Effect of Oriental beech root reinforcement on slope stability (Hyrcanian Forest, Iran)

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ABSTRACT: Vegetation significantly affects hillslope mechanical properties related to shallow landslides and slope stability. The objective of this study was to investigate and quantify the effect of Oriental beech root reinforcement on slope stability. A part of Hyrcanian forest in northern Iran was selected for the study area. To do the research, the Wu model (WM) was used and data related to the distribution and tensile strength of Oriental beech roots were collected. Root distribution was assessed using the concept of the root area ratio and trenching method. Laboratory tensile tests were conducted on fresh roots for strength characteristics. The factor of safety was calculated for two different soil thicknesses (1 and 2 m) and slope gradients between 10 and 45°. The results showed that the root distribution generally decreased with increasing soil depth and the mean root strength value was 38.23 ± 1.19 MPa for 0.35–5.60 mm diameter range. The results verified a power relationship between tensile strength and root diameter. The reinforcement effect (C_r) decreased with depth and the strongest reinforcement effect was in the second soil layer (10–20 cm) which showed a shear strength increase of 1.47 kPa. The increased factor of safety due to the presence of roots in one- and two-metre soil thicknesses was 27–44% and 15–26%, respectively. The improvement effect of roots was increased with increasing slope gradient and shallower soil thicknesses.

Keywords: root distribution; slope stability; soil reinforcement; tensile strength; Wu model

Past experiences show that slopes under vegetation are stable and more resistant to erosion (Gray, Sotir 1996; Genet et al. 2008; Mao et al. 2012). Natural slopes (like mountain forests) have usually been formed over long periods of time and each change (e.g. road construction) may cause these slopes to fail (Genet et al. 2005). Unstable slopes create numerous problems for forest management and may destroy the road network and prevent access to the forest. Soil bioengineering is a solution and defines the use of plant (grass, shrub or tree) materials to perform some engineering functions like soil reinforcement that can prevent instability. Among different parts of vegetation, roots are known as an important material for bioengineering purposes. Roots increase the soil shear strength directly by mechanical reinforcing, anchoring the soil layer and forming a binding network within the layer, and indirectly through water removal by transpiration (Waldron 1977; de Baets et al. 2008). Roots also affect some properties of the soil, such as infiltration rate, aggregate stability, moisture content, shear strength and organic matter content, all of which control soil erosion rates to various degrees (de Baets et al. 2008). The magnitude of root reinforcement mostly depends on root distribution and root mechanical properties (especially root tensile strengths) (Bischetti et al. 2005; Genet et al. 2008; Ji et al. 2012; Naghdi et al. 2013). The most common index for root density in bioengineering studies is the root area ratio (RAR) which provides a measure of root density within the soil. Root density, in particular, shows an extremely large spatial variability, both in the vertical and the horizontal planes. One of the important mechanical characteristics of roots is that they are strong in tension. On the other hand, the soil is strong in compression and weak in tension. A combined matrix of soil and roots results in a reinforced soil (Genet et al. 2005; Vergani et al. 2012). When the soil is sheared, roots mobilize their tensile strength whereby shear stresses that develop in the soil matrix are transferred to the root fibres via interface friction along the root length (Gray, Barker 2004) or via the tensile resistance of the roots (de Baets et al. 2008). The root tensile strength has an important role in soil reinforcement and is highly variable, with reported values from thousands to millions of pascals in previous studies (Simon, Collison 2002).

Despite the large and extensive amount of studies on root density (e.g. Jackson et al. 1996; Danjon et al. 1999), most of them focus on root growth, phenology (Cazzuffi et al. 2006) and eco-physiological behaviour of vegetation and do not provide any data useful for root reinforcement estimation. Nevertheless, due to the complexity of reinforcement mechanisms, the variety of species and environments and the spatial variability of characteristics driving the processes, these studies can be considered site-specific and more experimental data are still needed for the complex understanding and generalization of the phenomenon.

During the last two decades, several investigations have been conducted to improve our understanding of root reinforcement of soils all around the world (e.g. Abernethy, Ruthefurd, 2001; Bischetti et al. 2002; Genet et al. 2005, 2008; Naghdi et al. 2013) but few studies have been conducted investigating the influence of *Hyrcanian* plant roots on the soil strength (e.g. Biba-lani, Majnonian 2007; Abdi et al. 2009, 2010) and information on *Hyrcanian* plant root characteristics and their use for soil erosion control is very limited. Therefore the objectives of this paper were (1) to assess strength properties of Oriental beech roots as a common species of *Hyrcanian* forests and (2) to investigate and quantify the effect of root reinforcement on slope stability.

