*The following papers were included in a symposium on* "High Altitude Ecology" *held at the 1966 Conference.*

# SOME ECOLOGICAL ASPECTS OF REVEGETATION OF ERODED KAIKOURAN SOIL AT BLACK BIRCH RANGE, MARLBOROUGH

K. F. O'CONNOR and N. C. LAMBRECHTSEN

*Grasslands Division, D.S.I.R., Lincoln*

## INTRODUCTION

In their report on high altitude tall tussock grasslands, the Tussock Grassland Research Committee (1954) drew attention to the scarcity of exotic plants in the high altitude zone after depletion of the snow tussock. In this zone, soil exposed among tussocks is subject to frost lift and wind erosion. Subsoil and eventually parent material are exposed. In some localities, shorter native grasses such as *Festuca novae-zelandiae, F. matthewsii, Poa colensoi, Notodanthonia* species and *Chionochloa australis* may cover the exposed soil effectively, but depletion of the grasses results ultimately in extreme erosion. Such a situation exists in the *Notodanthonia setifolia–Celmisia spectabilis* grasslands on Black Birch Range, Marlborough.

Two sets of experiments to evaluate the ability of several grasses to grow and survive and to withstand frost heaving in this environment were laid down in the spring of 1962 near the temporary Black Birch Observatory at 4,450 ft. The site was an area previously prepared for an airstrip; the hummocks of *Notodanthonia* and *Celmisia* had been graded off and the subsoil was exposed. One set of experiments dealt with the influence of mulches and fertilisers on the establishment of sown grasses and clovers (O'Connor, Macarthur and Archer, unpublished); the other is discussed here and deals with the influence of fertilisers on the growth and survival of space-planted grasses and oversown white clover. Some results of the mulching experiment of O'Connor *et al.* are discussed and conclusions are drawn about the grasses useful for two phases of revegetation — establishment on bare subsoil and survival following establishment. From the two sets of experiments, the importance of climate and soil fertility to revegetation is assessed and the probable plant succession following experimental revegetation is indicated.

## CLIMATE AND SOIL

Detailed meteorological observations at Black Birch Range have been presented by Bateson (1964). Records of hours of fog were made from June 1961 to April 1963 and of hours of sunshine from March 1962 to March 1963. A summary has been compiled for the period April 1962 to March 1963 (Table 1) which shows that this site was in fog for approximately one third of the year*.

TABLE 1. *Hours of fog and of bright sunshine at Black Birch Observatory, April 1962–March 1963.*

| | HOURS OF FOG | | | Hours of bright sunshine |
|---|---|---|---|---|
| | Total | (Night) 6 pm.–6 am. | (Day) 6 am.–6 pm. | |
| | (1) | (1) | (2) | (3) |
| April | 224.4 | 89.0 | 135.4 | 173 |
| May | 525.8 | 151.2 | 374.6 | 132 |
| June | 93.6 | 46.2 | 47.4 | 156 |
| July | 234.0 | 94.8 | 139.2 | 123 |
| August | 218.0 | 81.9 | 136.1 | 157 |
| September | 195.8 | 100.5 | 95.3 | 177 |
| October | 310.8 | 113.6 | 197.2 | 158 |
| November | 197.4 | 91.2 | 106.2 | 210 |
| December | 245.7 | 107.1 | 138.6 | 221 |
| January | 117.9 | 43.4 | 74.5 | 268 |
| February | 312.0 | 124.8 | 187.2 | 182 |
| March | 247.0 | 98.0 | 149.0 | 183 |
| Total | 2922.4 | 1141.7 | 1780.7 | 2140 |

(1) Compiled from Bateson (1964) Table 36
(2) Calculated by difference
(3) Compiled from Bateson (1964) Table 17

For a high proportion of "daylight hours" the site was either in bright sunshine or in fog.

Coulter (1967) stressed some of the remarkable features of the climate at this site. The main ones are: it is humid, cool in summer, with no month free of screen frosts, and moderately cold in winter.

* Because of the particular convention used in the original compilation of fog records, this summary of fog duration represents a slight over-estimate of real conditions.

TABLE 2. *Chemical characteristics of a 5° slope variant of Kaikoura sandy loam, Black Birch Range.*

| Horizon | pH | C % | N % | C/N | Ca m.e. % | Mg m.e. % | K m.e. % | Na m.e. % | T.E.B. m.e. % | C.E.C. m.e. % | B.S. % | Phosphorus Truog. mg. % | Phosphorus N.$H_2SO_4$ mg. % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A (1″– 7″) | 4.8 | 3.4 | 0.23 | 15 | 0.8 | 0.3 | 0.18 | 0.1 | 1.4 | 15.3 | 9 | 1 | 42 |
| B (7″–13″) | 5.3 | 1.0 | 0.08 | 13 | 0.2 | 0.0 | 0.04 | 0.1 | 0.4 | 8.0 | 5 | — | 65 |
| C (13″–16″) | 5.6 | 0.5 | 0.04 | 14 | 0.1 | 0.1 | 0.04 | 0.1 | 0.3 | 6.7 | 4 | — | 82 |

Compiled from unpublished data, Soil Bureau, D.S.I.R.

