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TILLER AND RHIZOME GROWTH ON EXCAVATED SLOPES IN TWO *Carex* SPECIES FROM COLONIES ON LANDSLIDES

*Teruo Arase[1], Tetsuo Okano[1], Tetsuoh Shirota[1], Masaaki Furuno[2] and Taizo Uchida[3]

Faculty of Agriculture, Shinshu University, Japan; Faculty of Industry, [2]Graduate School of Engineering, Kyusyu Sangyo University, Japan; [3]Faculty of Architecture and Civil Engineering, Kyusyu Sangyo University, Japan

*Corresponding Author, Received: 30 Nov. 2021, Revised: 26 Dec. 2021, Accepted: 30 Jan. 2022

ABSTRACT: To assist with the revegetation of excavated slopes, experimental revegetation sites were established using two terrestrial sedges, *Carex oxyandra*, and *C. satsumensis*, which typically colonize landslides in the Kiso Mountains, Japan. The experimental design comprised a randomized block design with a two-way layout; 2 species × 2 soil types (black-colored soil and weathered granite soil) × 2 replicates. The plot size was set to 1.5 × 0.9 m. Rootstocks of the sedges were collected and 15 rootstocks per plot (1 to 3 tillers per rootstock) were transplanted in May 2019. The number of tillers per ramet was measured at one-month intervals. Rhizome growth was measured by sampling two ramets from each replicate in December 2020. Based on the increase of tillers, both species were capable of growth on both soil types; *C. oxyandra* showed superior growth on the black-colored soil, while *C. satsumensis* grew better on the weathered granite soil, and both species showed poor growth in the plot under shaded conditions. Rhizome growth was influenced significantly by species, soil type, and their interaction; the total rhizome length per ramet in *C. oxyandra* and *C. satsumensis* was 15.9 to 28.6 cm and 182.1 to 746.2 cm, respectively. The former species produced short rhizomes and dense tussocks from concentrated tillers, while the latter produced numerous extremely long rhizomes and sporadic foliage from horizontally scattered tillers. Since the characteristics of growth differed between the two species, using an optimum combination of both species is considered suitable for early revegetation of excavated slopes.

Keywords: Carex oxyandra, Carex satsumensis, Tiller, Rhizome, Excavated slope

1. INTRODUCTION

Wild plant species that are indigenous to specific areas are attracting attention for revegetation projects given the important roles they play in the conservation of biodiversity and landscape ecology [1]. While some wild plants, such as Japanese pampas grass (*Miscanthus sinensis*) and Japanese mugwort (*Artemisia princeps*), have already been used for revegetation projects [1], using wild plant species is often complicated by the lack of basic information on their ecology, germination, and growth, and reproduction. In addition, compared to cultivated pasture grasses, wild plants often show considerably less uniformity in their germination and growth patterns as they need to survive in natural areas affected by occasional disturbances. It is, therefore, necessary to collate information on how these wild plant species can be applied to revegetation projects.

The increased frequency of severe typhoons and heavy rainfall events in recent years has meant that landslide disasters are also increasing across Japan [2]; for example, a record of 3,459 landslide disasters occurred in the country in 2018 [3]. While saving human life and providing aid to people adversely affected by these events is a universal concern, construction work to prevent landslides is also urgently required to protect and stabilize susceptible areas., Revegetation projects focusing on stabilizing these areas in Japan have formerly employed exotic pasture grasses, but these species are regarded as problematic at present because their rapid and uniform growth may be difficult to limit once established [1]. Two approaches can be adopted when using native plant species for revegetation: developing technological improvements to promote rapid vegetational succession, and searching for native species with excellent growth characteristics. In the present study, we employed the latter approach and focused on terrestrial sedges native to Japan.

Sedges, herbaceous species in the genus *Carex* (Cyperaceae), are perennials with rhizomes and tussock foliage. Sedges are very familiar to Japanese people; the foliage of some *Carex* species has been used as a traditional fiber to make straw lampshade-hats, raincoats, and sacred festoons in some areas, and variegated-leaf varieties are planted as ornamental garden plants [4]. Of the approximately 2,000 *Carex* species that have been described to date, approximately 250 species are found in Japan where they inhabit environments such as riparian areas, wetlands, grasslands, forests, alpine areas, and coastal areas [5]. While the growth characteristics of sedges are relatively similar to those of grasses (Poaceae), most revegetation projects using sedges have been limited to riparian areas and wetlands [1, 6–7].