MATERIALS AND METHODS

Study area. Of the five floristic regions of Iran, Oriental beech occurs wild in only one, the Hyrcanian forests. This area falls within the northward slopes of the Alborz Mountains of Northern Iran to the southern shores of the Caspian Sea. The study site (latitude 36°29'N, longitude 50°33'E) is located in the middle part of the Hyrcanian forests. The site has the relatively thin clay soil mantle, underlain by the calcareous bedrock (Jura, Cretaceous) that contains discontinuities and cracks which are penetrable by roots. Usually critical failure planes have 1–2 meters in depth in the study area and are classified as shallow slides, therefore roots may have a significant effect in reinforcement. The soil texture in the Unified Soil Classification System (USCS) is CL with 1.48 $kN \cdot m^{-3}$ maximum dry density and 26% optimum moisture content. The strength parameters (C and ϕ derived from a direct shear test) of soil are 0.03 kPa (cohesion) and 25° (internal friction) for an undisturbed soil sample (Abdi et al. 2010). The average annual rainfall at this site is 1,200 mm, falling mostly as rain and including a cover of snow in winters. The mean summer and winter temperatures are estimated to be 22.5°C and 10°C, respectively.

Oriental beech (is known as the most important commercial species in these forests) is a large deciduous tree that can grow up to 32 m in height. It produces a spreading, rounded crown of shiny dark green foliage. It occurs at elevations up to 2,200 m a.s.l. Data on biotechnical properties of this species is very limited especially in Hyrcanian forests.

Root distribution. Variation in root distribution can be assessed using the concept of root area ratio (RAR), which has been defined as the ratio of the sum of the root areas to the area of the soil profile they intersect (Wu et al. 1979). In order to obtain RAR values, a profile trenching method was used (Abernethy, Rutherfurd 2000; Bischetti et al. 2005). Five sample trees were selected randomly and around each sample tree two trenches were excavated by hand at a distance of one meter from the stump, down to the maximum rooting depth (Abernethy, Rutherfurd 2001). The trenches were located up and down hillsides to represent the average condition of root system on the hillside (average RAR values of each two pairs were considered for samples). Terrain gradient, aspect and soil depth were the same for all samples as we restricted the area to a uniform hill. Trenches (ten trenches) were excavated to expose the fresh profile of rooted soil. Ten cm thick layers were marked on the vertical profile walls using pins and string (Fig. 1).

Diameters of all roots intersecting the trench wall were measured with a vernier calliper (Sun et al. 2008). Then the relation between RAR distribution and soil depth was calculated.

Root tensile strength. For tensile tests live roots were collected randomly from soil by excavating pits or trenches (up and downslope) at a depth of about 30 cm below the soil surface (Cofie, Koolen 2001). In order to prevent pre-stress effects, none of the roots was pulled; instead they were cut with sharp scissors, put in plastic bags and loosely sealed (Bischetti et al. 2005). Tensile tests were carried out on fresh roots within two days from sampling (Bischetti et

Fig. 1. The position of soil layers in the trench wall

al. 2005 showed that one-week storage did not have any significant effect on tensile properties). In the laboratory the roots were thoroughly inspected for possible breakage. Root hairs were carefully dismembered and suitable root samples of lengths of about 150 mm were cut (Cofie, Koolen 2001). Before the beginning of each experiment, average root diameter was found out by measuring diameters at about three different positions along the length of the root (de Baets et al. 2008; Abdi et al. 2010). Tensile strength testing was carried out using an Instron Testing Machine (Model 4486, Norwood, USA). The root ends were clamped and a strain rate of 10 $mm \cdot min^{-1}$ (Bischetti et al. 2005; Mattia et al. 2005; Abdi et al. 2010) was applied until rupture occurred. The applied force required to break the root was taken as the measure of root strength. Tensile strength was calculated by dividing the applied force required to break the root by the cross-sectional area of the root at its rupture point.

$$TS = \frac{F_{max}}{(\frac{\pi}{4}) \times D^2} \qquad (1)$$

where:

TS – tensile strength,

F_{max} – maximum force to break the root,

D – root diameter.

Tests subject to slippage, or those roots that broke because of crushing at the jaw faces, were disregarded (Cofie, Koolen 2001; Bischetti et al. 2005; Mattia et al. 2005). Sixty-three root samples were analysed for strength characteristics.

