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Revegetation Condition and Morphological Characteristics of Grass Species Observed in Landslide Scars, Shintategawa Watershed, Fukuoka, Japan

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Abstract: A general trend of decreasing soil loss rates with increasing vegetation cover fraction is widely accepted and is a critical parameter of empirical and process based soil erosion prediction model. The spatial distributions of vegetation types indicate subsequent erosional state. In this study, we examined the ecological and morphological characteristics of colonized plant communities in six years old landslide scars. The morphological characteristics of plants like cover, root features, biomass, root: shoot ratio, pullout resistive force for individual grass species are investigated. The landslides scars have slope gradients of about 34-36^0 with soil depth range from 0.3 to 0.6 m. In some cases during six years periods 60-70% of landslide scars area was covered by herbaceous plants. The quadrat sampling method was done to examine quantitative vegetative attributes (relative density, relative frequency and relative cover). The Important Value Index (IVI) of an individual plant was identified to know the relative dominance. The plant types colonized was influenced by landscape orientation i.e., aspect. The pullout resistive force of different grass species was ranged between 6 to 49 Newton. The pullout resistive force has shown positive co-relationships with morphological parameters like shoot height, diameter and numbers of roots.

Key words: Landslide scar, re-vegetation, root morphology, pullout resistive force, Japan

INTRODUCTION

Rainfall induced shallow landslides were occurred in the forested landscape of Shintategawa watershed, located near Fukuoka city, Southwestern part of Japan (Fig. 1). In June 1999, the heavy storm event, which was recorded as daily maximum of 218 mm with intensity of 100 mm h^{-1} has triggered shallow landslides particularly along the cut slopes (Joshi, 2002). As a consequences, tree species were uprooted, damaged forest road and concrete check dams (Mikawa, 2000). Again in 2004, additional one shallow landslide (No. 2 site in Fig. 1) was occurred due to heavy rainfall. The configurations of these shallow landslides are still visible and are not affected by further slide expansion or erosion activities. However, some grasses and other plant communities are colonizing in the landslide scars (Fig. 2).

Vegetation coverage can indicate state of erosion and is a critical parameter of empirical and the process-based soil erosion prediction models (Boer and Puigdefabregas, 2005). Repeated erosive conditions can restrict natural colonization and establishment of vegetation (Rey *et al*., 2005). The plant communities can prevent soil erosion by intercepting raindrops, enhancing infiltration, transpiring soil water and by providing additional surface roughness by adding organic substances to the soil (Styczen and Morgan, 1995).

In recent years the study of re-vegetation processes on past landslide scars is receiving increasing attention from both ecological and geomorphological prospective (Puigdefabregas, 2005). The time required for the partial or full recovery of landslide scars by soil development and vegetation colonization is controlled by site specific environmental variables. The understandings on morphological characteristics of colonized plant species are equally important to know the role of vegetation in erosion processes. The re-vegetation state of landslide scars have been reported in previous studies in different environmental conditions (Howell, 1999; Peart *et al*., 2005; Tanokuchi *et al*., 2004). However for the study area, the information on vegetation recovery state and morphological characteristics of colonized plants are seldom available. In this study, an attempt is done to know the (1) state of re-vegetation on the six years old

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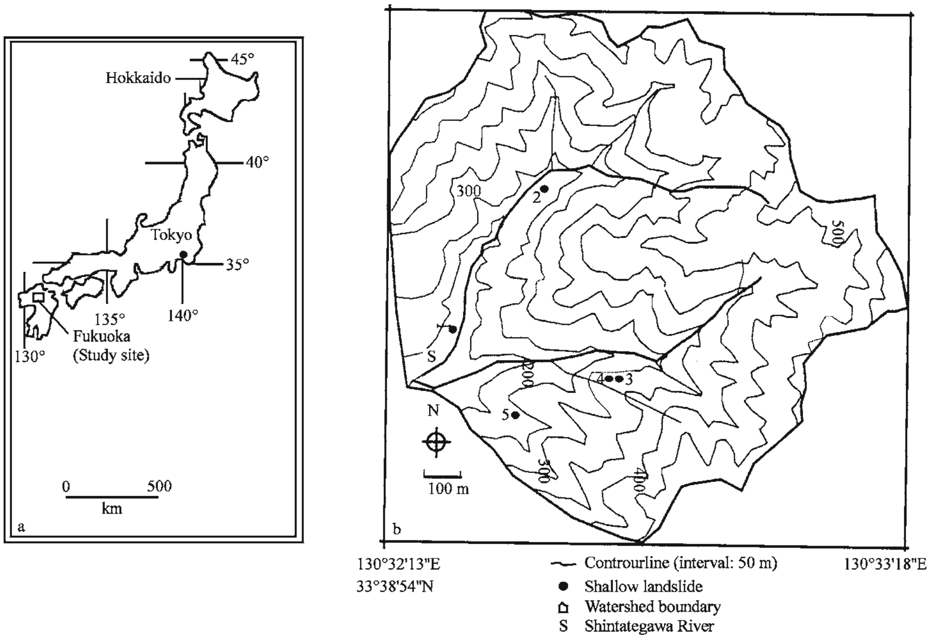


