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The use of *Deschampsia beringensis* and *Deschampsia caespitosa* in reclamation

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SUMMARY

Deschampsia beringensis and *Deschampsia caespitosa* were grown in pure stand and various binary mixtures, in an upland area in Iceland on sandy soils, where aeolian deposition was prominent. The main aim of the experiment was to identify suitable species mixtures to use in soil reclamation under such conditions. The experimental plots were both subjected to grazing and protected from grazing and two fertilizer application rates were used. The plots were sown 1986 and observed for the following three years. Grazing greatly influenced the performance of the grass species, *D. beringensis* is completely intolerant of intensive grazing, whereas grazing enhances the vegetative cover of *D. caespitosa*. More aeolian sediments were collected in *D. beringensis* plots than in plots containing other species, but it still showed good tolerance to the sediments. The lower fertilizer rate led to poorer growth and persistence of all species than the higher fertilizer rate. It is advantageous to sow *D. caespitosa* in a mixture with *Festuca rubra* under intensive grazing, whereas *D. beringensis* is more suited to growth in pure stand where grazing intensity is low or absent.

Keywords: aeolian sediments, grass mixtures, grazing, revegetation.

YFIRLIT

Beringspuntur og snarrót til uppgræðslu

Beringspunti og snarrót var sáð í hreinrækt og í blöndu með ýmsum tegundum (1. tafla) í uppgræðslutilraun á Hafinu norðan Búrfells á Gnúpverjaafrétti (1. mynd). Helmingur tilraunarinnar var girtur af og fékkst því mat á stofnana á bæði friðuðum og beittum reitum. Jafnframt voru tvenns konar áburðarskammtar notaðir, 50N og 100N á ha. Tilraunin var á gróðursnauðum mel og talsvert áfok var ofan af afréttinum. Sáð var vorið 1986 og fylgst var með reitunum næstu þrjú árin.

Í ljós kom að beringspuntur þoldi alls ekki beitarálagið og hvarf fljótt úr beitta hluta tilraunarinnar. Snarrót aftur á móti var með betri þekju utan girðingar en innan (3. tafla) og hafði auk þess dreifst þar í aðra reiti (4. mynd). Skoðun á rótarkerfi plantnanna utan girðingar leiddi í ljós að hlutfall milli róta og stöngla var miklu lægra í beringspunti (2. tafla) og leiddi það til verra rótarhalds. Af 30 plöntum sem skoðaðar voru reyndust 23 beringspuntsplöntur vera lausar en ekki nema ein snarrótarplanta, þrátt fyrir að snarrót væri meira bitin (2. tafla).

Beringspuntur var langkröftugastur innan girðingar og gaf þar mikla uppskeru (4. tafla). Áfok var mikið á tilraunasvæðinu og var það verst á nyrstu reitunum sem næst lágu afréttinum þaðan sem áfokið barst (3. mynd). Heldur meira áfok safnaðist í beringspuntsreiti en aðra (5. tafla) en beringspunturinn þoldi áfokið mjög vel vegna þess að hann getur myndað nýjar rætur og sprota á stöngulliðamótum (5. mynd). Snarrótin aftur á móti virtist kafna undan áfokinu. Af hendingu lágu margir snarrótarreitir í norðurjaðri tilraunarinnar sem verst varð úti í áfokinu og skýrir það að hluta lélega þekju hennar í friðaða hlutanum (4. mynd).

Íslenski túnvingullinn 0305 varð gjörsamlega undir í samkeppni við beringspunt á friðuðu reit-

unum sem fengu hærri áburðarskammtinn en var töluverður hluti þekjunnar á blönduðum reitum með snarrót, bæði á friðuðum og beittum reitum (4. mynd). Vallarsveifgrasið Fylking lifði sæmi-lega með báðum tegundunum í friðuðum reitum en hvarf úr blöndu með snarrót á beittum reitum. Blanda með einæru rýgresi jók þekju hjá hvorugri tegundinni.

Blásveifgras var í fyrsta sinn prófað í þessari tilraun og stóð það sig ekki sem skyldi. Var það sæmilegt fyrsta árið en lét fljótt undan síga, sérstaklega í samkeppni við snarrót (4. mynd). Leik túnvingull var einnig með í hreinrækt og stóð sig vel innan girðingar en var nær því horfinn utan girðingar í lok tilraunarinnar.

INTRODUCTION

Recent studies have revealed that *Deschampsia beringensis* and *Deschampsia caespitosa* are the most promising grass species to use in soil reclamation under various conditions in Iceland (Helgadóttir, 1988ab), the former being more suitable for areas protected from grazing and the latter for grazed areas. Up to now grass varieties in reclamation trials have almost entirely been sown in pure stand. It was, however, suggested in the studies quoted above that it should be advantageous to sow a mixture of adapted species and varieties as their performance is highly dependent on environmental conditions. Consequently, a study was initiated in 1986, where these two species were compared in binary mixtures with various grass species.

The study was located in a barren upland area where aeolian deposition from erosion fronts is considerable, thus excerting stress on plant growth. Plots were either protected from grazing or open to grazing in order to study the effects of grazing upon the various mixtures. In addition, high and low inputs of fertilizer were used, as it was of interest to see whether acceptable plant cover could be obtained at the lower level, thus saving on fertilizer costs.

Three grass species were chosen to grow in the mixtures. These were *Festuca rubra*, var. 0305 and *Poa pratensis*, var. Fylking, both well adapted and which have proved their value for use in reclamation (Helgadóttir, 1988a). The third species, *Lolium multiflorum*, was used as a cover crop. It should be able to produce considerable amounts of biomass in the sowing year. The dead plant material remaining the following year could improve growing conditions for the companion grass by providing shelter, storing nutrients such as N and retaining water in the top layer of the soil. In addition, an Icelandic wild population of *Poa glauca* was grown in pure stand and in a mixture with *D. caespitosa*. This species is a common pioneer on open wasteland where soil fertility is low and it is quite common on gravelly and sandy soils. Seed production of *P. glauca* is easy (Jónatan Hermannsson, personal communication). It has never been tested before but could be of value in revegetation.

