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Tussock Grasslands & Mountain Lands Institute – May 1980

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P.O. Box 56 Lincoln College, Canterbury N.Z. Phone Christchurch 228-029
Livestock production and performance in South Island high country

I. G. C. Kerr, K. R. Lefever, E. J. Costello

The Tussock Grasslands and Mountain Lands Institute has now completed three series of surveys of livestock, production and performance in the high country of the South Island. What follows summarises:

(a) the changes in production and performance of 289 high country runs between each series of surveys, and
(b) the variation in production, performance and some factors influencing production within the 300 runs in the 1976/78 series.

Data for each survey within each series have been collected in personal interviews with individual runholders and are strictly confidential.

The authors gratefully acknowledge the willingness of all runholders to participate in the study and the considerable assistance given by many others.

A summary analysis of all information collected from each property, together with average data from the appropriate region, have been forwarded to the runholders concerned. Further analysis and comment are available to individual runholders on request.

Number and Area

The number and area of high country properties within the 1976/78 series of surveys and classified according to province and climate zone (Hughes, 1973), are shown in Table 1 below.

<table>
<thead>
<tr>
<th>Province and Climate Zone</th>
<th>Number</th>
<th>Total Area</th>
<th>Average Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marlborough Moist (MM)</td>
<td>23</td>
<td>505263</td>
<td>21968</td>
</tr>
<tr>
<td>Canterbury Moist (CM)</td>
<td>51</td>
<td>432571</td>
<td>8482</td>
</tr>
<tr>
<td>Canterbury Wet (CW)</td>
<td>36</td>
<td>647193</td>
<td>17978</td>
</tr>
<tr>
<td>Otago Dry (OD)</td>
<td>46</td>
<td>362409</td>
<td>7878</td>
</tr>
<tr>
<td>Otago Moist (OM)</td>
<td>91</td>
<td>564519</td>
<td>6204</td>
</tr>
<tr>
<td>Otago Wet (OW)</td>
<td>36</td>
<td>537623</td>
<td>14934</td>
</tr>
<tr>
<td>Southland Moist (SM)</td>
<td>17</td>
<td>209027</td>
<td>12296</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>300</td>
<td>3258605</td>
<td>10862</td>
</tr>
</tbody>
</table>
Three Canterbury runs which are within the 'dry' zone are grouped with the Otago 'dry' runs to preserve confidentiality. Generally those runs within the 'wet' zone are the 'gorge' runs and those in the 'dry' zone are those in the most arid areas of the high country, principally in Central Otago. The predominant 'moist' zone encompasses those runs between these two extremes.

**Stock Units**

The changes in total stock units carried on the 289 runs common to all three series of surveys is shown in Figure 1.

(Figure 5) and a six per cent recorded fall in total cattle numbers between 1976/77 and 1977/78 shows that the peak in cattle numbers has, for the present at least, been reached. There is no doubt that low returns from sale stock (and the strong competition between sheep and cattle for limited forage) has caused runholders to re-examine cattle policies. Recent price advances may, at least temporarily, tend to reverse current trends.

Over the period of the series of surveys a steady increase in sheep numbers has been maintained, thus confirming runholders' confidence in sheep production.

**Figure 1. Changes in stock units 1965–1978**

<table>
<thead>
<tr>
<th>Year</th>
<th>Cattle</th>
<th>Sheep</th>
</tr>
</thead>
<tbody>
<tr>
<td>65/67</td>
<td>+26%</td>
<td></td>
</tr>
<tr>
<td>71/73</td>
<td>+9%</td>
<td>+100%</td>
</tr>
<tr>
<td>76/78</td>
<td>+12%</td>
<td>+7%</td>
</tr>
</tbody>
</table>

The substantial increase (26 per cent) in total stock units (mainly cattle), which was a feature of the period between the first two surveys, has not continued. Nevertheless, the increase (nine per cent) in stock units over the five years up to the 1976/78 series has been considerably in advance of the almost unchanged New Zealand total.

The earlier trend of rapidly increasing cattle herds appears to have waned sharply. Recent trading in cattle in the high country recently deer have become a feature on 30 runs and now account for well over 3000 stock units in total.

**Sheep**

The steady increase in sheep numbers which has continued in the high country since 1965/67 is substantially in breeding ewes. Breeding ewes have also replaced wethers to a significant extent (Figure 2).
The separate regional changes in sheep numbers are similar to the overall total. There has been an increase in the popularity of Merinos, but at the same time some variability in the popularity of halfbreds both between and within regions. A major part of the recent six per cent increase in sheep numbers has been in breeds other than Merino and halfbred.

The decline in store sheep sales has continued, but there has been an impressive increase in fat stock sales (lambs principally), which are now twice those of store stock (Figure 3).
Cattle

The doubling of cattle numbers between 1965/67 and 1971/73 was a feature of that period. A more moderate increase has occurred since, with a significantly lesser proportion of breeding cows. (Figure 4)

The number of cattle traded annually (Figure 5) has more than doubled over the survey period. The number of fat stock sold is reflected in the increase in the productivity of the runs, as is the policy of many runholders to add value to surplus stock rather than accept low store prices. There has recently been a significant reduction in the number of breeding stock.

Figure 4. Changes in cattle numbers 1965–1978
Performance

Along with the initially large and recently moderate increases in stock units carried on runs, there have been some changes in stock performance in sheep.

The reduction in wool production per sheep, though not substantial, is, however, disquieting. The reduction may be attributable to the nine per cent decline in wether numbers. It should also be recognised that the five per cent drop in wool/sheep was accompanied by a 15 per cent increase in overall sheep numbers.

The range in wool production per sheep for 300 runs in the 1976/78 series is illustrated in Figure 6.

Because wool is the major income earner for most high country runs, the two-fold range in wool per sheep indicates a vast avenue for improvement in wool production efficiency in many flocks. A 0.25 kg per sheep increase in wool production

Table 2
Stock Performance

<table>
<thead>
<tr>
<th></th>
<th>65/67</th>
<th>71/73</th>
<th>76/78</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wool/Sheep (kg)</td>
<td>3.9</td>
<td>3.8</td>
<td>3.7</td>
</tr>
<tr>
<td>Lambing (per cent)</td>
<td>79</td>
<td>85</td>
<td>86</td>
</tr>
<tr>
<td>Calving (per cent)</td>
<td>82</td>
<td>81</td>
<td>82</td>
</tr>
</tbody>
</table>
over the whole of the high country amounts to approximately $0.9m added annual return.

Production per sheep varies significantly between regions with noticeable advantage to those runs within the warmer and drier regions (Figure 7). This apparent advantage is likely to be significantly reduced if the wool clip is assessed on a clean basis.

Figure 7. Regional wool production per sheep 1976–1978
Lambing

Clearly the use of selenium and other management practices caused a marked increase in average lambing percentage between 1965/67 and 1971/73, but thereafter major cultural and environmental limitations have applied (Table 2 page 6).

With one notable exception (Canterbury 'wet') the average lambing percentage between regions currently varies by a maximum of only three per cent.

Over the series of surveys there has been an exceptional increase (nine per cent) in the average lambing percentage of the gorge runs of the Otago 'wet' region. Otherwise little improvement in reproductive efficiency has apparently taken place over the last five years.

A range in lambing percentage from 60% to 120% within the 300 runs in the 1976/78 series has been recorded. This extremely wide range applies to all regions.
New development
There was an overall reduction of 29 per cent in the total area of new development (cultivation, over-sowing, top-dressing and overdrilling) recorded between the 1971/73 and 1976/78 series of surveys (Figure 10).

Figure 10. Area of new development 1971–1978

Figure 11. Regional pattern of new development 1971–1978
When examined regionally, this drop in the rate of new development has, in aggregate, occurred principally in ‘dry’ and ‘moist’ regions of Otago. Similarly, the rate of development (of a much lesser area) in the Canterbury runs has fallen to half that of 1971/73. Conversely, runs in both Southland and Marlborough have increased the rate of development substantially.

The 8\% increase in the total area fertilised (initial and maintenance) for all runs is reflected in a drop in the rate of development (-29 per cent) offset by a 20 per cent increase in the area receiving maintenance fertiliser. Overall there has been an increase in total area (and total tonnes) fertilised of eight per cent, which corresponds approximately to the overall increase in stock units carried (Figure 12).

In the 1976/78 seasons there was a considerable variation between runs in the quantity of fertiliser applied per thousand stock units (Figure 13). The regional variations are shown in Table 3.

### Table 3

<table>
<thead>
<tr>
<th>Region</th>
<th>Tonnes/Run</th>
<th>Tonnes/1000 S.U.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marlborough MOIST</td>
<td>132</td>
<td>19.6</td>
</tr>
<tr>
<td>Canterbury MOIST</td>
<td>91</td>
<td>11.9</td>
</tr>
<tr>
<td>Canterbury WET</td>
<td>123</td>
<td>11.7</td>
</tr>
<tr>
<td>Otago DRY</td>
<td>75</td>
<td>13.7</td>
</tr>
<tr>
<td>Otago MOIST</td>
<td>97</td>
<td>16.2</td>
</tr>
<tr>
<td>Otago WET</td>
<td>144</td>
<td>15.5</td>
</tr>
<tr>
<td>Southland MOIST</td>
<td>225</td>
<td>21.4</td>
</tr>
<tr>
<td>All runs</td>
<td>104</td>
<td>14.5</td>
</tr>
</tbody>
</table>
Over the 1976/78 series of surveys maintenance fertiliser was applied at an average rate of 10.7 tonnes per thousand stock units, which was approximately the same rate (10.5t) as in 1971/73. The recent surveys indicate a rate of investment in fertiliser for new land development at three tonnes per thousand stock units, which is a reduction of 25 per cent since 1971/73.

Winter feed

The total amount of winter feed crop grown in each of the surveys is shown in Table 4.

Hay continues to be the dominant form of winter feed crop grown, accounting for approximately 70 per cent of the dry matter produced. Overall the total winter

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Winter feed crops grown</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area (ha)</td>
</tr>
<tr>
<td></td>
<td>1965/67</td>
</tr>
<tr>
<td>Greenfeed</td>
<td>2902</td>
</tr>
<tr>
<td>Brassica</td>
<td>3852</td>
</tr>
<tr>
<td>Grain</td>
<td>NA</td>
</tr>
<tr>
<td>Hay</td>
<td>NA</td>
</tr>
<tr>
<td>Silage</td>
<td>NA</td>
</tr>
</tbody>
</table>
feed grown amounts to about 40 per cent of the normal maintenance requirements of all the stock units run in the high country. The importance of winter rougahge to supply the vast majority of winter feed requirements should not be underestimated.

Drenching

In the 1976/77 season less than three per cent of runs did not drench hoggets with an anthelmintic, with or without selenium added. Seventy-two per cent of runs drenched hoggets two, three or four times and all but 11 per cent reported the use of selenium.

Ewe drenching was not practised on 30 per cent of runs carrying ewes, but two-thirds of runs did drench either once or twice, and 81 per cent of these used selenium.

Wether drenching is comparatively rare, with 91 per cent of those runs carrying wethers reporting no drenching at all.

Since the 1971/73 series of surveys, drenching frequency of hoggets has increased marginally, and of ewes significantly (14 per cent). The use of selenium for hoggets has increased by 15 per cent.

The overall incidence and frequency of calf drenching is unchanged since 1971/73 when approximately 70 per cent of all calves were drenched at least once.

Labour

The labour input on high country properties averages 2655 stock units per labour unit, or 2.7 labour units per property. While there are but few runs with sheep only (14) or cattle only (3), there appears to be a much higher than average labour input into properties carrying only sheep. Seventy-eight runs (26 per cent) are managed by people other than the owner (although in several cases an owner—usually the father—contributes substantially to the labour input). Two hundred and twenty-three runs employ shepherds and 185 runs use casual musterers. The balance of the labour employed (apart from shearers) consists of tractor drivers, fencers, cooks and casuals.

Land use

The ‘average’ high country property currently consists of 10862 ha of land utilized as outlined in the table below.

Of the 300 high country properties, two-thirds are between 5251 ha and 16473 ha in area. The total range is from 500 ha to over 185,000 ha.

<table>
<thead>
<tr>
<th>Land Use</th>
<th>“Average” high country property</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dryland pasture</td>
<td>168 ha</td>
</tr>
<tr>
<td>Irrigated pasture</td>
<td>23 ha</td>
</tr>
<tr>
<td>Dryland lucerne</td>
<td>31 ha</td>
</tr>
<tr>
<td>Irrigated lucerne</td>
<td>4 ha</td>
</tr>
<tr>
<td>Oversown native pastures</td>
<td>998 ha</td>
</tr>
<tr>
<td>Fallow</td>
<td>6 ha</td>
</tr>
<tr>
<td>Crop</td>
<td>16 ha</td>
</tr>
<tr>
<td>Exotic trees</td>
<td>14 ha</td>
</tr>
<tr>
<td>Native trees</td>
<td>114 ha</td>
</tr>
<tr>
<td>Unimproved and waste</td>
<td>9488 ha</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>10862</strong></td>
</tr>
</tbody>
</table>
Land tenure

Table 5 summarises the variations in land tenure within the high country. Ninety-three per cent of high country runs are either farmed by the Crown (nine per cent), held under a Crown or public body lease (77 per cent) or occupied through a licence from a Crown agency (seven per cent).

Table 5
Land tenure
South Island High Country 1978

<table>
<thead>
<tr>
<th>Fee simple:</th>
<th>Runs</th>
<th>Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freehold</td>
<td>164</td>
<td>205033</td>
</tr>
<tr>
<td>Deferred payment licence</td>
<td>24</td>
<td>41348</td>
</tr>
<tr>
<td></td>
<td></td>
<td>246381</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Leases with right of renewal:</th>
<th>Runs</th>
<th>Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lease in Perpetuity</td>
<td>13</td>
<td>2930</td>
</tr>
<tr>
<td>Renewable lease</td>
<td>27</td>
<td>54939</td>
</tr>
<tr>
<td>Pastoral lease</td>
<td>240</td>
<td>2336085</td>
</tr>
<tr>
<td>Endowment lease</td>
<td>11</td>
<td>101203</td>
</tr>
<tr>
<td>County lease</td>
<td>12</td>
<td>15279</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2510436</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Leases with no right of renewal:</th>
<th>Runs</th>
<th>Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pastoral Occupation Licence</td>
<td>31</td>
<td>158188</td>
</tr>
<tr>
<td>Grazing permit</td>
<td>3</td>
<td>2135</td>
</tr>
<tr>
<td>Special lease</td>
<td>7</td>
<td>38328</td>
</tr>
<tr>
<td>Forest lease</td>
<td>7</td>
<td>8091</td>
</tr>
<tr>
<td>National Park lease</td>
<td>2</td>
<td>4746</td>
</tr>
<tr>
<td>Army lease</td>
<td>1</td>
<td>2913</td>
</tr>
<tr>
<td>Miscellaneous licence</td>
<td>28</td>
<td>8629</td>
</tr>
<tr>
<td></td>
<td></td>
<td>223030</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Other:</th>
<th>Runs</th>
<th>Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crown Land</td>
<td>8</td>
<td>278758</td>
</tr>
</tbody>
</table>

| Total:                          |       | 3258605   |

Weeds

The following table (Table 6) summarises high country runholders’ opinions of weed infestations on their properties in the 1976/77 season.

The distribution of major weeds (broom, gorse, brier, hieracium and fern) throughout the high country can be gauged from a table of the incidence of runs reporting ‘excess’ weeds within each county (Table 7)
Table 6

Percentage of runs reporting weeds 1976/77

<table>
<thead>
<tr>
<th>Weed</th>
<th>'Excess'</th>
<th>'Occurs'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broom</td>
<td>9</td>
<td>52</td>
</tr>
<tr>
<td>Gorse</td>
<td>6</td>
<td>45</td>
</tr>
<tr>
<td>Brier</td>
<td>30</td>
<td>80</td>
</tr>
<tr>
<td>Matagouri</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>Manuka</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Trees</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>Fern</td>
<td>9</td>
<td>26</td>
</tr>
<tr>
<td>Thyme</td>
<td>&lt;1</td>
<td>3</td>
</tr>
<tr>
<td>Hieracium spp.</td>
<td>11</td>
<td>45</td>
</tr>
<tr>
<td>Nodding Thistle</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Barley Grass</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>St John's Wort</td>
<td>1</td>
<td>18</td>
</tr>
<tr>
<td>Ragwort</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Hemlock</td>
<td>&lt;1</td>
<td>3</td>
</tr>
<tr>
<td>Tutu</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Spear Grass</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 7

Number of runs reporting ‘excess’ weeds 1976/77

<table>
<thead>
<tr>
<th>Runs</th>
<th>County</th>
<th>Broom</th>
<th>Gorse</th>
<th>Brier</th>
<th>Hieracium</th>
<th>Fern</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>Marlborough</td>
<td>2</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Kaikoura</td>
<td>2</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Amuri</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Hurunui</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Oxford</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Malvern</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Ashburton</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>Mackenzie</td>
<td>1</td>
<td>11</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Strathallan</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Waimate</td>
<td></td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Waitaki</td>
<td>3</td>
<td>2</td>
<td>12</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>54</td>
<td>Vincent</td>
<td>2</td>
<td>1</td>
<td>22</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>24</td>
<td>Maniototo</td>
<td>2</td>
<td>2</td>
<td>7</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>Lake</td>
<td>3</td>
<td>5</td>
<td>21</td>
<td>1</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>Tuapeka</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Southland</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>300</td>
<td></td>
<td>26</td>
<td>18</td>
<td>90</td>
<td>33</td>
<td>24</td>
</tr>
</tbody>
</table>
Pests

Throughout the high country as a whole the percentage of runs reporting animal pests in the 1976/77 season were as shown in Table 8.

‘Excessively’ high numbers of rabbits generally existed in the 1976/77 season in the Waitaki, Vincent and Lake Counties with many areas of localised concern elsewhere. The incidence of oppossums was widespread and apparently of growing importance as a serious animal pest.

Table 8
Percentage of runs reporting animal pests 1976/77

<table>
<thead>
<tr>
<th>Pest</th>
<th>‘Excess’</th>
<th>‘Occurs’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rabbit</td>
<td>16</td>
<td>84</td>
</tr>
<tr>
<td>Hare</td>
<td>4</td>
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<tr>
<td>Geese</td>
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<td>4</td>
</tr>
<tr>
<td>Pigs</td>
<td>0</td>
<td>8</td>
</tr>
</tbody>
</table>

References


Rules of the workshop

1. An object will always fall as to do the most damage.

2. Any tool dropped will roll to the exact geographical centre of the underside of the vehicle being repaired.

3. Experience gained is proportional to the amount of equipment ruined.

4. Warranties don’t cover things that break down.

5. Nothing is impossible for the person who doesn’t have to do it.

6. Rule A The boss is always right.

   Rule B When the boss is wrong refer rule A.

