water that has been leached through the soil. The resultant degradation of the irrigation water quality can be monitored by the ratio of sodium to calcium in the water. In general, irrigation increases downstream salt concentrations with associated changes in the chemical composition of the water.

Excess Irrigation—Waste Water

Irrigating a particular field with more water than the soil can store can be costly in several ways. If twice as much
water were applied in the above example (Figure 6), the surface system would show an apparent efficiency of 75/230, or 33 percent, and the sprinkler system would show an apparent efficiency of 36 percent. Since the crop would use or consume the same amount of water, the excess leaching might: remove nutrients, leach salts previously stored in the soil, and even decrease production. The concentration of the drainage water, however, would only be 1.57 parts of salt per 100 units of water, or 0.0157.

This "lost" water is wasted only if it is not used by someone else downstream. Most irrigated valleys in the west that have developed over the years are efficient overall but "inefficient" on a single field basis.Reuse of drainage water and other return flows is common. This has resulted in very efficient use of water when large composite areas are analyzed as a unit. Increasing the efficiency of irrigation on a single field will not change the amount of water needed by the crop and will therefore not change the total water supply. Improved "irrigation efficiency" resulting from better water distribution and better water management may increase yields but may also decrease downstream water quality. Higher yields generally mean more water consumed, and therefore potentially higher salt concentrations in drainage return flows. Also, if the water saved by increasing efficiency is used to irrigate more land, return flows may be still smaller in amount and higher in salt concentration.

**Conclusions**

Salt is a natural ingredient of both irrigation and drainage water. Good irrigation management will minimize the undesirable effects of salt concentration that naturally results from irrigation. Increasing irrigation efficiency by improving uniformity of water distribution may improve soil salinity management but will not affect the amount of water consumed by a crop. Increased irrigation efficiency that results in a greater consumption of water (i.e., increased crop yields) may reduce downstream return flows and increase salinity concentration in the remaining water.

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R. J. Hanks is a Professor of Soil Science and Biometeorology. His research interests lie primarily in irrigation, soil physics, and crop production modelling.

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FIGURE 1. Sweet Ann is a blushing yellow cherry developed for its resistance to western X disease. It could be used fresh or for processing.

FIGURE 2. Utah Giant is a delicious, large, sweet cherry for use in fresh market or canning.

FIGURE 3. Scanning electron micrograph of a freeze-fractured celery petiole. Bracket shows area of enlargement for Figure 4. (Magnified 50X.)

FIGURE 4. Scanning electron micrograph of the interior of a single sieve cell of celery infected with the western X mycoplasma. Spherical structures are mycoplasmas. (Magnified 2,000X.)

FIGURE 5. Bing cherries infected with X mycoplasma (left) are slow to ripen, small, pointed, and with an insipid taste. Healthy cherries from the same tree are shown on the right.

FIGURE 6. The Reel injection apparatus injects 2 quarts of antibiotic into an X-infected cherry within 1 to 2 minutes. Compressed nitrogen gas serves as the propellant.

FIGURE 7. Healthy Bing cherries from an antibiotic-treated tree. In previous years, fruit from this tree was not marketable.
WESTERN X DISEASE
NEW TREATMENT AND NEW RESISTANT CHERRIES
INJECTION TREATMENT OF WESTERN X DISEASE

WESTERN X DISEASE is a widespread and devastating disease of sweet cherry in northern Utah. It was first recognized in Utah in the mid 1930s. X disease is also a serious problem in California, the northwest, and many fruit-producing areas of the midwest and northeast. A closely related (perhaps identical) strain causes yellow leaf roll disease in peaches. In the eastern U.S., X disease is called eastern X but it may be caused by the same organism.

Western X disease is caused by a mycoplasma; an organism similar to a bacterium except in its lack of a cell wall. This morphology results in a structure somewhat like a water balloon. Figure 1 shows the spherical mycoplasma inside a phloem cell of celery, taken with the scanning electron microscope. The X disease mycoplasma is vectored (spread) by several species of leafhoppers. Controlling leafhoppers by insecticides has not been very successful, however, in preventing X disease.

In Utah, cherry trees are usually planted on either Mazzard or Mahaleb rootstocks. Those on the Mahaleb rootstock usually will and die within a few weeks after infection. Infected trees on Mazzard rootstock develop rosetted foliage, enlarged stipules, and small cherries that are usually sterile. With no effective way to control X disease, orchards were usually eliminated in four to six years after discovery of the first diseased trees. Such tremendous losses of trees meant poor financial returns for an orchardist and many declining orchards were therefore sold for housing developments. Recent research, however, has provided sources of genetic resistant cherry varieties and antibiotic treatments for infected trees. These new techniques provide promise for economic control of X disease.

Resistance
A long-term (and hopefully permanent) solution, is to plant resistant sweet cherry varieties as replacements for highly susceptible Royal Ann, Bing, and Lambert varieties. Resistant varieties have been under development at Utah State University for over 15 years. Dr. Bryce Wadley, formerly with USDA-SEA-AR and collaborator with the Utah Agricultural Experiment Station, was responsible for selecting and testing of the new X resistant varieties. He released Angola, a red-fruited sweet cherry in 1975. Two more releases—Utah Giant and Sweet Ann—are reported in this issue of UTAH SCIENCE.

These resistant varieties were selected from open-pollinated Napa Long Stem Bing seedlings. They were tested for resistance to X disease by grafting infected buds into trees grown on Mahaleb rootstocks. Evaluations for disease were made one year later. The Angola and Sweet Ann varieties have not shown any disease in inoculated trees nor any natural spread. Utah Giant has moderate resistance, since occasional plants have become infected when bud inoculated. Growers can use the highly resistant varieties to replace missing or diseased trees in an orchard with X disease or as starting stock in a geographical area where X disease is endemic.

Injection Treatment
The X disease pathogen is found only in the phloem (vascular tissue) of infected trees. Leafhoppers that feed on the plant juices of the phloem acquire the mycoplasma and spread it to healthy trees. The internal nature of this pathogen precludes the effective use of foliar or surface applications of pesticides.

New technology developed in the last seven years, however, allows a microbial inhibitor to be injected into the vascular system of trees. The antibiotic oxytetracycline (Terramycin) is temporarily registered by the EPA for this use. This injection technique has been used successfully in California to treat over 750,000 pear trees to control a similar disease called pear decline (Reil 1979). Eastern X disease of peach has also been controlled by injections of oxytetracycline (Pearson and Sands 1978).

The treatment technique involves drilling three 1/4-inch holes in the trunk of the infected tree and inserting hollow injection screws into the holes. The antibiotic is injected into the tree via the injection screws using the Reil pressure injection machine (Reil 1979) with compressed nitrogen gas at 100 to 250 psi as the propellant (Figure 3). Usually one to two quarts of a solution of 600 to 1200 ppm of the antibiotic are injected within one to two minutes. The tree species, season, time of day, health of tree, and many other environmental factors influence the ease of injection. In some cases, trees will not take up the material.

The results of these injections have been very encouraging. Treated trees show excellent recovery and produce high quality fruit. Severely infected trees on Mazzard rootstock were returned to full production in a single year. For example, in a local cherry orchard the grower had discontinued harvesting the fruit because of the high incidence of poor quality diseased fruit. In 1980, most trees that had been injected in October of 1979 appeared normal. Many of the previously infected trees produced over 20 boxes of excellent fruit (Figure 4).

The treatment is not permanent and probably should be repeated every two to three years. For severely infected trees, two treatments in consecutive years may provide satisfactory remission of symptoms. Even multiple treatments offer economic advantages relative to losing mature trees. To replant and regain full production of a tree may require 10 years. The injection technique costs approximately $5 per tree, per injection, and returns a tree to full production within one year. No commercial companies currently provide this service, nor are there any companies manufacturing specifically suitable equipment. In 1979, the cost of adaptable injection equipment was approximately $400 to $500. Assistance in treating infected trees, locating or assembling injection equipment may be obtained from the author.

Summary
Growers of sweet cherries can now reduce western X disease to a minor problem. They need to combine gradual replacement of susceptible trees (or to plant new orchards) with western X resistant sweet cherry trees and the injection of oxytetracycline antibiotic into diseased trees.