MATERIALS AND METHODS

Experimental site

The experiment was located in south central Iceland, Hafið, at an elevation of 250 m (Figure 1). The experimental area is barren with predominently sandy soil, with few coarse fragments 2–50 mm in diameter. The sand is a mixture of alluvial and aeolian materials, which are rich in vulcanic glass and pumice. The top is a thin gravel pavement layer. Under the surface layer is a 10 cm layer of loamy materials over sandy deposits. No signs of glaying were seen within the top 60 cm of the soil. The area is well drained but rills were noticed so water obviously sits on the surface during spring thaw.

The site was virtually barren, with a vegetation cover of less than 1%. The following species were found: *Equisetum arvense, Silene vulgaris, Armeria vulgaris, Rumex acetosella, Cardaminopsis petraea, Poa alpina, Festuca rubra*. *E. arvense* and *R. acetosella* were most common, with above ground shoot density of 11.7 and 1.7 per m², respectively.

Species and varieties

Deschampsia beringensis, variety IAS 19 from Alaska, and *Deschampsia caespitosa*, an Icelandic wild population, were grown in pure stand, in a mixture with each other and in binary mixtures with *Festuca rubra*, variety 0305 from Iceland, *Poa pratensis*, variety Fylking from Sweden and *Lolium multiflorum*, variety Billion (Table 1). In addition, *Poa glauca*, an Icelandic wild population, was also grown in pure stand and in a mixture with *D. caespitosa*. *Festuca rubra*, variety Leik from Norway, which has been extensively used by the Soil Conservation Service in their reclamation work, was sown in pure stand and used as a control. In addition, one plot was left unsown.

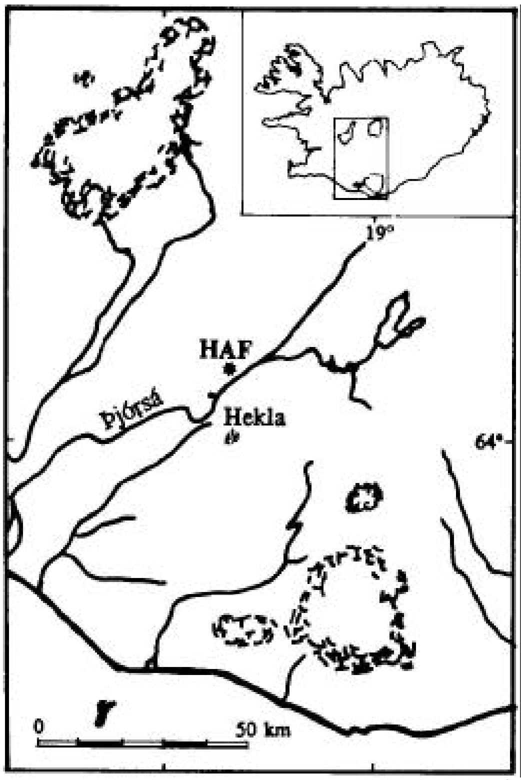

Figure 1. Geographic location and elevation of the experimental site, Hafið, in south central Iceland.

1. mynd. Landfræðileg staðsetning tilraunasvæðisins á Hafinu, Gnúpverjahreppi.

Experimental layout

Each experimental plot was 6×15 m², running lengthwise from east to west. One half of the experimental area was fenced off and the other half was open to sheep grazing. Within each half there were two complete blocks with two fertilizer levels, 50 kg N, 13 kg P, 16.5 kg K, 10 kg Ca and 5 kg S/ha and 100 kg N, 26 kg P, 33 kg K, 20 kg Ca and 10 kg S/ha, forming sub-plots. The thirteen treatment plots were then randomly arranged within each fertilizer level, thus being sub-sub-plots.

The experiment was sown on 19 June 1986 and the fertilizer was applied at the time of sowing. In subsequent years the same amount of fertilizer was applied on 19 June in 1987 and on 20 June in 1988 and 1989.

Evaluation

Plots were visually evaluated for total vegetation cover in spring 1987 and 1988, on the scale 0–9, where 9 equals full cover. In August during the same two years total dry matter yield on the ungrazed plots was measured by harvesting the plots with an Agria mower. The whole plots were mown and the herbage removed.

In spring 1987 grazing frequencies of individual plants of *D. beringensis, D. caespitosa* and *F. rubra* were estimated on that part of the experiment which was open to grazing. At least 30 plants of each species were randomly collected and subsequently devided into two groups, grazed and ungrazed. The root:shoot ratio of the ungrazed plants was then estimated.

Aeolian deposition is considerable in the area and the amount of aeolian sediments was visually evaluated on 15 August 1988 and measured on 16 August 1989 by making holes through the sediments down to the old surface at five points in each plot. At the same time a detailed vegetation analysis was

Table 1. Species and varieties sown in pure stand and various binary mixtures and the seed rates used.
1. tafla. Grastegundir og stofnar sáð í hreinrækt og blöndur í tilraunina á Hafinu ásamt sáðmagni sem notað var.

Treatment *Meðferð*	Species *Tegund*	Variety *Stofn*	Seed rate *Sáðmagn* kg/ha
A	*Deschampsia beringensis*	IAS 19	25.0
B	*Deschampsia caespitosa*	Wild—*Vilt*	25.0
C	*Poa glauca*	Wild—*Vilt*	25.0
D	*Festuca rubra*	Leik	20.0
E	*D. beringensis/D. caespitosa*		12.5/12.5
F	*D. caespitosa/Poa glauca*		12.5/12.5
G	*D. beringensis/F. rubra*	IAS 19/0305	12.5/12.0
H	*D. beringensis/P. pratensis*	IAS 19/Fylking	12.5/10.0
I	*D. beringensis/L. multiflorum*	IAS 19/Billion	20.0/5.0
J	*D. caespitosa/F. rubra*	Wild/0305	12.5/12.0
K	*D. caespitosa/P. pratensis*	Wild/Fylking	12.5/10.0
L	*D. caespitosa/L. multiflorum*	Wild/Billion	20.0/5.0
M	Unsown—*Ósáð*		

carried out where the cover of all occurring plant species was estimated using the Braun-Blanquet scale (Goldsmith and Harrison, 1976). Five 0.25 m^2 plots were analysed in each treatment plot, arranged with 2.5 m spacing along a straight line running through the plot from east to west. Only one out of the two blocks was used.

