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The Side Roots Pulling Effect of Alder (*Alnus glutinosa*) on River Bank Soil Strong in North Iran

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Abstract: To verify whether or not a pulling effect exists in the root system of Alder (*Alnus glutinosa*) in the Roudsar, North Iran and to study the importance and size of this effect, a direct *in situ* test was led at a site in the Chaboksar Forests. The results from the site showed that, in the surface soil (0-30 cm), side roots can provide a pull force of up to 450-860 N (Newtons) over a vertical cross-section area of 20-50 cm^2, or an enhance in the pulling stability of the rooted soil by 9.8-52.8%. The test results suggest that, together with the Alder vertical roots, which keep the little depth rooted soil zone to the deep and more stable soil mass, the side roots of the Alder, with their pulling effect, are able to make less against little depth instability in the forest slopes, such as little depth slide, to a certain degree.

Key words: Iran, alder, the side roots, forest, soil strong, *Alnus glutinosa*

INTRODUCTION

As the importance of river side vegetation for quality of water, aquatic habitat and stream restoration is well accepted, the effect of vegetation on river side are multiple and have not to be fully studied (Mosley, 1981; Hickin, 1984; Abernethy and Rutherfurd, 2000). Stream protection plan and river side vegetation shield need to be studied for long time period.

Many of the benefits of river side vegetation are connected to distribution of root systems in soil. River bank retreat typically results from erosion of the bank. Roots add to the resistance of soil, support them more resistant to erosion and bank landslide. Root systems of woody plants protect bank soils in place, adding to the soil critical shear stress. Additionally, root exudates may increase soil cohesion chemically (Abernethy and Rutherfurd, 2001; Mamo and Bubenzer, 2001). The erosion rate decreased linearly with increases in the percentage of root biomass. Rate of soil Erosion was inversely proportional to root length density and root volume, respectively (Wynn *et al*., 2004).

There is important discuss in the papers about the good related of herbaceous versus woody tree vegetation in river bank stability (Lyons *et al*., 2000; Simon and Collison, 2001). Herbaceous vegetation has a greater density of very fine roots, as compared with woody tree vegetation (Tufekcioglu *et al*., 1999). This high root density will probably produce greater soil critical shear stress under herbaceous vegetation; however, river side stabilization develops only with rooting depth (Thorne, 1990). While trees have little fine roots, they also have a large rooting depth (Gregory and Gurnell, 1988). Density of root at the river side toe is more critical for river side stability, as hydraulic shear stress increases with stream depth. As a research, undercutting of grass banks is commonly observed (Davies-Colley, 1997). Millar and Quick (1998) identified that the mean soil critical shear stress for forested river side was two to three times that of grass-covered river side.

The in-plane strength is the tensile strength of a soil-root combined membrane or skin that ties together the underlying soil (Fig. 1). It is present in contrast to the effect of vertically-enlarge roots, which strengthen the soil by increasing the shear strength of the rooted soil mass over the sheared surface. This side pulling effect is analogous to the lateral reinforcement phenomenon mentioned by Sidle (1991).

A network of roots and intertwined side roots at little depth form a continuous mat which provides good keeping and so, a significant degree of in-plane strength (Coppin and Richards, 1990). Dense networks of medium to small side roots strengthen the top soil so that it acts as a membrane of side or tensile strength that holds the below soil in place (O'Loughlin *et al*., 1982; Sidle *et al*., 1985; Sidle, 1991). Swanson and Wanston (1977) and