The injection of diseased trees with antibiotics can not be considered a permanent solution on its own. Growers should ultimately expect to replant their orchards with resistant varieties. The injection procedure will, however, allow economically practical production to continue as replacement occurs.
TWO NEW X DISEASE-RESISTANT CHERRIES FOR UTAH

UTAH GIANT

UTAH GIANT is a distinctive, mahogany-colored, sweet cherry with excellent horticultural qualities. (It was formerly designated LSB-88.) Visitors at the Farmington Experiment Station have consistently preferred this cherry over others. Its very large, firm fruit has an outstanding flavor. The fruit is larger and has a firmer texture than Bing or Lambert. The shape and stem length of Utah Giant resemble those of Van. Its flesh color is dark red.

This newly developed cherry blooms concurrent with Bing and is 5 to 7 days earlier than Angela or Star. 90 percent bloom usually occurs between April 13 and April 25. The pollination group is unknown and it is self-sterile. Fruit set (commonly as large clusters) is heavy in normal years but it is susceptible to early spring frosts. We have not observed any doubling, which is frequent in Bing and Lambert. The pit is medium in size and is partially free-stone. Trees of Utah Giant at Farmington were only slightly damaged by the severe winters of 1972 and 1978. Splitting under wet conditions is similar to that of Bing.

Utah Giant was selected from open pollinated “Napa Long Stem Bing” in a search for resistant varieties to X disease by Dr. Bryce Wadley, formerly a research plant pathologist with USDA-SEA-AR and collaborator with the Utah Agricultural Experiment Station. During recent years, Sherman V. Thomson, Extension Plant Pathologist, assisted in its development. Angela was the first western X resistant variety released by Wadley from his program. Another X resistant variety, Sweet Ann, is being released concurrently with Utah Giant. We consider Utah Giant to be partially resistant to western X disease. Inoculation of this variety with buds from X diseased trees indicate it has some resistance but not as much as Angela or Sweet Ann. It is more resistant than Bing, Lambert, or Van, however, and may have enough field resistance to be used in areas where X disease occurs.

The fruit of Utah Giant is excellent for canning since it retains its firmness, color, and flavor after processing. The cherries store well when refrigerated if not excessively bruised or without stems.

Utah Giant would make an excellent home yard tree and holds tremendous promise as a replacement for Bing in commercial orchards. Utah Giant’s moderate resistant to X disease may be beneficial in areas where X disease occurs. The visual appeal, large size, and flavor of the fruit should greatly enhance roadside sales.

Requests for budwood should be addressed to Sherman V. Thomson, Department of Biology, UMC 45, Utah State University, Logan, Utah 84322.

SWEET ANN

SWEET ANN, formerly known as LSB-7, is a medium-sized, yellow, sweet cherry with a pleasing blush covering half of each fruit. The fruits are firm with an excellent flavor and a small pit. It is slightly sweeter and more firm than Royal Ann and its blush is a brighter red.

Bud inoculations of trees grown on Mahaleb rootstock proved that Sweet Ann is resistant to western X disease. We have never seen any Sweet Ann trees become infected with western X in inoculation studies nor naturally in the orchard. Sweet Ann originated from open pollinated, Napa Long Stem Bing seeds collected in 1964.

This cherry is the second release of Dr. Bryce Wadley (in collaboration with Sherman V. Thomson, Extension Plant Pathologist) that has resistance to western X disease. Wadley also originated the dark-fruited, western X resistant Angela variety while serving as a research plant pathologist with the Agricultural Research Service, USDA, and Collaborator, Utah Agricultural Experiment Station, Logan, Utah.

Bloom and maturity occur in Sweet Ann at about the same time as in Bing. Trees regularly set a heavy crop of fruit with many fruits to a cluster. It is a good pollinator for Bing and Lambert but is self-sterile. Sweet Ann appears to be somewhat resistant to spring frosts, since it has set fruit when Bing and Lambert have been damaged. It is also winter hardy. Temperatures dropped to -29 C (-20 F) in the winter of 1978-79 during December and again in January. There was no damage observed on Sweet Ann trees and they set a heavy crop. Tree shape is similar to that of Bing.

High summer temperatures frequently cause up to 40 percent doubling in Bing cherries grown in northern Utah orchards and 80 percent in southern Utah. In contrast, doubles have not been observed in Sweet Ann, nor has splitting been a problem in the new variety despite heavy rains during the fruit ripening period in some years. Sweet Ann stems are of medium length and are quite persistent in the fruit. The fruits are excellent for canning since they remain firm and hold their color well.

Where western X occurs, Sweet Ann would make a good replacement for the highly susceptible Royal Ann variety. The new cherry’s medium size, light color, firmness, and persistent stem should make it an excellent candidate for brining purposes. Sweet Ann would also make a fine home yard variety.

Requests for budwood should be sent to Dr. Sherman V. Thomson, Department of Biology, UMC 45, Utah State University, Logan, Utah 84322.

REFERENCES


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Dr. Thomson is Associate Professor of Biology and Extension Plant Pathologist at Utah State University. His research efforts are directed toward control of fruit and vegetable diseases. He received his PhD in plant pathology from the University of Arizona, Tucson, in 1972. He was Assistant Professor of Plant Pathology at the University of California, Berkeley, for four years prior to coming to Utah State in 1978.
1. Immature alfalfa seed pods contain the beginnings of the seed growers' profits. M. Okuda

2. First instar alfalfa weevil larva, which has a voracious appetite for alfalfa. W. P. Nye

3. Alfalfa weevil adults overwinter in and around alfalfa fields. W. P. Nye

4. Three generations of lygus bugs can occur in Utah in one growing season. W. P. Nye

5. Two-spotted spider mite adults, which feed on alfalfa leaves, are shown here with their eggs. W. P. Nye

6. Damsel bugs prey on lygus bugs. W. P. Nye

7. Spotted alfalfa aphids inject toxins into alfalfa plants. W. P. Nye

8. Pea aphids feed on alfalfa plant juices. W. P. Nye

9. Green lacewing larvae feed on aphids as they develop toward adulthood. W. P. Nye

10. Green lacewing adult. W. P. Nye

11. Adult ladybird beetles and their larvae are pea aphid predators. W. P. Nye
INSECT PEST MANAGEMENT on alfalfa seed involves the integration of biological, cultural, and chemical control methods. The goal is to minimize short- and long-term control costs and to maximize net economic returns from the crop.

Alfalfa seed production warrants pest management for several reasons. It is a high-value crop returning up to $1,100 per acre annually in Utah. Alfalfa has several serious pests that require chemical control and it harbors a number of beneficial predatory insects. It is also a crop that requires bees to pollinate the flowers and set the seed.

Many Utah growers use alfalfa leafcutter bees. These bees nest in holes in banks, insect-made holes in wood, and other naturally available holes, as well as in man-made structures. The leafcutter bee has been domesticated and man-made nesting boards filled with these bees are regularly placed in shelters in and around alfalfa seed fields. To get a good seed crop, a grower must place three full boards of the bees, worth about $300, on each acre.

With such an investment in the bees, an insecticide application that harms them can result in major direct and indirect economic losses. Native groundnesting alkali bees and honey bees, which also pollinate the alfalfa, are similarly susceptible to insecticide damage. For these reasons, many alfalfa seed growers use pest management services like that offered by the USU Extension Service. Growers in Washington, Oregon, Idaho, Nevada, Montana, and Alberta are currently enrolled in alfalfa seed pest management programs.

In 1978, the first year of the USU pest management program, alfalfa acreage was sampled in west Millard County in central Utah. In 1979, the program was expanded to include acreage in Box Elder County in northwestern Utah. The 1,720 acres sampled in 1980 were in east and west Millard County and Uintah County in northeastern Utah.

How It Works—Sampling Program
Field scouts, who are available to growers on a request basis, collect information on pest and beneficial insect populations and mite damage on a weekly basis from mid-May until late August. The scouts sample fields for insects with a sweep net, and foliage samples are examined for mite damage.

Immediately after a field is sampled, the grower is provided with insect counts in chart form so that population trends and numbers of important arthropods in the field can be evaluated.

The program field supervisor helps the grower interpret the charts; provides information on insect and mite biology, damage, and control; and makes insect and mite control recommendations that provide pollinator bees with optimum protection.

The major arthropod pests for Utah's alfalfa seed growers include the lygus bug, pea aphid, spotted alfalfa aphid, alfalfa weevil, alfalfa seed chalcid, and the two-spotted spider mite. Alfalfa weevils are generally an early season problem. The adults overwinter in and around the alfalfa fields in protected places such as under debris and leaf litter. They lay eggs in the alfalfa plants during early spring and the major hatch of weevil larvae occurs in May to June, before the alfalfa starts to bloom. Left to their own devices, larvae defoliate the plants and damage the shoot tips. When an economic threshold level (population numbers that threaten to cause economic damage) of the larvae have been collected in a field and foliar damage is noticed, a spray is recommended.