7. When all else fails read the instructions.

8. If the facts do not conform to the theory they must be disposed of.

9. When you begin to see the light at the end of the tunnel it is the headlight of an on-coming train.

10. No matter what happens there is someone who knew it would.

11. Progress is made on alternate Fridays.
Establishing grasses by surface drilling in tussock country

G. A. Dunbar, R. F. Horrell and E. J. Costello

In the early 1950s there was an upsurge of interest in the improvement of tussock country by overdripping in the Mackenzie country. This was stimulated by Harry Sievwright's work at Tekapo in cooperation with L. W. Blackmore at the Department of Agriculture in Timaru. Much of the early work was carried out with conventional grain drills fitted with the "grassland tips", devised by Blackmore. These were torpedo-like attachments fastened onto the front of each coulter. However, while pasture establishment was fair, the results, in terms of the structure of the drill, were sometimes shattering, to say the least.

Later in the 1950s aerial topdressing and seeding were pursued with enthusiasm and this distracted attention away from the ideas of extensive overdripping. Moreover, for clover establishment alone, surface sowing from aeroplanes was successful over a wide range of country, and the degree of establishment of grasses from most overdripping was not sufficiently high to justify the extra work and cost involved.

Although various kinds of over-drilling equipment have appeared from time to time, the concept with many machines is for a rather massive construction, able to withstand the shocks of uneven surfaces and large immovable objects. Consequently they have often been beyond the power range of the ordinary farm tractor, as well as being expensive. There is also the school of thought which has maintained that, given clover dominant pastures for sufficient years to raise the fertility level, grasses can be established by surface broadcasting and intensive grazing management. Unfortunately grazing manage-
In 1977, the Coutts modified machine was lent to the New Zealand Agricultural Engineering Institute at Lincoln College for some introductory work in other areas. The Tussock Grasslands and Mountain Lands Institute assisted with the work and supported the idea. Some of the advantages seen for such a method of improvement are as follows.

(a) The capital cost of equipment is lower than that of conventional machines used for development.

(b) Partial, rather than full cultivation has an advantage in areas prone to wind blow; moreover some tussock vegetation remains for stock shelter especially at lambing time.

(c) The use of conventional overdrilling machinery does not usually result in good grass establishment.

(d) A small rotary-hoe has the advantage of mobility in hill country, being able to move relatively easily amongst rocks and gain access to small pockets of cultivable land.

(e) As is the case for all direct drilling techniques, the Coutts method is a “one shot” operation. If weather or pressure of other farm operations causes overdrilling to cease, the work done is complete in itself.

The modified rotary hoe is called a “roto-drill” although a final name has not yet been assigned to the machine.

Trials

The first trials were established in the spring of 1977 at one site in North Canterbury and four in South Canterbury, including the Mackenzie Basin. The establishment of grasses and clovers was recorded by sampling for the presence or absence of seedlings within a 20 × 20 cm square frame placed at predetermined intervals across the sowings. Because grass is much more difficult to establish than clover in normal surface sowing procedures most interest was centred on grass establishment. Cocksfoot and ryegrass were the grasses sown.

At Hunua, in North Canterbury, on an exposed rocky site, about 600 metres above sea level, a simple comparison was made between the results obtained using a roto-drill and those from surface broadcasting. No new grass seedlings were found in samples from the broadcast area, whereas in the roto-drilled area cocksfoot was found in 30 per cent of the total number of samples, and ryegrass in 50 per cent. Clover was found in 25 per cent of the samples from the broadcast area, and in 72 per cent from the drilled area.

At the South Canterbury sites, results from roto-drilling were compared with those from disc drilling and surface broadcasting. The disc-drill was a single disc type. Three months after sowing at three sites in the Mackenzie Basin, grass seedlings were present in from five to six times as many samples from the roto-drilled areas as from the disc-drilled areas. There were few cocksfoot seedlings and no ryegrass seedlings on the samples taken from the broadcast areas. Over the three sites cocksfoot was present in 44 per cent of roto-drilled samples and in nine per cent of samples from the disc-drilled areas. Ryegrass was present in 32 per cent of samples.
from roto-drilled areas and four per cent of samples from the areas disc-drilled. Differences were not so marked for the clover. The mean figures for presence at three sites were: 70 per cent of samples for the roto-drill, 43 per cent for the disc drill and 24 per cent for the broadcast areas. There was a heavy mortality of seedlings with all treatments during the growing season, particularly at two drier sites, but even so the grasses persisted better with the roto-drill than with the disc drill sowings.

The above results do need some qualification. Although the same rates of seed were sown for each hectare covered by each machine, the fact that coulters were spaced twice as far apart on the roto-drill as on the disc drill meant that seed was flowing at twice the rate per unit length of coulter row for the first machine as for the second machine. Thus if the comparison of results was based on the numbers of seedlings present in a sample, then there would need to be twice as many seedlings for the roto-drill as for the disc drill to give an equivalent result. The same numerical relationship may not necessarily stand on a simple presence or absence of seedlings within a 20cm length of drill, although theoretically the chances of finding a seedling must be 2:1 in favour of the roto-drill. But even allowing for this, the results above at almost 5:1 for cocksfoot and 8:1 for ryegrass do show the greater effectiveness of the roto-drill. This result gave sufficient encouragement for continuing the testing process in 1978.

In 1978, the Agricultural Engineering Institute modified a Howard Seedavator to a blade configuration that produced nine, 100mm wide cultivated strips at 250mm centres. This was the same spacing as that on the Coutts modification. This new machine was used at four sites. At two sites it was used to test the effect of different coulter types and the speed of rotor on establishment. The results of this testing are not appropriately discussed here.

At two South Canterbury sites, one a foothills site in about an 800mm rainfall zone, and the other in the Mackenzie Basin in a 300 - 400mm zone, the roto-drill was compared with a triple-disc drill. At these two sites, staff of Grasslands Division of Department of Scientific and Industrial Research were involved in testing the establishment of several grass and legume mixtures in a tussock and turf situation, using a triple-disc drill. The N.Z.A.E.I. modified roto-drill was used to sow three of the seed mixtures in a comparison alongside. As well as the comparison between machines, there was another between a superphosphate mixture, and a superphosphate/nitro-lime mixture.

The method of sampling was the same as that used in the previous year, but again

### Table 1: Percentage of samples with grasses present eight months after drilling

<table>
<thead>
<tr>
<th>Seed mixture</th>
<th>Site A</th>
<th>Site B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed mixture</td>
<td>Roto-drill</td>
<td>Disc drill</td>
</tr>
<tr>
<td>Super</td>
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<td>48</td>
</tr>
<tr>
<td></td>
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<td>Nitrogen</td>
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<td>56</td>
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<tr>
<td></td>
<td>3</td>
<td>60</td>
</tr>
</tbody>
</table>

Note: The calculated ratio of the seed rate in a unit length of roto drill compared with a unit length of disc drill is 1.66 to 1.
there was the complication of different coulter spacings with the roto-drill at 25cm and the triple-disc drill at 15cm. This meant a seed ratio of 1.66:1 in favour of the roto-drill on a comparable length of coulter row. Sampling showed however that seedling establishment exceeded the seeding ratio for each of the three mixtures at each site (Table 1).

Eight months after drilling at the wetter, foothill site, the comparison between the roto-drill and the disc drill with the superphosphate fertiliser, was 2.3 to 1, 2.3 to 1 and 2.8 to 1 for the three grass mixtures, with a mean ratio of 2.44 to 1. When nitrogen was added to the fertiliser mixture, the comparison for the same three grass mixtures was 3.4 to 1, 1.9 to 1 and 2.6 to 1, with a mean of 2.55 to 1.

At the much drier Mackenzie site, although there had been good spring rains, the comparison in favour of the roto-drill was much more striking. Because of nil or very low figures for grass presence in the disc-drilled area, ratios cannot be used. With superphosphate fertiliser the presence of grass seedlings within the roto-drilled area was 55 per cent, 42 per cent and 22 per cent of the samples from the three mixtures respectively. For the disc drilled, the figures were 3 per cent, 0 per cent and 0 per cent. When nitrogen was added, presence within the roto-drilled area was 89 per cent, 39 per cent and 78 per cent of the samples, compared with 3 per cent, 3 per cent and 6 per cent in the disc drilled area.

Compared with grasses, the establishment of legumes appeared to be little affected by the type of drill used (Table 2). At the foothills site there were very high frequency records for legumes, under all treatments. Only one treatment with one machine failed to give a figure of more than an 80 per cent presence. The sampling technique was not precise enough to determine real differences between treatments at this level. At the Mackenzie site, in the "superphosphate only" treatment the results were generally of the order of 1.5 to 1 in favour of the roto-drill. Clover establishment was severely depressed where nitrogen fertiliser was added. The effect was considerably more drastic in the disc-drilled area. However, taking into account the seed ratios between the two machines, and neglecting on practical considerations the disc drilling of a grass/legume mixture with nitrogen, the conclusion is that from the viewpoint of legume establishment the roto drill has little advantage over the triple disc drill.

During spring 1979, further trials were established in Canterbury and Otago, with staff of the Forest Research Institute and the Research Division of the Ministry of Agriculture and Fisheries co-operating in some aspects of the work. These trials will test the machine over a wide range of conditions and further define the best type of coulter for general use.

Table 2
Percentage of samples with legumes present eight months after drilling

<table>
<thead>
<tr>
<th>Seed mixture</th>
<th>Site A</th>
<th>Site B</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Roto-drill</td>
<td>Disc drill</td>
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<td>Super</td>
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</table>

Note: The calculated ratio of the seed rate in a unit length of roto-drill compared with a unit length of disc-drill is 1.66 to 1.
Research Report

Water yield from high-altitude snow tussock grassland in Central Otago

A. F. Mark, Jennifer Rowley & D. K. Holdsworth

The results of a six-year study, designed to measure water yield associated with different types of plant cover in the high-altitude snow tussock grassland zone at 1000m on the Rock and Pillar Range, are given. An important role of snow tussock in supplementing water intake by intercepting moisture from dense fog is indicated and could explain the significantly higher water yields obtained under such a cover. Similar studies initiated in 1977 at six other sites, two at higher altitudes on the Rock and Pillar Range and four at 550 – 980m on the nearby Lammerlaw Range, confirm the higher yields of water with a snow tussock cover in the high-altitude snow tussock zone.

Introduction

With Government policy on future use of the high country emphasising erosion control and water management (and involving retirement of Class VIII and severely eroded Class VII run country), an important aspect to consider is the capacity of the land to produce water. This is particularly so on those catchments where it has a special value for use in agriculture, municipal supply, or hydro-electric generation. Water production must also be one of the important roles of Class VII high country, above about 1000m, that is likely to be retained as run country since this land has a relatively large production potential. After all, these regions are the prime source of water for the increasing and often conflicting demands in the low country.

There are difficulties in obtaining reliable measurements of water yield in the high country, both in terms of the logistics of equipment installation and servicing, and of finding suitable areas to meet the special requirements for such a study, so there is little relevant information available on which to base management decisions.

The traditional method of measuring amounts and patterns of water yield from mountain regions has been through the use of small catchments, with stream flow monitored continuously through weirs (Pearce et al. 1976). However, there are often several problems inherent to the application of this approach in New Zealand. Among these is the difficulty of locating and identifying water-tight catchments, particularly east of the main divide in the South Island, either because of deep-fractured greywacke rock or, in the subdued topography of the schist country of Otago, because of poorly defined catchments. This is apart from the high cost of installing, servicing and maintaining the necessary equipment.

A small study of water yield using the alternative, cheaper approach of small tanks (non-weighing lysimeters) seen by one of us (A.F.M.) in use by F. H. W. Green in the Scottish Highlands (Green 1958) in 1966, was begun later that year in the snow tussock grassland zone at about 1000m on the eastern slope of the Rock and Pillar Range, the easternmost mountain range of Central Otago. The plan of this study was to measure
the amount of water surplus (or yield) associated with various types of plant cover. These types were:

Relatively unmodified snow tussock grassland typical of the area.
Recently burned or heavily grazed snow tussock.
A short turf of blue tussock grassland.
Bare soil.

Although providing only very small sample areas of about a quarter square metre, the tanks were undoubtedly water-tight, which can rarely be guaranteed with experimental catchments. More detailed results of this study have been published elsewhere (Mark & Rowley 1969, 1976; Rowley 1970) but they probably have not reached many readers of Review.

Methods

In the spring of 1966 a rectangular area of narrow-leaved snow tussock grassland (Chionochloa rigida), in good condition, that had not been burned since 1962, was fenced to provide three equal areas each 25 x 25 m. One of these was burned, the second clipped to simulate severe grazing and the third left untreated. Twelve tanks made from 200 litre (44 gallon) tar drums of 56 cm (22 in.) diameter, reduced in height to 75 cm and with an outlet pipe at the bottom, were buried to leave a 5 cm rim for the deflection of surface water. The outlet pipe led downslope through polythene hose to provide minimum gravity flow and reach the surface a short distance downslope where it emptied into a container within a covered drum. Three tanks were placed in the untreated plot, three in the burned plot and six in the area of clipped tussocks. Single average-sized snow tussocks were dug up with sufficient intact soil to fit snugly over a filter of fine rock chips into each of nine tanks (Fig. 1), three in each area of treatment.

FIGURE 1. Cross section of a lysimeter tank with snow tussock, including three collection tanks within a covered drum. Reprinted with permission from Rowley (1970).
The tussocks were then either burned, clipped, or left, so as to resemble the area around them (Fig. 2). Turves of blue tussock were added to the remaining three tanks and in 1970 three more tanks were installed in the area that had been burned, and the soil in these tanks left bare. The surface area of the tanks (0.25 sq. metre) was not much less than the average area of ground dominated by a single snow tussock at the site (about three tussocks per square metre). Although each tank represented approximately one unit area of snow tussock grassland, this should not be taken to imply that results might simply be extrapolated to estimate catchment water yields in comparable situations. Air temperature, humidity and solar radiation were continuously recorded and monthly measurements were made of water yield, precipitation, evaporation, soil moisture (both in the tanks and surrounding soil), soil temperature, snow depth and wind speed. In addition, precipitation was followed at 11 other sites spread between the valley floor (380m) and summit ridge (1360m) of the range along the spur on which the study was made — seven were placed below the site and four above it.

As results came to hand, three other studies suggested themselves — measurement of the gains through interception of fog by the tussock leaves, of the water losses from tussocks through transpiration, and of the distribution of rainfall around the bases of single tussocks.

Results

The water balance equation in its simplest form: precipitation = evaporation + throughput ± storage, states that the precipitation received is lost from the site either into the atmosphere by evaporation from both the soil and plant surfaces, or as throughput (surface or subsurface flow), while some may be stored within the soil profile. Since we found, with monthly measurements using soil moisture blocks, that the water content of the soil both inside and outside the tanks was rarely below its maximum retention value (field capacity), we assumed the storage factor could be ignored.
During the first two years the water yield from the untreated snow tussocks was significantly greater than that from any of the other three treatments, but as the burnt and clipped tussocks recovered, so the yields of water associated with them increased (compare values for 1966–67 and 1967–68 with those of the subsequent four years in Figure 3).

For a six-year period, untreated snow tussocks provided the greatest water yield: 63 percent of the rain gauge catch at the site, while the sward of blue tussock provided significantly less (49 percent). Snow tussocks which had been either burned or clipped gave intermediate values, 60 per cent and 54 per cent, respectively (but both increased over the period, as they recovered). Water yield under bare soil (56 per cent) was also intermediate between the values for normal snow tussocks and the blue tussock sward.

Monthly values for precipitation and water yield from normal snow tussock and the blue tussock swards, averaged over the six-year period (Fig. 4), showed that the biggest discrepancy between precipitation and yield occurred during the period of greatest snowfall (June-September). Not only did much of the snow that fell on the site (and was recorded in the rain gauges) blow away, but the amount that accumulated and eventually melted at the site, varied with small irregularities in the ground surface and with the vegetation height (Fig. 5).

For the snow-free period (October-April) during six years, yield under the normal snow tussocks amounted to 70 per cent of the mean precipitation for these seven months (774 mm), while the comparable value for blue tussock was significantly less, at 51 per cent.

![Figure 3](image-url)

**FIGURE 3.** Total annual precipitation and mean water yield for triplicate lysimeter tanks containing five treatments for a six-year period (but bare soil for only a two-year period). Annual periods are November to October in all cases. Reprinted with permission from Mark and Rowley (1976).
FIGURE 4. Mean annual precipitation (solid columns) and yield (throughput) of lysimeter tanks containing normal snow tussocks (left) and a blue tussock sward (right) for a six-year period (November 1966–October 1972). Reprinted with permission from Mark and Rowley (1976).

FIGURE 5. Variation in depth of snow caused by its redistribution related to differences in microtopography and height of plant cover. Site adjacent to the study area on Rock and Pillar Range. 29 June 1975. Reprinted with permission from Mark and Rowley (1976).
Perhaps surprisingly, there were five of the 72 months when the yield under normal snow tussocks slightly exceeded that recorded with the pair of rain gauges. This might happen when servicing takes place during or just following a storm, before all surplus water had drained through the soil, but usually it occurred when there were extended periods of fog.

Under conditions of dense fog, substantial amounts of water appeared to be intercepted by the tall, fine leaves of snow tussock and were channelled down through the tussock bases and into the soil. (Anyone who has walked through snow tussocks in foggy weather will be well aware of the water which catches on the leaves).

The magnitude of the contribution by fog to water input was tested by mounting 32 snow tussock tillers (stems and attached leaves) on top of a recording rain gauge and comparing the catch with that of a standard recording gauge, and another with a wire gauze fog interceptor mounted on top (Fig. 6). At the Rock and Pillar site, during six foggy periods of one to two days without rain in January-March 1970, the fog interceptor recorded two to eight times the amount collected by the standard rain gauge, while the snow tussock leaves collected 10 to 36 times as much (Fig. 7).

Presumably a single snow tussock that consists usually of several hundred tillers would substantially increase water input to the soil during a dense fog.

FIGURE 6. Recording rain gauges comparing catches of a fog interceptor (right) and snow tussock leaves (left) with that of a conventional gauge at the Rock and Pillar study site. Reprinted with permission Mark and Rowley (1976).
FIGURE 7. Comparisons for five "storms" of rain gauge catches over short periods, using either a standard gauge (solid line), a fog interceptor (x—x), or snow tussock leaves (.—.—) mounted on the gauge (see Fig. 5) Reprinted with permission from Mark and Rowley (1976).
Another experiment was set up to test how much water was evaporated from a normal snow tussock, and from tussocks recovering from either burning or grazing that had only new foliage. Nine average-sized snow tussocks were each transferred to nine-litre plastic buckets in autumn and brought to Dunedin where they were sunken into a lawn. A polythene tunnel was built over them to keep off rain (Fig. 8).

