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Protection Roles of Tea Scrubs (*Thea sinensis* L.) On Slopes in Iran

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Abstract: A study has been carried out on the effect of roots on slope stability, in particular for tea (*Thea sinensis* L.). The study area was located in Roudsar Township, in Gilan State of N Iran. Some parts of this area have been planted with tea. Soil samples with and without roots of the mentioned species were taken, on an area of approximately 15 ha large, 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 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 which corresponds to *Thea sinensis* L. vegetation with 20-40% crown cover, a soil internal friction angle of 15° and a slope angle of 15°. When soil internal friction angle equals 20° and slope angle is more than 23°, slope stability can not be increased by Tea vegetation species.

Key words: Root reinforcement, Gilan, landslide, factor of safety, soil internal friction angle

INTRODUCTION

It is well understood that vegetation influences slope stability mechanical effects. The shear strength of the soil is increased through the mechanical effects of the plant root matrix system. The density of the roots within the soil mass and the root tensile strength contribute to the ability of the soils to resist shear stress. The effects of soil suction and root reinforcement has been quantified as an increase in apparent soil cohesion. This study investigates the effects of vegetation on the stability of slopes using the finite element method. Parametric studies were performed to assess the sensitivity of the stability of a slope to the variation in the key vegetation and soil parameters. Results show that vegetation plays an important role in stabilizing shallow-seated failure of slopes and significantly affects stability.

Slope instability is one of the major problems in geotechnical engineering where disasters, like loss of property, do occur. 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 increase population over recent years, the exploitation of renewable natural resources has increased dramatically. One of the effects of consequences has been the destruction of some of forests and this has been particularly noticeable over the last ten years. Natural disasters, such as floods, droughts and sea levels rise have also had an effect on the life condition of many people (Wu, 1984). In particular, Iran has a long history of landslides, which have caused a 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 vegetation cover and concluded that the shear strength contributed by 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 a result of a particular combination of geology, topography and climate. Furthermore, the cause of landslides may be due to 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 about strategies for stability in this region would be of particular interest to local stakeholders and farmers.

Vegetation has long been considered to improve slope stability (Bibalani, 1996; Bibalani *et al*., 2006); In particular, the roots of vegetation 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, this reducing moisture content, therefore helping to increase the stability of the slope. Therefore the root influence of vegetation 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):

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

This study investigates the effects of vegetation on the stability of slopes using the Bishop method. To limit the scope of this study, only the effects of root reinforcement are incorporated in the slope stability analysis. The variability in the vegetation are considered for <20, 20-40, 40-60 and >60% canopy cover for Tea and soil properties are not considered in this study. Six homogenous slopes with angle of inclination 15, 18, 21, 23, 27, 30 and 33° degree 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 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.

Wu *et al*. (1979) incorporated the effects of vegetation in slope stability analysis by using 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 roots improved the stability of slopes.

The main contributory factors which affect slopes stability are as follows; (Watson, 1995), angle of slope, Angle of internal friction and percentage of vegetation covers (by effect with 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 and earthquake and tectonic forces.

These factors have not been considered in this study: As Iran has a long history of landslides, our research deals with the effect of scrubs on slope stability, in particular, the economic interest such as tea (*Thea sinensis* L.). The study was carried out in Roudsar Township in Gilan State of Iran. In this area of 15 ha were considered suitable for the purposes of this study. A large part of the area had slopes of steep gradients on which tea garden was present.

MATERIALS AND METHODS

The experimental site was situated in SE Roudsar, Iran with latitude 36°58'N, longitude 50°21'E, altitude 150 m on a north-facing slope. It is a part of the Rahimabad District of Roudsar Township (Fig. 1). The site was characterized by a silt clay soil. A part of the study area (about 15 ha) has hillsides of steep gradients, with tea vegetation that have been established after clearing the previous forest vegetation about 15 years ago. This planting of tea has caused instability of the steep slopes and landslides occur mainly in these areas.

The mean annual precipitation is about 1700 mm. A rainy season starts normally in early September and ends in the end of May (Fig. 2). The field tests were carried out from June to August 1998- 2001.

