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VEGETATION SUCCESSION ON CUT SLOPES COVERED WITH EXOTIC GRASSES FOR EROSION CONTROL, MT. SAKURAJIMA

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ABSTRACT: The utilization of exotic grasses as cover plants for erosion control has received considerable attention in recent years, particularly because these exotic grasses have the potential to become invasive. This study examined succession of exotic grass communities that have been established on the cut slopes of the volcano, Mt. Sakurajima. The results showed that although the exotic grasses, such as *Cynodon dactylon*, *Festuca rubra* and *Dactylis glomerata*, that have been used for erosion control on the cut slopes were dominant for the first two years, marked decreases were observed as the native herbaceous plant, *Miscanthus sinensis*, became dominant after three years. By the sixth year, all of the exotic grasses vanished completely. This high rate of succession would result in the suppression of exotic grass dispersal on Mt. Sakurajima. It was also suggested that the chemical properties of volcanic soils, and the bio-engineering technique employed on Mt. Sakurajima may have facilitated this high rate of succession.

Keywords: Cut slope, Erosion, Exotic grass, Succession, Volcano

1. INTRODUCTION

There are 110 active volcanoes on the islands of Japan, which is located on the Pacific Ring of Fire [17]. Among these volcanoes, Mt. Sakurajima in Kagoshima Prefecture in southwestern Japan is very active (Fig. 1), periodically erupting pumice, scoria and ash, and emitting volcanic gases [23], [30], [40]. As a result of this activity, natural vegetation from the summit to halfway down the slopes of the mountain is poorly established, causing soil erosion and the development of rills and gullies, and frequent debris- and mud-flows down the mountain [18-19], [27], [38]. To prevent and mitigate damage caused by erosion, and debris- and mud-flows, a large number of check dams have been constructed from the foothills to halfway up Mt. Sakurajima (Fig. 2). In addition, cut slopes resulting from the construction of the check dams have been covered with exotic grasses, such as *Festuca arundinacea*, *Cynodon dactylon*, *Agrostis alba* and *Dactylis glomerata*, for erosion control. However, given the emphasis on conserving biodiversity in recent years, concerns have arisen regarding the utilization of these exotic grasses for erosion control, particularly because they may become invasive.

Numerous case studies have been conducted on the application of exotic grasses to erosion control on volcanic slopes (e.g. Mt. Sakurajima, Mt. Unzen and Mt. Usu) [14], [19], [33-34]. However, relatively few studies have examined the plant biodiversity on volcanoes, particularly in the area of succession and dispersal of exotic grasses used for erosion control. The aim of this study was therefore to examine the succession of exotic grasses that have been applied as cover plants for erosion control on Mt. Sakurajima by surveying the vegetation and environmental characteristics of the cut slopes in four different districts.

2. MATERIALS AND METHODS

2.1 Study Site

A total of 40 cut slopes of check dams were surveyed in the four districts of Hattani-Sawa, Hikinohira-Sawa, Saidou-Gawa and Matsuura-Gawa on Mt. Sakurajima (Fig. 1). Permission for the study was obtained from the Forestry Agency, Ministry of Agriculture, Forestry and Fisheries. The slopes in the study area were located at 366 to 655 m above sea level and their angles of inclination ranged from 25 to 70°. The geological features of the slopes were classified as "Recent Ejecta", "Hikinohira Lava Dome" or "Taisho I Lava Flow" [7]. Exotic grasses, such as *Eragrostis curvula*, *Festuca rubra*, *F. arundinacea*, *C. dactylon*, *A. alba* and *D. glomerata*, have been introduced in this area for use as cover plants for erosion control on cut slopes using a bio-engineering technique known as the Slurry Application Method, which is a way employed for aerial seeding work.

According to data from the Automated Meteorological Data Acquisition System (AMEDAS) for the years 2005 to 2014, the surveyed area is situated in the laurel forest zone (warm

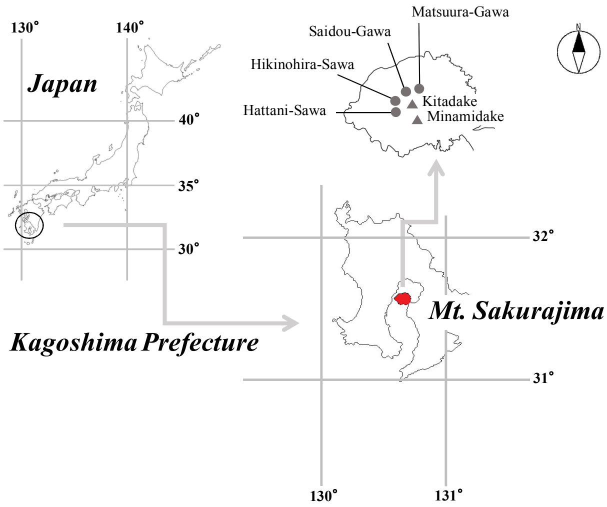

Fig. 1 Location of the study site.