Data analysis

Data for cover and yield estimates were subjected to standard analysis of variance. The aeolian sediments data were used to plot a map of the amount of sediments in the experimental area. For the vegetation analysis the Braun-Blanquet scale was converted to a percentage scale, where the following values were used: •=0.1%; +=0.5%; 1=3.0%; 2=15.5%; 3=38%; 4=63% and 5=88%. The values for each plot were then standardized so that the total cover equals 100%. The resulting cover figures were plotted on a bar chart.

RESULTS

Establishment

Establishment was slow in the experimental plots and in the autumn of the sowing year plant cover was very poor. The following spring cover in the plots had improved and growth was well under way. Measurements of the root:shoot ratio of three plant species on the grazed part of the experiment revealed that *D. beringensis* had allocated smaller part of its biomass production to the roots than either *D. caespitosa* or *F. rubra*, Leik (Table 2). At the same time it was investigated how well the roots were fixed into the ground. Distinction was made between plants showing the top of their roots above ground and those where roots were not visible at all. Thirty plants were collected at random and the analysis revealed that the ratio of loose to fixed plants was 23:7, 19:11 and 1:29 for *D. beringensis*, Leik and *D. caespitosa*, respectively. It was also apparent that *D. beringensis* was more intensively grazed than the other two species (Table 2).

Vegetation cover

The overall mean vegetation cover, visually estimated, was only 3.4 and 2.9 out of maximum of 9.0 for the first two years of the

Table 2. Number of grazed and ungrazed plants of *Deschampsia beringensis, D. caespitosa* and *Festuca rubra* var. Leik randomly collected from the grazed part of the experiment and root:shoot ratio of ungrazed plants.
2. tafla. Fjöldi bitinna og óbitinna plantna af beringspunti, snarrót og Leik túnvingli á beitta hluta tilraunarinnar og hlutfall róta og sprota óbitinna plantna. Tilviljun var látin ráða við val plantnanna.

	Grazed[a)] *Bitið*	Ungrazed[a)] *Óbitið*	Total *Samtals*	Root/Shoot[b)] *Rætur/sprotar*
D. beringensis	4	26	30	0.29
D. caespitosa	15	18	33	0.48
F. rubra var. Leik	10	20	30	0.49
Total—*Samtals*	29	64	93	

a) X_1^2=7.65 (P=0.02).
b) LSR (P<0.05) for root:shoot ratio is 1.15—*Minnsta marktæka hlutfall (P<0,05) róta:sprota er 1,15.*

experiment but had increased to 5.0 three years from sowing (Table 3). The vegetation cover was considerably denser on the plots receiving the higher fertilizer rate, but grazing little influenced total cover. There were significant differences (P<0.001) between species combinations sown, on the ungrazed part of the experiment, but the differences did not always persist with time (Table 3a). In the first year from sowing *P. glauca* had the highest cover, significantly better than Leik and *D. caespitosa* in pure stand, but this was reversed in the following year. There were significant interactions between species and fertilizer level only in the last year, where *D. caespitosa* in pure stand did very poorly on the 100N plots compared to *D. beringensis* in pure stand, whereas the opposite occurred on the 50N plots.

Interactions between species combinations and grazing were significant in the second and third year, but not in the first year (Table 3b). The main pattern was that all species had less cover on grazed plots, except those containing *D. caespitosa*, where the cover remained the same or was better.

Yield

The yield of the ungrazed experimental plots was generally low and, in some cases, not measurable on the low fertilizer plots the first year after sowing. It doubled from 1987 to 1988 from 3.0 hkg/ha to 6.2 hkg/ha, respectively, and it was significantly higher on those plots receiving the higher fertilizer rate, where the mean yield over the two years was 7.5 hkg/ha compared to 1.6 hkg/ha on the plots receiving 50 kg N/ha (Table 4). In 1988 the mean yield on the 100N plots was 10.1 hkg/ha, with pure stands of *D. beringensis* giving the highest yield of 20 hkg/ha. Plots containing *D. beringensis* yielded considerably more than other plots, whereas plots with *D. caespitosa* were generally low yielding, especially the pure stand plots.

Aeolian sediments

Aeolian deposition is considerable in the area and some of the plots were strongly affected by the sediments (Figure 2). The sedimentation was significantly greater on the ungrazed part of the experiment (Table 5) where more sediments were generally collected on plots containing *D. beringensis* than on plots containing other species, though some of the *D. caespitosa* plots also contained considerable amounts. On the grazed part, on the other hand, plots containing *D. caespitosa* had the thickest layer of sediments. The standing herbage on the plots clearly influenced the interception as there was a

Table 3. Vegetation cover, on the scale 0–9; 9=max., of the experimental plots 1987–1989, protected from grazing at two fertilizer levels, 50 kg N/ha and 100 kg N/ha (a) and ungrazed and grazed averaged over fertilizer levels (b). Visual estimates 1987–1988 and measured 1989.
3. tafla. Þekja, á skalanum 0–9; 9=hámark, á friðuðum reitum við tvenns konar áburðarskammta, 50 kg N/ha og 100 kg N/ha (a) og á friðuðum og beittum reitum (meðaltal áburðarskammta) (b) árin 1987–1989.