Apart from the period November to February, there is only a small diurnal temperature fluctuation. The site is exposed to frequent strong winds, often associated with snow or rain. Details of its microclimate were recorded by Gradwell (1962).

The soil of the summit ridge of Black Birch Range is an easy slope variant of Kaikoura sandy loam. Table 2 shows the chemical analysis of a soil sampled at 4,700 ft. The means for horizons B and C probably characterise the soil at the trial site. The values for carbon, nitrogen, available phosphorus and total exchangeable bases are extremely low.

## MATERIALS AND METHODS

Three fertiliser treatments with three replicates were laid down on 31 October 1962, in an animal-proofed area on an east-facing slope of 3° on the subsoil described above. The treatments were:

i) no fertiliser
ii) superphosphate at 1,000 lb./acre
iii) superphosphate at 1,000 lb./acre plus urea at 250 lb./acre.

Twenty sets (five plants per set) of eleven grass species were planted as 4–10 tillered plants in each of the nine plots. A foot square planting grid was used to facilitate the assessment of the ability of plants to grow and to withstand frost heaving. The whole area was oversown with inoculated "Huia" white clover (*Trifolium repens*) at 4 lb./acre.

The twenty grasses used were:

*Notodanthonia setifolia:* transplanted at site.

*Anthoxanthum odoratum:* sweet vernal from four lowland localities in New Zealand : Kaikohe (K), Te Awa (TA) near Palmerston North, Lincoln (L) and Gore (G).

*Lolium:* (A) "Manawa" ryegrass (from *L. perenne* × *L. multiflorum*); cool-season active. (I) "Ariki" ryegrass (from *L. perenne* × Manawa ryegrass); with good year-round activity. (D) No. 2195, *L. perenne*, from Sweden; winter-dormant.

*Dactylis:* (A) "Currie" cocksfoot, *D. glomerata*, from Australia; cool-season active. Clonal material was used. (I) "Apanui" cocksfoot; with fair to good year-round activity. (D) No. K.845, *D. glomerata*, from Denmark; winter-dormant.

*Phalaris:* (A) *P. tuberosa*; cool-season active. Clonal material from one plant was used. (I) *P.* hybrid (from *P. tuberosa* × *P. arundinacea*); with year-round activity. Clonal material from one plant was used. (D) *P. arundinacea* from Waimate Gorge; winter-dormant.

*Bromus:* (A) *B. unioloides* (*B. catharticus*) from commercial seed; cool-season active. (I) *B. "popovii"*; with year-round activity. Clonal material from one plant was used. The identity of this material is being investigated; the plants strongly resemble *B. carinatus*. (D) *B. inermis*, selected from "Lincoln" smooth brome; winter-dormant in Canterbury.

*Festuca:* (A) No. 68, *F. arundinacea*; with year-round activity but tending to summer dormancy. Clonal material from one plant was used. (I) "S.170", *F. arundinacea*; with year-round activity, but tending to winter dormancy. (D) No. 54, *F. arundinacea*; with year-round activity but especially summer active. Clonal material from one plant was used.

The letters (A), (I), (D) are abbreviations for the degrees of cool-season activity: active, intermediate, dormant.

Measurements were made on all plots on 24 April and 18 September 1963, and on 3 June and 28 October 1964. No additional fertilisers were applied and no plants were replaced. Observations were made on: emergence of tillers, growth of leaves, development of flowering stems, changes in basal diameter, and reactions of plants to frost heaving.

TABLE 3. *Survivors* of 15 spaced plants at Black Birch.*

*(Numbers shown in italics are cumulative totals of plants heaved out of ground after each winter)*