The lygus bug decreases seed production by feeding on the plant sap in the seed and injecting a toxin. It also destroys alfalfa buds and causes the flowers to drop off the plants. In Utah, two to three generations of these insects are found during one growing season. It is important to control the first generation since the second and third are generally larger and more difficult to control. The USU weekly sampling program is crucial to good lygus bug control since spray applications must be matched to lygus bug susceptibility.

Two general predators, the big-eyed bug and the damsel bug, are important bio-control agents of the lygus bug. During the latter part of the growing season their populations are able to attain high enough levels to control economic threshold levels of the lygus bug. In general, the damsel bug is more numerous and important than the big-eyed bug.

Pea aphid nymphs and adults feed on juices from alfalfa leaves, stems, petioles, and flower buds. They usually feed in the growing tips and at high population levels can prevent plant growth and flowering. The plants become stunted, wilt, and turn a yellowish-green. The economic threshold is 300 to 500 aphids per standard 90-degree sweep.

The spotted alfalfa aphid is more damaging than the pea aphid and therefore has a lower economic threshold. When feeding on the alfalfa plant it injects a toxin that causes yellowing of the lower leaves and stunting of established plants. At high levels the plants are killed. In 1980, the spotted alfalfa aphid was a problem for Utah growers from June through July.

The aphid predators taken in samples include the damsel bug, the big-eyed bug, the ladybird beetle, and the green lacewing. Ladybird beetle larvae and adults are voracious predators of the pea aphid. Prior to egg laying, one member of one species consumes about 600 aphids, often exceeding 50 per day. The green lacewing larvae are also avid aphid seekers.

The two-spotted spider mite has caused losses to some alfalfa seed growers in central Utah during the past two seasons. This mite forms colonies on the lower surface of leaves where they feed on and destroy the photosynthetic tissue. This causes white stippling on the upper leaf surface. When high population levels are present, the plants appear to be dry and severely stressed. The mites are difficult to control at high population levels. Since they have a short life cycle and can rapidly reach economic threshold levels, weekly monitoring is important in preventing plant damage.

The alfalfa seed chalcid is a small wasp that lays its eggs in alfalfa seed. Each developing larva feeds on the seed from which the adult wasp emerges. The first adults are seen in the early spring and give rise to several generations during the growing season. Damage to second crop seed is generally more severe than to first crop seed, since the insect has had time to build up to higher population levels when the second crop is susceptible to attack. (Alfalfa that is grown for seed from the beginning of the season produces first crop seed. Alfalfa that is cut for one crop of hay and then grown for seed produces second-crop seed.) This insect cannot be effectively monitored with a sweep net. Instead, damage caused by the chalcid wasps is determined by seed analysis. Since chemical controls are not effective,
cultural methods must be used to keep population levels at sub-damaging levels. These include destroying: seed that remains in the field after harvest, chaff stacks, and volunteer alfalfa in waste areas and along roadsides. Where the alfalfa seed chalcid is a major problem, it is advisable to grow first crop rather than second crop seed.

**Integrated Approach**

A major emphasis has been placed on grower education by pest management experts. Information sessions have been held to inform growers of new developments in bee, insect, mite, weed, and disease management. Similar information is also placed in local newspapers. As a result of this effort and the sampling program, participating and non-participating growers have improved their pest control efforts since the program was introduced in 1978. We suspect that the program has generated greater awareness of pest management and led to growers in general paying more attention to the insects, mites, weeds, and diseases in their fields. Also, growers are more aware of the need to properly manage and protect their bees.

USU Extension Service personnel and USU research biologists are now cooperatively developing an integrated pest management program for Utah's alfalfa seed growers. Dr. Jay Karren (USU Extension Entomologist) is supervising the project. Dr. Jim Bushnell (USU Agronomy Extension Specialist) conducted a weed survey of program fields and made weed control recommendations to the growers. Dr. Jack Evans (Associate Professor of Plant Science at USU) has put out weed control plots to help solve weed problems. A plant disease survey made by Dr. Sherman Thomson (USU Extension Plant Pathologist) determined that the most prevalent alfalfa diseases were crown rot and Phytophthora root rot. Dr. William Brindley (Associate Professor of Biology at USU) and Diefalla Osman's (graduate student) insecticide bioassay technique (see UTAH SCIENCE-Spring 1980) was used to evaluate lygus bug resistance to a chemical that has provided erratic control of this insect. Cases of lygus bug resistance were found with this technique. Other insecticide-related research involved chemical pesticide plots set up by Dr. Donald Davis (Professor of Biology at USU) and Larry Jech (graduate student).

**Economic Realities**

Growers participating in the program use less pesticides than do non-program growers. At the same time, participating growers have recorded higher than average yields than non-participants. In 1980, the program acreage in Millard County averaged 335 pounds per acre versus 252 pounds per acre for non-participants. At $1 to $1.25 per pound for seed, program participants averaged $83 to $103.75 more per acre than non-participants, while spending less on pesticides.

**Future of Pest Management**

As the integrated approach to pest management becomes a practical reality for alfalfa seed growers we expect comparable applications to alfalfa hay and tree fruits in Utah. Pest management programs have been developed for these crops in other regions of the U.S. as well as in Utah. An alfalfa hay program is being developed in Cache Valley by Dr. Donald Davis.

**ABOUT THE AUTHOR**

Michi S. Okuda is IPM Field Supervisor, USU Extension Agent in Millard County.
1. Antelope bitterbrush flourishing on deer winter range, Boise River drainage, Idaho.

2. Such typical bloom by mature bitterbrush plants may produce over 15,000 seeds annually if not damaged by insects.

3. These plump bitterbrush fruits typify the productivity of insect-free shrubs. Defoliation by spanworms prevented fruits in our seed orchard from developing in 1979 and 1980.

4. Our bitterbrush seed orchard near Nephi on May 22, 1979. An enormous population of tiny, immature loopers was already on these shrubs but were as yet undetected because they had not yet begun to cause visible damage. G. Van Epps

5. The same orchard on June 6, 1979, after the loopers had matured and stripped the shrubs of leaves and flowers. G. Van Epps

6. Insecticide being applied by a tractor-driven sprayer to control young larvae in 1980. The application is made prior to when the spanworm larvae develop into their destructive last instars. G. Van Epps
7. Third instar (less than half grown) spanworm loopers on bitterbrush. Up to this stage of development, the loopers mainly just etch the leaves. Hereafter, however, growth is rapid and leaves and flowers are consumed.

8. This fourth instar larva (on ceanothus) has assumed its stick-like, motionless stance in preparation for molting. Larvae often lock into this position when ready to molt, usually supported by a silk thread extending from larval mouth to leaf.

9. Mature, fifth instar looper greedily reaching for its final bite of a bitterbrush leaf. Conical wart-like projections on front segments of body are characteristic of this species.

10. Male pupa of the walnut spanworm. The female is similar but stouter and is hunch-backed in side profile. The insects overwinter as pupae in the soil beneath defoliated shrubs.

11. Adult male moth with its prominent feathery antennae, which are presumed to aid in locating the wingless females.

12. Wingless female on a twig containing a cluster of eggs. This species depends on wind to disperse its young larvae, although females may sometimes be transported by animals or conveyances.
GORDON A. VAN EPPS and MALCOLM M. FURNISS

Introduction

AN ATTRACTIVE AND USEFUL WILDLAND SHRUB named antelope bitterbrush is an anomaly in our western environment. A member of the rose family, its scientific name, *Purshia tridentata*, is derived from the eminent 19th century botanist, Frederick A. Pursh, and the 3-toothed appearance of its leaves. The common name describes how it tastes to humans (it is sometimes called quininebrush); the anomaly occurs because deer and other ungulates relish it, as we would ice cream. As a further surprise, unlike ice cream, bitterbrush is chock-full of nutrition, matching that of alfalfa in terms of total digestible nutrients.¹

The many browsers that use bitterbrush include: domestic sheep, goats, and cattle, along with big game animals such as deer, elk, moose, pronghorn antelope, and big horn sheep. Bitterbrush seeds constitute a major part of the diets of rodents and birds, and (unfortunately) are a favored food of several insects such as stink bugs and a mysterious midge that so far has evaded specific identification.