Studies on *Carex* species have generally focused on aspects such as taxonomy and phytogeographical distribution [8–9], seed dispersal [10], growth responses to water [11–12], and vegetational succession [13]. Within the context of practical applications, some aquatic and hydrarch species have been studied for use in riparian areas and wetlands [1, 6–7], as mentioned above; however, a recent study examined the application of sedges to water purification [5]. Most of the studies that have been conducted on terrestrial sedge species in Japan have focused on their undesirable characteristics, such as how they behave like weeds and cause nutritional deterioration of pasture [14], and how they can suppress the regeneration of tree seedlings in natural forests [15–16].

However, some terrestrial sedge species have been reported to be pioneer plants that colonize landslides in riparian areas [9] and bare ground in abandoned mine quarries [13]. The species that colonize disturbed areas as pioneers could potentially play an important role in maintaining plant community structure and in protecting the soil, at least in the early stages of vegetational succession. Given the broad range of habitats colonized by *Carex* species, it is considered that there must be some species that are well suited to revegetating disturbed terrestrial areas (i.e., areas in addition to riparian areas or wetlands), such as landslides or excavated slopes.

In this study, we established experimental revegetation plots using two terrestrial *Carex* species on excavated slopes. The species were selected based on the results of a previous study on *Carex* flora found in the subalpine and alpine zones of the Kiso Mountains, Central Japan [9]. By monitoring the increase in tillers and elongation of rhizomes after planting, the growth characteristics of these species were analyzed and their potential for application to revegetation projects is suggested.

2. RESEARCH SIGNIFICANCE

The significance of the present study is that it focuses on two native terrestrial *Carex* species and assesses whether they can be applied to practical revegetation experiments on excavated slopes in two different soil types. Specifically, the increase in aboveground tillers was measured at monthly intervals over 18 months after planting, and the development of underground rhizomes and buds was monitored. The obtained data and findings are considered to be useful for promoting the use of native terrestrial *Carex* species to revegetation projects.

3. METHODS

3.1 *Carex* Species Used in the Present Study

The flora and habitat of *Carex* species were previously investigated in the subalpine and alpine zones (at elevations of approximately 1,230 to 2,650 m) of the Kiso Mountains in central Japan [9]. A total of 14 *Carex* species were observed, and of these, two species (C. *oxyandra* and *C. satsumensis*) were evaluated as being potentially suitable for revegetation applications as they typically colonized areas comprising accumulated detritus or gravel associated with landslides.

Fig. 1 *Carex oxyandra* in natural habitat at an elevation of 1,430 m in the Kiso Mountains in May 2019.

Fig. 2 *Carex satsumensis* in natural habitat at an elevation of 1,230 m in the Kiso Mountains in May 2019.

Carex oxyandra (Fig. 1) had a broad vertical distribution at elevations ranging from 1,300 to 2,650 m (from low-mountain to the alpine zone) in the Kiso Mountains [9]. In addition, this species has been reported to have colonized the bare ground of an abandoned mine quarry [13]. This species has also been reported to have suppressed the growth of tree seedlings [15-16].

Compared to *C. oxyandra*, *C. satsumensis* (Fig. 2) had a narrower vertical distribution and was found at elevations of 1,200 to 1,400 m [9]. Little information is available for this sedge, except that it emerged as a pioneer species in a clearing experiment conducted in an alpine grassland [17].

3.2 Establishment of Experimental Sites

Experimental revegetation sites were established in two areas with different soil types: black-colored soil (Andosol; derived from volcanic ash) on the Campus Research Farm, and weathered granite soil in the Terasawayama Research Forest, both of which belong to the Faculty of Agriculture at Shinshu University. In each area, excavated slopes covered with almost no vegetation were selected as experimental sites.

The experimental design comprised a randomized block design with a two-way layout; 2 species × 2 soil types (black-colored soil and weathered granite soil) × 2 replicates. The plot size was set to 1.5 × 0.9 m, where 1.5 m was set along the slope direction. Table 1 shows the environmental conditions at the experimental sites.

Rootstocks of the sedges were collected from their natural habitats in the Kiso Mountains and 15 rootstocks per plot (1 to 3 tillers per rootstock) were transplanted at the end of May 2019. The experiment was started on June 1, 2019.