| Fertiliser Treatments | Nil | | | | | | P | | | | | | N + P | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DATES OF OBSERVATIONS | 4/63 | 9/63 | | 6/64 | 10/64 | | 4/63 | 9/63 | | 6/64 | 10/64 | | 4/63 | 9/63 | | 6/64 | 10/64 | |
| LOLIUM | | | | | | | | | | | | | | | | | | |
| 'Manawa' | 14 | 10 | *4* | 5 | 0 | *10* | 15 | 14 | *1* | 9 | 0 | *8* | 15 | 15 | *0* | 13 | 0 | *5* |
| 'Ariki' | 15 | 13 | *2* | 3 | 0 | *7* | 15 | 12 | *3* | 9 | 2 | *9* | 15 | 15 | *0* | 13 | 4 | *7* |
| No. 2195 (Swedish) | 14 | 7 | *7* | 4 | 0 | *13* | 15 | 13 | *0* | 12 | 2 | *5* | 15 | 14 | *1* | 13 | 4 | *4* |
| DACTYLIS | | | | | | | | | | | | | | | | | | |
| 'Currie' | 15 | 6 | *9* | 0 | 0 | *15* | 15 | 15 | *0* | 7 | 2 | *10* | 15 | 14 | *1* | 12 | 5 | *6* |
| 'Apanui' | 15 | 15 | *0* | 13 | 9 | *5* | 15 | 15 | *0* | 15 | 14 | *0* | 15 | 15 | *0* | 15 | 15 | *0* |
| No. 845 (Danish) | 15 | 12 | *3* | 11 | 2 | *7* | 15 | 15 | *0* | 15 | 14 | *1* | 15 | 15 | *0* | 15 | 14 | *1* |
| PHALARIS | | | | | | | | | | | | | | | | | | |
| *P. tuberosa* | 14 | 4 | *10* | 0 | 0 | *14* | 15 | 6 | *4* | 0 | 0 | *7* | 15 | 15 | *0* | 0 | 0 | *4* |
| *P.* hybrid | 15 | 8 | *7* | 1 | 0 | *15* | 15 | 15 | *1* | 8 | 0 | *8* | 15 | 15 | *0* | 4 | 2 | *5* |
| *P. arundinacea* | 15 | 5 | *10* | 2 | 0 | *15* | 15 | 15 | *1* | 12 | 5 | *4* | 15 | 15 | *1* | 14 | 5 | *5* |
| BROMUS | | | | | | | | | | | | | | | | | | |
| *B. unioloides* | 15 | 3 | *12* | 0 | 0 | *15* | 15 | 12 | *3* | 3 | 0 | *12* | 15 | 13 | *2* | 2 | 0 | *7* |
| *B. "popovii"* | 15 | 4 | *11* | 3 | 0 | *15* | 15 | 15 | *0* | 12 | 2 | *11* | 15 | 15 | *1* | 9 | 2 | *14* |
| *B. inermis* | 15 | 4 | *12* | 3 | 1 | *15* | 15 | 13 | *3* | 7 | 2 | *9* | 15 | 15 | *0* | 14 | 4 | *8* |
| FESTUCA | | | | | | | | | | | | | | | | | | |
| No. 68 | 15 | 4 | *14* | 3 | 0 | *15* | 15 | 15 | *0* | 14 | 2 | *5* | 15 | 15 | *0* | 11 | 2 | *5* |
| 'S. 170' | 15 | 6 | *12* | 2 | 1 | *15* | 15 | 14 | *2* | 11 | 0 | *9* | 15 | 15 | *0* | 13 | 2 | *5* |
| No. 54 | 15 | 7 | *8* | 3 | 0 | *13* | 15 | 15 | *0* | 14 | 4 | *7* | 15 | 15 | *0* | 11 | 3 | *5* |
| ANTHOXANTHUM | | | | | | | | | | | | | | | | | | |
| ex Kaikohe | 9 | 4 | *5* | 1 | 1 | *8* | 12 | 6 | *6* | 6 | 3 | *9* | 13 | 10 | *3* | 10 | 8 | *4* |
| ex Te Awa | 12 | 9 | *3* | 0 | 0 | *12* | 12 | 10 | *2* | 8 | 4 | *7* | 12 | 10 | *2* | 9 | 9 | *3* |
| ex Lincoln | 13 | 7 | *5* | 5 | 2 | *10* | 12 | 5 | *4* | 3 | 3 | *6* | 13 | 9 | *4* | 7 | 5 | *8* |
| ex Gore | 12 | 11 | *1* | 4 | 4 | *8* | 11 | 10 | *1* | 10 | 7 | *4* | 11 | 9 | *2* | 9 | 7 | *4* |
| NOTODANTHONIA | | | | | | | | | | | | | | | | | | |
| *N. setifolia* | 11 | 6 | *3* | 5 | 0 | *11* | 12 | 11 | *1* | 7 | 0 | *7* | 13 | 13 | *0* | 13 | 2 | *6* |

* Including live plants heaved from ground

## RESULTS

### *Survival*

Table 3 presents the survival of the 15 plants in each fertiliser treatment and the number of plants heaved out. All grasses survived the first growing season well, except sweet vernal. Plants of this species had not been thoroughly hardened before transplanting and this could account for the large initial number of dead plants. After one winter many grasses had died in untreated plots but very few in manured plots. Many deaths occurred during the second growing season in "Manawa" ryegrass, "Currie" cocksfoot, *Phalaris tuberosa*, and *Bromus unioloides*, even on manured plots.