Although bitterbrush is less common than sagebrush (*Artemisia* spp.), for example, the shrub (including a related species, desert bitterbrush, *P. glan­ dulosa*) ranges over 138 million hectares (340 million acres) in 11 western states, including Utah. It has, however, disappeared from parts of its range due to various causes, including wild fires. Natural resource agencies have made substantial efforts to rehabilitate deer winter ranges by either planting or encouraging bitterbrush. Sustaining these efforts depends on access to a reliable source of reasonably priced bitterbrush seed from plants known to be compatible with the area to be planted.


Establishment of Seed Orchard

Seed collecting from wild shrubs is a chancy business at best. Crops fluctuate with weather, insect damage, and other factors. Sometimes, just when seeds are ripe, hailstorms or wind strip the fruits from plants before they can be collected. Then too, a majority of wild-produced seeds may be non-viable, due to feeding by juice-sucking stink bugs or infestation by an unidentified species of midge. Commercial sources of wild seed may have seed from plants that are not adapted to the desired planting site. As an example, seeds from plants growing in the Snake River and Columbia Basins on soils derived from igneous parent material produce plants that do poorly when planted in soils derived from sedimentary parent material as occurs in the Great Basin.

In response to these problems and agency needs, an experimental bitterbrush seed orchard was established in 1966 by the Utah Agricultural Experiment Station. Resulting bitterbrush plants were thinned and optimum spacing for maximum seed production was determined. A productive bitterbrush plant can produce upward of a pound of seed annually, valued at $11 to $17.60/kg ($5 to $8/lb) depending on year and source. The potential annual production of seed in an orchard of this size, even considering the varied spacing, is on the order of 182 kg/ha, with a value of $2,000 to $3,200/ha.

On the Trail of the Looper’s Identity

In the orchard, the loopers soon dropped to the ground, burrowed into the soil, and transformed into immobile pupae. There they overwintered until emerging in late March, 1980. We speeded up the life cycle in the laboratory by refrigerating pupae for several months, then removing them to a warm room. Finally, we had the gray, winged male with its enormous featherlike antennae and the hunchbacked, wingless gray female with her threadlike antennae.

Through the help of Dr. Douglas C. Ferguson, a knowledgeable lepidopterist employed by the USDA’s Systematic Entomology Laboratory in Washington, D.C., we learned that the insect was the walnut spanworm, *Phigalia plumogeraria*, described in 1888 by an entomologist named George D. Huist. A few adults had been collected in flight previously in Utah, but it was unknown then where its immature stages had occurred. In fact, the only account of the insect in nature was by D. W. Coquillette, describing an outbreak in 1893 in an English walnut orchard in California.

Discovery of the Looper Outbreak

In 1979, the 1.6 m (5 ft) tall, 13-year-old, well-tended bitterbrush shrubs in the seed orchard south of Nephi reached full bloom on May 20. The pleasant fragrance of the abundant yellow flowers filled the air. Personnel responsible for maintaining the shrubs sensed that this was the year they would reap the long-awaited bumper seed crop in reward for their investments of time and personal care.

After the May 20 viewing, the workers turned to other tasks awaiting their next scheduled visit in early June. By June 6, however, they could only stare in disbelief at an expanse of bare stems—all that remained of the once luxuriant vegetation. Only on a few plants did a leaf or developing fruit remain.

Examination of the denuded shrubs disclosed thousands of gray 18 to 35 mm long, stick-like loopers. The army walked in looping fashion along the stems because each member had legs only at opposite ends of its body. A sample of these geometrid “measuring worms” was sent to specialists for identification. But, as is often the case, the invaders could not be identified in their immature stage because species descriptions are based invariably on the adult stage (winged moth, in this case).
Description of Life Stages and Behavior

The mostly gray male moth is 10 to 11 mm long and has a wing span of about 50 mm. Its most conspicuous feature, however, is the very broad, featherlike antennae. The hunch-backed gray female is 7 to 11 mm long. Her wings are functionless pads and she must walk wherever she goes. The oblong eggs are 0.9 mm long, being the color of pewter or sometimes with a brassy tinge. Under magnification, they appear to have been dented at their ends with a ballpeen hammer.

Upon hatching, the larvae, or loopers, are blackish and only 2 or 3 mm long. In this stage, they readily drop themselves from plants on silk threads and are dispersed by wind. They molt five times, growing geometrically in size until their fifth instar at which time they may be up to 35 mm long. The orchard’s sudden defoliation between May 20 and June 6, 1979 occurred because little visible damage is done by the insects until their fourth and (mainly) fifth instar stages—both of which occurred after May 20. Younger larvae tend to merely etch the leaf surface.

In the laboratory, we found that larvae also thrived on other shrubs such as redstem ceanothus (Ceanothus sanguineus), mountain mahogany (Cercocarpus ledifolius), wild rose (Rosa woodsii), serviceberry (Amelanchier spp.), and Scouler’s willow (Salix scouleri ana). Although the wingless condition of the females limits their dispersal, several species of shrubs are potential sources of outbreaks, given suitable conditions. For any spanworm population to persist, however, adjacent soil must be friable and readily penetrable by the larvae as they seek to pupate and overwinter. A concentration of host plants in the neighborhood is essential to females so they can ascend and lay eggs, and to the first instar larvae, which disperse and spread by wind.

In spite of the virtually complete defoliation of the bitterbrush orchard in 1979, the shrubs refoliated fairly well later that year, drawing on their stored reserves. No fruit was produced, however, because the loopers had destroyed the flowers. Flowers were again lacking in 1980, apparently due to the 1979 feeding damage done to terminal buds, but the shrubs did leaf out normally.

Repeat Performance Headed Off

With attention firmly riveted to spanworm activities within the orchard, we set about sampling the abundance of their eggs on bitterbrush on April 10, 1980. Astoundingly, each egg cluster averaged 159 eggs, and there were nearly 8 egg clusters per shrub. The orchard was calculated to contain a half million eggs, viability of which was found to be 83 percent. Further devastation seemed inevitable unless action was taken.

We began monitoring the larval population after eggs hatched. Meanwhile we consulted Dr. Jay B. Karren, Extension Entomologist, Utah State University, regarding possible controls for measuring worms. We were too late to consider use of sticky bands around the bases of shrubs to prevent females from climbing them to lay eggs. However, a chemical spray, consisting of 2.93 ml of Sevimol-4 (40 percent carbaryl) per liter of water was said to be relatively safe and effective against similar larvae.

On May 19, we determined that there were nearly two loopers per 7.5 cm (3 inches) of sample twig. They were still in their first and second instars, and not yet large enough to cause visible feeding damage. On May 20, a garden sprayer powered by a gasoline engine and pulled with a garden tractor was used to apply the diluted insecticide to shrubs in the one ha (2.5 ac) orchard at a rate of 593 l/ha (50 gals/ac) or 1.7 l actual carbaryl/ha (1/2 pt/ac). Results were remarkable. Two days later only five larvae were found during our examination of thirty plants.

Lessons Learned

The defoliation caused by this insect, which was previously unknown on bitterbrush, indicates that even such a well-studied shrub species may be subjected to devastation by new causes. Other examples abound. Consider seed orchards of fourwing saltbush (Atriplex canescens), which have suffered defoliation by the casebearing caterpillar (Coleophora atriplicivora) and feeding damage by spider mites. Recently, an even lesser known geometrid moth has defoliated and permanently damaged or killed mountain mahogany over thousands of acres on Sheldon Wildlife Refuge in northwestern Nevada.

The possibility of plant diseases being vectored to shrubs by introduced or native insects is even less well studied. And, of course, monoculture seed orchards of any shrub species are likely to present conditions that may be successfully exploited by damaging insects. This is true partly because weeding denies some parasites and predators needed habitats, and also because any plant grown in monoculture is apt to be more susceptible than when it grows among other plant species. For example, we found only one predator of the walnut spanworm—a bombyliid fly—and that occurred rarely in the clean-cultivated bitterbrush seed orchard.

Because the values at stake were so high, we were forced to impose control measures on the spanworm infestation without predetermining ultimate effects. Nor were we able to compare the orchard situation with a comparable infestation in a natural bitterbrush stand so as to determine other possible ways (and/or need) to control the insects. Should spanworm outbreaks occur in the future, however, the means are now available for identifying the insect in any of its stages. We are also able to evaluate the insect’s abundance as well as anticipate its seasonal history and development when scheduling control. Similar knowledge needs to be developed about the remaining myriad of shrub-infesting insects.
Acknowledgments

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Moths were identified by Dr. Douglas C. Ferguson, USDA Systematic Entomology Laboratory, Washington, D.C. Eric Christensen, Utah State University, and Blaine Moore, Snow College, assisted with field data. Assisting with rearing and laboratory work were Charles R. Hepner, Jeffrey L. Littlefield, and Frances M. Bales, USDA Forest Service, Moscow, Idaho.