Water use was measured with an auto-irrigation system that maintained an adequate supply to the roots. After a period of standardization over winter, three tussocks were burnt, three severely clipped, and three were left untreated. Weekly water use of each tussock was then measured throughout a full growing season.

We found that the normal tussocks used substantially more water — only after 27 weeks did losses from the clipped tussocks occasionally equal those from the untreated plants. Losses from the burnt plants were still less after 35 weeks although, when calculated on the basis of leaf area, they lost less water than the normal tussocks. Evaporimeter measurements among the tussocks suggested that a normal snow tussock could use about 340 ml a day, or about 10 litres a month at the Rock and Pillar site during mid-summer. This would be equivalent to 30–40 mm of precipitation per month which was within the range of values actually measured with the lysimeters for the December-February period.

Rainfall catches made at ground level around the bases of single tussocks showed that tussocks redistribute rain in a way related largely to the direction and strength of the wind. Drips from their leaf tips may in-
crease the fall around the edge of a tussock while on its leeward side the fall may be reduced beneath the canopy by up to 80 per cent. This effect is probably due to the channeling of water down the leaves into the tussock crown.

Discussion

This study within the high altitude snow tussock grassland zone of Central Otago's Rock and Pillar Range demonstrated differences in water yield from small plots, associated with the type and condition of plant cover, but its relevance to yield both in the water-short Taieri catchment and elsewhere may be questioned. The significant difference between a 63 per cent yield that was associated with unmodified snow tussock, compared with a 49 per cent return from a sward of blue tussock, amounts to 14 per cent of the mean annual rain gauge catch (1344mm) or 188mm of water for an average year.

This difference could mean a substantial increase in water yield from a catchment if it applied to an extensive area of mountainside. Since, interception gains from fog appear to be the most important factor accounting for the differential yields, records of fog incidence might provide some guide to its potential contribution in this and other regions. Unfortunately, we have no detailed fog records from the Rock and Pillar Range, though the pattern appears to be similar to that on the Old Man Range 70km to the west. There, daily records for two years showed a steady increase in fog incidence with altitude. In the zone of high altitude snow tussock grassland at 1100–1400m, 18–71 percent of the days per month or 44 per cent of the days per year were foggy, while in the high-alpine zone, above about 1400m, the annual average was almost 60 per cent fog days (Mark 1965, Mark & Bliss 1970).

This pattern, together with that of increased precipitation with altitude that has been demonstrated for two mountain ranges in Central Otago, (Mark 1965, Mark and Rowley 1976) is probably a common feature in New Zealand. Because of the absence of any notable deficiencies in soil moisture within or above the snow tussock zone these are undoubtedly the most productive zones for water on the mountainside and appear to be the source of much of the base flow. Clearly the high-altitude snow tussock zone, mostly Class VII country, is likely to be the most responsive to management or manipulation of its vegetation for water yield.

An extension of this study in 1977 *has been carried out, using slightly larger tanks to achieve a closer match to a unit area of snow tussock grassland. This extension includes two higher altitude sites on the Rock and Pillar Range (1200m and 1370m) and four on the nearby Lammerlaw Range in the Deep Stream-Deep Creek catchments (550m, 700m, 870m, 980m) from which Dunedin City now draws a substantial proportion of its water supply. Early results confirm the importance of vegetation type, soil moisture status, and foginess in determining the areas where vegetation plays a significant role in affecting water yield. Only in the zone of high-altitude snow tussock grassland, above the upper limit of fescue tussock (Festuca novae-zelandiae), does a snow tussock cover increase the water yield.

The importance of interception gains from fog by condensation of moisture on the long fine leaves of a snow tussock was assessed with a study on Mt Cargill (676m), a fog-prone area within view of Dunedin. Here at c. 620m 12 snow tussocks, with soil and roots removed, were mounted singly over wire mesh in polythene buckets which were buried to their rims and spaced 3m apart in a line at right angles to the fog-bearing northeasterly wind. The tussocks were mounted on the buckets only during days with fog. This way, up to half a litre of water per hour was intercepted from dense fog by individual tussocks. To test the effect of different densities of tussock on the amount of

*Substantial financial contributions from the Water Resources Council and Dunedin City Council for this extension are gratefully acknowledged.
water intercepted from fog, other snow tussocks were then planted around those being monitored so as to provide a range from 1 to 5 per square metre (note, there are 3 to 4 tussocks per square metre in most intact stands). With some 20 runs to date we found, as expected, that the amount of moisture intercepted per tussock from fog decreased steadily with increasing tussock density but when interception was expressed on a unit area basis (per square metre of ground surface), gains were greatest at the higher densities (Fig. 9).

It seems clear then, that vegetation type and condition can affect water yield within the zone of high-altitude snow tussock grassland but it will be more difficult to ascertain whether a differential yield response to the vegetation at a site on a mountainside really means that there is an important difference in total catchment yield.

To hydrologists, engineers and particularly administrators faced with decisions on land use options, however, it is obviously an important question that warrants testing on a catchment scale. For this purpose small experimental catchments are presently being installed in this region by both the Ministry of Works and Development and the N.Z. Forest Service. The fate of water within catchments has been receiving increasing attention in New Zealand, and several other studies have begun in recent times. Results over two years in the depleted tussock grassland zone of the Torlesse Range, typical of the drier eastern high country of Canterbury, have indicated the importance of the stream channel and riparian zone as the source of storm flows. Moreover it seems that summer low flows are strongly influenced by summer rainfall (Hayward 1976). This finding has led to a tentative interpretation that alteration to evapotranspiration from the catchment through modification of its vegetation by management, would be unlikely to substantially affect the water balance.

However, more results of water yield in relation to vegetation type and condition are

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Figure 9. Interception gains of moisture from fog by individual snow tussocks as affected by the density of tussocks. Values are based on 20 fog days on Mt Cargill (620 m) and are expressed relative to the amount intercepted by a single fully exposed tussock (= control). Treatments were duplicated and minor differences between individual tussocks and sites have been allowed for.
required before we could dismiss water yield, particularly increased low flows, as a valid object of management for those catchments of the high-altitude snow tussock country which are valuable for water production.

Of the vegetation zones of the central and eastern South Island mountains that comprise most of the run country, the high-altitude snow tussock zones, most of it Class VII land, is likely to respond most to management or manipulation of its vegetation for water yield. Here options for land use should be kept open, at least until these important questions of water yield have been more satisfactorily answered. The higher alpine (Class VIII) land, while receiving substantial precipitation, is generally more depleted and also much less responsive to management, because of severe climatic limitations to plant growth. In the short term there appears to be little scope for modifying its vegetation in ways that might increase or regulate the water yield, but wherever a snow tussock cover remains in this zone every endeavour should be made to preserve it, for these and other values in water and soil conservation. In other areas where a snow tussock cover has been lost, long term management should be aimed at restoring it, for both its soil conservation and water management values, though such restoration is likely to prove difficult or costly. (Fig. 10)

Results from an experimental snow fence on this class of country in the upper Fraser

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FIGURE 10. A 20×20m area planted out in 400 snow tussocks in February 1975 on the damaged verge of a newly constructed road on the summit of the Old Man Range at c. 1690m among dwarfed cushion vegetation (Class VIII land). Snow tussocks (Chionochloa rigida) came from Class VII land in the zone of high altitude snow tussock lower down the range at c. 1250m. An additional area of snow tussocks is being planted immediately beyond the first planting. December 1975.
catchment on the Old Man Range, while interesting (Fig. 11), could not justify widespread use. Neither is the environment suitable for even the hardiest of trees, which at lower altitudes, might prove useful for trapping additional snow.

Areas of mixed fescue-snow tussock at lower altitudes (mostly Class VI land), with lower and less reliable precipitation and higher evaporation, have substantially lower water yields. These, when combined with a greater potential for pastoral productivity, give less justification for management of such land for water production purposes.

On the assumption that total water yield, and particularly low flow yields from Class VII high-altitude snow tussock land, show the greatest response to alteration of the type and condition of plant cover, it is desirable that these snow tussock-dominated lands be carefully managed with emphasis on water production, at least until more information on water yield has been obtained.

The measured yield of 63 per cent from a 1350mm annual rainfall, associated with snow tussock grassland at an altitude of 1000m on the Rock and Pillar Range, agrees reasonably well with a 69 per cent yield ("runoff ratio") for the nearby Deep Stream catchment (median elevation 850m) on the basis of runoff records and mean precipitation estimated using evaporation derived from energy balance data (Brash and Murray 1978). These yields from the water-short Taieri catchment in Central Otago are substantially less than the 80 to 90 per cent yield from precipitation calculated for the Torlesse catchment of Canterbury, by Hayward (1976) and the 60 per cent return obtained from 2600mm annual rainfall in the Maimai catchment in lowland Westland rain-forest near Reefton (Pearce, et al. 1976).

But, as Cuff (1977) has stated for South Canterbury, where fog and interception gains from it may be significant, "if this extra water can be produced from the higher tussock country, then from the nation's point of view this may be better land use than the on-site production of meat and wool."

It may even prove desirable to designate important water production regions in the high country under regional, and district schemes, within the terms of the Town and Country Planning Act, 1977, in order to stress this particular value and also to define the range of permissible activities appropriate in such areas.
References


The Old Botanist's Farewell to the Southern Alps

Farewell to the moorlands, farewell to the mountains,
Farewell to the dark cliff and deep-shadowed dingle!
No more shall I drink from the icy cold fountains
That gush in their glory from out the grey shingle.

No more shall I watch from the high windy ridges
The cloud-shadows drifting with indolent motion,
The bright silver rivers, the gossamer bridges,
The far margin lit with the gleam of the ocean.

No more shall I climb in the pale dawn with passion,
The dew from the snowgrass with eager feet shaking,
And hear the nor'west wind come charging and crashing
And break on the sharp rocks with tumult and quaking.

No more shall I see on a day of still weather
Far range upon range to infinity dwindle,
Snow-crowned and ice-girdled, all slumbering together,
Erebus and Arrowsmith, d'Archiac and Tyndall.

No more shall you charm me, dear dainty Ourisia,
Your broad fields of mountain-musk starred with white blossom,
Euphrasia, Raoulia, Phyllachne, Celmisia,
No more shall you strike the deep chord in my bosom.

No more shall I pore on the hard tawny grasses
That colour the steep spurs and long level reaches,
No more shall I haunt the high desolate passes
Where the elfinwood sprawls on the fringe of the beeches.

No more shall I see, as the high sun is westering,
In the steep dusky valleys that look to his setting,
Thin streams in the late light all twining and glistening,
Like threads of fine silver the purple gloom fretting.

No more shall I hear the white mountain gull crying
Among the bare rocks where the great gusts go booming,
Six thousand feet up where in rough hollows lying
The broody old tarns hang a-drowsing and glooming.

I shall see them far off in the magical distance,
With bloom like a ripe plum, so fresh and so tender,
They will beckon and woo me and call with insistence,
The big shining Alps in their pomp and their splendour.

But I camp no more in the beech-wooded valleys,
No more shall I sleep in the roar of the river,
Or wander alone in the cool shady alleys,
For my feet have come down to the lowlands for ever.

Arnold Wall.

(Reprinted by permission of the Librarian University of Canterbury)
Two thousand years ago the philosopher Seneca explained that rivers originated from the subterranean movement of water from the sea to the land. Rainfall was not involved.\(^1\)

Ten years ago a Soviet hydrologist, Molchanov, bluntly asserted that variations in river flow were mainly caused by variations in rainfall.\(^2\)

In the last eighty years, experiments in many parts of the world have shown that land uses can alter river flows. This had led some enthusiasts to make extravagant claims, for example, about the beneficial effects of afforestation on the incidence of floods. On the other hand, some engineers have totally dismissed such propositions.

This article considers some of the issues upon which the arguments depend. It gives some perspective to the conflicting claims and indicates the roles that land management might have in the management of our waters.

This article is concerned with water yield, the long-term volume of stream flow. Low flow refers to a flow rate during a specific period of time. Although these terms are frequently used synonymously, they refer to distinctly different hydrological phenomena.

In the beginning

Contemporary watershed management is generally believed to have had its origins in 19th century Switzerland.

In the 18th and 19th centuries the population of the Swiss Alps increased as entrepreneurs clear-cut forests for the rapidly developing down-country iron and glass industries. Erosion and flooding went largely unheeded until the Vienna Congress of 1848. This gave political stability to the region. Disasters in the 1870s and 1880s convinced the Swiss Government that remedial action was necessary. In 1876, and again in 1902, the Swiss Constitution and forest legislations gave authority to the Government to undertake remedial work with Federal money.

In 1902 Arnold Engler began the Emmenthal project which studies the effects of forests on stream flow. There are at least two features of the early Swiss experience which should be understood. First, the political decision to rehabilitate mountain lands preceded research into forest influences by about 25 years. Second, the early forest hydrologists were apparently experienced and practical foresters, who not only believed in the Government’s policies of rehabilitation, but also felt personally responsible for them.\(^3\)

At about the same time, settlers in the western United States were recognising the importance of water for irrigation. Their concern over the limited availability of water was, in part, responsible for Congressional legislation in 1897 which created forest reserves for the prime purpose of “securing favourable conditions of water flows”. In 1911 the Week’s Forest Purchase Act extended land purchase to the “acquisition of land for the purpose of conserving the navigability of navigable waters”.\(^4\)
the same year (1911), the United States Forest Service and Weather Bureau set up a co-operative paired catchment study into the effects of forests on stream flow at Wagon Wheel Gap in Colorado, the results of which were not reported until 1928.\(^5\)

However, in 1912, Raphael Zan attempted to enlighten the U.S. Congress and public with his report “Forests and Water in the Light of Scientific Investigation”. Forests, he reported, were not only beneficial to stream flows but they actually caused increases in precipitation.\(^6\) Although the latter view is now discredited it was, at the time, an important contribution to the developing concern about forest influences.

Again, the political action to conserve forests for their impact on river flow preceded research into forest influences.

**More recent experience**

Water yield has been the single most frequently studied topic in the last 50 years of small watershed research. From the first study at Wagon Wheel Gap (Colorado), to the Arizona symposium on the status of knowledge of forest influences,\(^7\) American experience has repeatedly shown that forest cutting is associated with increases in water yield. On the other hand some Soviet experience has shown that water yields can be increased with forest planting.\(^2\) (This conflict has nothing to do with differing political ideologies. It can be explained by differences in land form and climate. Snow which blows across the Russian Steppes can be trapped by shelter belts and accumulate as snow banks. In the North American alpine forests, clear forest areas trap and accumulate snow that may otherwise be blown over the catchment.)

Leaving aside the Russian experience, the conclusions from most studies are that within one climatic region, the size of the water yield increase following forest clearance appears to depend on the size of the cut. In areas with summer rainfall much of the response appears during the low flow periods of mid summer and autumn. In regions with dry summers and wet winters the response appears as extra water in autumn and winter.

Some years ago Hibbert reviewed 39 water yield experiments that had been carried out mostly in North America.\(^8\) He concluded that:

1. The reductions of forest cover increased water yield.
2. The establishment of forest cover on sparsely vegetated land decreased water yield.
3. The response to treatment is highly variable and for the most part unpredictable.

However, further examination of Hibbert’s data helps to clarify the “unpredictable” nature of the response.

For the 31 North American catchments that he reviewed, water yielded by the catchment was between 10 per cent and 60 per cent of the incoming rainfall. The notable exception was the Naselle River (Washington) where 80 per cent of precipitation was returned as stream flow. It is also significant, that in that basin no change in runoff could be detected in response to logging.

The Naselle River experience may be more relevant to New Zealand than most other North American studies.

For example, in the Torlesse Stream catchment it was found that 80 per cent to 90 per cent of precipitation appeared as stream flow.\(^9\) From Ministry of Works data it can be calculated that in the Ahurirri catchment more than 90 per cent of summer precipitation appears as stream flow. (In this example only summer rainfalls were considered because winter snows confused the analyses.)

On the other hand, in the drier hill country of Banks Peninsula (Kaituna catchment) and Marlborough (Reynolds catchment) summer stream flow yields are 50 per cent and 40 per cent respectively of summer rainfall.

Some years ago J. T. Holloway cautioned against excessive enthusiasm for managing
mountain lands for water yield\(^{(10)}\). Recent experience supports Holloway’s concern and suggests that water yield management may be of less importance in some mountain areas than in some drier hill country.

However, even in areas where water yield management might be possible, information which comes from small plots or points on a catchment should be used with care. Such information should not be automatically applied to the catchment as a whole.

The conversion of rainfall to stream flow is one of the most complex of all the naturally-occurring physical processes. There are at least thirty separate processes involved which interact both throughout the catchment and throughout time. Despite much research effort in the last half century the responses of catchments to rainfall are, in general, only poorly understood. We do know, however, that responses observed at one point on a catchment may be completely masked by other more important factors, and may be undetectable further down slope or in the stream channel. For example, tall plants on a mountainside may intercept water from fog or light rain and provide additional water to the soil. However, as that water moves down slope it may be transpired by down slope plants or by willows growing along the stream’s edge. We cannot assume that merely because there is additional water on the upper slopes there will also be additional water in the stream.

**Conclusion**

There is clear evidence that some land uses affect water yields. The problem to be faced, however, is not the general truth of this evidence but its relevance and significance for mountain lands.

The available evidence suggests that water yield management might be more appropriate to drier hill country. For the mountain lands there may be more truth in Molchanov’s statement “the changing volume of water which (rivers) carry is accountable first of all by variations in precipitation . . . ”\(^{(2)}\)

Put simply, if we want water from our mountain catchments, we should pray for rain.

**References**


3) KELLER, H. M. Personal communication.


Avalanche!

by K. Lefever and P. Dingwall

Avalanches are common throughout the mountain ranges of the world, yet the majority go unnoticed, as they occur in remote areas. However, upon the introduction of human activity into these areas, avalanches become a hazard with the potential to kill unwary climbers and skiers and to destroy buildings, highways, railways and communication lines. Although challenging skiing conditions generally coincide with avalanche-prone areas, the avalanche risk on ski-fields can be reduced if appropriate hazard evaluation procedures and control measures are adopted.

As an increasing number of people with limited awareness of the potential danger venture into steep mountain terrain, there is a corresponding increase in the need for public education about the avalanche hazard. There is also a need to ensure that inexperienced mountain users are not exposed to unnecessary risks.

In this paper, the authors give an introduction to the conditions under which avalanches may occur, review some of the research and discuss the current safety programme in New Zealand.

July 5, 1975: Mangaehuehu Glacier, Tongariro National Park — Three climbers were engulfed in a slab avalanche while descending from Girdlestone Peak. All were buried while being carried 400 metres downslope but finished up on the surface. All survived.

July 5, 1975: Mount Egmont National Park — A slab avalanche came down from the bowl of snow above Tahunangi Lodge, through the narrow gorge and past Tahunangi Lodge. It severed a television translator tower power cable and demolished part of the road.

July 23, 1975: Ball Pass, Mount Cook National Park — An instruction party of 27 was caught in a slab avalanche while digging snow caves. Four people were killed.