Fig. 1: Location map showing, a: Study site, Fukuoka at southwestern part of Japan, b: Topographic map of Shintategawa watershed including landslides

Fig. 2: Revegetation conditions in landslide scares and view of quadrat design

landslide scars (Fig. 2) and (2) morphological characteristics of colonized herbaceous plants such as standing biomass, root morphology and pull out resistance force.

MATERIALS AND METHODS

Site characteristics: The Shintategawa watershed, consisting area of 1.6 km^2. This is located inside Kyushu university experimental forests about 12 km northeast from Fukuoka city (Fig. 1) and is extending between 160 m to 550 m (relief 390 m) with average mean slope gradient of 33 degree. It is characterized with temperate climatic zone and receives about 1790 mm annual rainfall. Coniferous species like *Cryptomeria japonica* (Sugi), *Chamaecyparis obtusa* (Hinoki) are commonly distributed species. It also comprises other associated

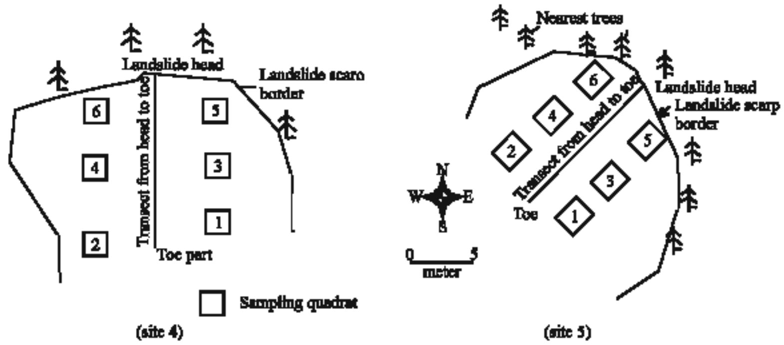
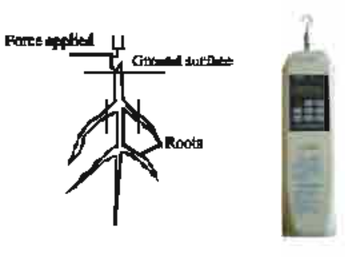


Fig. 3: Configuration of landslide scares and lay out position of sampling quadrats



a b

Fig. 4: Schematic view of pullout experiment and instrument used
a: Pull out view of individual plant
b: Instrument used for pulling plant

species like *Quercus glauca*, *Quercus myrsinaefolia*, *Aucuba japonica*.

Despite the presence of forest tree cover the landscape of the watershed was dissected by shallow landslides (depth < 1.0 m). From field observation, it was revealed that sediments derived from landslides was not transported long distance and was deposited either at the foot parts of slope or over the forest road. The soil was yellowish brown in color with more fractions of silt particles. Geologically the area is underlain by green schist, a metamorphic rock of Paleozoic age (Urata, 1961., Matsushita, 1967).

