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The Role of Forest-and Nonforest Species on Slope Stability in the North of Iran

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ABSTRACT

Slope instability due to landslides is particularly common in Iran. It is possible to fight against these hazards thanks to the roots of trees, which provide an important contribution towards the stability of hillslopes. However, our knowledge of the effectiveness of roots for slope stability needs improvement. Therefore this study was carried out on the effect of tree roots on slope stability, in particular for the following species: tea (*Thea sinensis* L.) and citrus (*Citrus spp*.), which are of economic interest; and Lilaki (*Gleditshia caspica* Dsf.) and Angili (*Parrotia persica* D. C.), without economic interest. The study area was located at Roudsar Township in Gilan Province of Iran. A large part of the area had slopes of steep gradients on which natural vegetation was present. Other parts of the same area have been cleared and planted with tea and citrus crops. Soil samples with and without roots of the mentioned species were taken, on an area covering approximately 70 ha, for testing in the laboratory. Soil shear tests were carried out on these samples and the Factor of Safety (FS) was calculated. Results showed that the FS was increased in soils with tree roots present. The global slope FS was then determined using Bishop's method. We calculated FS in order to protect slopes where the gradient exceeds 25%. In this case study, minimum FS corresponds to e.g. *Parrotia sp.* vegetation with 40-60% crown cover, a soil internal friction angle of 15° and slope angle of 21°. When the soil internal friction angle equals 15° and the slope angle is >31°, slope stability cannot be increased by any mentioned vegetation species. The most important results show that the main contributory factors which affect slopes' stability are: angle of slope, angle of internal friction, and percentage of vegetation cover.

Keywords: Factor of safety, Root reinforcement, Roots, Roudsar, Slope stability.

INTRODUCTION

Slope instability is one of the major problems in geotechnical engineering where disasters, like loss of property, do occur. The majority of these slope failures are of harvested vegetation or forested natural slopes. A natural slope is different from an embankment or a man-made slope in that the effects of vegetation and soil variability play an important role in their stability (Griffiths and Lane, 1999). Due to the population increase over recent years, the exploitation of renewable natural resources has increased dramatically. One of the consequences of this has been the destruction of some forests, and this has been particularly noticeable over the last ten years. Natural disasters, such as floods, droughts and sea level rises have also had an effect on the living conditions of many people (Wu, 1984). In particular, Iran has a long history of landslides, which have caused major loss of life along with damage to infrastructure and agricultural lands (Bibalani, 1996). It has been impossible to recover some of the damages caused by landslides, and where it has been possible, it has been at a high financial cost.

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The effects of vegetation on the stability of slopes are well recognized. Vegetation affects slope stability through modification of the internal fraction of soil which, in turn, causes a variation in soil stability. Vegetation can enhance the stability of a slope by root reinforcement. Wu *et al*. (1979) investigated the stability of slopes before and after removal of forest cover and concluded that the shear strength contributed by tree roots is important to the stability of slopes. The study indicated that vegetation could contribute shear strength to the slopes through root reinforcement. Wu *et al*. (1979) showed that slope failure would have occurred if the effects of vegetation were not taken into account in slope stability analyses. The main reason for the high number of landslides in Iran is as a result of a particular combination of geology, topography and climate. Furthermore, the cause of landslides may be geomorphologic phenomena combined with other factors such as climate changes, vegetation cover, geology and the tectonic situation. Gilan Province in the North of Iran is particularly susceptible to landslides, because of the special topographical and geological conditions in this province, it may be possible to prevent landslides with relatively little expense and labour (Bibalani, 2003). Therefore, research on strategies for the stability of this region would be of particular interest to local stakeholders and farmers.

Vegetation has long been regarded as improving slope stability (Bibalani, 1996; Bibalani *et al*., 2006). In particular, the tree roots provide an important contribution towards the stability of hill slopes. In the soil, they act very similarly to steel fibers in reinforced concrete and provide resistance to shear and tensile forces induced in the soil. In addition, the roots also absorb water from the soil, reducing moisture content and therefore helping to increase the stability of the slope. The influence of different species on the soil reinforcement of slopes can be studied using different methods. Measurements of soil shear strength provide an indicator of the contribution of roots to slope stability, when combined with calculations of the slope's factor of safety (FS). The formula used to calculate the FS of the critical landslide surface has been defined by Watson (1995) as follows:

$$Safety\ \ factor(FS) = \frac{Soil\ \ shear\ \ resistance}{Soil\ \ shear\ \ stress} \quad (1$$