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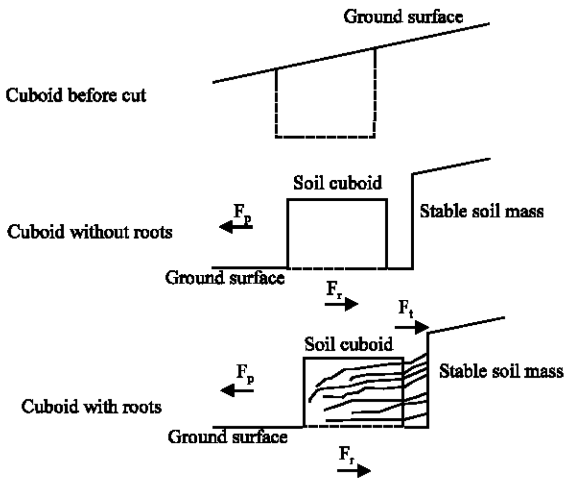

Fig. 1: Schematic diagram of the ideal soil cuboid on slopes (the in-plane strength). F_p: pulling force, F_r: stability of the cuboid, F_t: root tractive force

Schroeder (1985) implied that side strong across planes of weakness at potential failure sites may be an important resistance mechanism in little depth and even deep soils.

Collected stability is moved to the stressed mass, in the form of tensile stability in the roots, to increase its in-plane tensile strength. The magnitude of the pulling effect depends upon the strength of the soil and roots and the strength of the root-soil bond. If the maximum stability by the roots does not balance the stronger sliding or pulling force, roots will be either pulled out from the soil (i.e., bonding failure), or broken (i.e., tension failure) and the pulling effect fails. Where the roots are dense, they tend to be more effective in stabilizing the rooted soil (Bibalani *et al*., 2005).

Generally, soil-mass sliding or creep results in a number of crevices on the slope surface at an early stage (Hunan Province Institute of Water Conservancy, 1983). In any rooted soil, a number of roots will be found crossing the crevices from both sides.

Alder (*Alnus glutinosa*) is widely distributed in Chaboksar, Roudsar, at N Iran. Alder trees have a tap root system, normally 0.5-1.80 m deep. The little depth side roots are very well developed, with over 75% of the total root system growing within 60 cm of the surface. These side roots intertwine with each other and ramify to form a root network which is more or less parallel to the soil surface. They taper gradually, extending over a relatively long distance. A little depth pulling effect very likely exists in the side roots of these forests and is probably significant for little depth stability. The purpose this study is to examine the pulling effect of the Alder trees and quantify its magnitude.

The cuboid will produce a shear-resisting force, arising solely from the shear strength of the soil, to resist the pulling force (F_p). If there are some roots coming from the soil mass behind and passing through the cuboid, the bonding force at the soil-root interface and the tension in the roots will be mobilized at this time. Thus, a root tractive force will be produced to offset the pulling force. As a result, the soil cuboid receives extra stability, due to the tractive force and is able to bear a higher pulling force without changing the actual shear strength on its bottom surface. If there are no roots in the cuboid, however, the cuboid will resist the pulling force only with the shear-resisting force of the pure soil and the pulling force will be directed wholly towards shearing the soil cuboid.

MATERIALS AND METHODS

The Chaboksar forests are located in the North region of Iran, in Gilan Province with latitude 36°, 33', 16½ N and longitude 50°, 41', 25½ E (Fig. 2). The land forms have developed into V-shaped valleys, with slope gradients of about 40% and a vertical altitudinal range of about 950 m. Because of the steep slopes and the clearing of Alder vegetation, the surface slope materials move down-slope. In most areas of the Chaboksar forest, little depth mass instability is also predominant. The mean annual precipitation is 1540 mm. A rainy season starts normally in early December and ends at the end of June (Fig. 3). The field tests were led from July to September 2007.

Except for the occasional, relatively gentle cultivated slope, most of the Chaboksar forests area is covered with natural vegetation. Tree vegetation is the main vegetation type and is dominated by Alder (*Alnus glutinosa*). These forests have average canopy coverage of 65%, with only an Alder canopy layer. Trees are 8-25 m in height and their diameter of tree is normally about 10-40 cm. The grass layers under the trees are poorly developed. Trees' tap roots normally extend 1-3 m downward into the soil and unconsolidated weathering products; the longest side root observed during this study was 4.75 m. Many medium to small side roots were observed spreading more or less parallel to the ground and down the slope.