The landslide distribution was identified by field visit. The detail survey was conducted for two typical landslides scars (site 4 and 5 in Fig. 1) because of their good re-vegetation state. In other sites the revegetation state was very sparse either due to new scars age or presence of underlying rock conditions. The configuration of two typical landslide scars and its surroundings conditions was obtained by compass survey. The soil samples were collected from landslide surroundings and were tested in the laboratory to know soil density, cohesion, porosity and permeability. The soil depth and soil compactness was examined the field directly by using Hasegawa Cone Penetrometer. In this instrument the cone, fixed at the end of rod was pushed into the ground by constantly hitting with knocking load of 2 kg mass falling from a vertical distance of 50 cm. The depth (cm) penetrated per stroke indicates the compactness of soil. The soil compactness provides valuable insight to understand the soil strength (Lampurlanes and Martinez, 2003) and also influenced for root growth and their longevity (Atwell, 1993). Compactness of the soil does not only affect root growth but also influence on infiltration, movement of water and erosion processes (Horton *et al*., 1994).

Vegetation investigation: The condition of naturally colonized vegetation on landslide scars was examined in September 2005, by field investigation. Initially the central transect line from landslide head to toe part was drawn as shown in Fig. 3 and along the both sides of transect line a total of six quadrats of 2×2 m^2 size were established (Fig. 3). In all quadrat plots, individual plant species were identified, counted and measured to investigate the quantitative vegetation parameters. The parameters such as relative frequency, relative density and relative cover for each plant species was examined as proposed by Oosting (1957), Chul and Moody (1983). The Important Value Index (IVI) for each species was obtained by direct summation of relative frequency, relative density and relative cover following Curtis and McIntosh (1951). The species having the highest IVI are considered as the leading dominants of the community (Arshad *et al*., 2002).

$$\text{IVI} = \text{Relative frequency} + \text{Relative density} + \text{Relative cover}$$

The above and below ground morphological characteristics of plants like stem height, root numbers, maximum rooting depth were identified from extracted plants. All the root tendrils of each species was counted manually, maximum diameter and lengths were measured by caliper and measuring tape, respectively. The roots were separated from the stem by using sharp blade. The soil on the root was separated carefully by hand wash and then was placed inside the room ten days for air dried.

The root: shoot ratio of each uprooted plant was calculated as the weight of dry root mass over the dry weight of shoots (Bohm, 1979).

Pull out resistance of grass species: The uprooting resistance force provides significant information on role of root hairs played in anchorage (Bailey *et al*., 2002). When a plant is pulled vertically from soil, force is transmitted to the root system, the root-soil bond and the strengths of the roots themselves in tension. A single vertical force applied to a stem will be transmitted to numerous roots, either because of lateral branching or because of adventitious roots from the stem base (Enno, 1993). In order to investigate the pull out resistance, ten plants per species with different sizes were randomly chosen. Before each pull out test soil surface around the plant was carefully cleared from litter exposing stem base. One end of a strong rope was tied around the stem base of the plant and another end of the rope was connected to a hand-held portable Push Pull Digital Gauge (CPU 9500 type) as shown in Fig. 4.

The vertical force was applied manually till plant was uprooted successfully (without mechanical damage to the root systems). In some tests, where roots were broken during extraction, tests were repeated. The peak force, at which plants were just started to break from the soil were recorded from the digital pulling gauge.

During uprooting, it was revealed that the resistive force was influenced by morphological characteristics such as shoot height, total numbers of roots present and root sizes of an individual species. The co-relationships between the pull out resistance with morphological characteristics (shoot height, roots numbers and size) were investigated for four dominant grass species.

RESULTS

Revegetation state and features of landslide scars: The landslide site specific characteristics such as topographic, soil as obtained from laboratory test and field investigation are summarized in Table 1. During six year period about 60-70% of total landslide surface area was covered by herbaceous plants. The types of species observed and quantitative vegetative parameters for two sites are presented in Table 2. The soil depths of these two typical landslides was varied (Table 1) and soil becomes less cohesive while saturating with moisture. The soil compactness has increased as depth increased as shown in Fig. 5.

Table 2 shows the colonized species in two scars are different despite their close locations (around 500 m far each others). This is due to the influence of orientation of the landscape.