This paper investigates the effects of vegetation on slope stability using the Bishop method. To limit the scope of this paper, only the effects of root reinforcement are incorporated into the slope stability analysis. Variability in the vegetation is considered for <20%, 20-40%, 40-60% and >60% canopy cover for tea, tea-citrus, *Parrotia Sp*. and *Gleditshia Sp*. and soil properties are not considered in this paper. Six homogenous slopes with angles of inclination of 15, 18, 21, 23, 27, 30 and 33 degrees were used to investigate the effects of vegetation on slope stability.

The ability of plant roots to strengthen a soil mass is well known. The inclusion of plant roots with high tensile strength increases the confining stress in the soil mass by its closely spaced root matrix system. The soil mass is bound together by the plant roots and the shear strength is increased by this effect. The contribution of root reinforcement to shear strength is considered to have the characteristics of the angle of internal friction (Wu *et al*., 1979). Wu *et al*. (1979) proposed a simplified perpendicular root model to quantify the increased shear strength of soil due to root reinforcement. They incorporated the effects of vegetation in their slope stability analysis by using the conventional limit equilibrium method. The shear strength of the soil along a potential slip surface is assumed to be fully mobilized at the point of failure.

Wu *et al*. (1979) incorporated the apparent root tensile in their slope analysis and found an increase in the factor of safety (FS) for slopes. The results indicated that tree roots improved the stability of forested slopes.

The main contributory factors which affect slopes stability are as follows: (Watson, 1995)

- Angle of slope.
- Angle of internal friction.

- Percentage of vegetation cover (by effect of roots).

Other factors may also play a part in the slope stability and these are as follows;

- Soil moisture content.
- Weight of soil mass and vegetation cover.
- Internal adhesion of soil particles.
- Wind loading on the soils and vegetation.
- Location of any underground water table.
- Earthquake and tectonic forces.

These factors have not been considered in this study.

MATERIALS AND METHODS

The experimental site was situated in SE Roudsar, Iran at latitude 36°58'N, longitude 50°21'E and altitude 150 m on a north-facing slope. It is a part of the Rahimabad District of Roudsar Township (Figure 1). The total surface area is about 1,800 hectares, of which 288 hectares were selected as being suitable for this study. The site is characterized by a silty clay soil. A large part of the study area has hillsides of steep gradients, with natural vegetation. In small part-areas, tea plantations and citrus orchards were established about 15 years ago after clearing the previous vegetation. This planting of crop species has caused instability of the steep slopes and landslides occur mainly in these areas.

The study area was divided into parts A, B, C and D, which A represents the district with tea-citrus vegetation ground cover, B the one with *Gledtisia sp.*, C the one with *Parrotia sp.* and D the one with tea vegetation. The mean annual precipitation is about 1,700 mm. A rainy season starts normally in early September and ends at the end of May (Figure 2). The field tests were carried out from June to August.

Twenty trial pits with 90 cm diameter and about 150 cm depth was excavated on a different slope (15, 18, 23, 27, 30 and 33 degrees) where no landslides had occurred. This area has been chosen in order to quantify the contribution of the vegetation to soil reinforcement. The numbers of roots, with diameters of 10 mm, 8 mm and 4 mm ranges were counted. Ninety random soil samples with a 20 cm diameter were taken from 70 hectares outside the landslide area on which laboratory tests were carried out in order to determine certain mechanical characteristics. Triaxial tests were carried out on forty soil samples without roots in the laboratory. Pore pressure was distinguished through triaxial