Soil reinforcement. The influence of root reinforcement can be expressed as an added cohesion term in the Mohr-Coulomb failure criteria (Wu 1976) where the soil-root composite shear strength (Sr) is calculated as follows:

$$Sr = c + \sigma \tan \phi + C_r \qquad (2)$$

where:

c – cohesion of the soil,

σ – stress due to the weight of the soil and water of the sliding mass,

ϕ – effective friction angle of the soil,

C_r – apparent cohesion due to the presence of roots.

In the model C_r can be represented by:

$$C_r = K \times t_R \qquad (3)$$

where:

K – 1.04,

t_R – mobilized root tensile strength per soil unit area.

K factor taking into account that roots are randomly orientated with respect to the failure plane which varies between 1.0 and 1.3 in most of the cases (Waldron 1977; Wu et al. 1979) and in this study we considered 1.04 (Abdi et al. 2010). The mobilized root tensile strength per soil unit area (t_R) can be written as:

$$t_R = T_r \times a_r \qquad (4)$$

where:

T_r – average tensile strength per average root cross-sectional area,

a_r – root area ratio.

a_r is computed as A_r/A, where A_r is the total cross-sectional area of all roots and A is the area of soil in the sample count.

Root tensile strength is affected both by species and by differences in size (diameter). The generally accepted form for the relationship between root tensile strength [T_r (d)] and diameter (d) is a simple power function (Bischetti et al. 2005; Gray, Sotir 1996; Mattia et al. 2005):

$$T_r(\mathrm{d}) = \alpha \times \mathrm{d}^{-\beta} \qquad (5)$$

where:

α, β – empirical constants depending on the type of species.

To account for the variability in root size Eq. (5) must then be rewritten as:

$$t_R = \sum_{i=1}^{N} T_{r_i} \frac{A_{r_i}}{A} \qquad (6)$$

where:

N – number of classes,

i – indicates the diameter class,

T_r – average tensile strength per average root cross-sectional area,
A – area of soil in the sample,
A_r – total cross-sectional area of all roots in the sample.

Slope stability. A slope stability analysis may be used to evaluate an existing condition or a proposed solution to determine if it meets the requirement of safety (Wu 1995; Mao et al. 2012). In this research slope stability was investigated by changing the slope gradients between 10 and 45° (the range of slope in the whole study area) and the thickness of the sliding mass of 1 and 2 m (as mentioned in previous sections most of the critical failure planes in the study area are 1–2 m). To determine the factor of safety (FS), SLIP4EX (Nottingham Trent University, Nottingham, UK) was used. SLIP4EX is a computer program for the slope stability analysis and helps to assess the contribution of vegetation to slope stability (Greenwood 2006). FS values were calculated for a soil with no reinforcement and for a soil reinforced by the roots.

RESULTS

Root distribution

A great variability was observed in the RAR values regarding depth and samples (long error bars in Fig. 2). RAR values generally tend to decrease with depth below the surface (except the second and third layers) and maximum values were in the first 30 cm. The minimum and maximum values along the profiles were 0.0004% and 6.15%, respectively (Fig. 2).

Root tensile strength

Tensile force-root diameter and tensile strength-root diameter data had a positive and negative relationship, respectively. The diameter of analysed roots varied between 0.35 and 5.60 mm and the mean strength value was 38.23 ± 1.19 MPa. The results exhibit a relatively great variability of the measured tensile strength of roots (Fig. 3).

The relation between tensile strength and diameter was tested by some regression models whose power was the best based on higher R square and lower standard error of the estimation simultaneously (R^2 = 0.45, standard error of estimation = 0.18).

The results of ANOVA showed that the model was statistically significant ($F_{1,62}$= 50.77, P = 0.000) and t-test also showed that the coefficient and the constant of the model are significant (t = –7.12, P = 0.000 for coefficient and t = 36.25, P = 0.000 for constant). The values of power law parameters (α and β) were 41.12 and –0.26, respectively. Data with the corresponding fitting curve (power) are shown in Fig. 3.

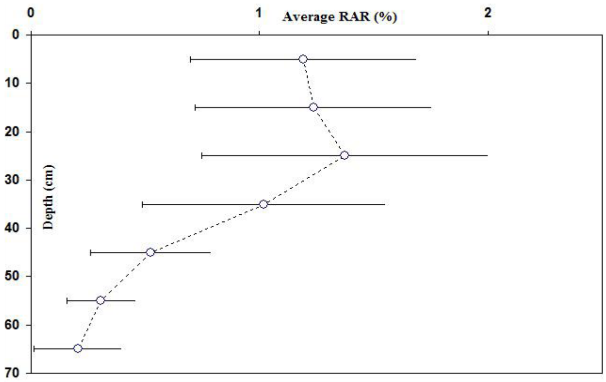

Fig. 2. Average RAR values versus soil depth (mean ± SE)

Soil reinforcement

Similarly like the RAR distribution, the reinforcement effect (C_r) decreases with depth. The strongest reinforcement effect is exerted by the second layer which shows a shear strength increase of 1.47 kPa. Standard error bars show a high variation of C_r (Fig. 4).