Disclaimer

This publication reports research involving a pesticide. It does not contain recommendations for its use nor does it imply that the use discussed has been registered. All uses of pesticides must be registered by appropriate state and/or federal agencies before they can be recommended.

The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by Utah State University or by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.
13. The delicate, yellow, five-petal flowers of bitterbrush testify to its kinship with the rose family, which contains several shrub species susceptible to walnut spanworm. The susceptibles include mountain mahogany, serviceberry, and wild roses. The narrow, leathery, greyish brown object is a persistent fruit of the previous year that had been infested by a midge.

14. Among the many other insects attracted to bitterbrush are stink bugs, which suck juice from developing seeds.

15. Once pierced by juice-sucking stink bugs, seed become spotted and their germination capacity is lowered to nearly half that of normal seeds.

16. Two third-instar caterpillars hotfooting across a leaf of mountain mahogany in the greenhouse where various host shrubs were being tested as to their appetite appeal.

ABOUT THE AUTHORS

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WHAT CAN BE PREDICTED about the cost/benefit tradeoffs associated with coal-fired electric power production in Utah's western desert?

Even when social and political factors are temporarily ignored, that question spawns such a tangled mass of variables and evaluative criteria that the complexities of their interactions are well beyond casual analyses. In contributing to a comprehensive research effort to answer the question, members of a USU team turned to computer simulation models.

Based on specified assumptions relative to: production and transportation costs, electricity demands, coal and water qualities and availabilities, plus air quality and other environmental components, the researchers identified specific production possibilities for particular areas of Utah's western desert. Prime restrictions seem to center around coal production and transportation costs, and adherence to air quality standards. Before valid decisions can be made about the desert and electricity production, however, more definitive data will have to be researched and inserted into the models.

For some time, the western desert area of Utah has lain still as a sleeping giant. Activity there has been mainly limited to the traditional rotation of sheep and cattle into winter range valleys, and the alfalfa, small grain, and dairy and livestock operations that continue in and around Delta, Fillmore, Milford, and Beryl. At the turn of the century, a mineral prospecting and mining industry flourished briefly in the Topaz, Mineral, and San Francisco mountains (and elsewhere) until poor prices and low yields closed it down. Farming has been productive whenever water has been available, and one can't help but imagine great farms and bountiful productivity if only the vast Escalante Valley had a Colorado River running through it.

But even without a Colorado, the sleeping giant now appears to be awakening. First came the decision to relocate the large Intermountain Power Project from eastern Utah to an area west of Lyndyl in Millard County. Then we heard the proposal to deploy a land-based missile system in several of the valleys west of Delta and Milford and westward into Nevada. Many smaller projects have developed in the past two to three years such as beryllium processing, uranium and molybdenum exploration, quick lime, and cement.

Three agencies of the federal government, the predominant landowner in the area, are laying special claims to the future of the western desert. For the U.S. Department of Energy, the motivation is the possible production of energy, particularly electric power. Agencies of the State of Utah are equally interested in what takes place in the western desert.

The combined federal and state interests resulted in an extensive investigation by researchers of the Utah Consortium for Energy Research and Education and of the Utah Agricultural Experiment Station. Their goal is to define the advantages and disadvantages of various general areas in the state for future electric power generation and alternative energy resource use. Areas in western Utah were investigated initially, and currently the potential of the Colorado Plateau area of Utah is being reviewed.

Extensive reviews of literature, the operation of public policy, and utility
decision making relative to facility siting generated a set of evaluative criteria:

1. Air quality deterioration.
2. Water availability.
3. Lands designated for alternative and incompatible uses.
4. Endangered animal or plant species.
5. Surface slope restrictions.
6. Known earthquake faults and seismic activity.
7. Uneconomic transportation requirements.
8. Uneconomic fuel requirements.
10. Limited transmission corridors and/or wheeling opportunities.
11. Regulatory delays of excessive costs.
12. Adverse socioeconomic impacts.

These criteria guided the evaluation associated with each research task. The USU research team was concerned with assessing the economic feasibility and environmental aspects of general areas in western Utah relative to potential energy facility siting. The major effort in environmental evaluation necessitated extensive air quality modeling to identify air quality decrements in Utah's western valleys under current and anticipated air quality standards. Other environmental issues were considered, but air quality turned out to be the most complex and restrictive.

Using economic feasibility modeling, the influence of each criterion on optimal (i.e., net return maximizing) future production of electricity in western Utah was traced. Simulations produced by a constrained model (a mathematical programming model) helped to determine electric power production limits for western Utah. Some of the results of the air quality and economic feasibility research are summarized in what follows. Other results of the total effort can be found in Glover (1980), Utah Consortium for Energy Research and Education (1980), Lewis (1980), and Wooldridge (1979).

**Air Quality Concerns**

Coal emissions vary according to chemical makeup. The main pollutants of concern in coal-fired electricity generation are those for which major standards have been derived, which include total suspended particulate matter (TSP), sulfur dioxide (SO₂), and nitrogen oxides (NOₓ). Attention in this study was centered on these three pollutants, and emission factors associated with various coal feed rates (use per megawatt of production) were calculated to identify potential emission problems (e.g., Table 1).

An atmospheric dispersion or "plume mixing" model was developed to aid in: screening broad areas or zones in western Utah, and defining existing and future production potentials. The coal feed rates used as inputs in the model determined emission factors, measured in tons of pollutants per hour per megawatt (TPH/MWe), and were calculated for various coal sources (mines or coal fields) and average boiler heat rates (Btu's per megawatt hour). Emissions are very sensitive to boiler types as well as to emission control technologies and their operation. We attempted to account for these variations; however, alternative generation technologies, and differences in their operation, would modify our projections.

The atmospheric dispersion model selected for screening the air quality of potential sites was the "limited mixing" model recommended by the U.S. Environmental Protection Agency for large elevated point sources. This steady-state Gaussian plume technique is applicable to rural areas having uneven terrain and can determine the maximum concentrations for averaging times between one and 24 hours due to point sources. In its application, no absorption of SO₂ is allowed at the surface, no decay of SO₂ to sulfates is postulated, and the power plant plume is allowed to impinge directly on terrain surfaces.

Calibration of the model for the western Utah region indicated that sulfur dioxide and the Preventive-Deterioration (PSD) Class I standard for sulfur dioxide concentrations were the most serious air pollutant and constraining air quality standards. At the present, all areas except the National Parks and Monuments (but not Dinosaur Monument) and nonattainment areas along the Wasatch Front are classified Class II, a less restrictive air quality standard.

The model was also used to examine the ability of the western Utah area to accommodate emissions relative to the restraints or advantages of various locations for future power production. Toward that end, allowable electric power generation was derived for: 1) three-hour maximum allowable increase impingement on an area with a given air quality class (such as PSD Class I versus Class II); 2) a control strategy of 90 percent sulfur clean up; and 3) specific sulfur and heat contents of coal.

A full grid analysis was first prepared for a coal emitting 0.0049 tons of SO₂ per hour for each megawatt of electrical power produced, normalized to a heat factor of 10,000 Btu per kilowatt hour. The quality of coal assumed matches that available from the Kemmerer, Wyoming field and is similar to some leases in the Wasatch Plateau and Book Cliffs fields in Carbon County, Utah. Using the air dispersion model, maps were developed illustrating maximum megawatt production capacity for a single source with such coal (e.g., Figure 1). The design capacity production levels shown reflect 90 percent SO₂ emission control and a 300-meter mixing depth. The mapped patterns would indicate higher electricity production levels if the mixing depth were increased, and lower production if 90 percent emission control were relaxed.