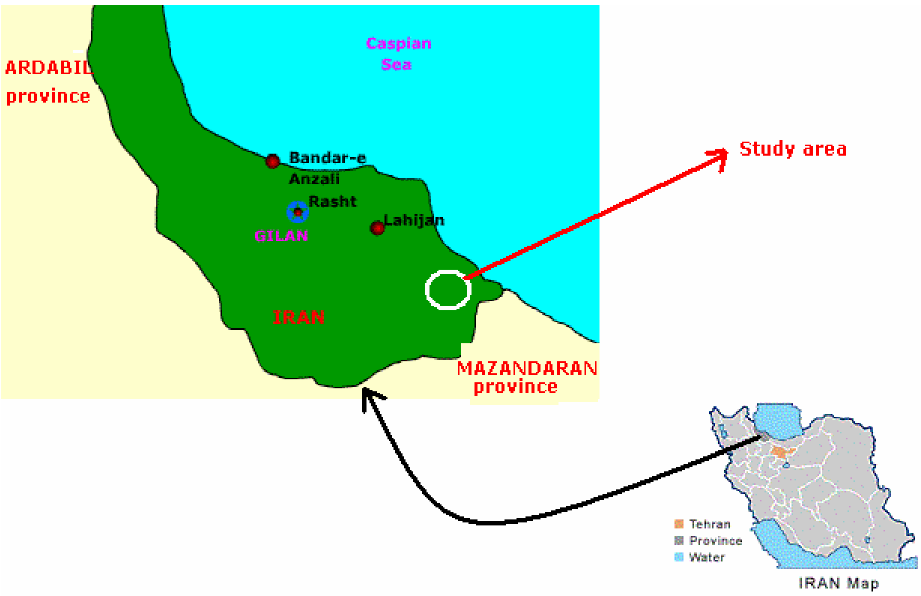

Figure 1. The geographical position of Gilan Province in Iran.

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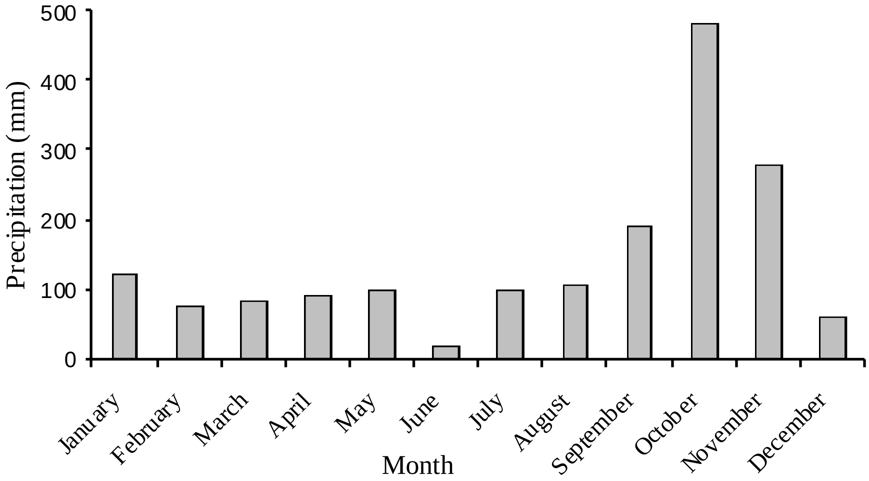

Figure 2: Average monthly precipitation in the study area.

tests on soil samples. Shear tests were carried out without roots in a soil laboratory. The following equation is used to determine the increase in shear strength of soils (ΔSR) containing plant roots (Bibalani, 2003):

$$\Delta SR = 1.15TR\frac{AR}{A} \qquad (2$$

Where:
TR= Tensile resistance (MPa) of the root was measured with root tensile test,
AR= Total surface area (cm^2) of roots in A,
A= Soil surface (m^2),

And 1.15 in this equation is a coefficient.

Slope stability was calculated using the Bishop method of analysis (Behniya, 1993) and a mean automatic procedure was developed for calculation purposes (Bibalani *et al.*, 2005). The FS is calculated from:

$$FS=\frac{L}{\sum w.\sin\alpha}.\sum[\{c.b+(w-u.b)\tan\varphi.b\}(\frac{\sec\alpha}{L+\frac{\tan\alpha.an\alpha.t}{FS}})] \qquad (3$$

Where:
FS= Safety factor,
α= Angle of slope (°),
w= Weight of soil on the slope (N),
c= Cohesion of soil (KN m^{-2}),
L= Length of slope (m),
u= Pore pressure (KN m^{-2}),
b= Width of area (m),
ϕ= Angle of internal friction (°)

The FS model was run to determine the influence of different species on slope stability and soil reinforcement with two ϕ (with and without roots).

On the basis of the amount of ΔSR, it is possible to calculate the angle of internal friction of the soil (ϕ_2) and the safety factor (FS) without (FS$_1$) or with (FS$_2$) plant roots.