Table 1 Environmental conditions of the experimental plots

Soil	Plots	Elevation (m)	Slope direction	Incline (°)
Black-colored soil (Research Farm on the university campus)				
	Upper slope	760	NE	25
	Lower slope	759	NE	16
Weathered granite soil (Research forest in Terasawayama)				
	Open slope	1,059	SW	36
	Shaded slope	1,061	SW	37

Plant height and number of tillers per rootstock were measured at one-month intervals from June 2019 to December 2020; no sampling was performed over the winter season as the sites were covered by snow.

To measure underground growth, two ramets per site (since the rootstocks developed rhizomes and numerous tillers after planting, we use the word ‘ramet’ hereafter to refer to the rootstock) were collected at the site with the black-colored soil (upper slope) and at the site with the weathered granite soil (open slope) in December 2020 i.e., 18 months after planting. The rhizomes were then untangled and straightened so that the condition of branching and the length of every rhizome section (from one bud to the next) could be recorded. The locations of apical and lateral buds on the rhizome were also recorded.

For the statistical analysis, the significance of each factor’s effect (species, soil types, and their interaction) was estimated by analyses of variance (F-test). Significant differences among the averages were then estimated using Tukey’s HSD test.

4. RESULTS AND DISCUSSION

4.1 Aboveground Growth

Each of the two species survived in both soil types during the experimental period. Colonization by each species was not observed in 2019 (i.e., 6 months after planting). Except for the plots on the shaded slope with weathered granite soil, the initial rootstocks became rather indistinguishable from each other due to an increase in foliage in 2020.

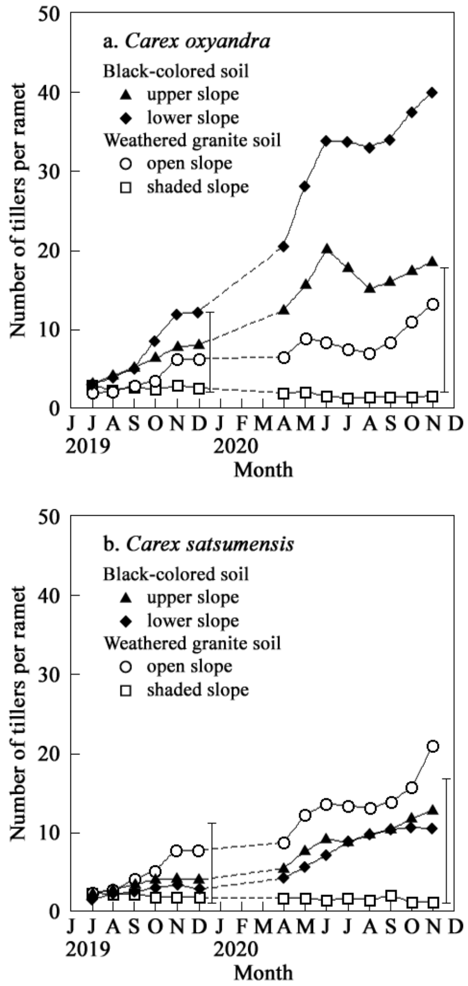

Fig.3 Growth of tillers per ramet after planting. Vertical bars indicate the least significant difference among averages (Tukey’s HSD, $p<0.05$).