An experimental site was chosen in the central area of the Chaboksar forest. This area has an elevation of 50 m, a slope of 15-40° and N aspect. Its soil has silty texture and bulk density of 1.32 g cm^{-3}. Volumetric soil moisture during the period of field measurement averaged 12.5%, at 15-20 cm depth. A large rectangular plot 30 by 40 m in size was chosen for the direct *in situ* test area.

To test the pulling effect, two groups of soil cuboids were selected randomly, from the large rectangular plot,

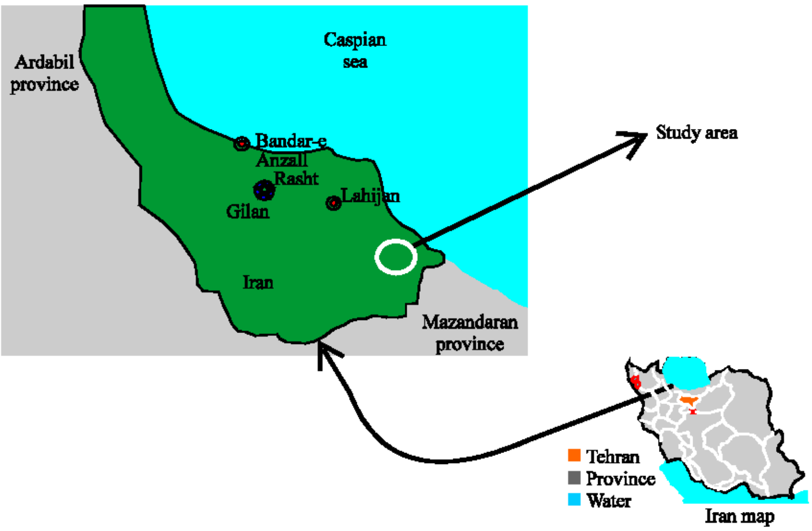

Fig. 2: The geographical position of Gilan Province in Iran

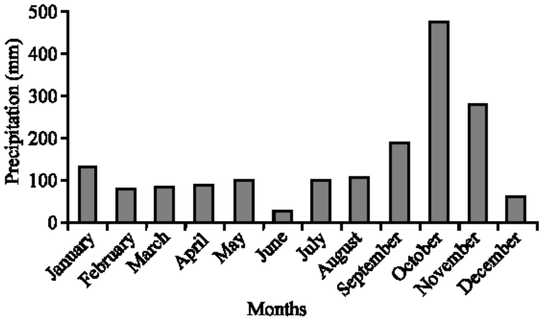

Fig. 3: Average monthly precipitation of Chaboksar area

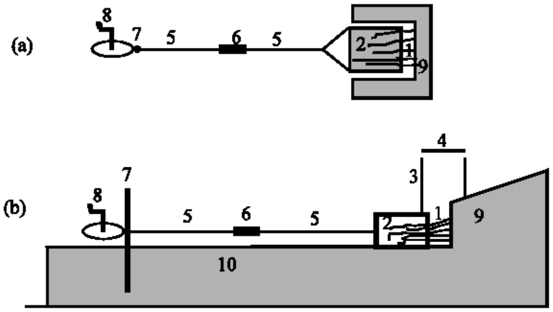

Fig. 4: Schematic diagram of the apparatus of the direct *in situ* test. (a: vertical view and b: side view) Roots (1), shearing box (2), displacement pole (3), meter (4), steel cable (5), stability strain gauge (6), steel thick nail (7), pull jak (8), stable soil (9), little depth soil layer (10)

one group with roots and one without; and all cuboids were cut at their four sides. This study does not consider the effect of the adjoining soil mass on the cuboids pulled, but only investigated the pulling-displacement behaviour of the cut cuboids and the tractive force by the roots on a fixed cross sectional area. In addition, it is only concerned with roots enlarge more or less in the direction of the pulling force, which bear tensile stress (Bibalani *et al*., 2006).