From ΔSR (additional soil resistance with roots) the angle of internal friction can be calculated with roots in soil (ϕ_2') using: (Behniya, 1993)

$$\tan\varphi_2=\frac{SR+\Delta SR-c}{h.b.l.dan} \qquad (4$$

Where:
SR= Soil resistance
ΔSR= Additional soil resistance with roots
h= Depth of soil (m),
b= Width of area (m),
l= Length of slope (m),
dan= Density of soil (kg m^{-3}).
c= Soil cohsion.

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RESULTS

FS_1 (safety factor without vegetation) was calculated using soil properties (u, ϕ_1, c, and dan.) and area characteristics (b, α, l and h) with equation 1, and additional soil resistance with roots (ΔSR) was calculated with equation 2; then the angle of internal friction without vegetation (ϕ_2) was calculated. FS_2 (safety factor with vegetation) was calculated using soil properties (u, ϕ_2, c, and dan.) and area characteristics (b, α, l and h) with equation1 (Table 1).

The relationship between angle of internal friction (ϕ) and the safety factor of soil without roots (FS_1) was shown for angles of slope of 15, 18, 23, 27, 30 and 33 degrees (Figure 3).

The relationship between the angle of internal friction (ϕ) and the safety factor of soil with different ground cover of tea vegetation (FS_2) was shown for an angle of slope of 15 degrees (Figure 4).

The relationship between the angle of internal friction (ϕ) and the safety factor of soil with different ground cover of *Parrotia sp.* (FS_2) was shown for an angle of slope of 15 degrees (Figure 5).

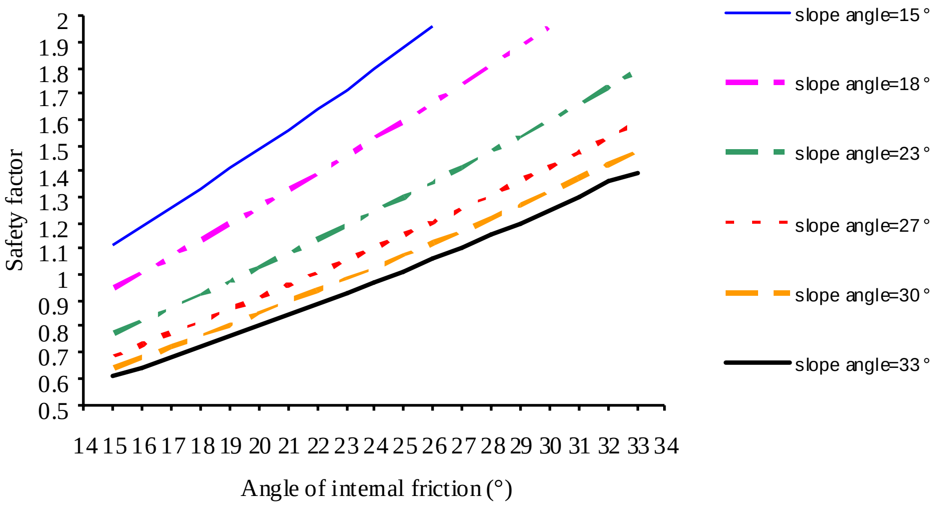

Figure 3. Safety factor of soil without vegetation cover on different slope angles.

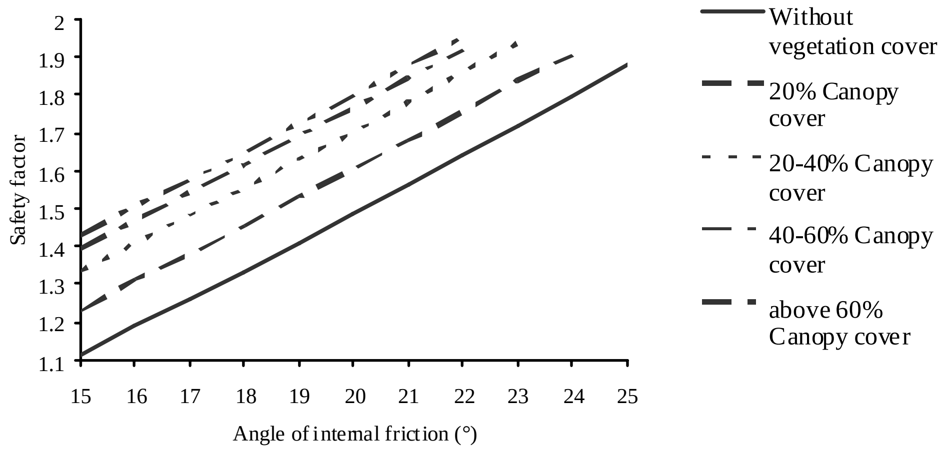

Figure 4. Safety factor of soil with tea plants on a 15° slope with different percent of canopy covers (CC %).