Fig. 2 Check dams on Mt. Sakurajima (Hattani-Sawa district).

temperature zone); values of Kira's Warmth Index [24] ranged from 158.9 to 172.0, and annual precipitation ranged between 1,530 and 2,942 mm.

2.2 Vegetation Survey

Surveys of the vegetation on cut slopes were performed at the end of September in 2013 and 2014. Three survey quadrats (10,000 or 40,000 cm^2) were randomly placed on each cut slope. The species composition of the plants in each quadrat was recorded and then scored using the Braun-Blanquet cover-abundance scale [3]. The plant nomenclature used in this paper followed that of Iwatsuki (1992), Miyawaki (1994), Baba (1999) and Shimizu (2003). All of the recorded plant species were categorized as native or non-native, and herbaceous or woody plants based on published literature [2], [16], [32], [35].

In addition, environmental variables considered likely to affect the succession of vegetation on cut slopes were also investigated, containing the number of years that had elapsed since the bio-engineering technique had been undertaken on the slope (NYE), and soil chemistries on the slopes. The NYE was calculated as shown in Eq. (1).

$$NYE=YVS - FY \quad (1)$$

Where, YVS and FY are the year of the vegetation survey and the fiscal year in which the bio-engineering technique was implemented, respectively. The soil chemistries (pH, EC, carbon-to-nitrogen ratio (C/N), cation exchange capacity (CEC), ignition loss (IL), NH_4-N, NO_3-N and P_2O_5) were analyzed on soil samples that were collected in each quadrat (approx. 500 ml of soil around the roots of the dominant plant species).

2.3 Data Analysis

The Braun-Blanquet cover-abundance scale (r, +, I, II, III, IV, and V) was transformed as follows: r and + were taken as 0.1%; I as 5.0%; II as 17.5%; III as 37.5%; IV as 62.5%, and V as 87.5%.

The cut slopes were classified into vegetation types based on their species composition and two-way indicator species analysis (TWINSPAN). In addition, a canonical correlation analysis (CCA) was performed to clarify the relationship between the vegetation types and environmental variables, such as pH, C/N and P_2O_5 of soil, excluding NYE. The statistical software package PC-ORD (ver. 4.0 for Windows, MjM Software Design, USA) was used for TWINSPAN and CCA.

3. RESULTS

3.1 Vegetation Type on Cut Slope

The TWINSPAN classified the vegetation on 40 cut slopes into three vegetation types, based on their species composition (Fig. 3). Type A, which was found on 23 cut slopes, could be separated from other types by the indicator species, *D. glomerata*. At the second division level, the remaining types were separated into Type B (n=14) and Type C (n=3), respectively, based on the indicator species, *M. sinensis*.

The species that dominated Type A were the exotic grasses, *C. dactylon*, *F. rubra* and *D. glomerata* that had been used as cover plants for erosion control (Table 1). Conversely, *M. sinensis*, which is a native herbaceous species, was dominant in Types B and C. However, the coverage of *M. sinensis* in Type C was larger than that in Type B, and also exotic grasses were not observed in Type C.

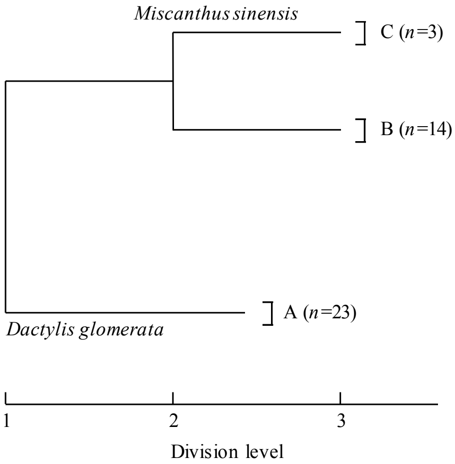

Fig. 3 Classification of vegetation on cut slopes by TWINSPAN using species composition (plant coverage data, %).