Early in the second winter (June 1964) only "Apanui" and Danish cocksfoot survived well without fertiliser; but by the end of that winter (October), deaths had increased among the Danish cocksfoot. Where there was high fertiliser application, only "Apanui" and Danish cocksfoot survived the second winter well, though the sweet vernal populations survived fairly well.

Most of the plants that failed to survive were heaved from the ground. However, it should not be inferred that frost heaving is the prime factor causing deaths in the grasses tested. Strong winds with rain or snow were also adverse to survival. Besides the cold injury evident from Table 4, wind-driven rain washed soil away from the roots, exposing them to desiccation. As indicated above, mortality of cool-season-active grasses during the second growing season was much higher on manured plots than it was during the previous winter.

The number of plants heaved out completely is shown in italics in Table 3 as cumulative totals at the end of each winter. It does not include living plants which may have suffered some heaving. After the first winter, all grasses in untreated plots suffered severe heaving except the New Zealand-bred ryegrasses, "Apanui" and Danish cocksfoot and some of the sweet vernals, but in treated plots heaving was negligible. After the second winter the untreated plots were almost devoid of plants except a few "Apanui" and

Danish cocksfoot plants, whereas in treated plots the same cocksfoots and some sweet vernal plants had suffered very little heaving. The possible relationship between resistance to heaving and plant basal area is discussed later.

During winter, leaves were bleached so that the photosynthetic area was reduced. Table 4 presents the estimates of greenness of three grasses of each of five genera on 18 September 1963. The three grasses were selected for different degrees of cool-season activity. Greenness was expressed as cm. of green tissue per leaf. The analysis of variance shows that the addition of fertiliser had an overall effect on greenness and that *Lolium*, *Dactylis* and *Festuca* were clearly superior to *Phalaris* and *Bromus*. The greenness of cool-season-active grasses is significantly inferior. Phosphorus and nitrogen fertilisers improved greenness of intermediate and cool-season-dormant grasses, especially among *Lolium* and *Dactylis*. In a high mountain environment cool-season activity not allied with cold tolerance clearly leads to severe injury from low temperatures (cf. Breese 1963).

TABLE 4. *Effective greenness of grasses of different cool season activity under different fertiliser treatments at Black Birch, 18 September 1963.*

(*cm. length of green tissue per leaf*)

| Grass | Cool-season activity | Nil | P | P+N |
|---|---|---|---|---|
| LOLIUM | | | | |
| 'Manawa' | Active | 0.7 | 1.3 | 3.0 |
| 'Ariki' | Intermediate | 1.7 | 3.3 | 5.3 |
| No. 2195 | Dormant | 1.0 | 3.3 | 4.7 |
| DACTYLIS | | | | |
| 'Currie' | Active | 0.7 | 2.0 | 1.7 |
| 'Apanui' | Intermediate | 3.3 | 4.3 | 6.3 |
| No. K 845 | Dormant | 3.0 | 4.0 | 5.3 |
| PHALARIS | | | | |
| *P. tuberosa* | Active | 0.0 | 0.0 | 0.0 |
| *P.* hybrid | Intermediate | 0.3 | 0.7 | 0.7 |
| *P. arundinacea* | Dormant | 0.3 | 0.7 | 1.3 |
| BROMUS | | | | |
| *B. unioloides* | Active | 0.0 | 0.7 | 0.0 |
| *B. "popovii"* | Intermediate | 0.7 | 1.7 | 1.3 |
| *B. inermis* | Dormant | 1.0 | 1.3 | 1.7 |
| FESTUCA | | | | |
| No. 68 | "Active" | 1.7 | 2.3 | 3.3 |
| 'S. 170' | "Intermediate" | 1.3 | 3.0 | 4.3 |
| No. 54 | "Dormant" | 1.7 | 2.7 | 3.3 |

*Means*:

| Genera | Cool-season activity A | I | D | Fertilisers Nil | P | P+N | Genus Mean |
|---|---|---|---|---|---|---|---|
| LL | 1.7 | 3.4 | 3.0 | 1.1 | 2.7 | 4.3 | 2.7 |
| DA | 1.4 | 4.7 | 4.1 | 2.3 | 3.4 | 4.4 | 3.4 |
| PH | 0.0 | 0.6 | 0.8 | 0.2 | 0.4 | 0.7 | 0.4 |
| BM | 0.2 | 1.2 | 1.3 | 0.6 | 1.2 | 1.0 | 0.9 |
| FS | 2.4 | 2.9 | 2.6 | 1.6 | 2.7 | 3.7 | 2.6 |
| | 1.2 | 2.6 | 2.4 | 1.2 | 2.1 | 2.8 | |

*Standard errors*:

| | |
|---|---|
| Activities | 0.278* |
| Genera | 0.356** |
| Fertilisers | 0.222* |
| F × G | 0.257** |
| G × A | 0.257** |

The oversown white clover survived initially in the shelter of the space-planted grasses but after the second winter it had persisted only within a few grass clumps and in one plot which may have been more sheltered or with slightly higher natural fertility. White clover never formed a protective cover.