Table 1. Seven soil sample properties from 90 soil samples in different slopes and areas (for illustration).

slope	Species	b	u	ϕ_1	c	α	L	h	dan	FS_1	DIA	n	TR	ϕ_2	FS_2	AR/A
1	*Parrotia Sp.*	25	0.4	25.3	0.3	31.9	15	3.5	1.45	1.0	1 0.8 0.4	1 30 41	50.1 55.8 59.1	36.6	1.6	0.21
2	*Parrotia Sp.*	20	0.3	26.4	0.2	29.3	15	3	1.5	1.1	1 0.8 0.4	1 32 39	50.1 55.8 59.1	38.9	1.8	0.22
3	*Gleditshia Sp.*	15	0.3	22.9	0.2	20.2	15	3.5	1.55	1.3	1 0.8 0.4	- 15 24	35.0 26.2 24.8	25.7	1.5	0.1
4	*Gleditshia Sp.*	12	0.4	23.8	0.3	24.8	15	2	1.88	1.9	1 0.8 0.4	- 16 23	24.8 26.2 35.0	28.6	1.4	0.11
5	tea	70	0.4	23.5	0.3	17.1	15	3.5	1.5	1.0	1 0.8 0.4	- 11 24	14.2 16.0 21.9	25.1	1.2	0.08
6	tea	45	0.3	21.2	0.2	26.5	15	3	1.5	0.9	1 0.8 0.4	- 14 23	14.2 16.0 21.9	23.3	1.1	0.1
7	tea	50	0.3	18.7	0.3	23.5	20	2.5	1.5	0.9	1 0.8 0.4	- 13 21	14.2 16.0 21.9	21.2	1.1	0.09

b= width (m), u= pore pressure (KN/m^2), ϕ_1= angle of internal friction without vegetation (°), c= cohesion of soil (KN/m^2), α= angle of surface (°), L= length of slope (m), h= depth of soil (m), dan= density of soil, FS_1=safety factor without vegetation, DIA= diameter of roots (cm), n=number of roots per m^2, TR= tensile resistance of the root was measured with root tensile test (MPa), ϕ_2= angle of internal friction with vegetation (°), FS_2=safety factor with vegetation, AR/A= relation between total surface area (cm^2) of roots and soil surface (m^2).

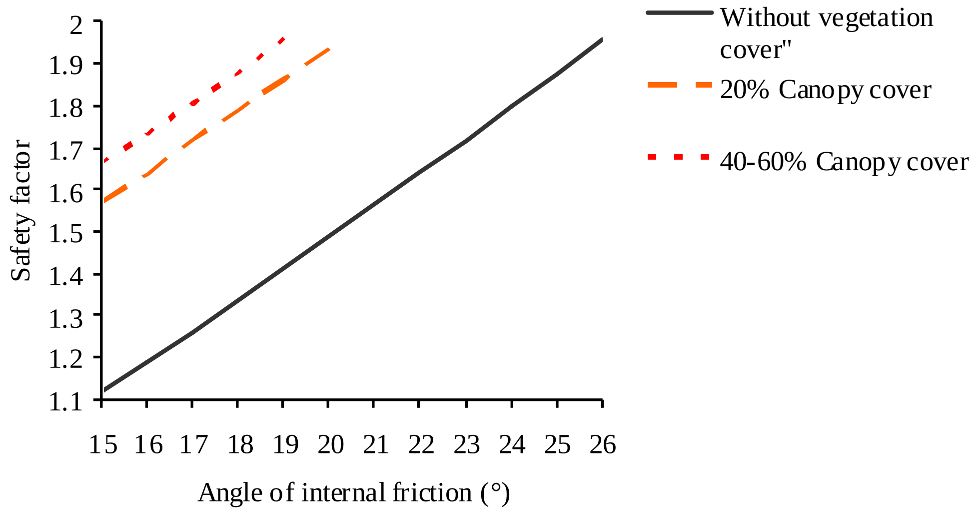

Figure 5. Safety factor of soil with Parrotia sp. on a 15° slope with different percent of canopy covers (CC %).