August 25, 1975: Mount Hutt — A slab avalanche caught a party of 25 while they were walking up the Mount Hutt road line. Two members of the party were overwhelmed by the avalanche, one was buried, but unhurt, the other was killed.

August 28, 1975: Temple Basin, Arthurs Pass National Park — Two people were swept away by an avalanche on the Page Hut track. One was found promptly and survived. The other was found buried and dead the following day.

August 26, 1976: near Mueller Hutt, Mount Cook National Park — An avalanche caught a party of 10 trampers. Six members were engulfed by snow and carried 150 metres down the slope. Of these, three were buried. All survived.

September 30, 1977: Porter Heights ski-field — Two people were buried under snow when an avalanche ran down the centre of the field. Thirty-six people were on the field at the time. The two people buried were found and survived. One ski-lift tower was structurally damaged.

Introduction

Many mountain users have a very real understanding of the potential danger associated with avalanches. However there are others, and their number is increasing, to whom this danger is completely meaningless, or, at best, poorly understood.

Similar trends are occurring overseas, albeit on a larger scale. A survey of avalanche accidents during the 1950–75 period in the United States (Williams, 1975a) showed that the number of avalanche fatalities in the United States was increasing, and that 75 per
percent of all avalanche victims were recreationists. Similar trends have been noted in Japan and Switzerland.

In a recent report (La Chapelle, 1979), the low avalanche accident rate in New Zealand has been attributed to the relatively low density of skiers and to a decade of relatively light winter snowfalls and consequently less avalanche activity. This may have encouraged a false sense of security about avalanche dangers on the part of ski-field operators and the general public.

It is important to make New Zealanders aware of the avalanche hazard and to show how the risks involved can be minimized. To this end, there is a vital need for well-informed planners, developers, ski-field operators and park managers to ensure that inexperienced mountain users are not exposed to unnecessary risks.

Features

Snow avalanches are large masses of snow which release suddenly and move rapidly down a mountain slope. They can range in size from a few cubic metres to the entire face of a mountain side. They may involve only the initial volume of snow released or they may add more snow, rocks and trees to their mass. The rates of descent can range from a few metres per minute to those in excess of 250 kilometres per hour.

The propensity of any given snow mass to release depends on its stability. Some snow covered slopes may never release, while others may do so spontaneously. The release may be triggered by some natural disturbance such as rock, ice or snow falling from higher slopes, or by the mechanical influence of human activity.

Any snowclad slope is a potential avalanche source. Overseas research (Martinelli, 1974) suggests, however, that most dangerous avalanches originate on slopes with gradients averaging between 30° and 45°. Steeper slopes rarely accumulate sufficient snow to constitute a significant hazard except in maritime climates, where wet and heavily rimed snow crystals can adhere successfully to steeper faces. At the other extreme, avalanches may start on slopes of less than 30° when, as the result of a prolonged
warming trend, heavy snowfall or unusual wind conditions, the snow cover on these slopes develops a high degree of instability. Avalanches are not confined to specific terrain features; they may follow narrow gullies or ravines for all or part of their path; they may occur on broad, uniform slopes or on ridges and spurs.

Three main factors contribute to avalanche potential:

- snow accumulation
- internal strength of the snow pack
- strength of the bond between the snow cover and the ground.

The degree to which these occur is dependent upon local wind patterns, the amount and rate of snowfall during the last storm, the history of ground and air temperatures, precipitation preceding current conditions (possibly by as much as several months), and temperature conditions since the last snowfall.

The snow pack is made up of a series of layers, each being the product of one or more snowfalls. The depth and internal structure of each layer is affected by the conditions during the snowfall and the ensuing temperature changes.

The overall internal strength of the snow pack is affected by the strength of both the bonding of snow within individual layers and the bonding between adjacent layers.

When snow avalanches occur, release is frequently caused by failure of the bonding within one layer or between layers. Following such failure, which may also occur at the ground surface, the snow mass above the failure level begins to slide, either as loose snow or as large broken slabs, and frequently incorporates lower layers as well. Failure may occur spontaneously when stresses within the snow pack break the weakest stabilizing links or in response to an external force such as the added weight of a human being.

The internal structure of the snowpack continually changes. The physical properties of the snow within each layer may change in response to differences and changes of temperature, pressure and water vapour within the snowpack. These changes in the snow are called metamorphism. Some changes of this type tend to increase the stability of the entire snowpack or only certain layers within the snowpack. Other changes can decrease the stability of the snow already accumulated on the ground or create a weak surface unable to support future snowfalls.

Survival

The chances of an avalanche victim surviving are usually dependent upon good luck, the victim’s actions and the actions of any witnesses. With good luck and the employment of a determined swimming motion while being transported by the avalanche, the victim may emerge on the surface of a small avalanche relatively unhurt. In those instances where the victim remains buried beneath the surface of the avalanche debris, survival depends upon the promptness of rescue. After 30 minutes under snow, the survival rate is only 50 per cent. On average if completely buried, the victim has only one chance in three of survival, regardless of any other considerations. Chances of survival are remote where victims are buried at a depth greater than two metres or for longer than eight hours (Williams, 1975b). Although accounts of successful rescue after much longer periods do exist, these cases are rare and only serve to illustrate the crucial importance of immediate rescue.

Guidelines

In a number of overseas countries, basic public safety programmes and management guidelines have been developed to minimize the risks to mountain users in winter. Useful publications include:

- field safety guides;
- an avalanche rescue manual;
- a field guide to snow crystals;
- a guide to the identification and evaluation of avalanche sites;
- a practical handbook on all aspects of avalanche safety;
- readable and informative collections of avalanche accident case histories.

Publications of a more technical nature discuss avalanche forecasting and hazard
warning systems, structures for preventing or deflecting avalanches, artificial release with explosives and patrolling as part of ski-field safety programmes (see selected bibliography at the end of this article).

In addition, considerable research has been conducted primarily in Canada, Europe, Japan, the Soviet Union and the United States on various facets of avalanche dynamics — the physical properties of snow, the relationship of weather systems to snow accumulation, the changes that take place within the snowpack and factors relating to avalanche potential. A review on avalanche research, published by the New Zealand Mountain Safety Council (Owens and O’Loughlin, 1979) provides a useful source of information on this research.

There is little documented information available on the nature of snowfall, the snowpack and avalanche formation in New Zealand. A detailed understanding of the relationships between snow properties, weather patterns, terrain and the relative stability or instability of the snow pack is needed. Various guidelines can be applied to the New Zealand situation in the light of overseas experience to assist with the preparation of material for public safety management plans for ski-fields and for public education in avalanche risk awareness. However the effectiveness and efficiency of these methods would benefit from a better understanding of local snow conditions.

Safety programme

In November 1976, the N.Z. Mountain Safety Council and the National Parks Authority jointly convened a seminar in Christchurch on the avalanche hazard in New Zealand (Dingwall, 1977a). This provided a forum for the expression of concern about avalanches and public safety and for an assessment of interest and review of research in snow and avalanches in New Zealand. Subsequent action the following year resulted in the establishment of the N.Z. Mountain Safety Council Avalanche Committee. This is a project committee of the Council, responsible to and deriving its fund-
Slab avalanche.  

Photo: Mount Cook National Park Board
To provide a source book on avalanche information the Council has published a comprehensive review of avalanche literature from New Zealand and overseas (Owens and O'Loughlin, 1979). Workshops and training sessions have been conducted for professional mountaineers, guides, ski patrollers, park rangers and ski-field managers. These have dealt with aspects of snowfall and snow pack measurement techniques, terrain analysis, the evaluation of avalanche hazard, control methods and rescue techniques.

Avalanche hazard atlases and maps are under preparation for the Milford Road, Arthurs Pass National Park and the Craigieburn Range — while these are a first for New Zealand, they are widely used as development and planning tools overseas.

The Mountain Safety Council is actively promoting research and assisting university staff and students undertaking avalanche studies, notably in the Mount Cook, Arthurs Pass and Craigieburn areas. The Council has also assisted some New Zealanders to visit locations overseas for instruction and information gathering.

In addition to the Avalanche Committee working parties, other groups are also active in showing interest in avalanches and public safety — notably a major snow monitoring and avalanche control programme is in operation at Porter Heights ski-field. Other ski-fields such as Mount Hutt and Coronet Peak are developing avalanche hazard evaluation programmes and an avalanche monitoring programme has been undertaken by Mount Cook National Park staff.

**Summary**

Although New Zealand has experienced only a few avalanche fatalities to date, current trends suggest that increasing numbers of unwary winter mountain users are exposing themselves to avalanche hazards. Fortunately, the major increases in mountain recreation over the past decade have coincided with a series of low-snowfall years, and avalanche problems have been minimal. Through research, a wider understanding of New Zealand snow conditions, improved education and publicity and the adoption of appropriate avalanche control measures, it will be possible to prevent more serious avalanche accidents.

**Selected Bibliography**


Appendix

Avalanche reporting forms

"In this appendix, written on behalf of the New Zealand Mountain Safety Council Avalanche Committee, Mr Lefever explains the use to which Avalanche Reporting Forms will be put."

The previous article in this issue on avalanches outlines the present avalanche safety programme in New Zealand. Over recent years, the increasing popularity of winter mountain recreation has exposed greater numbers of mountain land users to the avalanche hazard. It is important that this risk be minimized.

One of the primary objectives of the proposed avalanche research is the prediction of avalanches. Few data are available on the frequency or size of avalanches, or on the triggering mechanisms and associated weather patterns in New Zealand. Such information is necessary for the development of prediction techniques.

Consequently, the New Zealand Mountain Safety Council Avalanche Committee is interested in collecting data on avalanches and would be grateful if interested individuals would:

1. Send copies of any avalanche records they may have to the address given below; records can be copied and returned.

2. Fill in copies of the Avalanche Reporting Form, whenever an avalanche or avalanche debris is seen. Copies can be obtained from the address given below. They should be returned when completed to the same address:

   Ken Lefever
   Avalanche Data Centre
   T.G.M.L.I.
   P.O. Box 56,
   LINCOLN COLLEGE.
Public co-operation in this matter will assist the Avalanche Committee to build up a data base to test prediction techniques.

A sample of the Avalanche Reporting Form is given here. Additional details beyond the scope of this form will be welcomed. It is in two parts: a classification chart for the observers' information and the reporting form which is to be completed.

Data received from these reporting forms cannot provide researchers with all of the required information. For a more complete information coverage, a systematic research programme involving regular meteorological records, snow descriptions and avalanche occurrences is required. On the basis of such a programme, the recording of non-occurrence of avalanche events becomes relevant also. In contrast, these reporting forms will describe isolated occurrences of observed avalanches. However, these data are of importance in assisting researchers to gain an overall understanding of avalanche occurrences in New Zealand.

Avalanche Classification Chart

<table>
<thead>
<tr>
<th>Type of snow</th>
<th>Loose snow avalanche</th>
<th>Slab avalanche</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movement</td>
<td>Airborne</td>
<td>Flowing</td>
</tr>
<tr>
<td>Depth of sliding surface</td>
<td>Full depth</td>
<td>Surface</td>
</tr>
<tr>
<td>Humidity of snow</td>
<td>Dry</td>
<td>Wet</td>
</tr>
</tbody>
</table>
# AVALANCHE REPORTING FORM

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>Date of Avalanche</th>
<th>Is date actual or estimated?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude of Starting Zone of Avalanche</td>
<td>Observer’s Name and Address</td>
<td></td>
</tr>
<tr>
<td>Altitude of End of Avalanche</td>
<td>Date Sighted:</td>
<td></td>
</tr>
</tbody>
</table>

## CLASSIFICATION (See classification chart)

## TRIGGER (In your opinion what caused the avalanche to start)

## PAST WEATHER (rain, snow, wind, temperature, etc.)

## WEATHER AT TIME OF OCCURRENCE

## ANGLE OF SLOPE      ASPECT OF SLOPE      OBSERVER’S LOCATION

## COMMENTS: (e.g. width, length, size, snow conditions etc.)

## HUMAN INVOLVEMENT (none or else: party size, number involved; injuries, fatalities; rescue; damage to property & equipment)

If you see an avalanche or its debris please complete this form and send to:

Ken Lefever  
Avalanche Data Centre  
T.G.M.L.I.  
P.O. Box 56  
LINCOLN COLLEGE
Authors

I. G. C. KERR is a Senior Research Officer with the Tussock Grasslands and Mountain Lands Institute, Lincoln College. He graduated B.Agr.Sc. from Lincoln College in 1962 and in 1962–63 lectured in Agriculture at the University of North Sumatra. In 1964–65 he lectured in agronomy and farm management at the University of Malaya, Kuala Lumpur and worked on the planning and development of a commercial and demonstration farm. He joined the Waitaki Catchment Commission as Soil Conservator at Lake Tekapo in 1966. He was appointed to his present post in 1976. K. R. LEFEVER is Statistician at the Institute, being appointed in 1974. He graduated B.A. (Mathematics) from the University of British Columbia in 1971. E. J. COSTELLO is Technical Officer at the Institute, joining in 1972. He has been closely associated with survey projects and with mountain revegetation research.

G. A. DUNBAR is a Principal Research Officer with the Institute, his main interest being the revegetation of mountain lands. Graham Dunbar graduated from Lincoln College with a B.Ag.Sc. degree in 1948 and was appointed Technical Research Officer at the Tara Hills Research Station of the Soil Conservation and Rivers Control Council. His work there was concerned with the improvement of cover on denuded and eroded tussock and snow grass areas. For 8 years he was a Senior Scientific Officer with the Department of Agriculture. In 1952 he completed his Masters degree and in 1964 joined the staff of the Institute. R. F. HORRELL is Technical Officer with the N.Z. Agricultural Engineering Institute at Lincoln College, E. J. COSTELLO is Technical Officer at the Tussock Grasslands and Mountain Lands Institute, joining in 1972. He has been closely associated with survey projects and with mountain revegetation research.

A. F. MARK is Professor of Botany at the University of Otago and a past Fellow, presently Advisor on Studies to the Miss E. L. Hellaby Indigenous Grasslands Research Trust. His plant ecology studies have concentrated on mountain vegetation, particularly the snow tussock grasslands of Otago. He is a Fellow of the Royal Society of New Zealand, and serving his second term as an elected member of the Otago Catchment Board (currently Chairman of its Regional Water Committee) and is also Chairman of the Guardians of Lakes Manapouri and Te Anau. JENNIFER ROWLEY (MRS J. A. HICKMAN) graduated M.Sc. from Otago University and now lives in Wellington. D. K. HOLDSWORTH is a Ph.D. student in the Botany Department, University of Otago. All three held Miss E. L. Hellaby Indigenous Grasslands Research Fellowships.

J. A. HAYWARD, well known to many people in the high country, joined the Institute in 1964. He graduated B.Ag.Sc. from Lincoln College in 1961 and Ph.D. in 1979. He was appointed Director of the Joint Centre for Environmental Sciences, University of Canterbury/Lincoln College in 1979. His principal research interest has been in the hydrology and sediment behaviour of mountain catchments. During 1974/75 he served as visiting Professor of Watershed Management at Colorado State University.

K. LEFEVER joined the Tussock Grasslands and Mountain Lands Institute in 1974. While a University student and after graduation, he worked as a prospector and assistant geologist for seven seasons on mining exploration projects in the British Columbian mountain ranges and the Canadian Arctic. During the 1972–73 summer, he was a Field Assistant for the Antarctic Division, D.S.I.R. in Antarctica. His interest in snow and avalanches comes from his work in the mountains and from ski mountaineering in British Columbia. His experience with New Zealand snow conditions is limited, but this has not detracted from his interest in the new avalanche safety programme in New Zealand. P. DINGWALL is a scientist with the Lands and Survey Department, and is convenor of the N.Z. Mountain Safety Council Avalanche Committee.
The review of the role of the Institute, and its terms of reference, undertaken at the direction of Cabinet by the Department of Lands and Survey and the National Research Advisory Council was completed in June 1978, and accepted by the Minister of Lands, the Council of Lincoln College, and the Committee of Management.

The new terms of reference substantially are:

1. The Institute shall be a centre to facilitate the co-ordination of research and the dissemination of information from activities intended to provide knowledge, technology, and alternatives for the present and future productive use of the tussock grasslands and mountain lands; to promote and participate in such research and other activities, and to initiate new lines of research.

2. The Institute shall encourage and undertake investigations on all facets of resource management in the tussock grasslands and mountain lands including the development of techniques to aid management of these lands for pastoral use, agricultural and forest production, the preservation of wildlife habitat, water, and recreation and for the conservation of landscape, soil, flora and indigenous fauna; and to encourage and undertake investigations of alternatives for the present and future use of these resources and the inter-relations between them.

3. The Institute shall identify problems and indicate research requirements and disseminate research and management information to all interested parties.

4. The Institute shall provide a forum for all users of tussock grasslands and mountain lands and contribute to education, training and understanding in fields relating to terms of references 1, 2 and 3 above.

Now that this review is completed, it is the Institute’s task to look at its own policy within the framework laid down.

In view of the current economic situation in New Zealand, the role we must emphasise for the Institute must be one of endeavouring to increase economic returns from the tussock grasslands and mountain lands. The Institute recognises the need to look closely at its programmes of work with this in mind, paying special attention to ways and means of ensuring that available knowledge is quickly and efficiently transmitted to those who require and can use it.

With its work in research, its contacts in extension, and its role in publishing and information transfer, the Institute has a unique opportunity and must make the most of it. It is currently reviewing its own internal organisation and the new arrangement of work programmes and projects within them are used in this report.
Programme of pastoral utilization and animal production

GOAL: To contribute to knowledge and understanding of factors affecting pastoral utilization of herbage resources of hill and high country, and of factors affecting pastoral vegetation condition and animal production and to develop improved pastoral technology and alternative pastoral management practices.

Glenthorne grazing behaviour

(Project leader: Mr P. S. Harris. Assistants: Prof. K. F. O'Connor, Mr K. Lefever, Miss L. Budgeon, Mr G. Holgate (Lands & Survey)).

Following review, the Glenthorne grazing trial is being continued with the objective of studying the effects of partial area oversowing and topdressing during late October 1978. The work involves field measurement of herbage, observation of animals and faecal cuticle analyses.

The project, as a whole, is well on the way to fulfilment of its original purpose. To date much knowledge has been gained about the grazing behaviour of sheep in relation to their feed supply. In addition the study has opened new avenues of study for the future.

Pasture measurement study

(Project leader: Prof. K. F. O'Connor, Assistants: Messrs E. J. Costello, P. S. Harris and A. B. Edge.)

This project evaluates the use of "Charlie", an electronic capacitance meter, in estimating available dry matter in hill country situations. This meter has been used extensively in lowlands. Now in tussock country, it has been used in a wide range of plant associations. Correlations have been established between meter readings and fresh herbage weights as well as with laboratory-determined weights of herbage water and herbage dry matter. Improved techniques of calibrating "Charlie" have been developed and evaluated.