*Plant height, flowering and seed formation*

The height of plants from their base to the blade tip of the longest leaf at the end of the first growing season is given in Table 5. Although plants tended to be taller at higher fertiliser levels, fertiliser effect did not reach overall significance.

TABLE 5. *Plant height in cm. in first season at 24 April 1963.*

| | FERTILISER TREATMENTS Nil | P | P+N | Mean |
|---|---|---|---|---|
| LOLIUM | | | | |
| 'Manawa' | 10.0 | 10.7 | 16.3 | 12.3 |
| 'Ariki' | 8.0 | 9.7 | 11.0 | 9.6 |
| No. 2195 | 7.0 | 6.7 | 9.0 | 7.6 |
| DACTYLIS | | | | |
| 'Currie' | 11.3 | 10.7 | 12.7 | 11.6 |
| 'Apanui' | 13.3 | 15.3 | 20.0 | 16.2 |
| No. K 845 | 14.7 | 12.7 | 17.7 | 15.0 |
| PHALARIS | | | | |
| *P. tuberosa* | 9.7 | 9.3 | 12.3 | 10.4 |
| *P.* hybrid | 10.3 | 10.0 | 17.0 | 12.4 |
| *P. arundinacea* | 10.0 | 10.0 | 13.3 | 11.1 |
| BROMUS | | | | |
| *B. unioloides* | 13.7 | 18.3 | 16.3 | 16.1 |
| *B. "popovii"* | 10.7 | 13.7 | 13.0 | 12.4 |
| *B. inermis* | 6.0 | 9.3 | 9.7 | 8.3 |
| FESTUCA | | | | |
| No. 68 | 10.0 | 12.3 | 11.7 | 11.3 |
| 'S. 170' | 11.7 | 14.7 | 13.3 | 13.2 |
| No. 54 | 9.7 | 11.3 | 12.0 | 11.0 |
| ANTHOXANTHUM | | | | |
| ex Kaikohe | 6.7 | 6.7 | 9.0 | 7.4 |
| ex Te Awa | 6.7 | 7.7 | 10.0 | 8.1 |
| ex Lincoln | 8.0 | 8.3 | 9.3 | 8.6 |
| ex Gore | 6.0 | 8.0 | 10.7 | 8.2 |
| NOTODANTHONIA | | | | |
| *N. setifolia* | 9.7 | 9.7 | 9.3 | 9.6 |
| Means | 9.6 | 10.8 | 12.7 | 11.0 |

Standard error variety mean 0.73**
Standard error fertiliser mean N.S.

Flowering was most abundant among New Zealand-bred ryegrasses and sweet vernal in treated and untreated plots in the first growing season (Table 6). Nitrogen fertiliser doubled flowerhead production. Although few cocksfoot flowerheads were formed in the first season, there was abundant flowering in the second season. Viable seed was set and seedlings were seen in 1964 in the high-fertility plots, where seedlings of ryegrass and sweet vernal also became established. Sweet vernal seedlings were found in the wild wherever some cover protected them against frost heaving. Self-sown cocksfoot and sweet vernal plants flowered profusely in the 1965–66 season in nearby topsoil remnants.