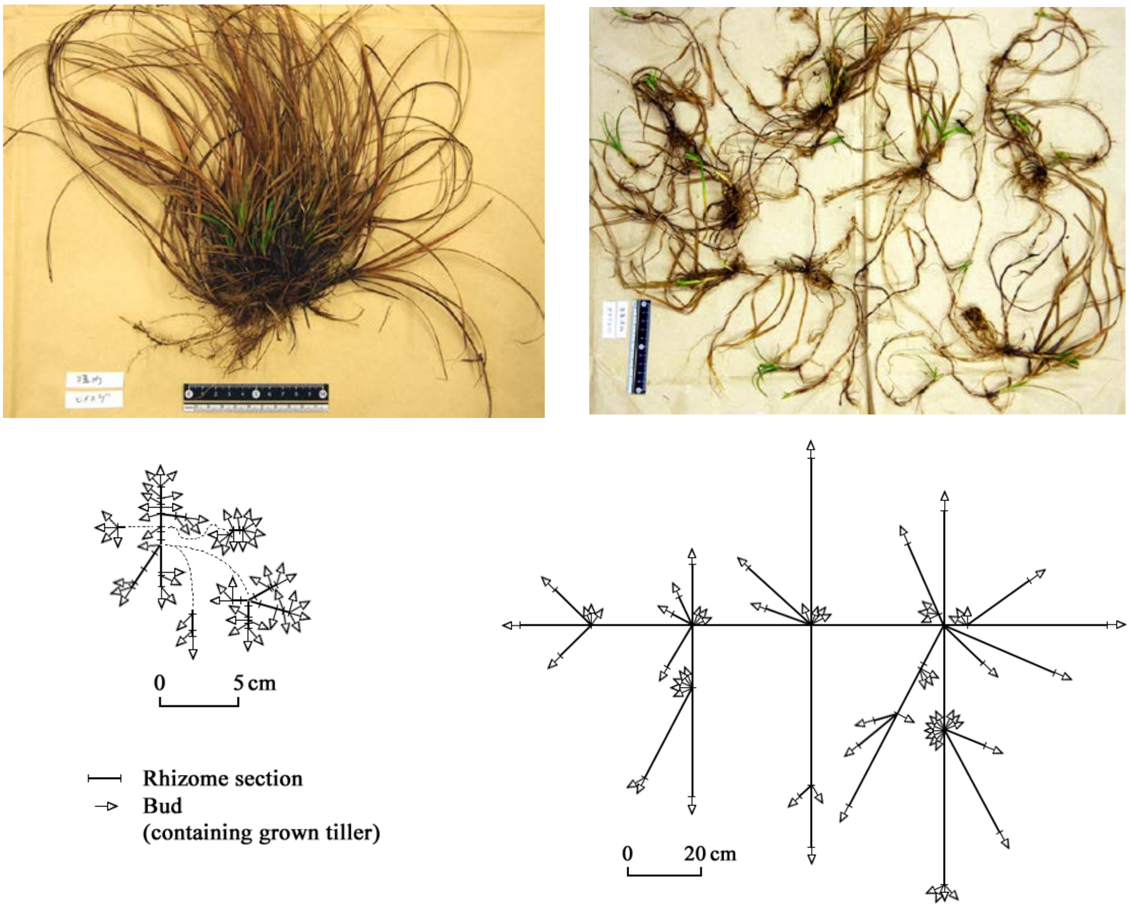

Fig. 4 Examples of ramet growth of *Carex oxyandra* (left) and *C. satsumensis* (right) at 18 months after planting. The upper row shows photos (black rulers are 10-cm long), and the lower row shows the corresponding depictions of rhizome sections and buds.

Fig. 3 shows the increase of tillers per ramet in each of the two species. Based on tiller development, *C. oxyandra* showed superior growth in the black-colored soil, while *C. satsumensis* showed superior growth in the weathered granite soil; in December 2020, the average number of tillers per ramet of *C. oxyandra* was 18.4 to 39.9 in the black-colored soil and 1.5 to 13.3 in the weathered granite soil, whereas that of *C. satsumensis* was 10.4 to 12.7 in the black-colored soil and 1.0 to 21.0 in the weathered granite soil. Each species showed poor growth in the plot on the shaded slope in the weathered granite soil.

In examining the aboveground growth of tillers, it was found that each species was able to grow for at least 18 months in both of the soil types. However, regarding long-term survival, the poor growth observed in both species in the plots under shaded conditions is considered to be problematic because, as vegetational succession advances, tall herbaceous plants and arboreal species will shade out smaller plants in the lower layer. Since the habitat of the two terrestrial *Carex* species used in the present study comprised open landslides, shady conditions might restrict their germination and growth as *Carex albata*, a weedy sedge in pasture whose seeds needs light (i.e. gap formation) for breaking the dormancy [14]. Consequently, when considering vegetational succession at disturbed sites, shade-resistant *Carex* species will be required for revegetation projects.

4.2 Rhizome Growth

Fig. 4 shows representative examples of ramet growth of *C. oxyandra* and *C. satsumensis* at 18 months after planting. Although elongation of the rhizomes did not always proceed linearly, the rhizomes depicted in the figure were extended linearly to facilitate interpretation of the differences in rhizome length.