Table 1: Features of landslide scars

Features	Landslide site 4	Landslide site 5
Scar size (m^2)	285	205
Slope gradient (degree)	34	42
Soil depth (m)	0.6	0.3
Soil hardness (mm)	15	12
Porosity (%)	63	62
Permeability (cm sec^{-1})	0.024	0.006
Cohesion (kN m^{-2})	7.9	7.3
Density of soil (kN/m^3)	12.74	11.76
Soil color (-)	5/2 Grayish yellow brown	5/2 Dull yellow brown

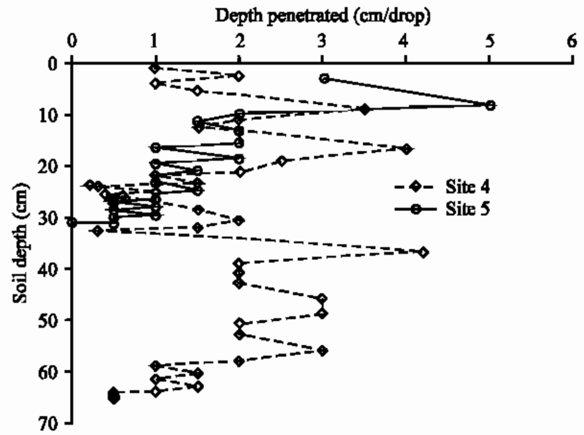


Fig. 5: Soil compactness variation with respect to depth as obtained by cone Penetration Test

Table 2: Quantitative characteristics of colonized plants in landslide scars

Site 4					Site 5				
Plant species	R_d	R_f	R_c	IVI	Plant species	R_d	R_f	R_c	IVI
Boehmeria spicata	15.1	10.3	22.8	48.2	*Hydrocotyle ramiflora*	28.9	11.3	22.4	62.6
Miscanthus sinensis	5.8	10.3	24.2	40.3	*Rubns minusculus*	14.8	9.4	19.5	43.7
Solidago altissima	12.7	10.3	12.0	35.0	*Microstegium vimineum*	22.5	7.5	1.3	31.3
Trifolium sps.	12.2	6.0	10.1	28.3	*Sphenomeris chineusis*	5.9	11.3	13.7	30.9
Hydrocotyle ramiflora	11.9	8.6	2.8	23.3	*Thelypteris glanduligeva*	7.0	11.3	11.0	29.3
Carex lanceolata	8.8	8.6	4.5	21.9	*Athyrium niponicum*	6.6	11.3	8.5	26.4
Equisetum sps.	10.0	8.6	1.6	20.2	*Boehmeria cylindrica*	3.7	7.5	3.9	15.1
Reynoutria japonica	2.8	6.8	6.7	16.4	*Reynoutria japonica_B*	1.7	5.6	3.4	10.7
Sphenomeris chinensis	3.7	6.8	5.2	16.3	*Ambrina ambrosioides*	1.3	1.8	6.8	9.9
Erigeron canadeusis	5.4	6.8	0.6	12.8	*Autenoron filiform*	1.9	5.6	1.6	9.1
Theypteris glanduligeva	6.3	8.6	6.2	21.1	*Carex lanceolata*	1.7	5.6	0.8	8.1

Table 2: Continued

Site 4					Site 5				
Plant species	R_d	R_f	R_c	IVI	Plant species	R_d	R_f	R_c	IVI
Artemisia sps.	3.1	3.4	2.3	8.8	*Achyranthus japonica*	1.7	5.6	0.8	8.1
Lespedeza juncea	1.6	3.4	0.3	5.3	*Pleioblastus simonii*	1.2	3.7	1.6	6.5

R_d: Relative density, R_f: Relative frequency R_c: Relative cover, IVI: Important Value Index.