a.	19.6.1987		20.6.1988		14.8.1989	
	50N	100N	50N	100N	50N	100N
D. beringensis	3.5	4.0	3.0	4.0	2.5	7.9
D. caespitosa	1.9	3.5	2.5	4.5	5.5	3.0
P. glauca	3.0	5.5	1.5	2.5	4.8	6.5
F. rubra, Leik	2.5	3.0	2.5	5.0	3.4	8.4
D. ber.+ D. caesp.	3.0	3.5	2.5	4.0	3.1	7.9
D. caesp.+ P. glauca	2.9	5.0	2.5	5.5	3.2	7.6
D. ber.+ 0305	4.0	4.0	3.5	3.0	3.1	5.3
D. ber.+ Fylking	3.0	5.5	3.0	4.5	4.2	8.0
D. ber.+ L. multifl.	3.0	4.0	3.0	4.0	2.2	5.6
D. caesp.+ 0305	2.9	3.5	3.0	5.5	4.1	8.7
D. caesp.+ Fylking	2.9	4.0	2.5	5.0	3.3	8.9
D. caesp.+ L. multif.	3.9	3.5	3.0	4.5	3.0	2.0
Unsown—*Ósáð*	0.9	1.5	1.0	2.0	3.3	4.8
Mean—*Meðaltal*	2.9	3.9	2.6	4.1	3.5	6.5
SED—*Staðalskekkja mism.*	0.74		0.77		0.95	

b.	19.6.1987		20.6.1988		14.8.1989	
	Ungrazed *Friðað*	Grazed *Beitt*	Ungrazed *Friðað*	Grazed *Beitt*	Ungrazed *Friðað*	Grazed *Beitt*
D. beringensis	3.7	3.5	3.5	1.2	5.2	4.1
D. caespitosa	3.0	3.0	3.5	3.8	4.2	6.2
P. glauca	4.2	3.7	2.0	2.5	5.7	3.4
F. rubra, Leik	2.7	3.5	3.7	1.5	5.9	3.5
D. ber.+ D. caesp.	3.2	4.0	3.2	3.5	5.5	7.2
D. caesp.+ P. glauca	4.0	3.5	4.0	3.0	5.4	6.3
D. ber.+ 0305	4.0	3.5	3.2	1.7	4.2	5.3
D. ber.+ Fylking	4.2	3.7	3.7	1.0	6.1	4.5
D. ber.+ L. multif.	3.5	3.7	3.5	1.5	3.9	3.2
D. caesp.+ 0305	3.2	3.7	4.2	3.5	6.4	6.8
D. caesp.+ Fylking	3.5	3.5	3.7	3.2	6.1	6.4
D. caesp.+ L. multif.	3.2	3.7	3.7	4.5	2.5	6.7
Unsown—*Ósáð*	1.2	0.7	1.5	0.7	4.0	2.1
Mean—*Meðaltal*	3.4	3.4	3.4	2.4	5.0	5.0
SED—*Staðalskekkja mism.*	0.52		0.50		0.67	

significant correlation between yield and the amount of sediments in August 1988 on the ungrazed part of the experiment ($r=0.49$; $P<0.001$).

The amount of sediments did though not only depend on the species in the plots as it obviously mattered where the plots were located within the experimental area (Figure 3). The main direction for aeolian deposition is from the north, the wind carrying

Table 4. Mean yield (hkg DM/ha) of experimental plots, protected from grazing, at two fertilizer levels, 50 kg N/ha and 100 kg N/ha, 1987 and 1988.
4. tafla. Meðaluppskera (hkg þe./ha) á friðuðum reitum við tvenns konar áburðarskammta, 50 kg N/ha og 100 kg N/ha, 1987 og 1988.

	20.8.1987		15.8.1988	
	50N	100N	50N	100N
D. beringensis	3.1	12.1	2.9	20.0
D. caespitosa	0.0	2.2	0.9	1.2
P. glauca	0.4	1.7	1.2	10.7
F. rubra, Leik	2.2	9.2	2.0	11.8
D. ber.+ D. caesp.	1.4	4.1	2.4	13.9
D. caesp.+ P. glauca	0.0	0.9	1.2	4.5
D. ber.+ 0305	2.5	9.1	1.2	14.6
D. ber.+ Fylking	2.4	6.4	3.3	17.5
D. ber.+ L. multif.	3.5	12.4	6.4	18.3
D. caesp.+ 0305	0.0	2.0	1.0	5.8
D. caesp.+ Fylking	0.0	2.1	1.7	6.5
D. caesp.+ L. multif.	0.0	1.1	1.7	1.1
Unsown—*Ósáð*	0.0	0.9	2.6	5.1
Mean—*Meðaltal*	1.0	4.9	2.2	10.1
SED—*Staðalskekkja mism.*	1.96		2.34	

eroded material from the near by rangelands. Hence, plots situated in the northern end of the experimental area were most affected. In the ungrazed part of the experiment these happened to be predominantly *D. caespitosa* plots.

Vegetation analysis

Detailed vegetation analysis from 1989 shows how each species component originally sown has persisted during the course of the experiment (Figure 4). On the ungrazed part of the experiment the sown species generally persisted well, especially on the plots with the higher fertilizer level. Other species coming in are mainly *D. caespitosa* and wild red fescue, as well as *Rumex acetosella* on the low fertility plots. *D. beringensis* dominates in the binary mixtures, especially at the high fertilizer level, whereas *D. caespitosa* generally makes up less than half of the vegetation cover in the binary mixtures. It is worth pointing out that at the high fertilizer level, the plots with pure stand *D. caespitosa* and *D. caespitosa*, originally sown in a mixture with ryegrass, were both badly affected by the aeolian sediments mentioned earlier. The plot originally sown with a mixture of *D. beringensis* and *D. caespitosa* was completely dominated by the former species at the high fertilizer level.

The situation is very different on the grazed part of the experiment. *D. beringensis* has virtually disappeared and has been replaced by *D. caespitosa*. Wild red fescue also comes in and *R. acetosella* makes a significant contribution to total plant cover. The cover of *D. caespitosa* sown is generally better in the grazed part than in the ungrazed part of the experiment and, contrary to the ungrazed plots, dominates in the mixture with *D. beringensis*.

A list of minor species occurring in the experimental plots is given in Table 6. *Equisetum arvense* and *R. acetosella* occur most frequently. This is not surprising as these two species were most common at the experimental site at the onset of the experiment. Other species occur more sporadically. In general, there were more species found

Table 5. The amount of aeolian sediments on the experimental plots averaged over fertilizer levels.
5. tafla. Áfok í tilraunareitunum. Meðaltöl eru gefin yfir áburðarskammta.