The instrument system used consisted of four main parts: a pull jack to create the pulling force, a shearing box to apply the pulling force (F_p) on the cuboid, a Stability Strain-gauge, consisting of a stability meter to measure the magnitude of the force and a displacement device to measure the displacement of the cuboid (Fig. 4).

The size of soil cuboids dug in the field was 35 cm wide, 30 cm long and 20 cm deep from the ground surface. Each cuboid was cut at the front surface facing down-slope and its bottom surface was left connected to the soil mass below. At the side and back surfaces, small troughs, 20 cm in depth and about 5 cm width, were carefully carved so that the penetrating roots exposed in the back trough were left intact as much as possible. These roots came from the stable soil mass up slope, enlarge into the cuboid from the back surface. Some roots enlarge perpendicular to the pulling direction occasionally also extend into the cuboid from its side surface, but were cut when found. Altogether, seventeen soil cuboids were examined at this area (Chaboksar forests). Nine of them were control samples, which were cut completely on all four sides, without any roots side roots entering into the cuboid. All the plots for the cuboid test were randomly chosen from the top, middle and bottom parts of the large rectangular plot.

After the soil down slope from the cuboid was cleared and the three small troughs excavated (back and sides), the shearing box was installed, which was assembled around the soil cuboid. F_p was increased as evenly as possible and the shearing box was slowly displaced. After each cuboid was sheared off and the shear box later disassembled, the roots penetrating into the cuboid were collected and weighed, to determine the relationship between root biomass and the tractive force exerted by the roots.

At any time during the pulling process, the pulling force on the cuboid (F_p, N) could be read from the stability meter. Using the following Eq. 1, the tractive force by roots at the time the cuboid was sheared off (F_{Tf}, N) was then was calculated.

$$F_{Tf} = F_{pf} - F_{control\ ave} \tag{1}$$

F_{pf} is the F_p at the time the cuboid fails and $F_{control\ ave}$ is the average pulling stability force on the non-rooted cuboid.

RESULTS

When the shearing box was assembled, it was pulled slightly forwards so that there was no space left between the soil cuboid and the box frame at the back. The sampled cuboid did not move much in the beginning of the test when the pulling force (F_p) alone was imposed. It became somewhat deformed at the back of the shearing box, to differing degrees. The soil in this area expanded upwards slightly under the great pressure induced by the shearing box. At this stage, although the stability value on the stability meter quickly rose, the whole cuboid continued to stay in approximately the same place and resisted the F_p.

Some displacement of the shearing box was measured at this time. This was caused partly by soil deformation at the back of the cuboid and partly by a minor movement of it, normally being too little to be observed at this stage. When F_p was increased to a higher value and the displacement went beyond a specific displacement, or critical displacement, the cuboid's bottom surface then was sheared off and it suddenly moved forwards. In the case of the non-rooted samples, it was pulled away after failure and F_p declined to a low level of the residual stability. For the rooted samples, F_p did not drop immediately after the failure and sometimes its value rose slightly again. This is probably was because different roots broke at different times and some roots still resisted F_p shortly after failure of the cuboid. Most roots were broken when they provided stability; very few were pulled out.

It was assumed that the difference in soil property between the rooted and non-rooted cuboids was negligible and that all the roots examined were more or less equally involved in the pulling effect. When pulled, the two groups resisted the pulling force F_p to different degrees. This difference in response to the F_p is assumed to be an indication of the result of the pulling effect and an indication of the magnitude of the Alder (*Alnus glutinosa*) root tractive force. Generally, the F_p values of the rooted samples at critical displacement (critical X), beyond which the soil cuboid failed, are higher than those of the non-rooted ones, showing their greater F_p at critical displacement (F_{pf}). F_{pf} for the rooted samples averaged 689.8 N, with a variation from 450-860 N (Table 1), compared with an average F_{pf} for the non-rooted samples of 405.5 N (290 N-520 N). The rooted cuboids reached their F_{pf} a bit later (displacement reaches about 6.5 mm) than those of the non-rooted ones (average 3.7 mm), indicating a larger critical X of the rooted samples.