In *C. oxyandra*, rhizome sections were densely arranged with numerous buds and tillers, whereas in *C. satsumensis*, rhizome sections were more loosely spread out with small clumps of buds and tillers scattered throughout (Fig. 4).

Table 2 shows the average measurements obtained for underground growth at 18 months after planting. The reason why the number of buds seems larger than the average number of tillers

(Fig. 3) is that the former contains both developed tillers and young buds. *Carex oxyandra* showed similar underground growth patterns in both black-colored and weathered granite soils (44.0–44.5 buds and 17.7–20.8 cm-length rhizome, respectively). Conversely, *C. satsumensis* showed a markedly superior underground growth pattern in the weathered granite soil (20.8 buds and 763.9 cm-length rhizome) than in the black-colored soil (19.5 buds and 191.1 cm-length rhizome); rhizome length and the number of buds were approximately four times larger in the weathered granite soil than in the black-colored soil. However, even in the inferior growth, the length of the rhizomes in *C. satsumensis* was several tens-of-times greater than the plant height, which is comparable to Japanese lawn grass (*Zoysia japonica*) and alang-alang (*Imperata cylindrica*) [18], both of which can be widely observed in Japan in frequent-cut grassland such as a ridge between rice fields.

Table 2 Number of buds and total rhizome length per ramet of the two *Carex* species at 18 months after planting

Item	Species	Soil	
		Black-colored soil	Weathered granite soil
Number of buds			
	C. oxyandra	44.5 ab	44.0 ab
	C. satsumensis	19.5 b	72.5 a
Total rhizome length (cm)			
	C. oxyandra	17.7 c	20.8 c
	C. satsumensis	191.1 b	763.9 a

Average values with different letters were significantly different (Tukey's HSD, p<0.05).

Fig. 5 shows a histogram of rhizome section length in ramets of each species. In *C. oxyandra*, the data have a lognormal distribution with a peak at $10^{-0.2}$ to $10^{-0.4}$ cm (i.e., 0.40 to 0.63 cm) in both the black-colored soil and the weathered granite soil. However, in *C. satsumensis*, the data have a bi-modal distribution, with a small peak at 10^{-1} to $10^{-0.5}$ cm (i.e., 0.10 to 0.31 cm) and a large peak at 10^{1} to $10^{1.5}$ cm (i.e., 10.0 to 31.6 cm) in both soil types. The maximum rhizome length was 55.0 cm in the weathered granite plot. These results imply that *C. satsumensis* develops two types of rhizomes, a small number of very short rhizomes and a large number of long rhizomes. This differentiation of rhizome sections is considered to correspond to the differentiation of functions in long shoots (the space-capture strategy) and short shoots (the light-capture strategy) in terms of the general shoot development patterns of trees [19].

Concerning the marked variation observed in the exceedingly long rhizome sections of *C. satsumensis*, we attempted to clarify the cause of elongation. Twelve long rhizome sections were sampled and the number of internodes (accumulation of internodes comprises a rhizome section) were counted in both soil types.

Fig. 6 shows the relationship between the length of the rhizome section and the number of internodes. A logarithmic regression curve was obtained for each soil type, in which the number of internodes increased as the length of the rhizome section increased. An analysis of covariance detected a significant difference between the *y*-axis intercepts (*p*<0.01, F-test), with the intercept for the black-colored soil being larger than that obtained for the weathered granite soil (-26.7 and -32.6, respectively). The coefficient of log *x* was similar between the two regression curves and the difference was not significant. Thus, the relationship shown in Fig. 6 implies that the relationship between an increase in the number of internodes and rhizome elongation is almost the same in both soil types, but a larger number of internodes is likely to be produced (i.e., each internode becomes slightly smaller in the black-colored soil compared to the weathered granite soil.