The effect of different roots of 20-40% vegetation on FS_2 was compared with FS_1 on an angle of slope of 15 degrees (Figure 6).

The effect of different slopes (18, 23, 27, 30 and 33 degrees) on FS_2 was compared with FS_1 roots of *Parrotia sp.* vegetation with ground cover of over 60% (Figure 7).

Finally, the least amount of ground cover of different vegetation that could stabilize soil on a slope with different amount of angle of internal friction (ϕ) and different surface angle to the horizon, was shown in Table 2.

DISCUSSION AND CONCLUSION

This study has revealed and quantified the effect of tea (*Thea sinensis* L.), citrus(*Citrus spp*.), Lilaki (*Gleditshia caspica* Dsf.) and Angili (*Parrotia persica* D. C.) in the north-

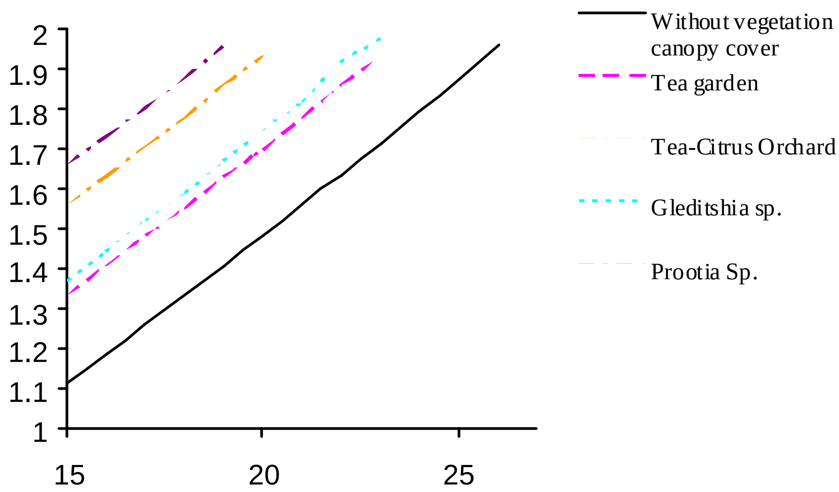

Figure 6. Safety factor of soil with different species on a 15° slope with different crown cover (20–40 %).

ern Iran, a phenomenon by means of which the vegetation stabilizes the slopes in the Roudsar and probably also in other areas where this vegetations are growing.

Although there are several factors which may affect slope stability and lead to small and shallow landslides in the study area, the main factor has been the removal of the natural forest cover of the slopes to create a tea garden and citrus orchards. In order to increase the FS of the slopes in this area with gradients of more than 25%, the lowest FS with attention to the angle of internal friction of soils (ϕ), the gradient of the slope (α) and for different vegetation cover is given for stabilizing slopes.

This study was carried out to determine which forest and crop species provided the best reinforcement to slopes in Gilan Province. Soil shear tests were carried out on samples with and without roots of different species (*Thea sinensis* L.; *Citrus spp*.,

Table 2. Stability of slopes with attention to the angle of internal friction of the soil, angle of the slope and vegetation coverage percentage.