Table 3: Morphological characteristic of colonized grass species

Species	Height (cm)		R_l	T_r	D_{max}	Shoot mass (g)		Root mass (g)		R:S ratio	Ps
Name	Range	Mean	(cm)	(no)	(mm)	Nat.	Dry	Nat.	Dry	(Dry)	(N)
Boehmeria spicata	10-80	35	23	25	11	26.8	8.5	8.2	2.3	0.270	49.7±10.7
Erigeron canadeusis	56-105	76	10	29	8	5.2	1.4	0.8	0.2	0.142	27.6±9.9
Solidago altissima	42-120	71	26	18	12	48.7	21.3	11.3	6.6	0.309	44.4±8.0
Artemisia indica.	30-85	47	30	25	12	18.0	4.3	7.5	1.8	0.418	37.6±18.7
Trifolium repens	18-34	25	12	15	4	12.0	3	5.6	1.9	0.633	17.0±4.8
Equisetum arveuse	10-45	31	12	7	5	2.0	0.3	1.4	0.2	0.666	23.2±1.7
Houttuynia cordata	10-24	14	13	12	5	2.2	0.9	1.8	0.4	0.44	13.2±2.2
Miscanthus sinensis	38-120	72	18	23	3	42	14.3	9.2	3.8	0.41	34.7±7.4
Carex lanceolata	26-66	42	11	12	3	34	11.9	8.0	3.6	0.302	24.6±4.0
Autenoron filiform	24-60	44	9	25	7	15.5	3.4	3.5	1.1	0.323	24.0±2.0
Rubus minusculus	45-60	48	21	12	6	5.8	3.2	1.1	0.6	0.187	42.4±6.0
Achyranthus aspera	38-75	55	23	19	9	18	4.0	5.2	2.1	0.525	36.5±8.2
Boehmeria cylindrica	32-55	45	19	16	10	18.6	3.6	4.2	2.0	0.555	28.8±3.9
Sphenomeris chinensis	45-60	41	12	26	3	30.0	5.6	15.0	5.3	0.946	31.7±6.8
Ambrina ambrosioides	28-125	83	24	19	9	25.0	4.9	6.3	2.2	0.448	28.0±2.7
Hydrocotyle ramiflora	8-12	10	5	11	2	3.0	0.2	1.0	0.1	0.500	6.2±0.7
Athyrium niponicum	34-95	73	24	80	2	56	20.3	25	12.7	0.625	45.2±4.8

R_l: maximum length of root, T_r: total numbers of roots, D_{max}: maximum diameter of a root, Nat.: natural, R:S: root shoot ratio, Ps: pullout strength

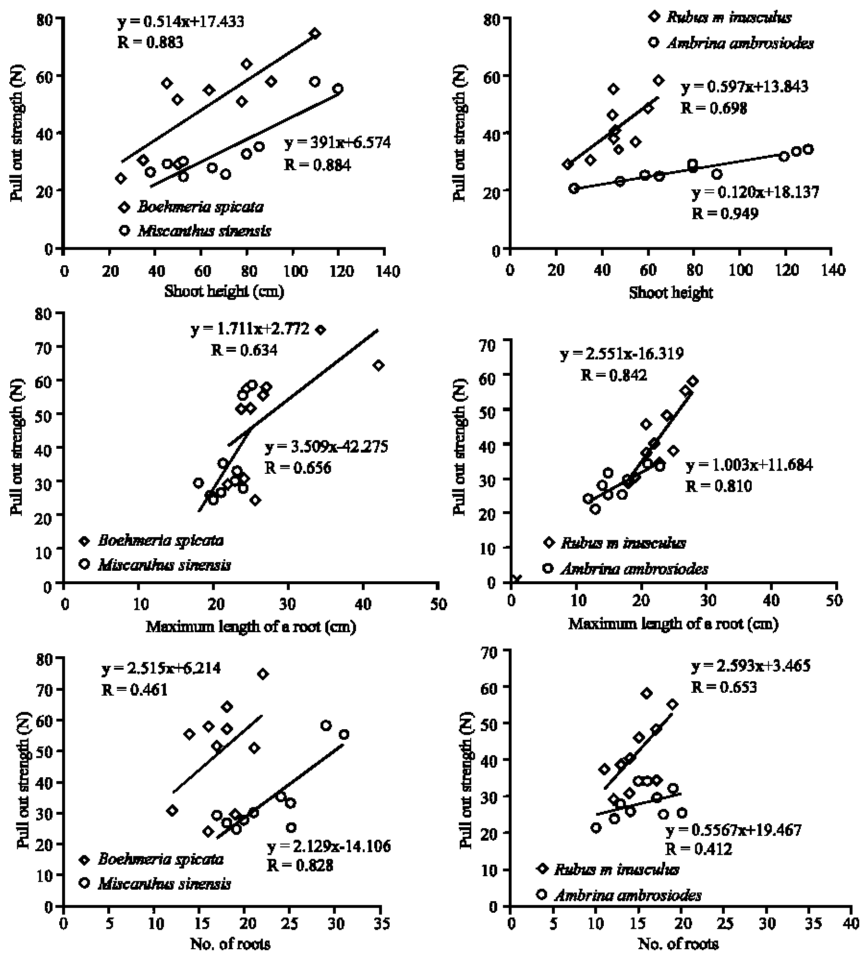


Fig. 6: Correlationships between plants morphological features and pullout strengths

The morphological characteristics such as shoot length, biomass, maximum rooting depths and numbers of roots for an individual plant are given in Table 3.