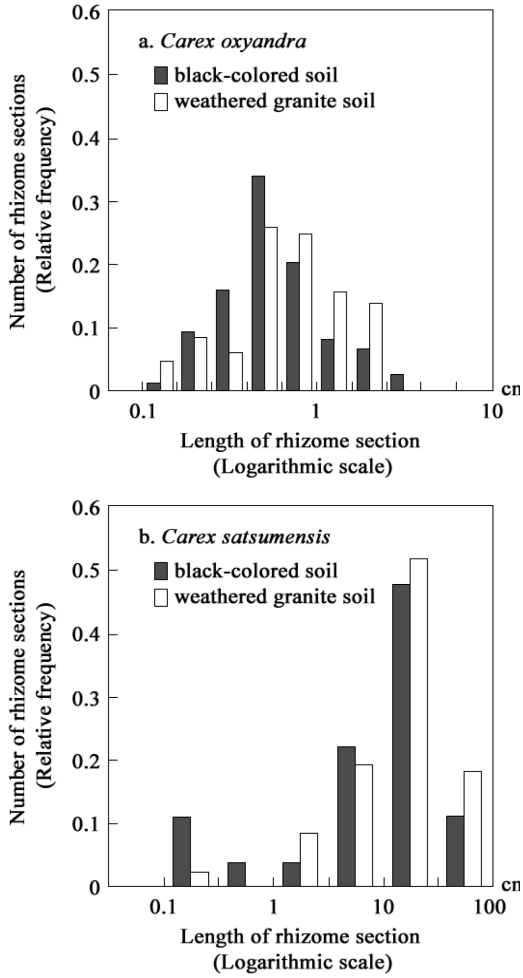

Fig. 5 Histogram of rhizome-section length in a ramet at 18 months after planting

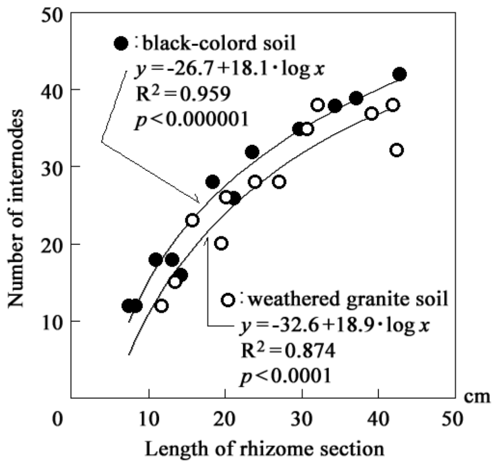

Fig. 6 Relationship between the length of rhizome section and the number of internodes in *Carex satsumensis*

These findings clarified the differences in growth properties between the two species; *C. oxyandra* benefits from steadily producing dense rhizome tillers around the mother rootstock, and underground growth showed no noticeable differences between the two soil types. Conversely, *C. satsumensis* benefits from rapidly spreading its rhizomes far from the mother rootstock, and the underground growth changed dramatically in the two soil types. This difference observed in the growth of *C. satsumensis* in different soils suggests that soil type plays an important role in deciding whether to use this species for revegetation applications. Since the persistence (i.e., life span) of *Carex* communities has been reported to differ among species [20], differences in underground growth may be responsible. Consequently, soil type should be carefully considered when using *C. satsumensis* for revegetation purposes.

5. CONCLUSION

To assess whether the native terrestrial sedges *Carex oxyandra* and *C. satsumensis*, both of which have been found to colonize landslides in the Kiso Mountains of central Japan, could potentially be used to revegetate disturbed areas, this study established revegetation sites on excavated slopes in May 2019. The experimental design employed a two-way layout; 2 species × 2 soil types (black-colored soil (Andosol) and weathered granite soil) × 2 replicates. The number of tillers per ramet was measured at one-month intervals and rhizome growth was measured in December 2020. The results were as follows:

1. As to the aboveground growth and increase in tillers, each species was capable of growth on both soil types; *C. oxyandra* showed superior growth on the black-colored soil, while *C. satsumensis* grew better on weathered granite soil. However, each species showed poor growth in the plot under shaded conditions.
2. As to the underground growth of rhizomes and buds, dense rhizome sections and numerous buds developed in *C. oxyandra*, while long widely spread rhizome sections with small scattered clumps of buds developed in *C. satsumensis*. Rhizome growth in *C. satsumensis* changed dramatically according to soil type.

Thus, the characteristics of tiller and rhizome growth in the two species were markedly different; *C. oxyandra* benefits from steadily producing dense rhizome tillers around the mother rootstock, whereas *C. satsumensis* benefits from rapidly spreading its rhizomes far from the mother rootstock. Since these characteristics are considered to complement each other, using an optimum combination of both species is considered to be well suited to the early stages of revegetating excavated slopes.

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