ϕ [a]	α [c] / Sp. [b]	15	18	21	23	27	30	33
15	tea	20-40%	U.st	U.st [e]	U.st	U.st	U.st	U.st
	Tea-citrus	<20%	20-40%	U.st	U.st	U.st	U.st	U.st
	Parrotia Sp.	<20%	<20%	40-60%	40-60%	40-60%	U.st	U.st
	Gleditshia Sp.	20-40%	>60%	U.st	U.st	U.st	U.st	U.st
16	tea	St [d]	20-40%	U.st	U.st	U.st	U.st	U.st
	Tea-citrus	St	<20%	40-60%	U.st	U.st	U.st	U.st
	Parrotia Sp.	St	<20%	40-60%	40-60%	40-60%	>60%	U.st
	Gleditshia Sp.	St	20-40%	U.st	U.st	U.st	U.st	U.st
17	tea	St	St	40-60%	U.st	U.st	U.st	U.st
	Tea-citrus	St	St	40-60%	U.st	U.st	U.st	U.st
	Parrotia Sp.	St	St	20-40%	40-60%	40-60%	>60%	U.st
	Gleditshia Sp.	St	St	U.st	U.st	U.st	U.st	U.st
18	tea	St	St	U.st	U.st	U.st	U.st	U.st
	Tea-citrus	St	St	20-40%	40-60%	U.st	U.st	U.st
	Parrotia Sp.	St	St	<20%	20-40%	40-60%	40-60%	>60%
	Gleditshia Sp.	St	St	>60%	U.st	U.st	U.st	U.st
19	tea	St	St	U.st	U.st	U.st	U.st	U.st
	Tea-citrus	St	St	20-40%	40-60%	U.st	U.st	U.st
	Parrotia Sp.	St	St	<20%	20-40%	40-60%	40-60%	>60%
	Gleditshia Sp.	St	St	40-60%	U.st	U.st	U.st	U.st
20	tea	St	St	40-60%	U.st	U.st	U.st	U.st
	Tea-citrus	St	St	20-40%	20-40%	>60%	U.st	U.st
	Parrotia Sp.	St	St	<20%	<20%	40-60%	40-60%	>60%
	Gleditshia Sp.	St	St	20-40%	40-60%	U.st	U.st	U.st
21	tea	St	St	20-40%	>60%	U.st	U.st	U.st
	Tea-citrus	St	St	<20%	20-40%	40-60%	U.st	U.st
	Parrotia Sp.	St	St	<20%	<20%	20-40%	40-60%	40-60%
	Gleditshia Sp.	St	St	20-40%	40-60%	U.st	U.st	U.st
22	tea	St	St	St	40-60%	U.st	U.st	U.st
	Tea-citrus	St	St	St	<20%	40-60%	U.st	U.st
	Parrotia Sp.	St	St	St	<20%	20-40%	40-60%	40-60%
	Gleditshia Sp.	St	St	St	20-40%	U.st	U.st	U.st

Table 2. (cont.)

φ [a]	α [c] / Sp. [b]	15	18	21	23	27	30	33
23	tea	St	St	St	20-40%	U.st	U.st	U.st
	Tea-citrus	St	St	St	<20%	20-40%	40-60%	U.st
	Parrotia Sp.	St	St	St	<20%	<20%	20-40%	40-60%
	Gleditshia Sp.	St	St	St	<20%	>60%	U.st	U.st
24	tea	St	St	St	St	>60%	U.st	U.st
	Tea-citrus	St	St	St	St	20-40%	40-60%	>60%
	Parrotia Sp.	St	St	St	St	<20%	20-40%	40-60%
	Gleditshia Sp.	St	St	St	St	40-60%	U.st	U.st
25	tea	St	St	St	St	U.st	U.st	U.st
	Tea-citrus	St	St	St	St	20-40%	20-40%	40-60%
	Parrotia Sp.	St	St	St	St	<20%	<20%	20-40%
	Gleditshia Sp.	St	St	St	St	U.st	U.st	U.st
26	tea	St	St	St	St	20-40%	>60%	U.st
	Tea-citrus	St	St	St	St	<20%	20-40%	40-60%
	Parrotia Sp.	St	St	St	St	<20%	<20%	<20%
	Gleditshia Sp.	St	St	St	St	<20%	40-60%	>60%

[a] Angle of internal friction of soil 15-26°; [b] Species of vegetation; [c] Angle of slope (such as 15, 18, 21, 23, 27, 30, and 33°); [d] Stable, [e] Unstable with any vegetation.

Gleditshia caspica Dsf. And *Parrotia persica* D. C.) and the slope FS calculated. Results are discussed with regard to practical implications in this area.

Hillslopes are stable with tea, tea-citrus, *Parrotia sp.* and *Gledishia sp.* vegetation with an angle of internal friction of soils above 16 and an angle of slope of 17 degrees and with an angle of internal friction of soils above 16 and an angle of slope of 18 degrees.

However, the contribution of plant roots to soil shear still needs much research, and much work also needs to be carried out on the suitability of different species for stabilizing slopes.