In some areas, as shown in Figure 1, the permissible electric power generation (assuming 90 percent SO₂ control) ranges upward to 5,000 megawatts. The pattern of restriction that the potential Class I PSD standard places on production can also be seen. In the example displayed in Figure 2, only the Deep Creek Range potential wilderness area in western Juab County and the National Parks were assumed to have a Class I restriction. High terrain areas restrict the production potential near Nephi and in southeastern Iron County. Similarly, Zion National Park's Class I rating sharply curtails production within a 50-kilometer radius of its borders. The general pattern of relative least restriction (Figure 2) includes northeast Millard County, western Juab County, Snake Valley in western Millard County, central Sanpete-Sevier Counties, the Milford-Black Rock area, central-west central Iron County, and western and northwestern Box Elder County.
The influences exerted by coal quality (sulfur content) and the PSD Class I standard assumed at Mt. Nebo, the Deep Creek Range, and Ashdown Gorge are illustrated in Figures 2 and 3, where, respectively, Henry Mountains and Salina Canyon coal type parameters were used in the model. The heat content of coal from the Henry Mountains field is higher at 12,833 Btu/lb, but its sulfur content is also higher at 2.03 percent. Salina Canyon coal is one of the lowest in sulfur (.45 percent) but is also lower in heat content at 11,360 Btu/lb.

**Some Least Restrictive Production Zones**

As a result of applying air quality criteria (as briefly illustrated above) in addition to considering endangered species, seismic conditions, water availability, gradient, and land use criteria (but not economic feasibility), representative zones with least restrictive characteristics were delineated in Utah’s Great Basin area. In addition to seven favorable zones, we considered the relatively sensitive areas of eastern Juab County and central-west central Iron County (which have been discussed by various groups for possible siting of generation plants) to obtain information on sensitivity.

Each of the zones (Figure 4) contains environmentally qualified sites, but some have more than others. The air quality criterion turned out to be one of the most critical and is emphasized here. The zones were not ranked in any order of priority. Such ranking is left to the political process, if, in fact, interest develops in locating future power production in western Utah. Certainly the Intermountain Power Project (now to be located in northeast Millard County) indicates a move in that direction.

**Air Modeling in the Zones**

The limited mixing model described earlier was used to identify electric power production constraints in each zone. Interactions between multiple plumes (from power plants only) were simulated during this phase of modeling to provide information about each zone’s approximate carrying capacity given specified air quality standards and the existence of more than one coal-fired plant. Initial production levels had to be assumed, with location and production tradeoffs derived from the modeling process. The mixing depth was lowered to 300 meters for areas where air could be restricted by stagnation, and open areas previously modeled as possible PSD (Prevent-Significant-Deterioration) Class III were changed to PSD Class II as they are now classified under PSD standard implementation.

The results obtained (which are detailed in Wooldridge 1979) included those for the Iron County zone, where two production levels (4,000 and 500 MW) were considered at a site near Beryl, Utah. A second site, which was assumed near Cedar City, allowed plume interaction since the two sites are nearly in a straight impingement line relative to Cedar Breaks National Monument (a Class I area).

Without interaction of the plumes from the two source locations, the maximum production limit at a Beryl site was 2,700 megawatts (MW), with a 300-meter mixing depth and the base coal quality parameters described earlier. Similarly, the maximum at the Cedar City site was 1,100 MW.

Three situations were indicated: 1) If 500 MW were assumed to be produced at a Beryl site, approximately 900 MW could be produced at a Cedar City site before concentrations of SO₂ at the Cedar Breaks area would violate the Class I PSD air quality standard. 2) If 500 MW were produced at a Cedar City site, approximately 1,500 MW could be produced at a Beryl site, and 3) If 1,000 MW were produced at a Beryl site, 700 MW could be produced at the Cedar site.

Three production points or corners were considered for the northeast Millard County zone, viz., Delta-Lynnndyl (assumed to produce 3,000 MW), the Soap Wash area, and the McCornik-Greenwood area. This configuration permitted allowable production at one corner assuming none at the other two corners. The amounts were 3,000 MW for the Delta-Lynnndyl corner, 5,600 MW at the Soap Wash corner, and 5,600 MW at the McCornik-Greenwood corner.

If one of the other two corners, Soap Wash or McCornik-Greenwood, was added to the assumed 3,000 MW at the Delta-Lynnndyl corner, production could be approximately 6,500 MW at that incoming corner site. This would allow a total carrying capacity of 9,500 MW for the zone assuming use of the base coal. Use of low sulfur coal would increase the capacity by approximately 2,000 to 10,000 MW, depending on whether the source was the Wasatch Plateau, Evanston, Wyoming, or Salina Canyon field. Other interactions that were modeled can be found in Glover (1980) and Wooldridge (1979).

**TABLE 1. Feed Rates and Emission Factors for Various Coal Sources from Utah, Wyoming, and New Mexico based on a 10,000 BTU/kwh Heat Rate Plant**

<table>
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<tr>
<th>Coal source</th>
<th>BTU's/lb</th>
<th>% S</th>
<th>% Ash</th>
<th>80% Capacity Feed Rate in TPH/MW</th>
<th>TPH</th>
<th>80% Emission Factors in TPH/MW</th>
<th>NOx</th>
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**WYOMING**

| Evanston          | 10,450   | 0.40| 7.20  | 3827                            | 0.02342 | 0.00291                       | 0.00344 |
| Kemmerer          | 9,683    | 0.50| 4.80  | 4130                            | 0.01717 | 0.00392                       | 0.00372 |
| Powder River      | 8,360    | 0.50| 7.35  | 4784                            | 0.02496 | 0.00454                       | 0.00431 |
| Rock Springs      | 9,210    | 0.60| 10.50 | 4342                            | 0.03905 | 0.00495                       | 0.00391 |
| Great Divide      | 8,377    | 9.00| 10.00 | 4777                            | 0.04058 | 0.00816                       | 0.00406 |
| Hanna             | 10,500   | 0.60| 6.00  | 3809                            | 0.01943 | 0.00434                       | 0.00324 |

**NEW MEXICO**

| Gallup            | 10,637   | 0.42| 7.95  | 3780                            | 0.02540 | 0.00300                       | 0.00320 |
| Star Lake         | 9,500    | 6.00| 20.00 | 4209                            | 0.07157 | 0.00480                       | 0.00358 |
Economic Feasibility Evaluation

Several factors influence the feasibility of siting electricity generating facilities in any particular location, not the least of which are the economic conditions associated with the production and sale of electricity. A utility firm has to assess eventual demand for electricity and the cost conditions for meeting that demand. The firm also has to take into account various public concerns about resource use in producing energy, e.g., do institutional restrictions to resource use exist; are public lands or public resources involved? Water, air, fuel, transmission capacity, and land resource availabilities affect electricity supply conditions and the relative efficiencies of alternative locations for supplying needed power.

In our economic evaluation of siting electric energy facilities in western Utah, the major task was to include the major economic decisions involved in siting and to assess the factors that would influence the economic feasibility of various locations for future electric power production. We first considered supply conditions and the factors that might alter these conditions given a known or expected demand.

An optimization model was developed to represent the decision process of a utility firm. We allowed for various major public and private concerns in a framework that could derive information for policy makers. Maximizing net returns constitutes the major economic objective of the model's decision process. The constraint system of the model includes the institutional, environmental, technological, and economic concerns or restraints (e.g., air quality decrements, water availability limits, transmission capacity, fuel transportation routes and capacities, and water quality maintenance specifications) within which the economic objective can be carried out (Figure 5).

We thus could make changes in constraints and trace their impacts on net returns, which helped in evaluating facility sites. Likewise, prices and/or costs could be altered and their effects on the feasibility of various locations similarly traced. Further detailed discussion of the model can be found in Keith (1980).

One major use of the model in our research into the economic feasibility of various areas in western Utah for future electric power generation, was in evaluating each zone, and combinations of zones. It was recognized that much of the financial burden of constructing new transmission lines to markets (California, Nevada, and Utah) would fall to the first plant or set of plants to come into operation. With the "first plant," the model was then used to analyze the impact that changes in the demand and supply sides of the western electrical energy market would have on carrying capacity in western Utah. Variations on the demand side were simulated by changing the price of electricity and/or area power needs. Changes in supply or cost conditions were represented by altering constraint system components (e.g., air quality decrements, water availability, and coal availability).

Evaluation of Initial Zone Feasibility

Initially, the total cost per megawatt hour (MWh) of building new transmission lines associated with each zone was included in the objective function of the model. We then used the model to provide information on the zone or zones in which power could be most cheaply generated while the initially required new transmission capacity was being developed. These solutions were derived for two different assumptions about SO₂ clean-up: viz., the mandated 90 percent SO₂ control imposed, and allowing the model (i.e., the economic conditions) to select the control level.

Our results indicated that: if SO₂ emission control were selected by economic conditions, and the average busbar (power plant gate price without delivery to use point) price of electricity is $25/MWh, SO₂ would be controlled at a 70 percent level. Power for California markets would then be produced in the Milford-Black Rock zone, while power for the Nevada and Utah markets would be more feasibly produced in the eastern Juab and Sanpete-Sevier Counties zones. No production from other zones in western Utah entered the optimal solution of the model at the base case average busbar price of electricity of $25 per MWh. The production, coal use, and transmission solution is illustrated in Figure 6.