	15.8.1988 Visual scores—*Mat* 0–5; 5-max.		14.8.1989 Thickness—*Þykkt* cm	
	Ungrazed *Friðað*	Grazed *Beitt*	Ungrazed *Friðað*	Grazed *Beitt*
D. beringensis	4.5	0.7	11.9	2.7
D. caespitosa	3.7	2.0	13.3	6.6
P. glauca	2.7	0.7	4.8	3.3
F. rubra, Leik	2.2	0.5	4.8	2.6
D. ber.+ D. caesp.	3.7	2.0	7.3	6.8
D. caesp.+ P. glauca	1.2	0.7	4.3	4.3
D. ber.+ 0305	3.5	0.5	12.7	3.8
D. ber.+ Fylking	3.7	0.2	6.9	3.1
D. ber.+ L. multif.	4.0	0.5	12.4	2.5
D. caesp.+ 0305	2.5	2.2	5.7	4.8
D. caesp.+ Fylking	2.5	1.0	6.6	4.9
D. caesp.+ L. multif.	2.7	0.7	9.5	4.6
Unsown—*Ósáð*	2.0	0.0	10.1	0.9
Mean—*Meðaltal*	3.0	0.9	8.5	3.9
SED—*Staðalskekkja mism.*	0.7		0.9	

on plots receiving the lower fertilizer rate than the higher fertilizer rate, both on grazed and ungrazed plots.

DISCUSSION

The main aim of the present study was to compare the response of *D. beringensis* and *D. caespitosa* to various environmental factors when sown for soil reclamation purposes. Fertilizer levels and original species companions were controlled, and grazing to a certain extent, whereas the amount of aeolian sediments could not be controlled. The performance of the two species is influenced by all these factors which, in addition, interact, rendering the interpretation of the results complex. However, several important points emerge.

Figure 2. Aeolian sediments in a plot grown with *D. beringensis*.
2. mynd. Áfok í beringspuntsreit.

Grazing

D. beringensis is obviously intolerant of grazing as it virtually disappeared from the grazed part of the experiment (Figure 4). Where it had been sown, it had in most cases been replaced by *D. caespitosa* and *R. acetosella*. *D. caespitosa*, on the other hand, had better cover under grazing than on ungrazed plots. The different response of these two species to grazing has been noted in earlier trials (Helgadóttir, 1988b). These differences emerge most clearly on the plots, where the two species were originally sown together.

On ungrazed plots *D. beringensis* had outcompeted *D. caespitosa*, whereas the opposite occurred on the grazed plots.

In the present study attempts were made to look at root characteristics of the species. By digging holes into the soil it was noted that the root system of *D. beringensis* is restricted and the roots grow straight down into the soil, whereas the root system of *D. caespitosa* is extensive and spreads both horizontally and vertically in the soil. These characteristics of the root system develop early as can be seen from the fact that the root:shoot ratio of *D. beringensis* is significantly lower than for *D. caespitosa* measured one year from sowing (Table 2), when the plants are probably most sensitive to grazing. This was reflected in the number of plants which had heaved from the soil, most probably by grazing sheep or as a result of frost heaving; out of 30 plants sampled these were 23 and 1 for *D. beringensis* and *D. caespitosa*, respectively. This happened in spite of the fact that the former species was much less intensively grazed (Table 2).

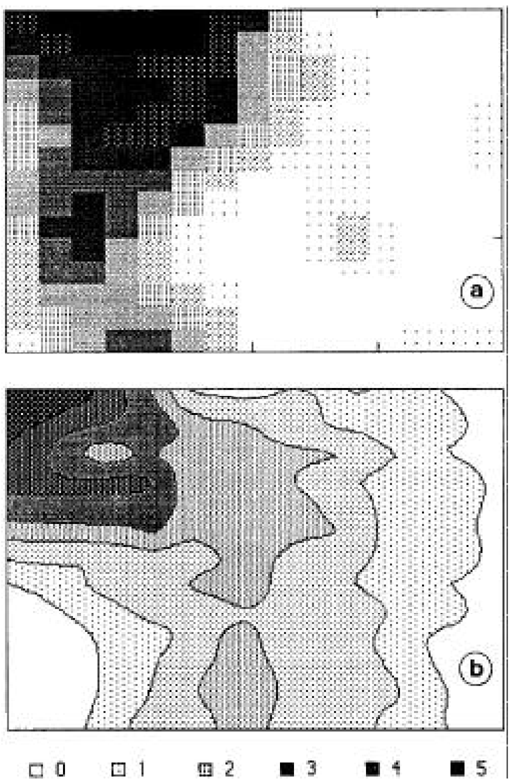

Figure 3. Aeolian sediments on the experimental plots, visually evaluated in August 1988 on the scale 0–5; 5=max. (a) and measured in August 1989 (b).
3. mynd. Áfok í tilraunareitunum, metið í ágúst 1988 á bilinu 0–5; 5=hámark (a) og mælt í ágúst 1989 (b).

In addition to contrasting root systems, *D. caespitosa* is densely tillering with the grow-ing point below the soil surface and prostrate leaves, whereas *D. beringensis* has open, erect tillers with the growing points well above the soil surface. The grazing sheep have thus much better access to plants of *D. beringensis*, weakening their tolerance to grazing.

Fertilizers

The lower fertilizer rate led to both less vegetation cover (Table 3) and lower dry matter yields (Table 4) than the higher fertilizer rate. This is not surprising as soils of alluvial and aeolian origin are typically very poor in both minerals and organic matter (Jóhannesson, 1960; Gunnlaugsdóttir, 1982) and leaching of chemical fertilizers is a serious problem (Arnalds and Pálmason, 1986).

Both *D. beringensis* and *D. caespitosa* responded to increased fertilizer. The former species responded very well on the ungrazed plots, giving relatively high yields, whereas the latter responded better on the grazed plots.