On average total numbers of roots contained by an individual species were ranged from 7-80, while maximum penetrated rooting depths was ranged from 5-30 cm. Similarly, maximum diameter of root tendril was ranged in between 2-12 mm. In most of the plants roots were fibrous types containing root hairs and do not reach far from the stem base. The penetrated maximum rooting depth in 50% species was confined below 15 cm.

Pullout tests: The Digital Push Pull Gauge (Fig. 4) was able to uproot all the grass species colonized in the study sites. While force was applied to uproot the plant, gradually started to decrease the resistive forces as the roots started to loose the connection with soil mass. The uprooting peak resistive force was measured for an individual plant species and the results are presented in Table 3. On average, the peak pullout resistive force of plants observed in the study sites was ranged from 6 Newton to 49 Newton.

The uprooting resistive force has shown dependency on morphological characteristics of a plant like shoot height, diameter of roots and total roots. The correlations analysis between the pullout resistance forces with morphological characteristics was investigated for four dominants species (two for each landslide site) and the results are shown in Fig. 6. For all the species, positive co-relationships were found between the uprooting force and all measured morphological parameters. In general taller plants with greater rooting depth have shown higher uprooting resistive forces. The plants with spread root system were able to resist uprooting better than the plants with root system that do not reach far from the stem base.

DISCUSSION

In the studied watershed, vegetation restoration was controlled by site specific characteristics. For instance, in case of underlying rocky and stony areas the scars are still bare or are sparse conditions. The types of species distributed in two sites were mainly influenced by landscape orientation i.e., aspect of landslide scars. In this context, results were resembled with the results obtained by Fu *et al.* (2004) in Beijing, China. Comparatively, the vegetation cover in study site 4 was good compared to site 5 which might be attributed due to soil depth variations (Table 1). In landslide site number 4, light preferring plants were growing well because of it was facing towards south direction. While in case of landslide site number 5, shade preferring species were growing well (Table 2). The shallow soil depth in the landslide scars might have act as prevented for the better development of plant communities. No signs of sheet or gully erosion were observed in the scars surface indicated that vegetation have protect the subsequent further surface erosion from the subsequent rainstorms.

The vegetation restoration in surface of landslide scar was related with site specific soil and other environmental characteristics. In the study site, time required to cover the landslide scar by colonized vegetation was approximately six years. However, the time required for coverage is varied for different environmental conditions. For instance, the recovery of vegetation on landslide in non-rock areas of Hong Kong and Uluguru mountains of Tanzania was taken from 1.6 to 5.6 years and 2 to 5 years, respectively (Peart *et al.*, 2005). In Chi-Feng-Er mountain landslide area of Taiwan it was nine months (Yang *et al.*, 2002). In case of Nepal Howell (1999) has stated that the landslide surface was covered fully by grasses after 5 years in Dharan-Dhankuta road side slope. In colder climates re-growth of vegetation might be expected to be slower (Rapp and Stromquist, 1976).

The correlation and regression analysis between measured morphological characteristics and pull out resistance force have indicated that taller plants with laterally distributed roots types are relatively more resistive against pulling compared to smaller plants consisting vertically directed roots. The pulling strength was the results of combined action of all morphological factors (shoot, root numbers and sizes, root shoot ratio) and consideration with single factor sometimes might results in to an error. For instance, *Athyrium niponicum* consist maximum roots numbers but fails to give maximum pulling strength (Table 2). It might be due to its root penetration structure and root tendrils size. Its roots are penetrated vertically downward without lateral spread and all the roots are fibrous type with maximum diameter of 2 mm. Thus to understand the role of an individual plant in erosion control the consideration of all morphological features are essential.

CONCLUSIONS

The present study investigated the conditions of vegetation in old landslide scars at the natural conditions. The vegetation analysis in eroded site might be a good indicator to know the site quality, subsequent erosion state and to examine the relationships between plant and soil. The pullout resistive strength of the plants was jointly determined by the morphological features of the plants like shoot height, roots morphology. The pullout resistance force of an individual species can provide better insight to know the role of an individual plant in erosion processes. The species with deep rooted with lateral spreading have shown greater pull out resistance and which are considered to be suitable species to prevent the landslide scars against surface erosion.

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