Trial pits with 90 cm diameter and about 150 cm depth was excavated on different slope (15, 18, 23, 27, 30 and 33°) where no landslides had occurred. This area has been chosen in order to quantify the contribution of vegetation to soil reinforcement. The numbers of roots, with diameters of 10, 8 and 4 mm ranges were counted. Random soil samples with 20 cm diameter were taken from 70 ha outside of landslide area on which Laboratory tests were carried out to determine certain mechanical characteristics. Triaxial tests were carried out soil samples without root in the Laboratory. Pore

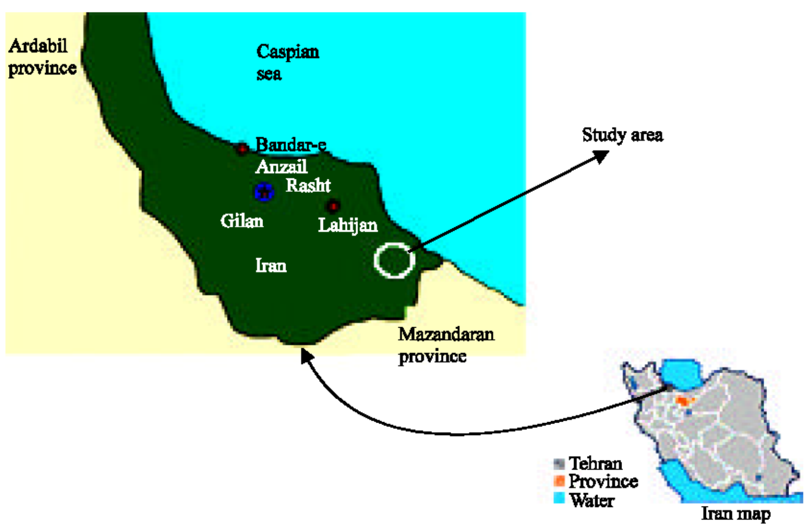

Fig. 1: The geographical position of Gilan State in Iran

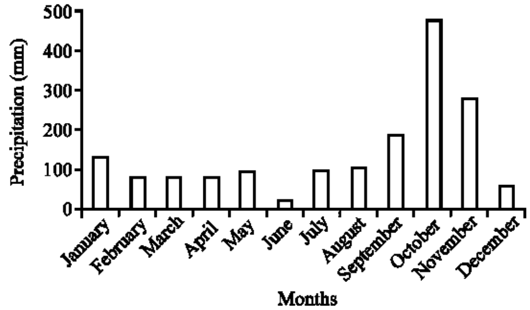

Fig. 2: Average monthly precipitation of study area

pressure was distinguished with triaxial tests on soil samples. Shear tests were carried out without root in soil Laboratory. The following equation is used to determine the increase in shear strength of soils (ΔSR) containing plant roots (Bibalani, 2003):

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

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 (Bahniya, 1993). Mean automatic procedure was developed for calculation purposes (Bibalani *et al*., 2005). The FS is calculated from:

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

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 amount ΔSR, it is possible to calculate the angle of internal friction of soil (ϕ_2) and safety factor (FS) without (FS_1) or with (FS_2) plant roots.

From ΔSR (additional soil resistance with roots) can be calculating angle of internal friction with roots in soil (ϕ_2') with: (Bahniya, 1993).

$$\tan\Phi = \frac{SR+\Delta SR-c}{h.b.l.dan} \tag{4}$$

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 cohesion

RESULTS

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

Relationship between angle of internal friction (ϕ) and safety factor of soil without roots (FS1) was shown for angle of slope 15, 18, 23, 27, 30 and 33 degrees (Fig. 3).