Professor O'Connor has been supervising a masterate study by Mr Edge of grazing pressure on three blocks at Tara Hills. His study includes an assessment of available dry matter by "Charlie" at transect sites, and visual estimation of botanical compo-

The Glenthorne grazing trial area.
sition. Grazing periods and stocking loads were also recorded. Extensive technical help was given in the field by Tara Hills (MAF) staff, as well as access to stock and meteorological records.

This study has indicated that a substantial proportion of the variation in records of “Charlie” may derive from uneven water to dry matter ratios of herbage. Such a variation might have affected the validity of herbage dry weight estimates by conventional cutting methods, unless strict attention was given to securing representative samples for moisture determination.

**Potential stocking rates**

Mr Harris has completed an estimation of potential stocking rates of different classes of high country properties in the Upper Waitaki at various levels of development. His estimates will be published as an appendix to Martin Whity’s report on the economics of pastoral development in the Mackenzie Basin.

Results of this project emphasised differences in present and potential levels between climatic regions; the relative benefit of extensive dryland development compared with small scale irrigation development, in its contribution to the overall energy supply of the property; the limited effect of changing flock-herd combinations and the likely significance of irrigation in reducing variability in comparison with dryland development.

**Pastoral utilization survey**

(Project leader: Prof. K. F. O’Connor, Assistants: Messrs E. J. Costello and M. Abrahamson)

This survey records the distribution of stocking loads on tussock country. Mr Costello, under the supervision of Professor O’Connor, has completed the analysis of 54 runs. Preliminary results for the Waitaki presented by Professor O’Connor to the International Rangeland Conference in Colorado show large ranges in stocking loads on improved tussock grasslands from 15 to 21 stock unit months (s.u.m.) per hectare, depending on terrain, up to from 42 to 114 s.u.m. depending on terrain. Mean values on the unimproved grasslands were about 6 s.u.m. and varied with terrain from 27 to 51 s.u.m. on oversown and topdressed land.

**Feed quality studies**

(Project leader: Prof. K. F. O’Connor. Assistants: Dr D. G. Clarke, Messrs B. Allan (MAF) and E. J. Costello.)

The Mesopotamia studies of management influence on feed quality have been completed and will be published in a series from late 1979.

Professor O’Connor’s study with Mr I. Fryer, Miss L. Budgeon and Mr R. McKenzie (Biochemistry Dept., Lincoln College) to determine the influence of plant nutrition on the anatomical structure, biochemical composition, and digestibility of fescue tussock has been completed.

Mr G. Dryden of Queensland Agricultural College, who worked at the Institute on influence of mineral supplementation on intake of fescue tussock for sheep, has written up his studies for publication with Mr W. Archie of Grasslands Division DSIR.

**Grassland agronomy and vegetation improvement**

**GOAL:** To provide knowledge and technology for improvement of grasslands and other vegetation for pastoral and other purposes.

**Riparian revegetation**

(Project leader: Mr G. A. Dunbar, Assistants: Messrs J. Follett and E. J. Costello, Botany Division DSIR and Department of Lands & Survey)

This project, to determine the suitability of some native plant species for revegetation in riparian situations in comparison with exotics, has been funded by the Department of Lands and Survey under contract.
Plantings were made in spring 1978 on a gravel bed site (Kowai River), a sub-soil site (Porter River) and in soil bins at Lincoln College.

Brief results to date are:
1. Gravel bed—Kowai River.
   Although plants appeared to establish well, the dry weather in autumn and suspected shortage of nitrogen in the gravels brought high losses. The broadleaf (Griselinia) and Hebe have shown best results so far for the native species, but are still well short of the survival rates of the willow species.
2. Subsoil—Porter River.
   Plants suffered a severe set-back, apparently from frost damage after fresh growth had started. Broadleaf and Olearia plantings were particularly affected. Again the willows have shown best growth and survival despite severe frosting.
   There has been good growth of the species planted in the bins at Lincoln in October, although initially there were high losses in Cortaderia (toe toe). The need for applying nitrogen at, or soon after, planting has been evident here, especially for the gravel in bins.

Forage quality improvement on Grampian Mountains

(Project leader: Mr G. A. Dunbar. Assistants: Messrs E. J. Costello and J. Follett)

Grasslands Division DSIR has collaborated in this project to develop ways of improving the forage composition and quality of the vegetation of higher and drier areas. During October 1978 trials were laid down on both the east and west-facing sites at 1450 metres altitude, to test the establishment from oversowing of two grass mixtures and four legumes, firstly with a sulphur superphosphate mixture and secondly with superphosphate plus nitrolime. There had been a limited degree of success from oversowing with a grass-legume mixture in the previous spring and this was re-topdressed this year.

Transplants of the introduced grass, sweet vernal, which is not yet generally present at this altitude, have shown that the species survives very well on both the east and west faces, and will no doubt increase naturally.

Agronomy of native revegetation

(Project leader: Mr G. A. Dunbar. Assistants: Messrs E. J. Costello and J. Follett)

The heavy winter snow of 1978 disturbed many of the planting trials on the west face. The snowgrass seedling trial was destroyed. The best survival rate (58 per cent) of Chionochloa rigidoid on bare subsoils was achieved with rooted tillers. Fresh tillers gave a survival of 36 per cent, slightly better than that of eight month-old seedlings, while most three month-old seedlings failed to survive the winter.

Autumn planting of rooted tillers of C. macra survived better on the east-facing site. The planting dates were February, March and April. Survival rates were: East site 85 per cent (best survival February), west face 25 per cent (best survival April), and summit 42 per cent (best survival March).

Transplants in both spring and autumn of young rooted blue tussock (Poa colensoi) tillers were very successful on the summit and on the difficult west face. However, there was only a limited success with the smaller native grasses Trisetum spicatum and Deyeuxia youngii on the same sites. Autumn-sown blue tussock seed sown at 1760m on the summit site gave good spring emergence and summer survival was good.

Subsurface introduction of grass and legumes


Initial work on this project, carried out in collaboration with New Zealand Agricultural Engineering Institute and Grasslands Division DSIR in 1977-78, had shown that at three Mackenzie County sites the estab-
lishment of cocksfoot and ryegrass when introduced with a modified rotary-hoe with seed box, was much better than when introduced with a disc-drill (single discs). By the end of the growing season there had been heavy mortality of seedlings under all treatments at the two driest sites, but even so grasses persisted better with the Roto Sod-drill than with the disc-drill. At the wettest site (250 mm of rain for the seven months from September to March inclusive) grass frequency had remained relatively stable with the Roto Sod-drill but had fallen away in the disc-drilled areas. This advantage was still clearly evident twelve months after establishment.

In the 1978-79 season the Institute has been co-operating further with the New Zealand Agricultural Engineering Institute in testing the effect which two different coulter designs on the Roto Sod-drill may have on seedling establishment.

**Programme for institute facilities information and extension**

**GOAL:** To maintain and improve Institute facilities in field and at Lincoln and to carry on functions of facilitation of co-ordination of research, dissemination and sharing of information, contribution to education and training, provision of forum for users and problem identification.

With Mr B. T. Robertson taking his duties in early December 1978, the Institute's Scientific Information Centre is now in being and is planning a Seminar for hill and high country farmers and senior public servants.

During the year Professor O'Connor delivered addresses at the Marlborough and Haldon High Country field days, and Mr Kerr at the Marlborough and Orari Gorge field days. A press release on Hieracium sent to all newspapers was widely used.

Mr G. A. Dunbar and Mr E. J. Costello working on the revegetation trial area at Molesworth Station.
Mr Lefever has continued his work on the avalanche bibliography, adding 75 references to the 600 prepared prior to 1978, and has prepared an Institute internal report on the computer design used. He is Institute and Lincoln College liaison officer for remote sensing, keeping in touch with Remote Sensing Section, Physics and Engineering Laboratory DSIR in Lower Hutt.

Contact was maintained with runholders during the high country production survey, assistance given in organising field days, and whenever possible informal visits made to agencies and organisations involved in extension, research or administration in the tussock grasslands. These activities are important in the Institute's work of being informed of events and changes in the tussock grasslands and mountain lands and in passing information on to those concerned.

Programme for earth and water processes and evaluation

GOAL: To contribute to knowledge and understanding of earth and water processes in the tussock grasslands and mountain lands and to provide information and techniques for evaluation of earth and water resources for alternative uses and for interpretation of their management needs.

Dr Hayward has led the work in this field and although he has left the Institute he will continue to oversee the Torlesse projects. These are due for review later in the year.

Bed-load sediment study—Torlesse

(Project leader: Dr J. A. Hayward. Assistants: Messrs P. Ackroyd, P. Shand, J. Small, I. Fryer and Mrs J. Smith)

This study, to determine the quantity and rate of loss of sediment from the catchment as bed-load, involves the collection and analysis of data from several weekly-run instruments together with monitoring of the sediment trap to record bed-load movement, if present. Results of the five years, 1972 to 1977, are being published. Bed-load monitoring will be continued for future storm events.

The most outstanding event of the year was the storm during April 1978—possibly a one-in-20 years event. This delivered approximately 800 tonnes of sediment in 70 hours. If this event is included in the results to 1977 the sediment yield rises from 30 tonnes/Km² of catchment a year to 60 tonnes/Km²/year. Thus short term results may significantly underestimate the long term yield, if low frequency events are not included in the results. After this storm only insignificant amounts of gravel were recorded leaving the catchment.

Suspended sediment study—Torlesse and Kowai

(Project leader: Dr J. A. Hayward. Assistants: Messrs P. Shand and J. Small).

This is a project to determine the quantity and rate of loss of suspended sediments from these catchments. Institute staff have been involved with the collection of suspended sediment samples with emphasis on flood events. Physical analysis of the samples was carried out in the Institute's laboratory.

The results indicate that, whereas bed-load is the dominant component of total sediment in the upper reaches of the system, suspended sediments become more important with distance downstream.

Partial area hydrology

(Project leader: Dr J. A. Hayward. Assistants: Mrs J. M. Riddell (M. App. Sc. student) and Mr P. Ackroyd.)

This project aims to better understand the conversion of rainfall to runoff within the context of a partial contributing area. A small catchment (Helen Stream) which contributes to the Torlesse Stream has been selected for detailed investigation. Studies include the weekly monitoring of precipitation, evaporation, soil moisture, ground water and stream flow.
Mr S. Harrison, Geology Department, University of Canterbury carried out a detailed seismic survey of the study catchment to determine depths of regolith.

Mr I. Brown, Plant Science Department, Lincoln College has undertaken detailed studies of vegetation, soil chemistry and soil physics including salivated rates of hydraulic conductivity.

The Torlesse and Helen Stream catchments form a nested system within the Kowai river catchment. The hydrological studies are aimed at ultimately providing a better understanding about the significance of small catchment treatments to larger catchment responses.

Water quality analysis

(Project leader: Dr J. A. Hayward)

This project involved the collection of water samples at midday and midnight over a three day period. Analysis of the samples was carried out by the Freshwater Ecology Section DSIR, Taupo. The project was a pilot study for a possible more detailed water quality sampling programme in the future that would involve both the DSIR and the Chemistry Department of the University of Canterbury, as a Joint Centre project. No formal project has been initiated.

Shingle resources investigation—Taranaki

(Project leader: Dr J. A. Hayward, Assistants: Mr P. Ackroyd and Taranaki Catchment Commission)

Investigative aspects of the project are now completed and the report sent to the Taranaki Catchment Commission. The principal findings were that there was a finite amount of material suitable for shingle production in the Taranaki rivers. As this material was being rapidly depleted (with possible consequent river-control problems) alternative sources and management options were suggested.

Proposed Patea River hydro scheme


A final report on this investigation has now been given to the Taranaki Catchment Commission. Several areas for concern were mentioned including:

(a) Control of sediment entering the proposed reservoir.

(b) Possible slumping in the steep reservoir banks.

(c) The occurrence of scouring and siltation downstream of the dam site.

S. C. C. B. Orari, Catchment Project

(Project leader: Mr K. Lefever, Assistants: S.C.C.B. staff)

The Institute has been assisting the South Canterbury Catchment Board in this study by providing computer programming and data processing services. Data was collected from 1276 sites by S.C.C.B. staff in 1976 and Mr Lefever was responsible for writing a computer programme to link point survey data with regional geographic map data. Programmes to load S.C.C.B. data on to a computer disk file and selectively to search data were written in 1977.

A simple data-retrieval system linking two very different types of data has been developed. An effective method of communication has been devised to give individuals involved in the project in Timaru access to the computer at Lincoln College.

Programme for systems ecology and environmental monitoring

GOAL: To contribute to understanding of the dynamics of tussock grassland and mountain lands environments and ecosystems and to develop technologies for the application of such understanding to practical problems of natural resource allocation and management.
Production-consumption modelling

(Project leader: Dr E. G. White)

The objective of this project is to examine the interactive effects of insects and livestock on tussock grassland herbage production, especially in relation to pastoral management. Computer modelling of grassland production-consumption systems has now proceeded to the evaluation stage. Computer-generated sequences of plant growth and stock and insect consumption need to be tested against field data. In May 1978 a project review committee comprising systems modellers from New Zealand, Australia, and the United States made a favourable assessment of the model's structure. Its performance and predictive capabilities as a tool to help evaluate grassland management practices now constitute the next phase of critical assessment. A preliminary paper is in press on this project.

Grasshopper census – Craigieburn

(Project leader: Dr E. G. White)

This work has been continued with the annual monitoring of grasshopper abundance in the Craigieburn Range plots for the tenth year. The accumulating data are providing a good base for the study of long term trends in population numbers.

Metacrias

The significance of Metacrias outbreaks is that they may represent severe local damage by a native insect in a native grassland. This is unusual, and provides an important reference point against which to compare damage by introduced insects in tussock grassland. A large Metacrias population has been discovered in a Tara Hills research area by Miss Budgeon, who has begun diet analysis of Metacrias in this pasture.

Nitrogen Study

(Project leader: Professor K. F. O'Connor. Assistants: Mr G. D. McSweeney (Ph.D. student), Soil Bureau DSIR and Microbiology Department Lincoln College.)

The project, to record and interpret nitrogen mineralisation and nitrification in topsoils under tall tussock and relate their seasonal occurrence to natural and cultural factors, has been completed. Related studies on mineral nutrition of tall tussocks from different localities have been carried out on high country soils amended with lime and phosphates in bins at the Institute.
Administrative, managerial and socio-economic programme

GOAL: To contribute to knowledge and understanding of administrative, managerial and socio-economic aspects of the uses of tussock grasslands and mountain lands and to provide information, technology and alternatives for their future conservation and productive use.

With the professional co-operation of Professor B. J. Ross and Mr. R. Frizzell of Lincoln College, Institute staff have completed a study “Review of theory and practice of pastoral rent”. The results of this study, which was made possible through the co-operation of the Department of Lands and Survey, the Valuation Department and the Economic Service of the New Zealand Meat and Wool Boards, are to be published.

Mr Kerr, and Mr N. W. Taylor, Director of the N.Z. Meat and Wool Boards' Economic Service, have been working together in reviewing the economics of South Island hill and high country farming since 1959. Surveys of both organisations have been used to establish the pattern of change in gross income and expenditure, capital growth, return on investment and the effect of stock performance on net income.

The high country production survey for 1977-1978 has been completed. Data from the current and earlier surveys have been checked and processed by computer. Results and analysis of all surveys will be presented in a series of publications from July 1979. Thanks are due to the runholders who supplied their data, making the survey possible.

Led by Mr M. C. Whitby (Drapers' Fellow), the study of the economics of Upper Waitaki pastoral development has involved an assessment of economic returns, in a range of run options, both under dryland farming and under irrigation. Potential major land development/land settlement schemes have been identified and evaluated. It has included an economic analysis of Soil and Water Conservation Plans in the area since their inception. This study has been completed, and will be published in 1979.

Institute staff assisted the planning consultants to the Waitaki Catchment Commission in producing the Lower Waitaki Resource Study. Information was supplied in resources, production functions, and possible resource uses.

Professor O'Connor has supervised postgraduate student Mr. M. Davis in carrying out a survey to identify land units and assess their significance and suitability for conservation of nature, including landforms, fauna and flora on the Old Man Range. This completes the first phase of a Lands and Survey programme to evaluate the summit ridges of the ranges in Central Otago for nature conservation.

Mountain land recreation in New Zealand.

(Project leader: Dr R. Aukerman, Colorado. Assistant: Ms J. Davison)

This major land study has been completed, and published reports will become available from May 1979.

Overseas Visits

In August Professor O'Connor presented a paper he had written jointly with Mr Kerr entitled “The history and present pattern of pastoral range production in New Zealand” at the First International Rangeland Congress, held in Denver, Colorado. He chaired one of the Plenary sessions at the conference and presented a New Zealand perspective on MAB3 from the Waitaki project.

Professor O'Connor was appointed during the year as Chairman of the New Zealand National Commission for UNESCO and in that capacity attended the General Conference of UNESCO in Paris at the end of October 1978.

At the request of the Management Committee Mr Dunbar also attended the Rangeland Congress to present his paper “Regeneration of high mountain rangeland sites in New Zealand after cultural treat-
ent" and visited briefly some research stations in USA and Canada.

**Staff Changes**

During the year Dr Hayward resigned from the Institute after 14 years service and took up the position of Director of the University of Canterbury, Lincoln College, Joint Centre for Environmental Sciences. He will be remaining in close contact with the Institute in continuing to supervise the Torlesse projects he originated, and from which he submitted his Ph.D. thesis “Hydrology and stream sediments in a mountain catchment.”

Mr Robertson commenced duties as Scientific Information Officer towards the end of the year, as did Mr Abrahamson in the management field. Mr Follett replaced Mr Fryer and Mrs Cattanach became secretary following Miss Greatrex’s resignation.

Although they are not always mentioned when projects are reported, the Institute gratefully acknowledges the assistance given by staff employed on a casual basis; they have played a very important role in the past year.

**Management Committee**

During the year there have been several changes in the membership of the Management Committee: Mr M. J. Conway, Chairman of Soil Conservation and River Control Council, replacing Mr R. Dixie; Dr A. J. Allison, Director of Invermay, replacing Mr N. A. Cullen as the Ministry of Agriculture and Fisheries nominee; and Dr G. W. Butler replacing Dr E. Wright as the Department of Scientific and Industrial Research nominee.

The February, 1979 meeting of Management Committee was held at Stoney Creek in the Mackenzie country, members and staff taking the opportunity to see the revegetation work being done on the Grampians and the problem weed, *Hieracium*, in that dry country.

J. M. Wardell
for the Committee of Management.

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Tussock Grasslands and Mountain Lands Institute Review No. 37.