When SO₂ emissions control was set at the 90 percent level, given the same price of electricity, then cheaper coal and transport costs determined the "first plant" zone configuration. The northeast Millard County zone became the most favorable generation zone for providing power to California, but the eastern Juab and Sanpete-Sevier Counties zones still provided power for Utah and Nevada. In this case, less power was generated overall in western Utah (Figure 7).

The model solution in this latter case suggested that, assuming higher emission control costs, a tradeoff could be made between transmission and cheaper coal (mining plus transportation). In such a case, coal costs would dominate transmission costs and power production would move closer to the coal source. The analysis showed that carrying capacities above approximately 2,000 MW would mean higher prices for electricity.

Model Results Assuming Varying Supply-Demand Conditions

Using results from our first simulations of the feasible "first plant" configuration of zones, the cost structure of the transmission systems was altered to reflect an in-place, initial generation plant complex in the three identified zones. The model was then optimized subject to various assumptions about supply and demand conditions given the existence of some initial generation from the three-zone original plant complexes as derived earlier. The primary changes assumed in supply conditions were in emission control and PSD standards. Demand changes were reflected in the price of electricity and expanded power needs, which were assumed. Among the major results of imposing such changes on the model were:

a) PSD Class II Everywhere, Except Class I in National Parks—$30/MWh Electricity Price. Additional electricity would be produced in all the originally selected zones (northeast Millard, eastern Juab, Sanpete-Sevier, and Milford-Black Rock) plus 1,300 MW in the central-west central Iron County zone. Considerable is generated for California markets in all of the five zones. Feasible SO₂ emission control would be at the 85 percent level and low sulfur coal from both western Wyoming and central Utah fields would be used.
b) PSD Class II Everywhere, Except Class I in National Parks—
$40/MWh Electricity Price—
California Transmission Route
Capacity Increased to 20,000 MW.
With very high growth in export
demand, carrying capacity in the
region would be increased to over
20,000 MW, and the northeast
Millard and eastern Juab County
zones would exceed their single
source production limits as derived
from the air dispersion model.
Those limits would be exceeded by
mixing low sulfur coal with coal of
high heat content as allowed by the
economic model. The Emery and
Kaiparowits coal fields would come
into production under the high
growth assumptions, but would be
mixed with the lower-sulfur western
Utah and central Utah coals.
Large withdrawals of water
can occur. In the Cedar-Beaver
drainage basin, increased generation to the
projected high levels would cause a
shift from full to partial irrigation of
alfalfa, and some 10,000 acres of
previously irrigated Class III land
would not be irrigated. Sprinkler
irrigation would increase in the
Sevier Basin to help control salinity and to compensate for water
moving from agricultural to energy
production uses. At the maximum
electricity production, some 14,500
acres would be withdrawn from
irrigated agriculture in the Sevier
and Cedar-Beaver Basins.
Ninety percent SO₂ control would be
feasible in the more environmen-
tally sensitive zones of
eastern Juab County and central—
west central Iron County and in the
Sanpete-Sevier Counties zone.
Eighty-five percent SO₂ control is
selected by the model in the more
open receptor zones such as the
Milford-Black Rock and northeast
Millard County areas.
c) PSD Class II Everywhere, Except
Class I in National Parks—
$30/MWh Utah/Nevada and
$40/MWh California—imposed 90
Percent SO₂ Control. Under these
assumptions, the northeast Millard
County zone became the leading
supply zone for the California
market, but production for that
market was also feasible in the
Milford-Black Rock, eastern Juab
County, Sanpete-Sevier Counties,
and Iron County zones.
d) PSD Class II Everywhere, Except
Class I in National Parks—
$30/MWh Utah/Nevada and
$40/MWh California—California
Demand Limited to 2,000 MW,
Utah Demand 1,500 MW, Nevada
Demand 1,000 MW—imposed 90
Percent SO₂ Control. Recent
studies of the short-term future
indicate that 2,000 MW, 1,500 MW,
and 1,000 MW will be needed in
California, Utah, and Nevada,
respectively. The Milford-Black
Rock zone would be the major
producing area for the California
market in this case, but some
electricity would also be produced
for that market in northeast Millard
County. The Iron County zone
becomes infeasible for any
production, and power from the
eastern Juab County zone would be
routed only to Nevada while only
the Sanpete-Sevier Counties zone
would be meeting the additional
Utah electricity demand.

Some Conclusions

Probably the most important charac-
teristic of the Great Basin area of Utah
for future energy production is the
availability of a substantial air quality
decrement under current air quality
standards. Of lesser importance, but
related to the air quality concern, is the
distance between the western tier of
counties in Utah and the state's scenic
land areas, national parks, national
monuments, and national forests. The
relative absence of industrial activity is
another attraction.

These characteristics have prompted
the electric power industry and
government agencies involved with
energy development to view the Great
Basin, and western Utah in particular,
as a favorable producing region. Serious
economic restrictions, however, are
associated with energy production in the
region. It is some distance from the
cheapest coal (in Wyoming and New
Mexico). While coal is abundant on the
nearby Colorado Plateau in eastern and
southeastern Utah, nearly all of it would
have to be mined underground at a
comparatively high cost.

An analysis of Weaver's (1980)
electricity demand projections for the
western states indicated that the
average annual growth in demand could
range between 2.7 and 4.7 percent
through the year 2000. In other words,
between 3,000 and 5,000 MW per year
will be required unless a future and
presently unanticipated change occurs
in consumption patterns. This does not
mean that a 3,000 to 5,000 MW annual
production is anticipated in western
Utah. Utah will have a share, however,
since coal is located within the state.

The results of our air dispersion
modeling effort indicated that a capacity
of some 40,000 MW could be installed
in western Utah if 90 percent SO₂
removal were assumed. If no SO₂
removal is enforced, then only a 4,000
MW production level or less could be
installed given current PSD increment
requirements. If costs of electricity
production are considered in addition to
air quality restrictions, current prices
would limit western Utah capacity to
less than 2,000 MW. Increasing prices
by about 20 percent would extend
capacity in the region to between
12,000 and 20,000 MW, depending upon
specific technological, environmental,
and other assumptions.

Electricity transmission costs are
dominated by mining, transportation,
and air quality maintenance costs. The
east-central zones delineated in western
Utah therefore appear to be relatively
feasible for future electricity generation.

Preliminary investigations of the
economic feasibility of Utah's Colorado
Plateau region, or of western Wyoming,
relative to the economic feasibility of
western Utah indicate that the cost of
transporting coal to western Utah for
power generation is quite expensive
compared to other options. In other
words, real costs are associated with
preserving air quality in areas where
coil is located. We must caution,
however, that the verdict on that issue
has not yet been reached, and the
authors are giving these concerns
further study. Preliminary indications
from air dispersion modeling of Utah's
Colorado Plateau suggests that air
quality maintenance on the Plateau is
quite restrictive in some areas. Further
information is needed on the tradeoffs
that exist between locations before valid
decisions can be made.

ABOUT THE AUTHORS

T. F. Glover is a professor in the Department
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J. E. Keith is an associate professor in the
Economics Department and his research
interests are in natural resource economics
and policy.
FIGURE 1. Permissible electric power production based on SO\textsubscript{2} emission rate of 0.0049048 TPH/MW and 90 percent SO\textsubscript{2} control (300 meter mixing depth).

FIGURE 2. Permissible electric power production based on Henry Mountains coal, 90 percent SO\textsubscript{2} removal, 10,000 Btu/KWH, 0.0150256 TPH/KW SO\textsubscript{2}.

FIGURE 3. Permissible electric power production based on Salina Canyon coal, 10,000 Btu/KWH, 0.0014783947 TPH/KW SO\textsubscript{2}.


FIGURE 5. General economic feasibility model.

FIGURE 6. Optimal initial production zones.

FIGURE 7. Optimal initial production zones.

REFERENCES


IT IS NO SECRET that nonmetropolitan counties throughout the nation had lost millions of residents in the decades up to the 1970s, including around three million during the 1960s (Beale 1975). In each year between 1970 and 1979, however, more people moved to than from sparsely populated areas.