The studies undertaken to elucidate the effects of tree roots of indigenous species on soil slope stability and the influence of deforestation and subsequent cultivation of tea and citrus have highlighted the importance of root strength properties. It was found that,

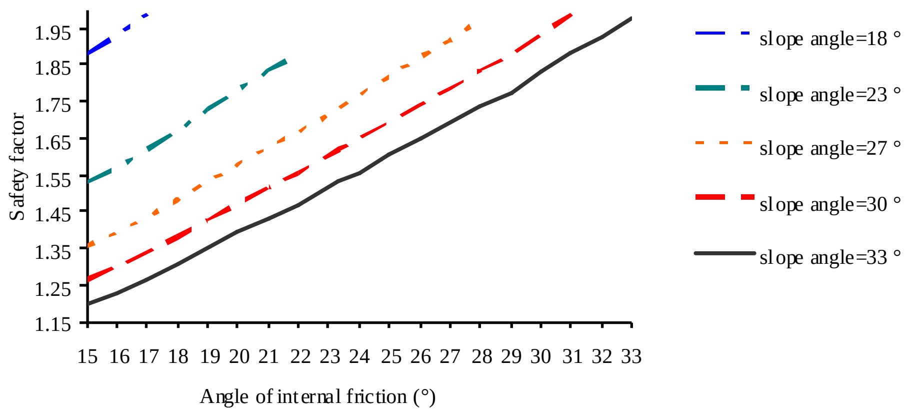

Figure 7. Safety factor of soil with *Parrotia sp.* with canopy cover >60% and different slope angles

of the species examined, the two forest species fulfilled the essential requirements for a tree species to be considered as a biotechnical slope stabilizing component. The two garden species, (tea and citrus) were not suitable with an increased slope angle. It is likely that two mature forest trees of this species would provide good root anchorage on slopes.

It is important to appreciate that the significance of mechanical stabilization of slopes by forest trees roots depends on slip surfaces, the likely failure mode and the steepness of the slope. As a consequence, it is essential to identify the specific slope conditions and relate these to the properties of the particular plant species.

Since this is a pioneer study, the results have provided estimations of the effect of the roots of this vegetation for the first time in Iran. The findings and methodology of the study may be applied in other areas and to other plants.

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نقش گونه‌های جنگلی و غیرجنگلی در پایدارسازی شیبها در شمال ایران

چکیده

ق. حبیبی بی‌بالانی و ب. مجنونیان

ناپایداری شیبها به دلیل بروز لغزش در شمال ایران به صورت ویژه قابل مشاهده می‌باشد. به منظور مقابله و جلوگیری این خطرات می‌توان از ریشه درختان که باعث ایجاد پایداری در مناطق شیبدار می‌شود، استفاده کرد. اگرچه در مورد آثار ریشه‌های درختان در افزایش پایداری خاک اطلاعات زیادی وجود دارد، با این وجود نیازمند تکمیل آن می‌باشد. به همین منظور مطالعه‌ای به منظور تعیین آثار ریشه درختان روی

پایداری شیبها با استفاده از گونه‌هایی از قبیل چای و مرکبات به عنوان گونه های کشاورزی و لیلکی و انجیلی به عنوان گونه‌های جنگلی انجام شد. مطالعه مورد نظر در شهرستان رودسر از استان گیلان انجام گرفت. بخش زیادی از منطقه مطالعه شده واقع در مناطق شیبدار به‌وسیله گیاهان طبیعی پوشانده شده و مقداری از آن نیز قطع یکسره شده و تبدیل به باغهای چای و مرکبات شده است. نمونه‌های خاک بدون ریشه و با ریشه گیاهان ذکر شده در سطحی در حدود ۷۰ هکتار برای انجام آزمایش در آزمایشگاه برداشته شد. آزمایش برش مستقیم روی نمونه‌های خاک انجام و ضریب پایداری (FS) برای آنها محاسبه شد. نتایج نیز نشان داد که با وجود ریشه در خاک، مقدار FS افزایش پیدا کرده است. برای محاسبه FS از شیوه جهانی بیشاپ استفاده شد. مقدار FS برای شیبهایی که درصد شیب آنها بیش از ۲۵٪ بود، محاسبه شد. در این مطالعه حداقل مقدار FS به منظور پایدارسازی شیب با پوشش گیاهی انجیلی با تاج پوشش ۶۰-۴۰٪ و با زاویه اصطکاک داخلی ذرات خاک ۱۵ درجه و زاویه شیب ۲۰ درجه اتفاق می افتد. وقتی که زاویه اصطکاک داخلی ذرات خاک ۱۵ درجه و زاویه شیب بیش از ۳۱ درجه می‌باشد، هیچ یک از پوششهای گیاهی مطالعه شده قادر به پایدارسازی شیبها نمی‌باشند. از مهمترین عوامل مؤثر بر پایداری خاک می‌توان از زاویه شیب، زاویه اصطکاک داخلی ذرات خاک و درصد پوشش گیاهی نام برد.

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