Mountain revegetation: technologies and objectives

K. F. O'CONNOR

Under its objects from its foundation the Tussock Grasslands and Mountain Lands Institute has always had a role in revegetation research. Originally its role was especially concerned with development of techniques of revegetation to achieve soil conservation and to mitigate consequent problems. Under its new objects the Institute's concerns with revegetation are wider, for it is now explicitly concerned with conservation and with a wide range of other possible productive uses. This broader concept of revegetation is in keeping with the interpretation of a current study of the National Research Advisory Council. For that study, revegetation includes recolonisation of bare soil, vegetation recovery and the change from one type of vegetation to another. Each of these forms of mountain revegetation has been an important concern for the Institute and it is clear from its new objects that each will become even more significant in the future. The Institute's involvement in revegetation research arises not only from its own research and development programmes but also from its function as a centre to facilitate the co-ordination of research in the tussock grasslands and mountain lands.

It is fitting at this time to trace the evolution of such revegetation research, especially as it has developed in different sectors and organizations. Mountain revegetation research in several government agencies has been recently summarised or reviewed, e.g. New Zealand Forest Service (Holloway 1969, 1970, Orwin 1978, Nordmeyer 1978a), National Water and Soil Conservation (van Kraayenoord 1978a), Grasslands Division DSIR (Scott 1977a, 1978) and Ministry of Agriculture and Fisheries (Douglas 1974, Cossens 1978). There are important common elements and interactions among the revegetation research histories of these several organisations but hitherto no attempt has been made to trace the thread or pattern of the overall fabric. It becomes the more important to do so now when technologies are being developed and new objectives in revegetation are being clarified.

It will be the aim of this review first to trace the history of the major trends in revegetation research. The second part will review the individual currents in each of the agencies involved, keeping the technological advances in the perspective of changing revegetation objectives. The third part will examine the implications for land use. Principally this review will be concerned with research applied to active revegetation but without neglecting the monitoring of natural revegetation. Only when other advances in vegetation or environment understanding have been important in redefining objectives for revegetation will such less applied research be included in this review.
Origins

Leonard Cockayne deservedly enjoys the credit as the founder of mountain revegetation research in New Zealand. Perhaps better than any scholarly observer before or since, Cockayne saw the vegetation of New Zealand in both a biogeographic and ecological perspective. In his magnificent monograph (Cockayne 1928) he integrated his understanding of all three aspects of revegetation here identified. He recognized the nature of plant succession both in recolonisation of bare soil and in recovery of vegetation stature, form and density. He also characterized the role of man in modifying vegetation, inducing one type of vegetation from another. His studies of dune, riverbed, scree and fellfield identified the kinds of habitat for which specialised plants existed in the New Zealand flora. He also recognized the role of such elements in the flora in revegetating man-induced habitats, such as Raoulia in “man-made deserts” of Central Otago.

Cockayne was the founder of mountain agronomy in New Zealand as well. His work in the regrassing of depleted lands of Central Otago (Cockayne 1922) with its attention to altitude and aspect as well as to the range of plant material and the agronomy of seed introduction and plant establishment set a standard of research quality which was scarcely to be matched for fifty years. This work was not an isolated effort within the Department of Agriculture for Macpherson (1911, 1912a, 1912b, 1913) devoted substantial attention to revegetation in Central Otago and the Mackenzie Basin. Unlike Cockayne’s work which extended into the upper montane zone, the Mackenzie agronomy was confined to the basin floor. Cockayne’s search for suitable cultivars and methods of sowing in the plots of the Northburn run was continued and extended by his successors in the Department of Agriculture (Tennent 1935, Calder 1938, 1944, Lunn 1951, Hercus 1954). The immediate results of Cockayne’s Northburn work were evaluated by a team of scientists and pastoral users and the appraisal published (Special Committee 1923). The longer term results of the Northburn work were reviewed by Douglas (1970) who also assessed grass introductions in Central Otago (Douglas 1966) and the significance of the range of grass species and cultivars in volunteer revegetation and in the principal revegetation experiments reported up to the early 1970s (Douglas 1974).

As the Tussock Grassland Research Committee (1954) pointed out, the early years of active revegetation research were confined to the montane zone where depletion had been a serious problem in the more arid areas. Such research had been oriented principally to the restoration of a pastoral asset. Only with the widening concerns of vegetation and soil conservation in the late 1930s and 1940s did revegetation research move out of the semi-arid montane zone. It was to the credit of J. D. Raeside of Soil Bureau, DSIR, that attempts were made in 1946, albeit with little success, to extend revegetation trials into depleted tall tussock associations (Tussock Grasslands Research Committee 1954). The extension of experimental success in the semi-arid zone to more humid grasslands had to await a more profound understanding of soil fertility. The practical implications of success in this early revegetation research in the dry montane zone were seldom demonstrated on a broad scale because of the persisting rabbit plague with which the depleted lands were affected. As rabbits were brought under control, the local experiments of Wilkie and of Moore at Molesworth (Moore 1976, McCaskill 1969) and Dunbar at Tara Hills (Dunbar 1950, Campbell 1955) were turned to good account in extensive oversowings, especially of cocksfoot. The adverse effects of soil frost (Gradwell 1954, 1955, 1960, 1962) and of harsh climate and
the counteracting influence of litter on seedling establishment were the subject of detailed research at Molesworth (Simpson and Moore 1955, Simpson 1957). A new and sustained period of agronomic revegetation research and practice was about to begin.

These beginnings of mountain agronomy or active revegetation research in New Zealand also have their foundation in another form of revegetation research—the monitoring and interpretation of vegetation change and the replacement of one kind of vegetation with another. Most such changes studied in mountain vegetation seemed, at least in the eyes of scientific observers, to be changes for the worse. The concern for the impact of animals on mountain forests (Perham, 1922), for the impact of fire on forest and flaxland for the extension of pasturage (e.g. Travers 1871), for the impact of fire on arid grasslands (Buchanan 1875, Cockayne 1910) and for the impact of fire on tall tussock in the neighbourhood of screes (Sadd 1920), represents an apprehension of a vegetation change that would prove deleterious and would not be easily reversed.

On the other hand, as Connor (1964, 1973) has indicated, the induction of short grassland from tall tussock by fire and grazing was a deliberate pastoral aim, a vegetation transformation in the strict terms of our definition, a revegetation objective. By 1928, Cockayne appears to have clearly recognized that at least some of our short tussock grasslands had been induced from tall tussock grassland. For this kind of vegetation replacement to be identified and quantified we had to await the series of phytosociologic studies in the Canterbury and North Otago grasslands of Connor (1961, 1964, 1965). In the dry sectors of Central Otago, Petrie (1883, 1912) and Cockayne (1919, 1928) had identified the progressive stages of depletion with grazing, especially by rabbits, of the lowland and montane tussock grassland to bare ground and its colonisation by scabweed (Raoulia). This also constituted a vegetation transformation but one that was hardly to be sought after.

Awareness of the possible impact of fire led to Cockayne's study of the recovery of mountain vegetation from fire in the Arthurs Pass district. Awareness of the impact of grazing animals led to the use, by several people, of fenced exclosures as a means of monitoring natural revegetation in both forest and grassland when the impact of grazing or browsing animals was discontinued. Similarly, as grazing or browsing was reduced in grassland or forest by "land retirement" or destocking or by wild animal control operations, numerous efforts were made to quantify the effect in natural recovery of vegetation. Important examples of such research efforts are the use of exclosures and line transects by the soil conservation staff of Catchment Boards, notably in North Canterbury, South Canterbury and Otago, the use of sampling plots or relevés in relation to altitudinal transects as a part of watershed surveys by the Protection Forestry Branch of Forest Research Institute, and the monitoring of vegetation recovery by a wide range of techniques including rephotographing from fixed reference points as was carried out by Moore (1976) at Molesworth.

There have been numerous reports of such studies of natural revegetation but with the exception of the Molesworth study few have yet been comprehensively reported. In many cases (e.g. Dick 1978a, Evans 1973, Wraight 1967) important findings have been illustrated from a few "typical" or representative situations. A summary statement of experience with natural revegetation of eroded surfaces in the mountains was attempted by O'Connor (1976, 1979a). A comprehensive summation of the whole of mountain revegetation experience is not yet possible. It became clear however, to many persons observing natural revegetation on the severely depleted, dry sunny slopes of montane grasslands such as at Northburn in Central Otago and at Molesworth, as also on eroded subsoils in the upper montane and sub-alpine zones in the drier eastern mountains, that progress through the primary phase of natural revegetation was initially slow or difficult.
With some truth then it can be said that agronomic revegetation research was born of strange parentage: by frustration and impatience with natural slowness, out of faith and hope in agricultural materials.

**The Advent of “Tussock Grassland Improvement”**

As the Southern Pastoral Lands Commission (Sadd 1920), the Sheep Industry Commission (1949) and Douglas (1974) have noted from early writers, many runholders had attempted to improve their pasturage by oversowing grasses, clovers and seed cleanings. With but one or two exceptions, such efforts prior to 1940 had been made without fertiliser. Grass establishment under such conditions was conditional on rabbit control, but it was dependent also on marginal instability of soil and vegetation to provide a seedbed and on sufficient natural soil fertility to support the introduced species. The present distribution of adventive grasses in the montane and subalpine tussock grasslands might be best explained by taking account of these three factors in pastoral history and geography.

Successful trial introduction of oversown clovers into tussock grasslands as a response to fertiliser topdressing was first reported by Saxby (1940) from the eastern part of Central Otago. A decade passed, including a World War, aggravation of the rabbit problem and the beginnings of rabbit control by community action, before this research was revitalised. Success of over-drilling with superphosphate as a means of clover introduction into tussock grasslands (Blackmore 1952), discovery of the importance to legumes in the South Island of sulphur and trace elements (Lobb 1953, Lynch 1954), the establishing of relationships of precipitation and time of soil formation to phosphorus availability in the hill and high country (Walker and Adams 1959, Ludecke 1962) and renewed attention to inoculation of legumes with rhizobia, led to a sustained surge of revegetation research and practice. The title it was to assume was “tussock grassland improvement”. In drier districts where depletion was severe, overdrilling became common on suitable terrain. In sub-humid areas, both overdrilling and oversowing came into vogue (Sievwright 1957). The advent of aerial technology of oversowing and top-dressing (Campbell 1955) gave tremendous stimulus of interest both for high country farmers and for agricultural scientists and technologists. In 1957 there were more than four hundred Department of Agriculture trials in the tussock grasslands and mountain lands, more than half of them examining the effects of different levels and forms of fertiliser on the establishment and growth of legumes introduced into tussock grassland (O'Connor 1957).

From the halcyon days of tussock grassland agronomy in the late 1950s and 1960s there followed a rather dramatic decline in the volume and distribution of “tussock grassland improvement” trials. Part of this decline is attributable to the passing of the easy primary phase of evaluation of legumes and fertilizer for initiation of grassland development. For some years, efforts at further agronomic improvement were directed at introducing grasses such as rye-grass and cocksfoot into tussock grassland associations (Douglas 1974). Debate waxed vigorous as to whether seed of grasses should be introduced with clovers at first oversowing and topdressed or delayed until fertility build-up was first achieved (White et al 1972). Research served to resolve differences in opinion as to the advisability of ensuring cover or exposure for grass seeding establishment (Cullen 1966, Radcliffe 1974, Scott and Wallace 1978), of grazing or protection from grazing (Cullen 1969). Seed coating was shown to improve grass establishment in some conditions (Vartha and Clifford 1969, 1971a, 1973, Scott and Hay 1974, Scott 1975a). Regardless of what was still in debate, it was widely acknowledged that clover in a tussock grassland gave little improvement in mid or late winter feed availability, although it was demonstrated by Vartha and Clifford 1971b, c) that it would have marked benefit on early winter livestock nutrition. Traditional grasses of higher fertility grasslands such as rye-grass
and cocksfoot or new introductions such as tall fescue or overdrilled cereals such as ryecorn were looked to for the provision of winter keep. Some runholders found ways of managing oversown grasslands for use as winter foggage (O'Connor 1971). Generally, however, herbage yields from clover introduction into tussock grasslands, well stocked with adventive sward grasses whether Yorkshire fog, sweet vernal, browntop or Kentucky bluegrass, have often been very substantial (O'Connor 1959, 1961c, 1966, McLeod 1974), although confined to the non-winter period. Additional gains in herbage yield from the introduction of ryegrass or cocksfoot have often been small or non-existent (O'Connor 1967a, Cullen 1969, Radcliffe et al 1977). We have been reluctant to accept that high fertility grasses owe their superior production principally to high fertility and that, given high fertility, low fertility grasses such as browntop, Yorkshire fog and the like, may produce in tussock grassland environments similar yields to those achieved by the likes of ryegrass and cocksfoot (O'Connor 1959, Vartha 1963).

The attack on subsoil and scree—the beginnings of high altitude agronomy

The discovery of sulphur, phosphorus and molybdenum deficiencies in the hill country soils first by Lobb (1952, 1953) in Otago and by his imitators Walker, Reynolds, Siewwright, Dingwall, Bennett, McLeod, Symons and O'Connor in Canterbury; Hercus, Ludecke, Lunn and Cossens in Central Otago; Fraser and Duffy in Waiataki; Beggs in Marlborough; Stephen, Sewell, Nixon, Cullen and Sly in South Otago and Southland, created a climate of renaissance in both science and high country farming practice in the late 1950s. In 1958 in the euphoric enthusiasm of the time, a series of 60 factorial experiments was established by several of these workers, extending from 200m to 1600m above sea level and from Southland to Marlborough. These trials examined the influence of sulphur and phosphorus on clover and cocksfoot establishment and growth. Quantitative results on clover distribution from about half of these experiments were reported by O'Connor (1962). Cocksfoot establishment and growth on the exposed subsoil of higher altitude sites in this series of trials was even more markedly benefited by phosphate than was clover. Most cocksfoot plants, being very small, were heaved out of these bare subsoils along with the clover in the first winter. The problems of grass establishment in exposed higher altitude subsoils were now being clarified: soil frost and soil infertility.

Marked responses to nitrogen additional to superphosphate and potash had been observed in cocksfoot oversown at 1300m on the Craigieburn Range in 1957 although no response was evident in snow tussock (O'Connor 1963a). In 1959 an exposed steepland subsoil at this site was oversown in ryegrasses, cocksfoot and clovers with a mixture of superphosphate, muriate of potash, nitrolime and urea. Despite intense grazing pressure from hares the resulting short ryegrass-dominant sward persisted in a slope-stabilising form with more than 40 percent ground cover for four years and remnants persisted for at least ten years. In 1961, R. S. MacArthur of the Marlborough Catchment Board had established cocksfoot under jute mulch with a mixed fertiliser on Black Birch Range at 1450m. At the instigation of the first Director of TGMLI Mr L. W. McCaskill, Grasslands Division of DSIR, collaborated with the Marlborough Catchment Board in an experimental revegetation programme at Black Birch. The goal of this research was to evaluate grass provenances, mulching and fertiliser materials for stabilisation of exposed subsoils. The immediate objective was to reduce the local dust nuisance affecting astronomical observations at Black Birch. O'Connor and Lambrechtsen (1967) reported from these trials responses to superphosphate and nitrogen and the superiority of intermediate New Zealand-bred grass cultivars to cool-season-active and cool-season-dormant counterparts from five genera. Essentially similar superiority of such New Zealand-bred intermediate
grasses was later demonstrated by O'Connor and Clifford (1977) at Pukaki in the montane zone. From another larger experiment at Black Birch, O'Connor (1967b) reported the positive interaction of nitrogenous fertiliser and superphosphate and the benefit of mulching, especially with hay held together with bituminous mulch. The outstanding early growth of ryegrasses and the persistence of cocksfoot and clovers encouraged further experiments at this and neighbouring sites by Lambrechtsen (van Kraayenoord, 1978a) and Dunbar (1970a, b).

At the same time as these encouraging developments, New Zealand Forest Service personnel were actively investigating slope stabilisation on road-sides. Their principal efforts at revegetation were, however, in tree establishment, especially in the Craigieburn Range in Canterbury and the Kaweka Range in the North Island but also at a number of other South Island locations. Holloway (1969) made it clear that the objective of the revegetation research by the Protection Forestry Branch was “the restoration of an effective plant cover, not necessarily of trees, to severely eroded, debris-producing areas”. Holloway (1969) posed the question whether the uses of grasses, legumes and trees could be combined in two or multi-stage processes of land rehabilitation. Could aerially-introduced grasses and clovers achieve enough site stability and enough improvement in soil fertility to allow the establishment of permanent cover?

Whereas the early Forest Research Institute work, from the establishment of the Protection Forestry branch in 1956, had been especially concerned with tree establishment and the evaluation of different tree species and provenances, from 1962 a collateral effort was devoted to assessment of soil fertility and altitudinal limitations to herbaceous revegetation, including both grasses and legumes. For Holloway (1970), the significance of soil fertility limitations in exposed mountain subsoils was inescapable. As he expressed it: “Vigorous growth, even of species ideally suited to the climate, could not be expected on the sites and soils in question without restoration of the soil nutrients that had been lost and, in particular, the reconstitution of an effective nitrogen cycle. One simple experiment in particular showed that soil, not climate, was the key limiting factor. A number of legumes were grown satisfactorily in a lowland soil transported to 5000 ft but the same species barely survived in soil from an eroded site at 5,000 ft transported to a lowland glasshouse”.

PART 2

THE EMERGENCE OF INDIVIDUAL APPROACHES IN MOUNTAIN REVEGETATION

The development of agronomic research for revegetation of exposed subsoils, screes and depleted grasslands represents a noteworthy convergence with the altitudinal extension of “tusock grassland improvement”. Despite this convergence, among the several scientific workers in different organizations, there soon emerged remarkable divergences in individuals’ special interests and approaches. Sometimes the divergences arose from the goals of the employing organization. Sometimes they arose from the background, training, experience or new perceptions of the individuals. Some of these divergences arose from different objectives for revegetation. Some workers were concerned principally with “protection” functions of grasslands or other vegetation and geared their research to that end. Others were concerned with improving “production” functions of grasslands. Some were concerned with one objective in one circumstance and with another kind of objective in other situations. But, divergences also arose from different emphases on plant materials and technologies. While formal arrangements for coordination of research remained at a minimum, personnel of each of the organiz-
ations involved knew sufficient of each other's work to benefit from it. Each pursued somewhat different approaches to the development of his preferred technology. The outcome has been not only improvement of technology but also the generation of a new range of possible objectives of revegetation. The sequence and pattern in each agency history are now summarily reviewed, with emphasis on agronomy and other processes of active revegetation.