Aeolian sediments

Aeolian sediments mainly formed on the ungrazed part of the experiment (Figure 3), as the plant materials intercepted the deposition. The amount of sedimentation depended to a certain extent on the yield of the plots and *D. beringensis* clearly collected more sediments than *D. caespitosa* (Table 5), which, on the other hand, suffered greater damage. The poor performance of *D. caespitosa* on ungrazed plots at the higher fertilizer rate can be attributed to a large extent to intolerance to aeolian sediments. *D. beringensis* is clearly adapted to growth in sandy soils which are on the move, as plants growing up through the sediments are able to form new roots and shoots on nodes on the stem (Figure 5). The original habitat of *D. beringensis* in Alaska is muddy shores (Hultén, 1968) where the plants have to be able to withstand continual new layers of muddy sediments. Plants of *D. caespitosa* are not able to form new roots and shoots on the nodes and, consequently, smother under the aeolian sediments.

Companion grasses

The Icelandic red fescue, 0305, was completely outcompeted by *D. beringensis* on the ungrazed plots receiving the higher fertilizer rate, whereas it made a significant contribution with *D. caespitosa*, both on grazed and ungrazed plots (Figure 4). *Poa pratensis*,

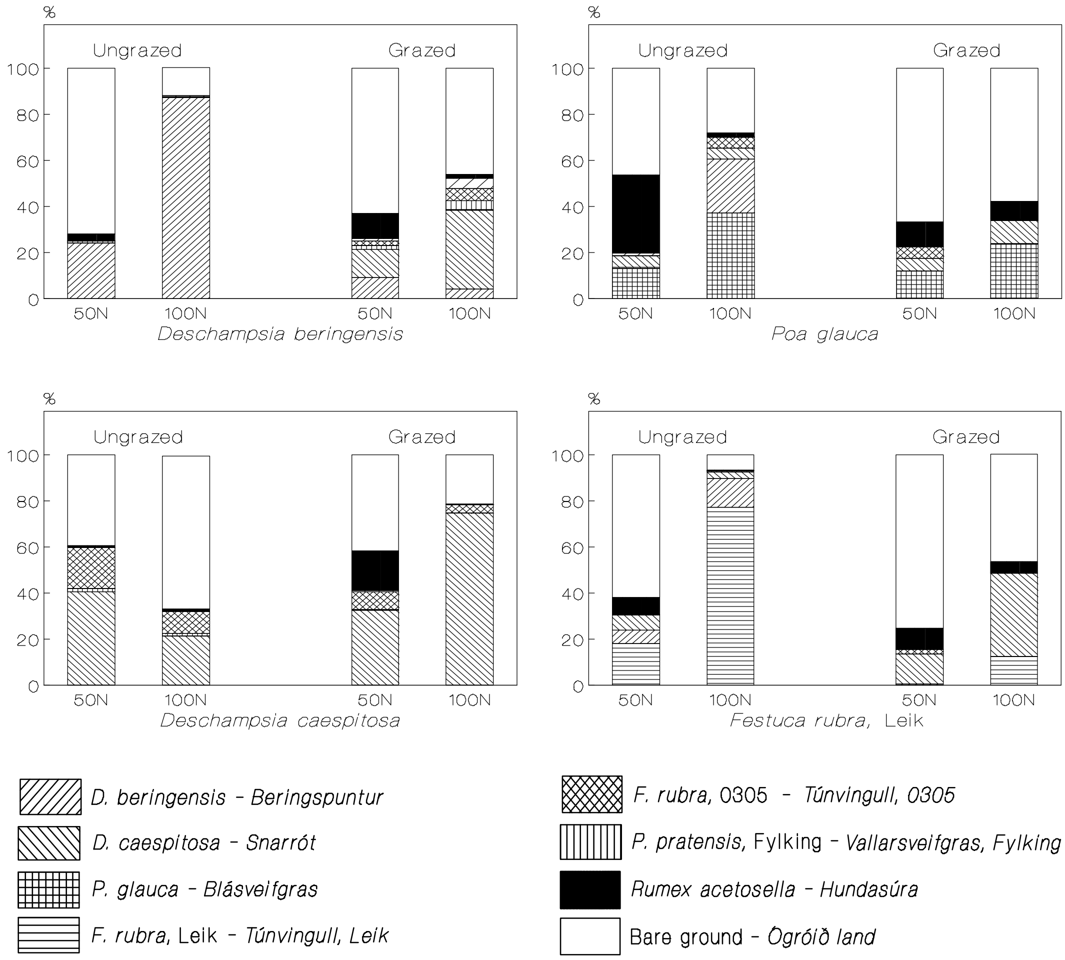

Figure 4. Mean percentage cover for some species in the various experimental plots (0.25 m^2, n=5) in August 1989.

4. mynd. Meðalþekja (%) nokkrurra tegunda á hinum ýmsu tilraunareitum (0,25 m^2, n=5) í ágúst 1989.