Table 1: Seven Soil sample properties from 90 soil samples in different slopes and areas (for example)

Slope	b	u	ϕ_1	c	α	L	h	dan	FOS_1	DIA	n	TR	ϕ_2	FOS_2	AR/A
1	70	0.4	23.5	0.3	17.1	15	3.5	1.5	1	1	-	14.2	25.1	1.2	0.08
										0.8	11	16			
										0.4	24	21.9			
2	45	0.3	21.2	0.2	26.5	15	3	1.5	0.9	1	-	14.2	23.3	1.1	0.10
										0.8	14	16			
										0.4	23	21.9			
3	50	0.3	18.7	0.3	23.5	20	2.5	1.5	0.9	1	-	14.2	21.2	1.1	0.09
										0.8	13	16			
										0.4	21	21.9			

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 = No. 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)

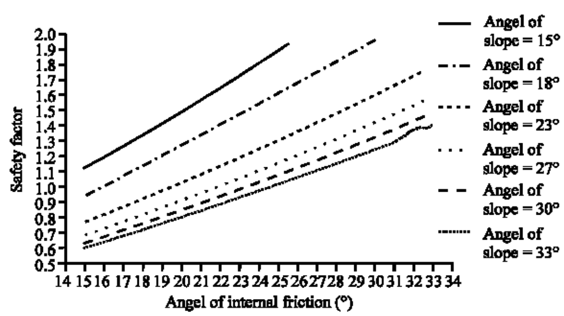

Fig. 3: Safety factor of soil without vegetation cover on different slope angles

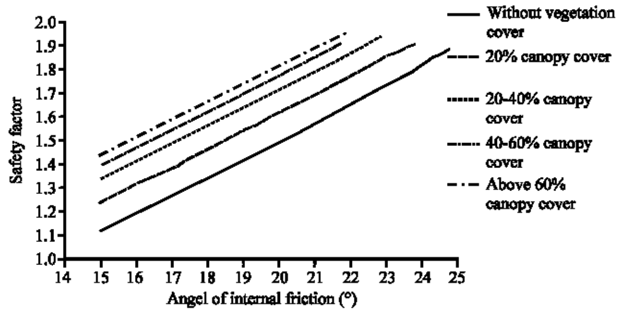

Fig. 4: Safety factor of soil with tea plants on a 15° slope with different percent of canopy covers (CC%)

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

$\phi\backslash\alpha$	15	18	23	27	30	33
15	20-40%	U.st	U.st	U.st	U.st	U.st
16	St	20-40%	U.st	U.st	U.st	U.st
17	St	St	U.st	U.st	U.st	U.st
18	St	St	U.st	U.st	U.st	U.st
19	St	St	U.st	U.st	U.st	U.st
20	St	St	U.st	U.st	U.st	U.st
21	St	St	>60%	U.st	U.st	U.st
22	St	St	40-60%	U.st	U.st	U.st
23	St	St	20-40%	U.st	U.st	U.st
24	St	St	St	U.st	U.st	U.st
25	St	St	St	U.st	U.st	U.st
26	St	St	St	20-40%	>60%	U.st

ϕ = Angle of internal friction of soil 15-26°, α = Angle of slope (such as 15, 18, 21, 23, 27, 30 and 33°), St = Stable and U.st = Unstable with any vegetation

Relationship between angle of internal friction (ϕ) and safety factor of soil with different ground cover of Tea vegetation (FS_2) was shown for angle of slope 15° (Fig. 4).

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

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

DISCUSSION

This study has revealed and quantified effect of tea (*Thea sinensis* L.) in the N Iran, a phenomenon by means of which the vegetation stabilizes the slopes in the Roudsar and probably also in other areas where tea gardens 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 is the removal of the natural forest cover of the slopes to create tea garden. In order to increase the FS of slopes in this area with gradients more than 25% the least 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 carried out to determine which crown cover of tea provided the best reinforcement to slopes in the Gilan Province. Soil shear tests were carried out on samples with and without roots of *Thea sinensis* L. and the slope FS calculated. Results are discussed with regards to practical implications in this area.

In this case study minimum FS which corresponds to *Thea sinensis* L. vegetation with 20-40% crown cover, a soil internal friction angle of 15° and a slope angle of 15°. When soil internal friction angle equals 20° and slope angle is more than 23°, slope stability can not be increased by tea vegetation species.

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 tea roots of garden species on soil slope stability. Tea dose not suitable when increase slope angle. It is likely that mature tea scrubs would provide good root anchorage on slopes.

It is important to appreciate that the significance of mechanical stabilisation of slopes by vegetation roots depends 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.

It is a pioneer study and the results have given estimations effect of the root 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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