Cut levels of 0, 20, 40, 60 and 80 were employed in the analysis.

The average NYE was 2.0 years for Type A, 5.8 years for Type B, 6.7 years for Type C.

3.2 Relation between Vegetation Types and Environmental Variables

A total of 37.2% of the variance in the CCA was explained by Axes 1 and 2, whose eigenvalues indicated 0.59 and 0.39, respectively (Table 2). Monte Carlo permutation test showed that each axis was significantly affected by environmental variables ($P<0.05$).

Axis 1 approximately divided vegetation types into Type A and the others; Type A was characterized by mostly positive scores, while Types B and C had negative scores (Fig. 4). Meanwhile, Axis 1 showed a strong correlation with positive environmental variables such as NO_3-N, IL, P_2O_5 and CEC, and negative environmental variables such as NH_4-N.

Incidentally, no obvious relationship between vegetation types and Axis 2 was observed.

3.3 NYE vs. Component Species

The relationship between NYE and component species is shown in Fig. 5. Within two years of the

Table 1 Plant coverage for each type classified by TWINSPAN.

	Vegetation types		
	A	B	C
Species	*n* =23	*n* =14	*n* =3
<Non-native herbaceous plants>			
Trifolium repens	r		
Erigeron annuus	r		
Cynodon dactylon †	I	r	
Festuca rubra †	I	r	
Dactylis glomerata †	II		
<Native herbaceous plants>			
Fallopia japonica	r	r	r
Artemisia indica	r	r	r
Lespedeza juncea	r		
Dennstaedtia hirsuta #		r	
Miscanthus sinensis	+	III	V
<Native woody plants>			
Rhaphiolepis indica		r	
Eurya japonica		r	r
Pinus thunbergii		r	
Ligustrum japonicum		r	
Rhododendron kaempferi		r	r
Duschekia firma	r	r	r
Indigofera pseudotinctoria		r	
Albizia julibrissin			r
Boehmeria spicata			r
NYE ‡	2.0 ± 1.1	5.8 ± 1.6	6.7 ± 2.9

†, exotic grasses as cover plants for erosion control; #, fern, and ‡, mean and standard deviation. In vegetation types Roman numerals and other symbols for each species indicate plant coverage classes, defined as follows: r, under 5%; +, under 10%; I, under 20%; II, under 40%; III, under 60%; IV, under 80%, and V, above 80%.

Table 2 Summary of CCA on Axes 1 and 2.

	Axis 1	Axis 2
Eigenvalues	0.59	0.39
Cumulative percentage of species variance	22.4	37.2
Species-environment correlations	0.81	0.72
P-values by Monte Carlo permutation test	0.02	0.01

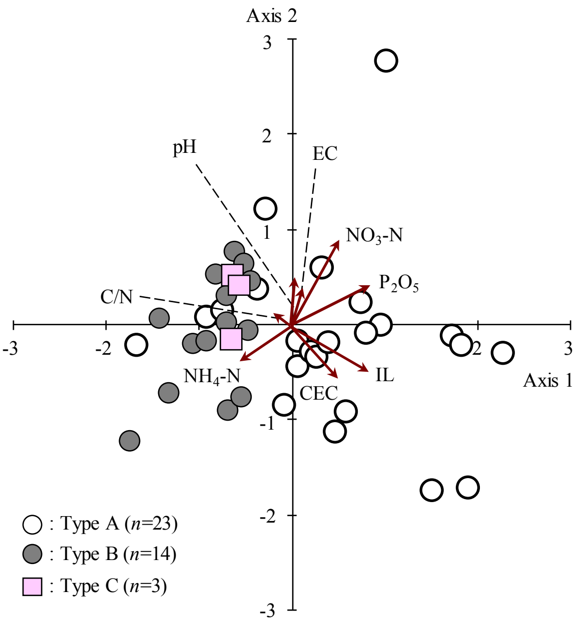

Fig. 4 CCA biplot of vegetation types.
Arrows indicate the direction and relative influence of environmental variables in the ordination.