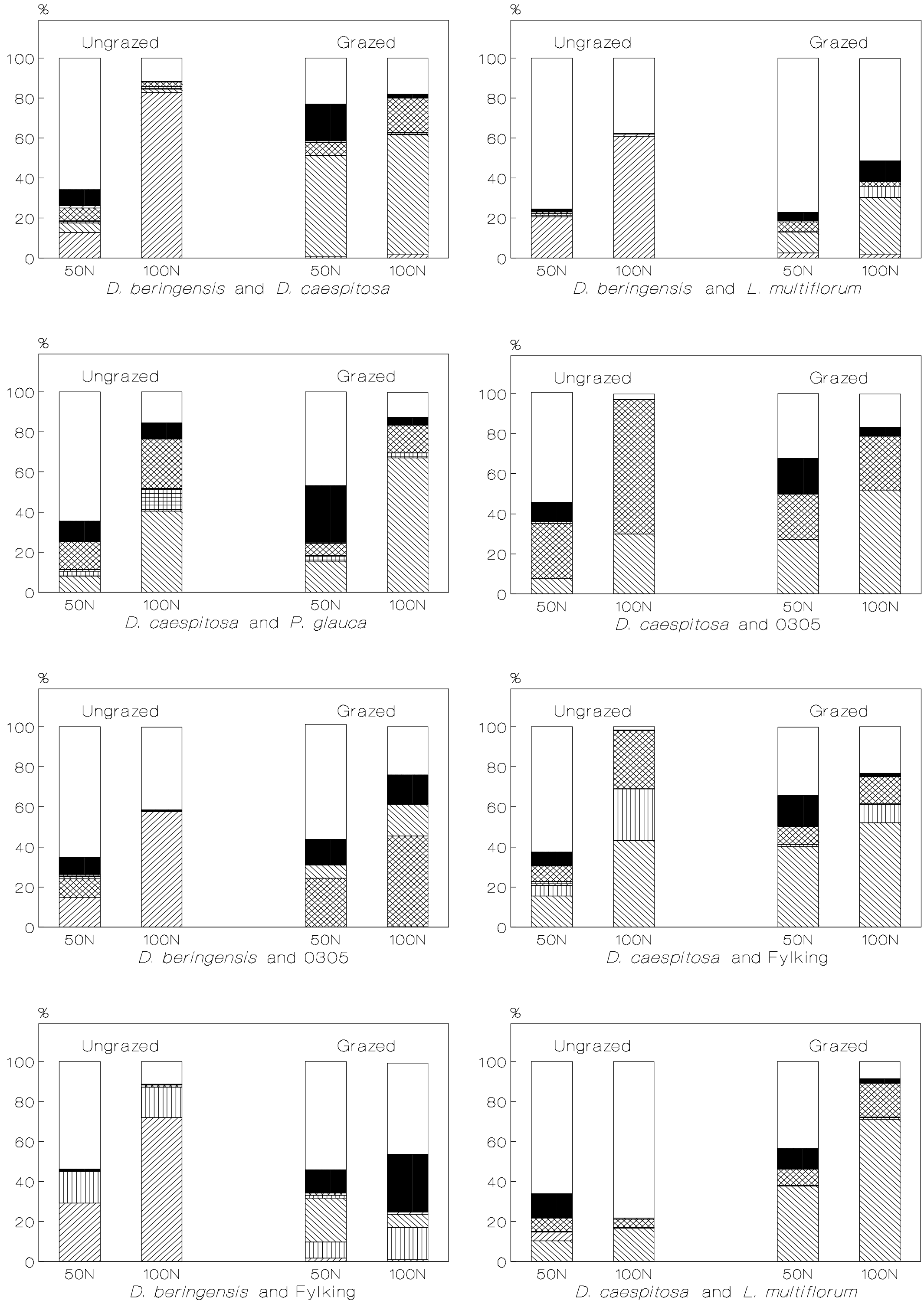
%
Ungrazed
Grazed
100
80
60
40
20
0
50N
100N
D. beringensis and D. caespitosa
D. beringensis and L. multiflorum
D. caespitosa and P. glauca
D. caespitosa and 0305
D. beringensis and 0305
D. caespitosa and Fylking
D. beringensis and Fylking
D. caespitosa and L. multiflorum

Table 6. Presence of indigenous species in the experimental plots in August 1989. The cover was in all cases less than 0.5%. The treatment plots are labelled as in Table 1.

a. Low fertilizer rate (50 kg N/ha), ungrazed—*Minni áburðarskammtur (50 kg N/ha), innan girðingar*.

Species—*Tegund*	A	B	C	D	E	F	G	H	I	J	K	L	M
Cardaminopsis petraea											+		
Equisetum arvense	+	+	+	+	+	+	+	+				+	+
Rumex acetosella	+	+	+	+	+	+	+	+	+	+	+	+	+
Silene maritima						+	+	+					+
Cerastium alpinum													
Stellaria media													
Agrostis stolonifera	+		+		+			+		+	+		
Cerastium fontanum			+	+					+				+
Galium normanii													
Alchemilla vulgaris													
Alopecurus geniculatus													
Arenaria norvegica		+					+	+					
Alchemilla alpina				+			+	+	+			+	
Sibbaldia procumbens													
Leontodon autumnalis													
Viscaria alpina													
Koenigia islandicus													
Festuca vivipara													
Carex maritima													
Luzula spicata													
Total number of species *Heildarfjöldi tegunda*	3	3	4	4	3	3	5	6	3	2	2	4	4

b. High fertilizer rate (100 kg N/ha), ungrazed—*Stærri áburðarskammtur (100 N), innan girðingar*.

Species—*Tegund*	A	B	C	D	E	F	G	H	I	J	K	L	M
Cardaminopsis petraea													
Equisetum arvense	+	+	+				+	+	+			+	+
Rumex acetosella	+	+	+	+	+	+	+	+	+	+	+	+	+
Silene maritima					+					+	+		
Cerastium alpinum											+		
Stellaria media													
Agrostis stolonifera													
Cerastium fontanum			+	+				+					
Galium normanii	+												
Alchemilla vulgaris							+						
Alopecurus geniculatus	+												
Arenaria norvegica		+											
Alchemilla alpina													
Sibbaldia procumbens													
Leontodon autumnalis													
Viscaria alpina													
Koenigia islandicus													
Festuca vivipara													
Carex maritima													
Luzula spicata													
Total number of species *Heildarfjöldi tegunda*	4	4	3	2	2	1	3	3	2	2	3	2	2

6. tafla. Villtar tegundir sem fundust í tilraunareitunum í ágúst 1989 og var þekja þeirra í öllum tilfellum innan við 0,5%. Tilraunareitir eru merktir á sama hátt og í 1. töflu.

c. Low fertilizer rate (50 kg N/ha), grazed—*Minni áburðarskammtur (50 kg N/ha), utan girðingar.*