**Ministry of Agriculture and Fisheries**

The Department of Agriculture had been among the first in the experimental field at high altitudes as well as in the montane zone (O'Connor 1962). Its officers developed its agronomic programme in the 1960s especially towards fertiliser needs for oversown clovers in sequences of soils (e.g. Ludecke 1962) but extended co-operatively such sequence studies in various soil aspects (Tan 1967). More recently moisture regime and altitudinal comparisons up to 1200m have been made with oversown legumes at different times and rates (Musgrave 1977, Douglas and Kinder 1975). Comparisons of conventionally established pastures and crops and of sod-seeded and oversown grasses and legumes in cultivated ground and tussock grassland which had been first made in the Waimakariri montane grasslands (Dingwall 1956) have also been made in the Otago uplands (Cossens 1975, 1978). The special needs of lucerne oversowing received particular attention for the drier mountain slopes (Douglas 1974, Musgrave et al 1974, Musgrave 1976a, b). In agronomic comparisons of different legumes which extended across the block mountains of Otago from east to west and to the altitudinal limits of the Tara Hills Research Station, the Ministry of Agriculture and Fisheries gave special attention to inoculation studies with rhizobia (Lowther and McDonald 1973, Lowther 1975a, b). Such agronomy and rhizobial technology not only contributed substantially to the field evaluation of traditional legumes and of new cultivars such as Maku *Lotus pedun-

culatus* but has also demonstrated for Otago the opportunities, potential and problems of upland pastoral agriculture. It would be therefore less than just to infer from van Kraayenoord's (1978a) remarks that the transfer of Tara Hills to the research arm of the Department of Agriculture led to a neglect of mountain revegetation research at the expense of animal husbandry. It is also noteworthy that Ministry of Agriculture and Fisheries officers have attended to some features of tree species in revegetation (e.g. Douglas 1970) and have co-operated with Forest Service personnel in the development and evaluation of tree shelter in high country farming (Boswell et al 1978).

In other parts of the South Island high country, Ministry of Agriculture and Fisheries personnel have shown different emphases in their work. In part at least these have been dictated by the different environmental circumstances. In South Canterbury, field research led by McLeod followed the early trial examinations for soil deficiencies for oversown clovers with a series of herbage production experiments in the montane zone carried out with different fertiliser regimes over several years (McLeod 1974). The early examination for soil deficiencies elsewhere in Canterbury and the conventional agronomy of the pioneer work at Craigieburn, Riversdale and Broken River in the Waimakariri (Sewell 1952, Dingwall 1956) were followed by a concentrated programme on the Hurunui soil set (Gregg, 1976, Radcliffe 1971) culminating in the intensive programme of pasture management, herbage and livestock production at Coopers Creek (Radcliffe 1979, Radcliffe et al 1976).

In summary, the Ministry of Agriculture and Fisheries agronomic research efforts in the tussock grasslands and mountain lands have had their main focus in the last two decades on pasture improvement for production. While they have occurred principally in the montane zone they have not been confined to it but have identified the potential seasonal value of sub-alpine pasture improvement.
University of Otago

In contrast with the Ministry of Agriculture and Fisheries agronomic work of vegetation transformation in the upland environments of Otago, Dr A. F. Mark of the Botany Department of the University of Otago has led an extensive programme, characterising the behaviour of tall tussock and its environment (Mark 1965 a, b, c, d), evaluating the productivity of tall tussock (Meurk 1978) and of herbage communities (Bliss and Mark, 1974). These quantified the influence of different conditions of vegetation on water balances of upland sites (Mark and Rowley 1976), and demonstrated the agronomic possibilities of transplanted *Chionochloa* species for the reconstitution of tall tussock grasslands. These contrasting approaches in Otago and current Forest Service research in the region can be expected to contribute substantially to the clarification of possible land use objectives for block mountain terrain where water production and regulation has previously been identified as actually or potentially competitive with pastoral agriculture (O'Connor 1958, McCaskill 1963) or with forest production (Watt 1971). In the wetter mountains of the west, Mark and his associates have given special attention to the natural recovery of vegetation following landslips (Mark et al, 1964) and following reduction in animal numbers (Mark 1978). An important contribution of the University of Otago is that many students have been guided by Professor G. T. S. Baylis into the study of mycorrhiza. For several of them this has provided a new dimension in their revegetation technology. The widespread attention that is now given to mycorrhizal relationships in many avenues of work is in no small measure due to him.

Grasslands Division, Botany Division and Soil Bureau of DSIR

Grasslands Division of Department of Scientific and Industrial Research had become involved in mountain revegetation from the establishment of its regional stations at Lincoln and at Gore. As Scott (1977a) notes, J. P. Lambert, then based at Lincoln, had begun experiments with plant introductions and superphosphate in the Mackenzie Basin several decades ago. The same person later pioneered agronomic revegetation at Mid Dome in Southland when stationed at Grasslands Division, Gore, work that was soon successfully intensified and expanded through Northwestern Southland by N. C. Holmes of the Ministry of Works (O'Connor 1957, 1963b) as a forerunner to the major successful agronomic programme in the area of the Department of Agriculture.

Grasslands Division involvement in tussock grasslands research was renewed from 1959. From initial concentration on evaluation of the botanical and soil fertility limitations to pasture production (O'Connor 1961 a, b, c), main efforts of the 1960s were on legume and grass establishment (O'Connor 1962, 1963b, 1967a), the interactive role of the grazing animal (O'Connor and Cliff ford 1966, O'Connor 1966) and on fire and other forms of defoliation on tall tussock (O'Connor 1963a, O'Connor and Powell 1963) and the interaction of fire with topdressing and oversowing (O'Connor and Lambrechtsen 1964).

As has been indicated earlier, frost lifting of seedlings was recognized as a major problem in revegetation of bare soils. The evaluation of establishment and growth of 65 grasses sown in rows in cultivated Craigieburn soil at Enys Flat in the Broken River Basin (O'Connor 1959, 1960) was followed by a considerable amount of frost lift of the plants. Degree of frost lifting in all groups of grasses was affected by shoot growth, but different relationships between shoot growth and frost lift suggested some further differences in susceptibility to frost heaving. On exposed sub-alpine subsoil of Black Birch, O'Connor and Lambrechtsen (1967) recorded a significant negative relationship over all 19 grass cultivars examined between mean basal area and percentage heaved out.

The significant benefit from hay and colas mulching on production of oversown
and manured ryegrass and cocksfoot at Black Birch (O’Connor 1967b) was examined further by microclimate recording with the co-operation of the Marlborough Catchment Board. It appeared from the imperfect record obtained that this mulching benefited grass growth principally by raising daytime temperatures in the basal meristematic zone immediately above the ground surfaces. This project demonstrated the initial productivity of ryegrass and cocksfoot at high altitudes provided that they had liberal superphosphate and nitrogen fertiliser. As fertility and cover declined the plots were invaded by both adventive and native species.

While this project had been undertaken to establish “protection” grasslands it had indicated that productive grasslands in such an environment were not impossible of attainment but it also suggested that climatic limitations to productivity would remain important even when fertility limitations were overcome. After several years of monitoring of this revegetation experiment, N. C. Lambrechtsen began a series of experiments at a range of sites on the Black Birch ridge, intended to evaluate cereals and other grasses as natural mulch producers, to compare slow-release and quick-acting fertilisers and a wider range of grass and legume materials and seed coatings. With the transfer of Dr Lambrechtsen to the Ministry of Works and Development in 1970, the Grasslands Division work on Black Birch was taken over by the Water and Soil Division of MWD (van Kraayenoord 1978a).

Grasslands Division work in the mountains in the last decade has been concentrated in the Upper Waitaki. In studies of plant establishment, attention was directed to the revegetation of bare surfaces, especially at higher altitudes (Scott, Archie and Clifford 1976) but work on mulching treatments was confined to lower altitude (640m) on both denuded topsoil and gravels. Much more attention was given by Scott and co-workers in the montane zone to clarify the influence of tussocks on microclimate (Scott 1961a, 1962), to assess the influence of resident vegetation on soil properties (Scott 1975b) and oversown seedling behaviour (Scott 1974, 1975c, Scott and Archie 1976), and to evaluate legumes and grasses of different provenances under different phosphate and lime regimes (Scott et al 1974, O’Connor et al 1972, O’Connor and Clifford 1977). Higher altitude work in Grasslands Division has included primary testing of plant introductions (Scott 1977b, Archer 1977), but its main areas of concentration have been the recording of climatic and hydrologic regimes (Archer 1970, Archer and Collett 1970), the interpretation of the influence of these regimes on vegetation succession (Archer et al 1973, Archer 1973) and the study of alpine soil chronosequences and hydrosequences (Archer 1976, 1979). Botany Division of Department of Scientific and Industrial Research has had continuing involvement in mountain revegetation research for some decades but with greatly different approaches among different personnel. Important elements in the research record as it bears on different forms of mountain revegetation are summarised.

Under the leadership of Dr H. H. Allan and following the survey of deterioration in vegetation conditions by Zotov (1938), Botany Division devoted a considerable proportion of its limited manpower to revegetation research. Photographic reference points were established at Mid Dome in Southland and at Molesworth in Marlborough to monitor progress in natural recovery of revegetation following reduction in grazing pressure. The classic study of vegetation recovery at Molesworth (Moore 1976) extending over 30 years, was built on mapping and charting vegetation, recording in small and large exclosures, quadrat frequencies and photographic reference points. It was facilitated by co-operation from personnel in several agencies. Moore’s study of vegetation recovery was supplemented by her phytosociologic study of the volunteer primary colonising role of such species as sheep’s sorrel (Moore 1954) and by grass establishment studies (Simpson and Moore 1955, Simpson 1957) and
row trials with grasses (Moore and Simpson 1961). Moore’s monitoring studies revealed both the initial slowness but eventual significance of natural recovery in vegetation following a reduction in grazing pressure and indicated the value of such natural recovery as a precursor to large scale seed sowing.

Other Botany Division scientists have been concerned with interpretation of soil-plant relationships in tall tussock species (Molloy and Connor 1970) and of changes in mountain vegetation that have occurred in Polynesian and European historical times e.g. Connor (1964) Connor and MacRae (1969), Molloy (1969a, b, 1977). Wardle (1971) has carried out experimental reintroduction of mountain tree species, especially in conjunction with the study of timberlines. Wardle (1972) monitored the natural revegetation of greywacke scree margins over a period of ten years at Craigieburn. He likewise studied the more recent phases of vegetation recovery from earlier fire in the wetter mountains of the Main Divide, providing a scientific link over several decades (Cockayne 1898, Cockayne and Calder 1932, Calder and Wardle 1969). Like Mark (1978) in Mt Aspiring National Park, Wardle (1979) has recorded the natural recovery of the high mountain vegetation in Westland following reduction in animal grazing pressure.

Although not formally concerned with active monitoring of vegetation recovery, the current studies of Botany Division ecologists of vegetation and landscape history in the mountains as well as the survey and characterization of mountain soils by officers of Soil Bureau, have had an important bearing on mountain revegetation research in other organizations. This influence has been considerable not only in the deeper understanding of revegetation materials and objectives but also in the discernment of which sites could be expected to benefit from cultural efforts at revegetation. The early reconnaissance of high country soil erosion (Gibbs et al 1945) in many respects constituted a reconnaissance of vegetation depletion and deterioration, thereby indicating in cartographic form the dimensions of possible revegetation opportunity. The meticulous studies of soil frost in South Canterbury and Marlborough (Gradwell 1954, 1955, 1960, 1962) demonstrated the need for vegetative cover to counteract frost heaving of soil. Studies of soil physics of mountain soils (McDonald 1961, 1968) and the extension of soil chemistry in conjunction with the general survey of South Island and New Zealand Soils (Soil Bureau 1968a, 1968b) have helped characterise the edaphic environment. Intensive studies of soil biology in tussock grasslands soils, first developed at Broken River, Canterbury and in Central Otago as well as at Waiouru in the North Island more than 20 years ago (Thornton 1958) have been renewed in an altitudinal sequence in Otago and South Westland (Molloy and Blakemore 1974). They may contribute materially to clarifying possible objectives for revegetation, especially by indication of the zones in which an active organic regime can be expected.

New Zealand Forest Service

By far the greatest volume and highest intensity of cultural revegetation research in the last 20 years at high altitudes, has been conducted by the Protection Forestry Division of the Forestry Research Institute. As Holloway (1969, 1970) has pointed out, this research derived from the experience of Forest Service scientists in assessing results of watershed surveys in the Protection Forests and the grasslands adjacent to them. Those who designed and carried out the experimental sowings and plantings of tree species and sowings of herbaceous vegetation had themselves participated in watershed surveys and were therefore clearly aware of the zones in which forest or other vegetation was likely to require cultural assistance for its restoration. As Wraight (1967) indicated for the Waimakariri, the urgency of cultural treatment was much greater in the somewhat drier mountains east of the Main Divide. In most situations west of or close to the Main
Divide, Forest Service watershed surveys indicated that natural revegetation ensued from strict control of wild animal populations alone. Forest Service watershed surveys have been repeated at intervals of a number of years with the aim of confirming indications of trend in condition of vegetation in different zones and thereby interpreting the effects of and needs for animal control. They have therefore provided valuable records of natural revegetation as well as of vegetation depletion (e.g. Evans 1973). Stimulated by their own awareness of grassland deterioration, a revegetation group in Protection Forestry Division has made dramatic progress in high altitude agronomy and tree culture during the last two decades. Many of these workers had their advanced training in agricultural science fields, soil microbiology, soil chemistry, soil fertility and genesis, grassland agronomy and ecology and plant physiology. Many of them were first exposed to the mountain forest and grassland experience while working during university vacations on watershed surveys. A strong sense of teamwork has prevailed within the Division especially engendered in such surveys in which watershed conditions, vegetation status and animal condition, density and habitat use could all be assessed. Characterisation of soil or rock substrate in both physical and chemical terms has been an important feature of the Forest Service research: (Kelland 1978, O'Loughlin 1965).

Nordmeyer et al (1978) have summarised the intensive series of field trials into legume evaluation and legume establishment and growth begun in 1965 and 1969 on the Craigieburn Range, in 1970 at the Craigieburn Range and at Makahu Saddle in the Kaweka Range, and in 1972 and 1973 at the Craigieburn Range and at Mount Morris in the Branch River catchment of Marlborough. Initial frost heave losses of legumes were counteracted by use of grass, especially Yorkshire fog with nitrogen. Superphosphate was of major significance but also magnesium, potassium and in some areas lime. The addition of a grass with nitrogen, depressed legume growth initially without reducing nutrient concentrations in leaf tissues. In the longer term, grass benefited legumes by ensuring survival. Evaluation initially of a range of common legumes led to increased emphasis on newer cultivars of Lotus pedunculatus and Lotus hybrids.

Nordmeyer and Davis (1976) have reported on the performance of Maku Lotus pedunculatus in comparison with white clover in high altitude revegetation. Ritchie (1972, 1978) has described the high fertility and low fertility field evaluations of a range of commercial and field collections of grasses, used in high altitude revegetation. Davis (1978) demonstrated the variation among different collections of cocksfoot in apparent phosphorus efficiency and aluminium tolerance. He has also demonstrated the tolerance of subsoil aluminium shown by various lines of Lotus pedunculatus and a Lotus hybrid in contrast with white clover which may suffer from serious aluminium toxicity. Nordmeyer (1978b, c) has demonstrated the varied significance of lime with superphosphate in stimulating rhizobia nodulation of white clover and in increasing total bacteria and rhizobia in soils under legume revegetation. Current research by the group led by Nordmeyer has been measuring the accumulation of carbon, nitrogen and other organic-held nutrients under such primary revegetation swards.

Early trials with exotic trees in high country were reported by Wendelken (1956). The initial wide array of tree species used in revegetation trials at the Kawekas (Cunningham 1978) and at the Craigieburns (Benecke et al 1978) has given way to strict attention to phenology of provenances (Benecke and Morris 1978), careful attention to the physiology of bud movement and shoot growth in relation to changes in climate with altitude (Benecke et al 1978), direct seeding trials into different vegetation and soil material substrates (Ledgard, 1978) production and storage of tree seedlings for planting (McCracken and Cath 1978,
McCracken 1978) and the evaluation of ectomycorrhizal and nodule symbioses for alder (Alnus viridis) and of mycorrhizae for conifers (Benecke 1978).

The current assessments of productivity and of potential yield from forest plantings in stabilised revegetation areas (Nordmeyer 1978a, d, 1979, Morris 1978) indicate quite clearly that a new range of land use alternatives has been generated by this revegetation research.

University of Canterbury and Lincoln College

From the establishment of the Cass Field Station in 1914, natural revegetation of riverbed and scree has proved an attractive topic for botanical research. Foweraker (1971), Oldridge (1922), Fisher (1948, 1952), Calder (1961) and Singleton (1975) have studied such habitats in the reconstruction of succession. Fisher (1968) and Burrows (1977b, c) have reviewed these topics. Harris (1968, 1970) made a particular study of climatic and edaphic adaptation in Rumex acetosella, a highly important plant in natural revegetation. Soons (1967, 1977), Soons and Greenland (1970) have examined the factors leading to the formation of needle ice and its significance to revegetation as well as to soil loss.

Lincoln College students over the years have carried out thesis studies on various aspects of cultural revegetation. Many of them (e.g. Sewell, Dunbar, Nordmeyer, Ludecke, Vartha, Davis) pursued somewhat similar lines of work in subsequent employment and are identified here in their agencies' record. Perhaps as many others have enjoyed their encounter with tussock grassland and mountain but found other milieu for their professional work. Perhaps the most significant Lincoln College contribution to mountain revegetation has been made through the work of T. W. Walker and his associates in Soil Science. It was Walker's unifying concepts in pedology and especially the pedogenic roles of phosphorus and nitrogen fixation (Walker 1965) that have pervaded such widely different phases of revegetation as vegetation succession with glacial retreat, tussock grassland improvement, reafforestation, and edaphic adaptation and succession in Chionochloa and native forests.

In the Plant Science Department, many projects have been concerned with the tussock grassland development role of native nitrogen-fixers such as matagouri and tutu (Daly 1969, Daly et al 1972), of lucerne (White 1966), subterranean clover (W. Scott 1969), white clover cultivars (Smetham 1972) or current work with Lotus cultivars and Caucasian clover (Trifolium ambiguum).

National Water and Soil Conservation Organization

In part because of its transfer from Ministry of Works to Department of Agriculture for a number of years and later its establishment in the Water and Soil Division of Ministry of Works and Development, the soil conservation staff of central government have had a somewhat erratic role in mountain land revegetation research. The acquisition of reserves at Wither Hills in Marlborough, Fruitlands in Central Otago, Tara Hills in North Otago and Mid Dome in Southland from the 1940s led to a phase of practical experimentation and demonstration that involved tree planting, oversowing, sometimes landscape treatment and fencing for stock control. At each reserve, emphasis in plant materials has varied according to the interests of personnel involved and to the circumstances in which they worked. For example at Mid Dome considerable early emphasis was given by N. C. Holmes to the willow planting of incised runoff channels and to the conifer planting of the eroded headlands of the major gullies. At Wither Hills D. R. Wilkie gave major early emphasis to the afforestation of worst tunnel-gullied areas. At Tara Hills, G. A. Dunbar gave principal attention to the evaluation of species for the widespread revegetation of depleted lands. The practical dividend in each case was eventually substantial but the formal research
findings were generally small. The record of such reserves has been stated by van Kraayenoord (1978a). At the present time two such reserves, Mid Dome acquired in 1947 and Black Birch acquired in 1969 are maintained with high altitude climatic recording for the interpretation of revegetation experimental work. These facilities are used by other agencies as well. More recently the Plant Materials Centre of the Ministry of Works and Development has begun screening trials of shrubs, primarily for soil conservation purposes and secondarily for forage potential for the brown grey earth zone represented by Olrig and Bendigo in Central Otago and Black Forest in the eastern Mackenzie country (van Kraayenoord 1978a). Sheeps burnet, a perennial herb, (Sanguisorba minor) is currently being selected for multiplication for ground cover and for winter-spring browse in semi-arid areas (van Kraayenoord 1978b).