When a sampled soil cuboid was pulled, its pulling force (F_{pf}) at different displacement intervals throughout the pulling process was recorded. Using the displacement intervals as the independent variable, from 0.5 to 1 cm on a log scale and the recorded F_{pf} values at different displacements, as the dependent variable, regression relationship diagram of F_{pf} with X can be drawn, which shows the X-F_{pf} curves were developed for the rooted and non-rooted soil cuboids. Figure 5 displays a scatter gram of the points along with two fitted regression lines for the rooted and non-rooted treatment, which can be used to predict F_{pf} values given a value of X. The two regression lines in Fig. 5, respectively, represent the general pattern for the F_{pf}-X curves of the 17 rooted and 9 non-rooted samples tested. It indicates that the rooted cuboids generally have higher F_p values than those of the non-rooted cuboids. The area between the two curves in Fig. 5 represents the increased F_{pf} on the rooted soil cuboids over the non-rooted ones and is an indication of F_T (the tractive force).

Table 1 and Fig. 5 suggest that side roots increase the pulling-stability force of the soil cuboid against F_{pf}. The higher F_{pf} for rooted samples indicates that F_{pf} has mobilized the tractive force (F_T) of the roots and the cuboids therefore receive an extra level of stability. When the cuboids are pulled, the average F_{pf} of the rooted samples increased beyond the average stability ($F_{control\ ave}$) of the non-rooted samples and the displacement increased beyond the critical X of the no rooted soil samples, before cuboid failure occurred.

The soil conditions of the cuboid were similar and therefore the soil-shear strength should not differ very much from place to place.

Table 1: Pulling force, tractive force and root biomass of Alder (*Alnus glutinosa*) at Chaboksar forest

	Aspect							
Samples	F_{pf} (N)	Critical X (mm)	F_{Tf}(N)	Increased F_{pf} (%)	Root biomass (g)	Mean F_{pf} (N)	Mean FTf (N)	Total increased F_{pf} (%)
Rooted samples								
1	820	6	414.5	50.5	372	689.8	284.3	39.5
2	518	5	112.5	21.7	175			
3	690	6	284.5	41.2	272			
4	620	7	214.5	34.5	240			
5	750	7	344.5	45.9	309			
6	790	8	384.5	48.6	336			
7	675	8	269.5	39.9	265			
8	645	7	239.5	37.1	245			
9	810	7	404.5	49.9	355			
10	550	6	144.5	26.2	190			
11	695	5	289.5	41.6	279			
12	770	8	364.5	47.3	324			
13	860	5	454.5	52.8	395			
14	450	5	44.5	9.8	150			
15	740	7	334.5	45.1	302			
16	660	7	254.5	38.5	260			
17	685	8	279.5	40.7	270			
Non-rooted samples								
1	350	4						
2	380	4						
3	390	3						
4	320	3						
5	425	5						
6	480	5						
7	290	3						
8	495	3						
9	520	4						

F_{pf} = pulling force at failure of the cuboids. Critical X = critical displacement. F_{Tf} = root tractive force at failure. Increased F_{pf} = increment of pulling stability due to the root pulling effect. Root biomass is the fresh weight