Species—*Tegund*	A	B	C	D	E	F	G	H	I	J	K	L	M
Cardaminopsis petraea		+	+				+			+			
Equisetum arvense	+	+	+	+	+	+	+	+	+	+	+	+	+
Rumex acetosella	+	+	+	+	+	+	+	+	+	+	+	+	+
Silene maritima			+										
Cerastium alpinum													
Stellaria media													
Agrostis stolonifera								+			+		
Cerastium fontanum			+	+			+	+					
Galium normanii													
Alchemilla vulgaris													
Alopecurus geniculatus													
Arenaria norvegica				+		+					+		+
Alchemilla alpina													
Sibbaldia procumbens	+												
Leontodon autumnalis													
Viscaria alpina								+					
Koenigia islandicus												+	
Festuca vivipara			+										
Carex maritima													
Luzula spicata											+		
Total number of species *Heildarfjöldi tegunda*	3	2	6	5	2	3	3	6	2	2	6	3	3

d. High fertilizer rate (100 kg N/ha), grazed—*Stærri áburðarskammtur (100 kg N/ha), utan girðingar.*

Species—*Tegund*	A	B	C	D	E	F	G	H	I	J	K	L	M
Cardaminopsis petraea													
Equisetum arvense	+		+			+	+	+	+				+
Rumex acetosella	+	+	+	+	+	+	+	+	+	+	+	+	+
Silene maritima													
Cerastium alpinum													
Stellaria media													
Agrostis stolonifera						+							
Cerastium fontanum	+							+					
Galium normanii													
Alchemilla vulgaris													
Alopecurus geniculatus													
Arenaria norvegica													
Alchemilla alpina													
Sibbaldia procumbens									+				
Leontodon autumnalis						+							
Viscaria alpina													
Koenigia islandicus													
Festuca vivipara													
Carex maritima													
Luzula spicata													
Total number of species *Heildarfjöldi tegunda*	3	1	2	1	1	4	2	3	3	1	1	1	2

Fylking, on the other hand, persisted with both species on ungrazed plots but virtually disappeared with *D. caespitosa* on grazed plots. *Lolium multiflorum* did not have a positive effect on the performance of the two species, probably because it grew very badly in the sowing year.

Comparison of D. beringensis *and* D. caespitosa *with other species*

Poa glauca was quite promising in the first year after sowing but did not persist. It contributed around 40% on ungrazed plots with the higher fertilizer rate at the end of the experiment, but only around 20% on grazed plots. In the mixture with *D. caespitosa* its competitive ability was poor and it had virtually disappeared. It is inferior to both *D. beringensis* and *D. caespitosa* and can therefore not be recommended for reclamation use under conditions similar to those prevailing in the present experiment. It may, however, warrant closer study under different conditions before it is written off for revegetation purposes.

F. rubra, Leik, equalled the cover of *D. beringensis* on ungrazed plots receiving the higher fertilizer rate but it gave less dry matter yield. On the grazed plots, on the other hand, it did very poorly and was inferior to *D. caespitosa* under those conditions.

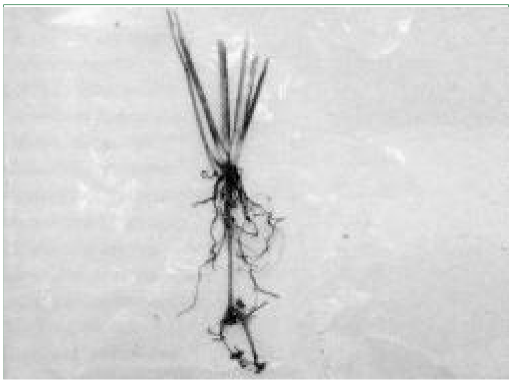

Figure 5. A plant of *D. beringensis* collected from a plot with large amounts of aeolian sediments.
5. mynd. Beringspuntsplanta sem tekin var úr reit er í hafði safnast mikið áfok.

Vegetational changes

The detailed vegetation analysis was carried out in August 1989, only three years from sowing of the plots. However, considerable changes had occurred which depended both on the species sown and environmental conditions. Only few indigenous species had though invaded the plots and their frequency was very low. Three years is a short time in the vegetational succession on barren land. Eventually the sown species give way to natural vegetation. It would therefore be desirable to follow further changes in order to study how the different species influence this process.

CONCLUSIONS

The results obtained in the present study may be specific for the conditions prevailing in the experimental area, of which the presence of aeolian deposition is of primary importance. Under such conditions it is important to establish extra plots around the experiment which would shelter the actual experimental plots by intercepting most of the sediments. However, it can be concluded that *D. beringensis* persists very well under such conditions providing that grazing intensity is low. It is very aggressive where reasonable amounts of fertilizer are applied and it is hardly worth while to sow other species with it in a mixture under such conditions. *D. caespitosa* has, on the other hand, once again proved its value for revegetation under grazing pressure and this study indicates that it is advantageous to sow it in a mixture with a well adapted variety of red fescue such as 0305. This mixture surpasses Leik in pure stand.

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REFERENCES

Arnalds, Ólafur & Friðrik **Pálmason**, 1986. Jarðvegur í landgræðslutilraunum á virkjunarsvæði Blöndu. *Fjölrit Rala nr*. **118:** 21 pp.

Goldsmith, F.B. & C.H. **Harrison**, 1976. Description and analysis of vegetation. In: *Methods in Plant Ecology* (ed. S.B. Chapman). Blackwell Scientific Publications, Oxford: 85–155.

Gunnlaugsdóttir, Elín, 1982. Vegetation development during restoration of eroded areas managed by the Icelandic State Soil Conservation. Studies in permanent plots in and near fenced areas 1974–1980. *Meddelanden från Växtbiologiska Institutionen* **1982(4)**, Uppsala: 115 pp.

Helgadóttir, Áslaug, 1988a. Leit að hentugum grastegundum til uppgræðslu á hálendi. *Búvísindi* **1**: 11–33.

Helgadóttir, Áslaug, 1988b. Testing grass species and varieties for land reclamation in Iceland. *Journal of Agricultural Science in Finland* **60**: 191–200.

Hultén, E., 1968. *Flora of Alaska and Neighboring Territories*. Stanford University Press, Stanford, California: 1008 pp.

Jóhannesson, Björn, 1960. The Soils of Iceland. *University Research Institute, Department of Agriculture, Reports* **B13**, Reykjavík: 140 pp.

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