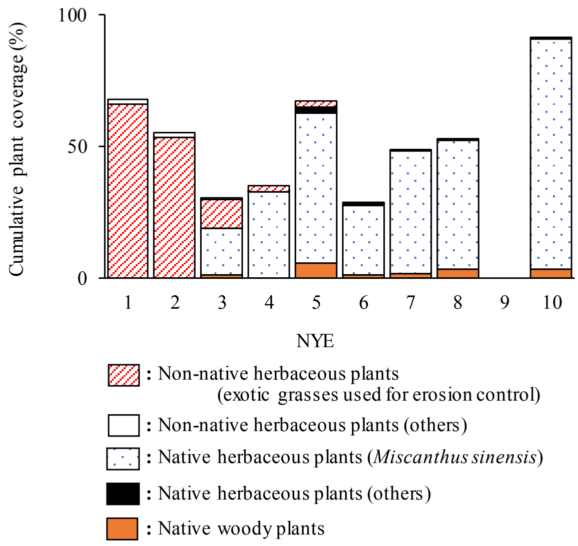

Fig. 5 Relationship between NYE and component species.

bio-engineering technique, most of the species on cut slopes were exotic grasses used as cover plants for erosion control, such as *C. dactylon*, *F. rubra* and *D. glomerata* (96.9% of total). However, these species decreased remarkably after the third year, and native herbaceous plants, mostly *M. sinensis* (98.7% of total), were dominant. Native woody plants were also observed after about three years, and non-native herbaceous plants including exotic grasses for erosion control vanished totally after six years.

4. DISCUSSION

4.1 Succession of Cut Slope Vegetation

Despite the large number of studies that have been published on primary succession and vegetation change associated with volcanism [1], [4], [8], [22], [29], [36-37], [41], relatively little research has been conducted on the succession of exotic grasses used for erosion control on volcanoes.

The findings of this study showed that the vegetation on volcanic slopes consisted of three types (Types A, B and C), which had average NYE values of 2.0, 5.8 and 6.7 years, respectively (Fig. 3 and Table 1). This indicates that the succession of cut slope vegetation after the bio-engineering technique on Mt. Sakurajima is likely to occur in the order of Type A, Type B and then Type C, which means that exotic grasses used for erosion control on cut slopes on Mt. Sakurajima would be replaced by native plant communities dominated by *M. sinensis*.

The high NO_3-N, P_2O_5, CEC and IL levels observed at the study sites may have facilitated the growth of Type A plants compared to Type B and Type C plants (Fig. 4). Indeed, the demand of exotic grasses for nutrients is typically very high, and soil nutrients are major growth limiting factors in these species [5-6], [9], [11], [42-43], [46]. Conversely, *M. sinensis*-dominated grasslands can be maintained under oligotrophic conditions without fertilizer application [10], [13], [25], [39].

We consider that the succession of cut slope vegetation after the bio-engineering technique on Mt Sakurajima is driven by a progressive decrease in soil nutrients. This decrease in soil nutrients would result from chemical properties of volcanic soils, e.g. N, CaO and K_2O leaching, and fixation of P_2O_5 [9], [12], [15], [28]. In addition, among the bio-engineering techniques, especially the Slurry Application Method requires the repeated application of additional fertilizer [31], [34];

however, no additional fertilizer has been applied to the cut slopes of Mt. Sakurajima.

4.2 Decline of Exotic Grasses

The exotic grasses that have been used as cover plants for erosion control were dominant for the first two years after the bio-engineering technique (Fig. 5). However, these plants declined rapidly thereafter and native herbaceous plants became dominant from the third year onward. By the sixth year, the exotic grasses vanished completely. Typically, exotic grasses on slopes start to decline six to ten years after the bio-engineering technique [11], [20-21], [46], but they can remain dominant for more than ten years, occasionally persisting for more than 20 years on slopes [26], [44-45].

Consequently, the disappearance of the exotic grasses on the cut slopes of Mt. Sakurajima is considered to have occurred in quite a short period of time.

5. CONCLUSION

Balancing the application of exotic grasses to erosion control against the need for the conservation of biodiversity is important. We consider that an optimal balance was achieved in this regard on the slopes of Mt. Sakurajima; coverage of exotic grasses used as cover plants was high shortly after the bio-engineering technique, which would be effective for erosion prevention. However, these exotic grasses declined and vanished much earlier than was expected, and then native plants became established at these sites, which would also result in the suppression of exotic grass dispersal.

It is proposed that, in combination with the chemical properties of volcanic soils, the bio-engineering technique "with little or no nutrient (fertilizer)" is well suited to using exotic grasses for erosion control on volcanoes such as Mt. Sakurajima.

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