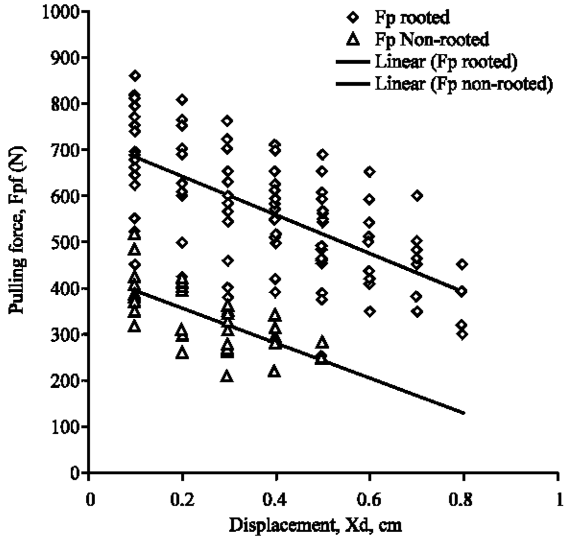

Fig. 5: Relationship between pulling force (F_{pf}) and displacement (X) for rooted and non-rooted soil cuboids at Chaboksar forest. Data on 17 rooted and 9 non-rooted cuboids

The root tractive force F_T at the critical X (or F_{Tf}), based on the average Fp, using Eq. 1 averaged 284.3 N. Based on individual F_p values the range was 44.5 to 454.5 N. Under the influence of this F_{Tf}, the average pulling stability force on the rooted cuboids increased by 39.5%, which is considerable.

Tractive force (F_T) varied more or less with the root biomass, as suggested in Table 1. Though exceptions existed, the higher the root biomass was in each soil cuboid pulled, the greater the tractive force measured. Correlation analysis yielded the following relationship with F_T positively related to the root biomass:

$$y = 0.6052x-138.73$$
$$R^2 = 0.9869 \qquad (2)$$

Where:

F_T = Tractive force
R_B = Root biomass

DISCUSSION

The pulling effect has a magnitude which may vary from point to point to a certain degree, due to the variations of roots and soil, but the variation should not be very large as indicated by the field test results (Table 1, Fig. 5).

It should however be noted that the direct *in situ* tests used in this study likely underestimated the magnitude of the pulling effect to some extent. In the field, after the small troughs had been dug to the rear of the cuboids, the penetrating roots were hung across the trough and consequently lost their original bearing points for the pulling effect. They may not have provided as great a tractive force as would otherwise have been the case. For these reason, the pulling stability of the cut cuboids tested is lower than it would have been under entirely natural conditions. Also, the direct *in situ* test further underestimates the tractive force in two ways. Firstly, roots below 2 mm in diameter were mostly destroyed during the excavation of the soil cuboids and they are not included in the measurements. Secondly, some roots from the stable mass may not have penetrated into the cuboid, but rather extended into the trough along on of the sides. Such roots also have not been taken into consideration.

Due to this underestimation by the direct test, the possible range of the magnitude of the potential tractive force, provided by little depth roots in the given vertical cross-section area within the top soil profile could be somewhat higher than the results of the direct test. Therefore, the *in situ* test could be considered the lower-limit estimate of the magnitude. At Chaboksar forests, the lower-limit estimate is 450 N.

The side roots of *Alnus glutinosa* provide tensile strength to the top soil and protect the soil mass below as well. On the Alder forests slopes, the combined effects of vertical and side roots function together: while the dense side roots bind the little depth soil mass to form a membrane with increased tensile strength, the vertical roots anchor the tensile membrane to the deep and more stable soil mass. With the combined effect, the side roots are able to stabilize the top soil against little depth slide and creep.

This study has revealed and quantified the pulling effect of the Alder tree in the Chaboksar forest lands, a phenomenon by means of which the tree stabilizes the slopes in the Roudsar and probably also in other areas where the Alder (*Alnus glutinosa*) is growing. Research indicated that river bank soil strong was strongly influenced by the side roots pulling effect of Alder. Further study on the effects of tree roots pulling effect on stream bank erodibility is necessary. Given the large variability in root pulling effect found in this and other studies, future studies should include river bank soil strong at the river bank. Results based on this samples or limited areas may be misleading and may not be applicable beyond the localized environment (Bibalani *et al*., 2006).

It is a pioneer study and the results have given estimates of the root tractive force of the Alder for the first time in Iran. The findings and methodology of the study may be applied in other areas and to other tree plants.

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