TABLE 6. *Numbers of emerged flowering stems per plant at 24 April 1963.*

| | FERTILISER TREATMENTS | | | |
|---|---|---|---|---|
| | Nil | P | P+N | Mean |
| LOLIUM | | | | |
| 'Manawa' | 3.6 | 2.4 | 10.3 | 5.4 |
| 'Ariki' | 3.3 | 2.8 | 8.7 | 5.0 |
| No. 2195 | 4.3 | 2.8 | 3.7 | 3.6 |
| DACTYLIS | | | | |
| 'Currie' | 0.9 | 1.3 | 2.8 | 1.3 |
| 'Apanui' | 0.0 | 0.0 | 0.0 | 0.0† |
| No. K 845 | 0.0 | 0.1 | 0.1 | 0.0† |
| PHALARIS | | | | |
| *P. tuberosa* | 0.3 | 1.6 | 2.6 | 1.5 |
| *P.* hybrid | 0.0 | 0.0 | 0.0 | 0.0† |
| *P. arundinacea* | 0.0 | 0.0 | 0.0 | 0.0† |
| BROMUS | | | | |
| *B. unioloides* | 1.0 | 0.8 | 2.0 | 1.3 |
| *B. "popovii"* | 1.5 | 2.4 | 4.0 | 2.6 |
| *B. inermis* | 0.3 | 0.9 | 0.2 | 0.4† |
| FESTUCA | | | | |
| No. 68 | 0.0 | 0.0 | 0.0 | 0.0† |
| 'S. 170' | 0.0 | 0.0 | 0.0 | 0.0† |
| No. 54 | 0.2 | 0.6 | 0.0 | 0.4† |
| ANTHOXANTHUM | | | | |
| ex Kaikohe | 3.9 | 4.4 | 8.6 | 5.6 |
| ex Te Awa | 1.2 | 2.8 | 3.7 | 2.6 |
| ex Lincoln | 2.1 | 1.9 | 1.9 | 2.0 |
| ex Gore | 2.8 | 2.2 | 5.9 | 3.6 |
| NOTODANTHONIA | | | | |
| *N. setifolia* | 0.7 | 0.5 | 0.3 | 0.5† |
| † signifies varieties not included in analysis of variance | | | | |
| Means (of 11) | 2.3 | 2.3 | 4.9 | 3.1 |
| Standard error variety mean | | | 0.85** | |
| Standard error fertiliser mean | | | 0.39* | |
| Standard error V × F mean | | | 0.83** | |

*Tillering and basal area*

Estimates of number of tillers per plant in the autumn after planting (24 April 1963) are given in Table 7. Nitrogen fertiliser significantly increased tiller number especially in the *Lolium* cultivars, "Apanui" and Danish cocksfoot and North Island populations of sweet vernal. Tillers in sweet vernal were counted for two consecutive years; data in Table 8 indicate relative stability in tiller number by the end of the second year.

TABLE 7. *Estimated number of tillers per plant at 24 April 1963*

| | FERTILISER TREATMENTS | | | |
|---|---|---|---|---|
| | Nil | P | P+N | Mean |
| LOLIUM | | | | |
| 'Manawa' | 10.3 | 12.7 | 27.3 | 16.8 |
| 'Ariki' | 11.7 | 13.7 | 31.7 | 19.0 |
| No. 2195 | 9.3 | 11.7 | 20.0 | 13.7 |
| DACTYLIS | | | | |
| 'Currie' | 4.3 | 6.0 | 5.3 | 5.2 |
| 'Apanui' | 8.0 | 7.3 | 18.7 | 11.3 |
| No. K 845 | 5.0 | 6.0 | 11.7 | 7.6 |
| PHALARIS | | | | |
| *P. tuberosa* | 2.3 | 3.0 | 5.0 | 3.4 |
| *P.* hybrid | 3.3 | 4.3 | 7.0 | 4.9 |
| *P. arundinacea* | 2.3 | 4.7 | 7.0 | 4.7 |
| BROMUS | | | | |
| *B. unioloides* | 3.3 | 3.7 | 4.3 | 3.8 |
| *B. "popovii"* | 3.0 | 4.7 | 5.0 | 4.2 |
| *B. inermis* | 2.7 | 4.0 | 5.0 | 3.9 |
| FESTUCA | | | | |
| No. 68 | 5.0 | 6.7 | 10.3 | 7.3 |
| 'S. 170' | 4.3 | 5.7 | 8.3 | 6.1 |
| No. 54 | 4.0 | 4.3 | 6.0 | 4.8 |
| ANTHOXANTHUM | | | | |
| ex Kaikohe | 8.7 | 9.0 | 20.0 | 12.6 |
| ex Te Awa | 10.3 | 12.0 | 21.7 | 14.7 |
| ex Lincoln | 10.0 | 8.0 | 10.7 | 9.6 |
| ex Gore | 10.0 | 9.3 | 15.7 | 11.7 |
| NOTODANTHONIA | | | | |
| *N. setifolia* | 12.0 | 12.0 | 13.0 | 12.3 |
| Means | 6.5 | 7.4 | 12.7 | 8.9 |
| Standard error variety mean | | | 1.82** | |
| Standard error fertiliser mean | | | 1.17* | |
| Standard error V × F mean | | | 2.08** | |

Estimates made of the basal area of all plants showed (as expected) that for each grass basal area tended to increase with tiller number. For example, on 3 June 1964 "Apanui" cocksfoot at high fertility averaged 45 tillers per living plant with a basal area of 55 cm.$^2$; on untreated plots the comparable basal area was 30 cm.$^2$ Under high fertility, smaller tillered plants such as "Ariki" ryegrass averaged nearly 60 tillers per plant with a basal area of about 25 cm.$^2$; at low fertility the basal area was 9 cm.$^2$