Catchment Boards have made appreciable contributions to revegetation knowledge, principally by their sustained monitoring of natural recovery of vegetation in exclosures or of changes in vegetation cover on open range. The North Canterbury Catchment Board supplied data for twelve line transects in the Waimakariri recorded annually from 1947 to 1963 (Hayward 1967). Graphs from most transects showed an initial increase in bare ground over the first three to six years but all tended approximately to stabilise or to recover slightly in subsequent years. Dick (1978a) presented statistical evidence for three of these transects from the upper montane or subalpine levels that supports the above interpretation of initial increase in bare ground but also indicates significant fluctuations from one year to another. Four comparisons of open areas with exclosures (Hayward 1967) reveal little difference in trend in total cover but Dick’s (1978b) data for one such comparison reveal a small total cover difference and marked floristic changes over 28 years.

Similar studies have been later established by the South Canterbury Board and have been maintained over recent years with stereo-photo transects to reduce observer contribution to year to year variations (J. Cuff, pers. comm.) In Otago, Ramsay and Cook (1973) reported little recovery in living vegetation if any from retirement from grazing over eight years at Mt Nicholas except in some terrain below 900 metres. The Otago Board has likewise maintained survey transects to monitor grazing controls since 1963 at Hospital Creek at Lake Hawea, and to monitor recovery from burning in 1958 in Kyeburn and on burnt and unburnt sites at St Bathans. Most of the Catchment Boards have been involved in monitoring at different intensities large scale agronomic revegetations such as at Grasmere in North Canterbury or extensive tree planting and sowing areas such as at Wye Creek in Marlborough.

Department of Lands and Survey

Research effort by the Department of Lands and Survey has been concentrated on monitoring extensive revegetation trials as part of the development of Management Plans, as at Porter River in Canterbury (Prouting 1978), Takitimus in Southland, Cloudy Peaks in South Canterbury, St Mary’s Range in North Otago (Holgate 1977, 1978) and as part of land management on department-operated properties e.g. Molesworth, Highland Farm Settlement, Ruataniwha and Cainard. Field trials with tall tussock transplants have been carried out at Porters Pass where aesthetic considerations warranted such treatment (Holgate 1976). Technical co-operation is also provided to skifields on Crown land for necessary revegetation planning.

Tussock Grasslands and Mountain Lands Institute

Initial revegetation activities at the Institute consisted of monitoring of co-operative demonstration areas of topdressed and oversown grasslands in the montane zone of Canterbury where grazing treatments were uniformly applied within each area (Dun-
bar 1964). At one of these areas, Mesopotamia, differential grazing and topdressing regimes were introduced for the evaluation of herbage quality (Allan et al. 1976 Clarke 1977). As part of studies of sheep grazing behaviour, selective topdressing and oversowing has been made of part of the Birdwood summer range of Glenthorne in the Harper Avoca catchment. More recently, new engineering developments in overdrilling technology have been evaluated in a series of cooperative experiments with the New Zealand Agricultural Engineering Institute and Grasslands Division DSIR.

By far the greatest Institute contribution to revegetation research has been the high altitude programme led by G. A. Dunbar over the last fifteen years. The first experiment in 1964 with Agropyron scabra with cover crops of rye or other cereal was done in the Craigieburn valley. (Dunbar 1970a). Rye was spectacular and led to the inclusion of mountain rye among the grasses, clovers and yarrow tested with and without complete macro-and micro-nutrient fertiliser at Porters Pass, Craigieburn and Olympus from 1965 (Dunbar 1970b). Basyn Yorkshire fog was best of all ten species at all three sites in early vigour and cover. Fertiliser did not affect establishment significantly but greatly affected persistence through the first winter. Sites differed in the persistence of brown top and clovers through the fifth season and also in the amount of volunteer species. A greater proportion of cover survived from brown top and clovers through the fifth season and also in the amount of volunteer species. A greater proportion of cover survived from brown top and chewings fescue than from fog and a ryegrass/tall fescue mixture but fog, browntop and chewings fescue were generally superior to other species in total residual ground cover (Dunbar 1971).

In 1965 soil was collected from ten eroded surfaces spread over a distance of 700 kilometres in South Island ranging from 840m to 1430m altitude with only two below 1100 metres. These subsoil materials were used in glasshouse trials examining the effects of several major and minor plant nutrients on growth of Basyn Yorkshire fog and Huia white clover. The initial experiment (Dunbar and Adams 1972) demonstrated the dominant importance of nitrogen and phosphorus for grass and phosphorus for clover with soil of all sites and allowed some experimental economy in the field trials with fog, cocksfoot and white clover in the following year. Responses to magnesium and potassium were widespread warranting field testing, lime was sometimes beneficial, sometimes adverse. On two soils the adverse effect of lime on fog was counteracted by magnesium. Results from molybdenum and sulphur were inconclusive. Little benefit was obtained from copper, boron and zinc. Field trials begun in 1966 demonstrated significant positive effects of magnesium on seven of the eight sites where oversowing was successful and also of potassium plus minor elements in early vigour. Sulphur had significant effects on three sites, lime positive effects by the third season on two sites, negative on one. Magnesium $\times$ potassium interaction was confirmed, the need for magnesium being especially demonstrated with potassium (Dunbar 1974b). Two sites failed to revegetate at first oversowing. One of these was successfully oversown from the repeat topdressing in 1970. All others have persisted with periodic retopdressing (Dunbar 1978).

In October 1967 short tussocks were precision oversown in two localities using five different previously established cover treatments. As had been observed with volunteers earlier at Black Birch there was a general inverse relationship between density of previous cover treatment and emergence of tussock seedlings, the more cover the less the tussock establishment (Dunbar 1970c). Nevertheless survival of tussock seedlings over 18 months was in direct positive proportion to amount of cover (Dunbar 1974a). A further experiment at Black Birch begun in 1968 has not confirmed this precisely nor have the later results from Porters Pass. Competition from slowly declining primary cover for the declining nutrient supply may adversely affect the survival of tussock seedlings. The response patterns to applied nutrients of the short tussock
species that have been studied are essentially similar on these subsoils to those of Yorkshire fog or other introduced grasses such as ryegrass and cocksfoot (Dunbar 1974a, c). In similar fashion, Chionochloa rubra and C. flavescens (Canterbury form) may respond to lime with nitrogen and phosphorus whereas C. macra and some examples at least of Agrostis tenuis do not (O'Connor et al 1972). Some evidence exists that within C. rigida there is variation in edaphic adaptation (Mugambi 1971). This is supported by field survey (Williams et al 1978) In practice, sufficient reapplications of fertiliser have been made to the revegetated areas to maintain some primary cover while allowing the ingress of volunteer native and adventive plants (Dunbar et al 1977).

The revegetation research programme of the Institute has included more than primary colonisation of bare surfaces. The expanding programme of tall tussock edaphic ecology (Williams et al 1978) and mineral ecology of other plants has been intended to contribute to the same work programme. Current studies in the propagation and nutrition of tall tussocks as well as in the autecology of such natives as Dichelachne crinita, Agropyron scabrum, Deyeuxia and Trisetum spp and the short tussocks of Poa and Festuca may contribute significantly to the eventual programme of successful practical revegetation. Rooting habits and shoot characters may both be important in resistance to frost heaving.

Improved understanding of the sediment production and transport role of catchment and channel systems in the mountains (Hayward 1979) has led to a new emphasis in Institute revegetation research. Revegetation of eroding bare surfaces away from channel margins is now recognized as enhancing future options as to possible resource use but it is seen as being of little material consequence to the “choking of channels with detritus” as the “sediment problem” was once represented. The perceived roles of riparian vegetation in channel maintenance, in stabilising zones of spring water emergence and in recolonising new surfaces produced by natural or controlled flood events, have now led to development of a riparian revegetation project which examines the capabilities of native and exotic vegetation elements. Similarly, awareness of the vulnerable condition of much high altitude grassland, even if in tall tussock of some kind has led to the initiation and development of a series of vegetation understanding and improvement projects, centred on the drier Grampians mountains.

As Holloway et al (1973) observed, “prevention must be accepted as the most urgent task.”

**PART 3**

**IMPLICATIONS**

Reflection on the evidence for considerable individuality in approach to revegetation problems leads one to the thought that the organizational aspects of such research could receive too much attention. It is clear that there are real differences between agencies in the motives and concerns that each has for sponsoring revegetation research. Despite such differences, it is clear that each organization is dependent in large measure on the individual skills and intuitions of its personnel. The fact that similar individual approaches may be found in several different agencies is reinforced by the evidence of individual persons continuing with their own personal approach after having transferred to another agency. Nevertheless there is little if any evidence of actual duplication even among those with basically similar approaches. Nor is there any evidence that any one individual has been acting in complete ignorance of what his fellows elsewhere may have been doing. Perhaps such a situation should be accepted as exhibiting a modest degree of coordination, effective arrangement of effort towards common purpose.

It is the question of commonness of purpose and harmony of objectives to which agencies and land users should give their
chief attention. The emergence of possible new land use objectives as an outcome of revegetation research has already been noted in this review. Some discussion is warranted of the implications for pastoral land use and for other uses including forestry and nature conservation.

We should do well to recall that the beginnings of mountain revegetation research and much of its development were for the purpose of improvement of pastoral resources and pastoral production. In implementation such revegetation has often been financed for the goal of soil conservation. I have pointed out elsewhere (O'Connor 1978) that the successful tools of soil conservation in the high country have been in “assistance to marginal lands, land utilisation, provision of fertiliser, extermination of rabbits and replacement of cover on depleted areas,” practices recommended by the Sheep Industry Commission (1949) as sufficient if carried out for there to be no erosion on a national scale in New Zealand. Technical means effective for the sustenance of sheep farming may well have been effective for the conservation of soil. We have clearly no reason for thinking that pastoralism can be sustained unless there is effective pursuit of the soil conservation goal. We have no assurance, however, that revegetation objectives pursued for soil conservation will be sufficient to sustain and benefit pastoralism. The time is overdue for us to examine our specific revegetation objectives to see whether they truly and effectively serve pastoral goals. Let us examine the practical and ecological implications of “tussock grassland improvement” by topdressing and legume introduction.

The practical implications of legume introduction into tussock grasslands have remained somewhat problematic. While there has been general acceptance of the practice by runholders, advisers and scientists in all districts there has always been substantial variation in specific objective. Clearly runholders would have gained economic benefits in improved livestock nutrition in terms of digestibility, available energy, mineral and protein content from the legume component of their “improved tussock grasslands” (Scott and Maunsell 1974, Grace and Scott 1974, Clarke 1977). As has been frequently noted, the benefits in nutrition were first reflected in better condition of sale stock, rather than in increased numbers in the flock. Economic benefits have also accrued in the form of higher unimproved land values as well as in the value of improvements arising from the application of the new technology (Kerr, Frizzell and Ross, 1979). Levels of herbage production have increased as well as its quality as a consequence of clover introduction and topdressing. Some research has indicated that herbage increase from experimental areas may be as much as from five to ten times the level of unimproved grassland (O'Connor 1959, 1966). There has been probably a large consequent reduction in grazing pressure on pastoral runs where livestock output rather than livestock numbers showed dramatic increase. This reduction has probably been greatest on the lands which have not been topdressed or oversown. Recent estimations of stocking loads on blocks which have been topdressed and oversown in the Upper Waitaki (O'Connor 1979b) show a mean fourfold to eightfold superiority over the unimproved, for four terrain classes. For each terrain class the range in stocking load at the improved level is very wide, suggesting considerable variation in agronomic success or in pastoral utilisation.

Runholders reveal substantial variation in individual revegetation objectives. Similar variation exists among scientists and advisers. Some people clearly want to transform improved tussock grasslands into “fully developed” sward grasslands. At the other extreme there are others who are not satisfied with anything less than a waving mass of dense tussocks. What is not generally appreciated is that between these two extremes, any vegetation target would be difficult to maintain for any sustained period. A mixed tussock grassland with intertussock grasses and clover seems to be
inherently unstable. There is now considerable evidence that such an association can be relatively easily attained in the first development phase. However, high managerial skill is essential to sustain such a balance for even a few seasons. Some of the factors contributing to this instability of the tussock/ward grass/clover association are the varied responses of different grasses to nitrogen, phosphorus, sulphur and lime (O'Connor 1963a, Vartha 1963, O'Connor and Vartha 1969, O'Connor and Clifford 1977), the high variability from year to year in seasonal precipitation and the significance of this variation to herbage production and composition and animal utilisation of pastures (O'Connor et al 1968, O'Connor 1976, Radcliffe 1979), the influence of different defoliation regimes on the tussocks themselves (O'Connor and Powell 1963, O'Connor 1965, 1967a, Scott 1961b, Mark 1965c, Williams and Meurk 1977) herbage production and composition (O'Connor 1961c, 1966, O'Connor and Lambrechtsen 1964), the competitive and allelopathic effects of different plants, including clovers, on their companions (Scott 1974, 1975c). Runholder experience suggests that differences in management of fertiliser or grazing regimes may result in unstable clover-rich tussock grasslands diverging into a wide range of associations varying from almost pure browntop or weed communities to dense tussock or tight grass-clover swards.

Despite this practical evidence of pasture instability and despite the evidence of wide variation in animal stocking loads on such pastures, runholders and their advisers alike have continued to support investments in "tussock grassland improvement" without clear enunciation of pastoral management objectives. Because of the uncertainty of spring and summer precipitation the level of herbage production has itself remained uncertain. Generally runholders have adjusted to such uncertainty by conservative stocking loads and in so doing they have ensured the persistence of instability. They have looked to grass introduction or tussock recovery as insurance against drought or cold but they have generally hedged their bets in compromise.

Such indecision and caution is not without justification. Clearly runholders cannot be expected to commit themselves to a policy of inducing highly improved grass-clover swards when such swards are virtually useless for providing grazeable herbage in late winter and when they are highly variable in production at any other time of the year. What we have failed to recognize is the possibility of a different strategy. A combination of different blocks of differently managed vegetation may represent a better strategy of revegetation for pastoral use than does the uneasy compromise of "tussock grassland improvement" as we have known it. In this respect revegetation may have suffered not from a want of technology but from inadequate clarification of management objectives.

Implications for Other Uses

Some people in water and soil conservation agencies have difficulty in understanding some runholders' anxiety to retain pastoral use of high altitude lands. There may also be a lack of comprehension for runholders' wish for partial improvement and use of "Class VIIe snow tussock country", when "Class VI fescue tussock country" remains undeveloped. A run plan which is to achieve pastoral goals of production and profitability must often give emphasis to high altitude, summer-reliable terrain even if such land has higher erosion risks and greater water production potential. Revegetation of such terrain for pastoral purposes may well be justified and should be considered on its merits in actual cases as part of the reconciliation of possible conflicting uses.

The zoning for use of high country terrain by altitude, soil sets, or other simplistic systems of land capability classification has for many years affected our formulation of land policy. Its application has been a costly exercise. It has not led to a very productive policy, either for the production of water or
for the achievement of a collective pastoral economy, if we were to judge by the evidence of the Waitaki (Whitby 1979). So long as public administration of such land is concerned principally with merely putative benefits for the nation at large it will remain difficult to justify public support for its revegetation or for any other programmes that involve spending large sums of money.

The outcome of high altitude revegetation research in recent years has been to introduce some new possible productive uses. As Gibson (1977) rightly stated: "We have been obsessed with primary production from all classes of land without stopping to consider that some may have uses other than for agriculture." Nordmeyer (1978c,d, 1979) points to the opportunity for productive use of revegetation forests. It should not be thought that such opportunity is confined to land which is unsuitable for pastoralism. Much of it is in some degree suited to pastoral purposes. Much of it is better suited to production forestry. Whether it should be used for one or the other or for both depends not simply on its suitability but also on the local, regional and national need for each use and for its benefit.

The success of high altitude revegetation techniques has not been universal nor is it confined to primary recolonisation. As shown in this review, success in some situations extends to pasture rehabilitation, to forest establishment and to succession towards tall tussock grassland. The costs of such treatment are not low and there is need and opportunity for further economy. Only in some cases of riparian land is it likely that revegetation will be justified by its downstream benefits. In some circumstances there may be justification in offsite water yield. In many roading cases it may be justified as landscape cosmetics. Its most common justification, where justification is possible, is likely to be in its productive use of what was hitherto a wasting asset. Just as the montane tussock grasslands might be demonstrated to be a net cost to the nation unless we accelerate their development for primary production, recreation, nature conservation and other uses, so also the sub-alpine and alpine areas of the mountains may remain for us a net cost, unless we quickly develop ways of integrating on them the range of uses for which they can be demonstrated to be suitable. Revegetation in all its forms should be recognised as the technological key to such goals and objectives for high mountain land use.

References


BUCHANAN, J. (1875): Sketch of the botany of Otago. Transactions of the New Zealand Institute 2nd ed.: 181–212


HERCUS, J. M. (1954): Recent research work; tussock grassland. New Zealand Journal of Agriculture 89: 397


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O’CONNOR, K. F. (1957): The present state of research in the rangeland and related forest land of New Zealand, with particular reference to needs for its co-ordination, development and organisation in the future. A report presented to the Co-ordinating Committee of the Soil Conservation and Rivers Control Council, Wellington, May 21.


O’CONNOR, K. F. (1963a): Studies on the management of snow tussock grassland. II. The effects of cutting and fertilizer on narrow-leaved snow-tussock (Chionochloa rigidula (Raoul) Zotov) at high altitude sites in Canterbury, New Zealand. New Zealand Journal of Agricultural Research 6: 368–75


PERHAM, A. N. (1922): Deer in New Zealand; report on damage done by deer in the forests and plantations in New Zealand. *Appendices to the Journals of the House of Representatives C-3A*: 6p.


SIMPSON, M. J. A. (1957): Seedling studies in fescue-tussock grassland. II. Performance in four sites. New Zealand Journal of Science and Technology 38A: 512–26


SPECIAL COMMITTEE REPORT (1923): The regrassing experiments in Central Otago, New Zealand. New Zealand Journal of Agriculture 26: 97–100


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Senecio bellidiioides