While investigating such migration patterns in Utah, we compared the migration plans of Utah’s 1975 and 1980 high school seniors. The migration rate of this age group is as much as triple that of people in earlier and later stages of the life cycle. We focused on migration intentions because they are relevant to future trends in migration. Migration plans may also be indicative of satisfaction with opportunities young adults perceive within various communities.

Our data were gathered shortly before high school graduation—when the individuals were likely to be giving serious thought to long-term plans. We then compared potential 1975 and 1980 migration flows between rural, urban, and metropolitan counties in Utah, and the out-of-state migrations that would have occurred if the respondent high school seniors had fulfilled their intentions.

Data
Samples of graduating high school seniors in 24 of Utah’s 29 counties were surveyed in 1975 and 1980. A total of 2,529 seniors participated in the 1975 survey, while 3,304 seniors participated in 1980. To facilitate comparisons, the 1980 survey replicated the 1975 survey—the same 44 high schools were surveyed and the same questionnaire was administered. Student participation was voluntary. Graduating seniors in the rural counties composed around 7 percent of the state’s graduating seniors in 1975 and 1980, whereas they amounted to approximately 34 percent of our respondents. Adjustments permitted comparable analyses regardless of county population.

The students’ counties of residence were classified as rural, urban, or metropolitan. A county was classed as rural if its largest population center was less than 2,500 people in 1970. Urban counties had at least one center of 2,500 population or more, but were not part of the Ogden, Salt Lake City, or Provo metropolitan complexes. Metropolitan counties were associated with the Ogden, Salt Lake City, or Provo metropolitan areas. When the rural, urban, and metropolitan samples were combined, data were adjusted to insure that the statistics were appropriate for the state as a whole.

Responses to questions asked in our survey that resembled questions asked in a state Board of Education survey of all Utah students were similar to those given to the Board. For example, our 1980 survey of 3,304 high school seniors indicated that 65.7 percent of Utah’s graduating seniors would be continuing their education, compared to 67.2 percent of the Board of Education’s complete survey of the 20,282 students. This closeness of results suggested that (when weighted) our samples are representative of the state’s graduates.

The students were asked to list the city and state in which they were most likely to live most of the remainder of their lives. We then identified county of current residence and preferred county of destination. From those data we derived the following classifications: (1) stayers—those remaining within their current county of residence, (2) migrants within Utah—those shifting to a different county in Utah, and (3) migrants outside Utah—those listing a place outside of Utah. Previous research has shown a close relationship between migration intentions and subsequent actual migration. While our data do not portray real flows, they do indicate strong potentials.

Analysis
In both 1975 and 1980, only about 50 percent of the high school seniors in Utah’s rural counties intended to stay put, while metropolitan counties had the highest percentage of stayers, over 70 percent. Of the high school seniors in urban counties, around 58 percent did not expect to move away (Figure 1).

The percentages of the seniors who intended to live most of the remainder of their lives in a Utah county other than their current county were also graphed (Figure 1). Overall, the rural counties had the highest percentage of youths intending to relocate within Utah; the metropolitan counties had the lowest percentage. Indeed, hardly any of the metropolitan youths, particularly in 1980 (4.8 percent) planned to move to another Utah county. About one-third of the rural and around a fifth of the urban youth intended to move within Utah.

The last section of each bar in Figure 1 illustrates the percentage of the high school seniors intending to leave Utah. Remarkably little variation occurred between the classes of counties. In both 1975 and 1980, urban seniors were slightly more likely to be intending to establish a long-term residence outside of Utah than were rural or metropolitan seniors. Each type of county had a higher percentage intending to leave in 1980 than in 1975, with the increase in rural being the greatest: 10 percent in 1975 compared to 19 percent in 1980.

The numbers of 1980 seniors intending to live in each of the 24 counties in which surveys were conducted were almost identical to the 1975 results (Figure 2). The results are shown separately for stayers and in-migrants (note that in-migrants are identified for the five counties in which surveys were not conducted). The metropolitan counties, which retain large numbers of their own graduates, clearly also attract in-migrants. Of the seniors planning to move to a rural county, most were living in another rural
county when surveyed. For example, in 1980 only six of the 2,152 seniors surveyed in urban and metropolitan counties were planning to move to one of Utah's 14 rural counties. In contrast, 198 of the 1,152 rural county seniors expected to move to an urban or metropolitan location in Utah. In 1975, only three students stated an intention to move to the rural counties while 151 intended to leave them. The concentration of stayers and in-migrants along the Wasatch Front, particularly Salt Lake County, is clearly evident.

Using our sample statistics to estimate the plans of all Utah's graduating seniors, we determined that 16,595 (85 percent) of the 1975 seniors and 16,045 (79 percent) of the 1980 seniors expected to spend most of the rest of their lives in Utah. To indicate the student distribution within Utah, each dot in Figure 2 represents approximately six students (with only one having been actually surveyed). If the 1980 graduates fulfilled their expectations, 850 would make their homes in rural counties, 2,516 would live in an urban county, and 12,679 would reside in one of Utah's four metropolitan counties. There would be 59 in-migrants among those residing in the 14 rural counties, 447 in-migrants in the 11 urban counties, and 849 in-migrants in the four metropolitan counties. The 1975 graduates staying in Utah would include 832 rural residents, 3,146 urban residents, and 12,617 metropolitan residents. The most notable difference between the 1975 and 1980 patterns is that the number of the 1980 metropolitan students planning to live in one of the state's urban counties was about half the number intending to do so in 1975.

Students planning to leave Utah listed 33 states in 1975 and 35 states in 1980 as likely places of long-term residence. In both years, California was cited more frequently than any other state—by 64 youths in 1975 and 129 in 1980. About 47 percent of the 1975 graduates and 54 percent of those in 1980 who anticipated leaving Utah listed another mountain state. Colorado was the most popular of these states, with 38 and 26 intending to move there in 1975 and 1980, respectively. Very few young adults intended to move east of the Rocky Mountains (Figure 3). The distributions were virtually identical in both survey years.

Summary and Implication

The dominant migration trend indicated by Utah's graduating high school seniors was from sparsely populated counties to the state's metropolitan centers. Large numbers of individuals would have to change their minds before the rural counties would retain their youth or attract young adults from metropolitan areas. These findings suggest a continued loss by rural counties of their home-grown young adults despite an overall growth trend. Many people seem to think that rural areas are beginning to hold their own with respect to exchanges of youths with metropolitan areas. Our results, however, suggest that the perceived growth of rural communities is probably the result of in-migration by people who are at other points in their life cycle. It is noteworthy that most of the high school seniors planning to leave Utah's rural areas intend to settle in other communities in the state while more of the urban and metropolitan youths intend to live out-of-state.

The implications of these results are too numerous to detail here. Our data certainly point to the need for students living in Utah's rural areas to be informed about life and occupations in large metropolitan centers, since about as many of them planned to live in these areas as planned to stay in rural areas. Educators might also want to consider the value of teaching high school students about the advantages and
disadvantages associated with rural and metropolitan life styles. Such adequate, accurate information might help reverse the exodus of youth from rural areas.

Previous research showed that Utah's rural adults believe that their communities urgently need youth-oriented recreational facilities (Geertsen et al. 1977). Ongoing research with the graduates of this study indicates that rural youth perceive a lack of community recreational facilities as a problem much more often than do urban or metropolitan youth. Obviously, however, the migration plans of the state's young adults are determined by a large variety of factors. It is important that their decisions be based on adequate information about opportunities within various settings and that community leaders identify the features of their communities that repel or attract youths. Research during the next few years will be focused on the 1975 graduates since most finished their education in the interim and may be about to establish long-term residences.

REFERENCES


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Michael B. Toney is an Associate Professor of Sociology at USU. William F. Stinner is Professor and Acting Head of the Department of Sociology, Social Work, and Anthropology. Both are conducting migration studies in the United States as well as research focused on Utah. Elias Nijim is an Assistant Professor of Sociology at the University of Toledo. His PhD, which he completed at USU, was based on the migration plans of Utah's 1975 high school seniors.

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FIGURE 1. Percentage of Utah's 1975 and 1980 high school graduate migration intentions.

a. Urban counties in which no survey was conducted are Box Elder, Grand, Iron, and Sevier.

b. Tooele was reclassified as part of Salt Lake City SMSA during the 1970s by the U.S. Census Bureau.

c. The metropolitan county in which no survey was conducted was Davis.

FIGURE 2. Illustration of number of Utah's 1980 high school seniors by county of intended residence and migration status.

FIGURE 3. Illustrative distribution of Utah's 1980 high school seniors by the state in which they intend to live.
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