TABLE 8. *Numbers of tillers per surviving plant of four sweet vernal populations at several dates at Black Birch.*

| Fertiliser | Nil | | | | P | | | | P+N | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| POPULATIONS | K | TA | L | G | K | TA | L | G | K | TA | L | G |
| 24 April 1963 | 9 | 13 | 13 | 12 | *9 | 12 | 8 | 9 | *20 | 22 | 11 | 16 |
| 18 Sept. 1963 | 2 | 5 | 8 | 8 | 3 | 9 | 18 | 5 | 22 | 31 | 7 | 20 |
| 3 June 1964 | 15 | — | 16 | 40 | 19 | 20 | 32 | 19 | 50 | 70 | 18 | 50 |
| 28 Oct. 1964 | 15 | — | 15 | 31 | 8 | 25 | 32 | 24 | 30 | 41 | 13 | 45 |

* For these fertiliser treatments at 24 April 1963, numbers are estimates only. For all other dates actual numbers by count are given.

## DISCUSSION

This experiment shows that at this site, grasses at present commercially available in New Zealand can grow with some vigour provided that they are well established and well manured. Soil fertility was shown to be extremely important for plant vigour, indicated by number of tillers and flowering stems; it was also important for plant survival. Fertiliser treatments did not affect all grasses in the same manner. The effect of fertilisers on tillering of ryegrasses, "Apanui" and Danish cocksfoot and the North Island sweet vernals was more pronounced. Nitrogen fertilisers increased flowering in New Zealand-bred ryegrasses, and in sweet vernal from Kaikohe and Gore. There were, however, large differences in survival among grasses; this appeared to be related to resistance to cold injury. Cool-season-active grasses had much less green tissue at the end of the first winter than intermediate and winter-dormant grasses. Fertilisers improved greenness, especially of the intermediate and winter-dormant grasses. For this cool high mountain climate, grasses with intermediate or year-round activity are to be preferred to cool-season-dormant grasses because of their superior growth, and to cool-season-active grasses because of their apparently higher resistance to cold injury, not only in mid-winter but also at other times of the year.

The higher survival of plants of "Apanui" cocksfoot, even in untreated plots, directs our attention back to the establishment or colonisation phase in revegetation. A relationship was found between percentage of plants heaved out and mean basal area for all grasses. It is expressed in the regression,

$$Y = 80 - 0.5 \pm 0.12\,X$$

where Y = % heaved out at October 1964 and X = mean basal area in cm.$^2$ at June 1964. This general relationship should be interpreted with caution. Gradwell (1955) showed that with increasing diameter of flat weed rosettes, there was less frost heaving and in 1960 he illustrated how ice needles could be formed close to the base of those snow tussocks where bare soil had little protection from foliage. Because some grasses were notably different from others in basal area, real differences among grasses in resistance to heaving could be obscured in the above equation. The effect of basal area on susceptibility to heaving needs examination within particular grasses but this was not possible in this experiment. The growth habit of grasses may have an important influence on susceptibility to heaving. The horizontal spread of grass leaves may prevent ice needle formation close to the roots so long as the mass of leaves persists. Where the mulch of leaves was removed in this experiment by wind or rain, ice needles damaged the unprotected roots. It was noteworthy that in untreated plots, erect plants such as *Festuca arundinacea* were heaved entire from the soil.

In a series of experiments including high altitude sites in several sectors of South Island, O'Connor (1962) reported disappointing results with the establishment of oversown clovers on eroded high altitude soils. All those trials were oversown with "Apanui" cocksfoot. Although phosphate often assisted the growth of cocksfoot in the first season, the small cocksfoot plants suffered the same fate as the clovers — frost lift in the first winter (O'Connor, 1963).

It is clear from the present experiment that "Apanui" cocksfoot plants are well adapted to survival provided that they are sufficiently large to avoid damage by heaving. With an average tiller number of 8 and an average height of 13 cm. no "Apanui" plant had been heaved during the first winter even in unmanured plots.

In the adjacent mulching experiment of O'Connor *et al.*, cocksfoot established from seed quickly on untreated, unmulched plots, but suffered severe heaving in the first winter along with ryegrass and clover. However, where this mixture was manured with urea and superphosphate, sufficient growth of ryegrass occurred in the first season, even on unmulched plots, to cover the soil sufficiently to prevent frost heaving.

We suggest that two different phases of revegetation may be recognised:

a) establishment on bare subsoil and production of sufficient mulch to counter ice needle formation in the first winter.

b) persistence of plants to maintain cover in subsequent years even under conditions of declining fertility.

## CONCLUSION

Although we used New Zealand-bred pasture plants in this experiment, our primary intention has not been to improve more acres for the grazing of sheep, cattle or deer. The difficulties of revegetating bare subsoil in a high mountain environment are clearly very considerable even on a nearly flat area in an animal-proofed enclosure. If animals had had access to this experiment, plant vigour might have been reduced more rapidly than did occur under the influence of climate and soil fertility. In this work we have not considered the possibility of pastoral use. Our intention has been to test grasses for their engineering merit in revegetating unstable or marginally-stable soil mantles so that plant succession may occur. For this succession we look principally to those plants, both native and exotic, which demonstrate their ability to withstand harsh climate and low soil fertility. Unfortunately, most of them cannot accomplish the primary phase of recolonisation unaided. Some of these plants are shown in the records of O'Connor, Macarthur and Archer as frequent occurrences in their oversown plots: *Rumex acetosella, Epilobium sp., Hypochoeris radicata, Notodanthonia setifolia, Deyeuxia* sp., *Celmisia spectabilis, Poa lindsayi, Luzula* sp., *Raoulia* sp., *Agrostis* sp., *Poa colensoi*, and *Anthoxanthum odoratum*. *Rumex acetosella*, the only one of these which has become established in untreated subsoil, is now present in 127 of the 150 oversown 1 m.$^2$ plots.

Bateson (1964), in his site selection survey for an observatory, referred problems of trees and soil cover to J. T. Holloway of the N.Z. Forest Service. Holloway's advice is quoted by Bateson: "To my mind the most profitable and sure thing to do would be to establish a good cover of grass. This demands primarily a heavy-handed application of fertilisers; the current depletion of the native vegetation being as much due to deficiencies in soil nutrients as anything else. Many acres could be treated in this way (with almost certain success) at the cost of planting an acre of trees (with slow and uncertain results). Then if tree cover is still advisable for shelter or any other purpose, we will have something to build on. Once the grass is there it will be easier to get the trees in."

The present report bears out the value of Holloway's recommendation. It also suggests that if improvements are to be made on the grasses currently produced commercially in New Zealand for such engineering purposes, it will be prudent to think in terms of two phases in revegetation: a grass to colonise and a grass to persist. It may be that these two abilities will be obtained in the one plant. Moore (1954) commented on the ability of *Holcus lanatus* to establish and survive in *Rumex acetosella* communities at Molesworth. If these two abilities are not easily found in one grass then we know now that we can use ryegrass to colonise and that we can establish cocksfoot with it. Cocksfoot appears to persist for long enough to allow succession of native and other naturalised plants.

## ACKNOWLEDGMENTS

The authors are indebted for assistance with this project to Mr. F. M. Bateson, now Astronomer in Charge, Mt. John Observatory, Tekapo; Mr. L. W. McCaskill, formerly Director, Tussock Grasslands and Mountain Lands Institute, Lincoln; Mr. R. S. Macarthur, Chief Soil Conservator, Marlborough Catchment Board, Blenheim; Messrs. A. C. Archer, P. T. P. Clifford, W. D. Radford and C. Riley of Grasslands Division, Department of Scientific and Industrial Research, Lincoln.

## REFERENCES

BATESON, F. M., 1964. Final report on the site selection survey of New Zealand. *Publ. Univ. Pennsyl., Astronomical Series* 10. 139 pp.

BREESE, E. L., 1963. Winter growth and winter hardiness. *Rept. Welsh Pl. Breed. Sta.* 1963: 28–29.

COULTER, J. D., 1967. Mountain climate. *Proc. N.Z. Ecol. Soc.* 14: 40–57.

GRADWELL, M. W., 1955. Soil frost studies at a high country station. II. *N.Z. J. Sci. Tech.* 37B: 240–57.

GRADWELL, M. W., 1960. Soil frost action in snow-tussock grasslands. *N.Z. J. Sci.* 3: 580–90.

GRADWELL, M. W., 1962. Physical properties and instability in South Island high country soils. *N.Z. Soc. Soil Sci. Proc.* 5: 18–21.

MOORE, L. B., 1954. Some *Rumex acetosella* communities in New Zealand. *Vegetatio* 5–6: 268–78.

O'CONNOR, K. F., 1962. Field experimental assessment of fertility in soils of the high country of South Island, New Zealand. *Trans. Jt. Mtg. Comm. 4 & 5, Int. Soc. Soil Sci.*: 691–7.

O'CONNOR, K. F., 1963. The establishment of grasses in humid tussock grassland regions. *Tussock Grasslands and Mountain Lands Review* 5: 20–4.

TUSSOCK GRASSLAND RESEARCH COMMITTEE, 1954. The high-altitude snow-tussock grassland in South Island, New Zealand. *N.Z. J. Sci. Tech.* 36A: 335–64.