Slope stability

Introducing the root reinforcement or C_r leads to higher FS and increased slope stability. Beech roots were able to stabilize the one- and two-metre thick soil up to a topographic gradient of 30 and 25°, respectively. For one-metre depth, FS of the soil without roots is greater than 1 only when the slope angle is less than 25°.

When the root reinforcement is introduced, FS becomes greater than 1 for slope angles less than 35°. For the soil of 2-m depth, slopes without roots are stable only for topographic gradients less than 25° and slopes with roots are stable up to a slope of 25° (Fig. 5).

For a given slope gradient, the influence of root reinforcement on slope stability is larger for shallow soil thicknesses and with increasing soil depth the influence of root reinforcement on FS is decreased. Also for a given soil depth, the influence of root reinforcement on FS is increased as the slope angle increases (Fig. 6).

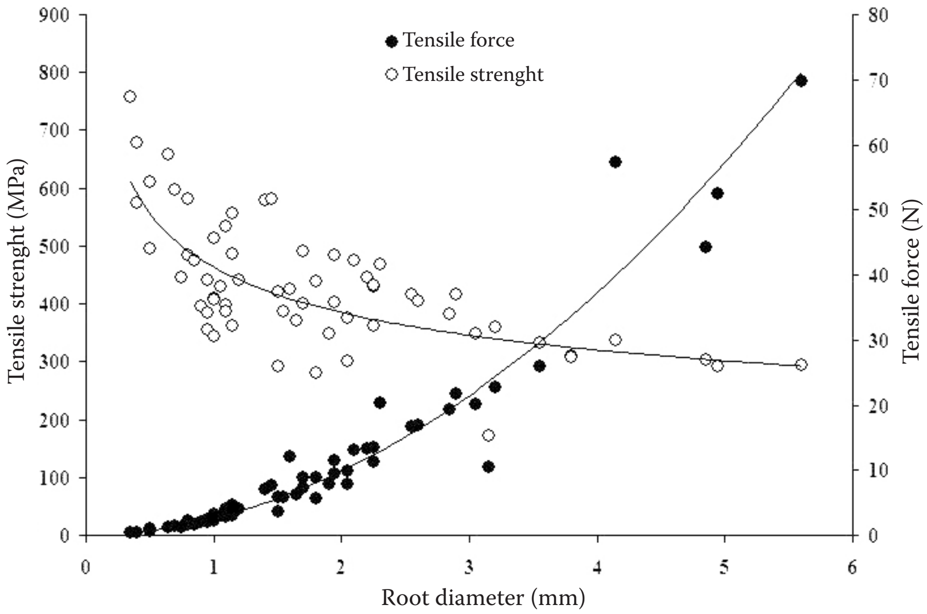

Fig. 3. Relation between force and root diameter ($y = 29.16x^{1.92}$) and tensile strength and root diameter ($y = 41.12x^{-0.26}$)

DISCUSSION

The RAR values are strongly influenced by both genetics and environment (local soil and climate characteristics). In general, the decline of root density with depth below the soil surface was documented by several authors (e.g. Greenway 1987; Nilaweera 1994; Bischetti. et al. 2005). This relation has been attributed to a decrease in nutrients and aeration, and to the presence of more compacted soil layers and bedrock (Bischetti. et al. 2005). We observed a similar RAR pattern where the maximum observed RAR values were located in the upper layers. This means that the highest reinforcement effect is exerted in the upper layers.

Root tensile strength is an important factor that influences slope reinforcement (Stokes et al. 2008) and tree anchorage (Genet et al. 2005). Variation in root tensile strength is high among species and environments (Bischetti et al. 2005) and even between individuals of a particular species within the same environments (Abdi et al. 2010). Tensile force-root diameter and tensile strength-root diameter data had a positive and negative relationship, respectively, as mentioned in previous studies (Nilaweera 1994; Gray, Sotir 1996; Bischetti et al. 2005; Vergani et al. 2012; Ji et al. 2012). Tensile strength data presented in this paper were compared with those for tree species (Greenway 1987). The tensile strength of Oriental beech (38.23 MPa) is comparable with some hardwood species including: *Quercus robur* 32 MPa and *Betula pendula* 38 MPa (Stokes 2002). However, Tosi (2007) stated that these comparisons are sensitive to the number of

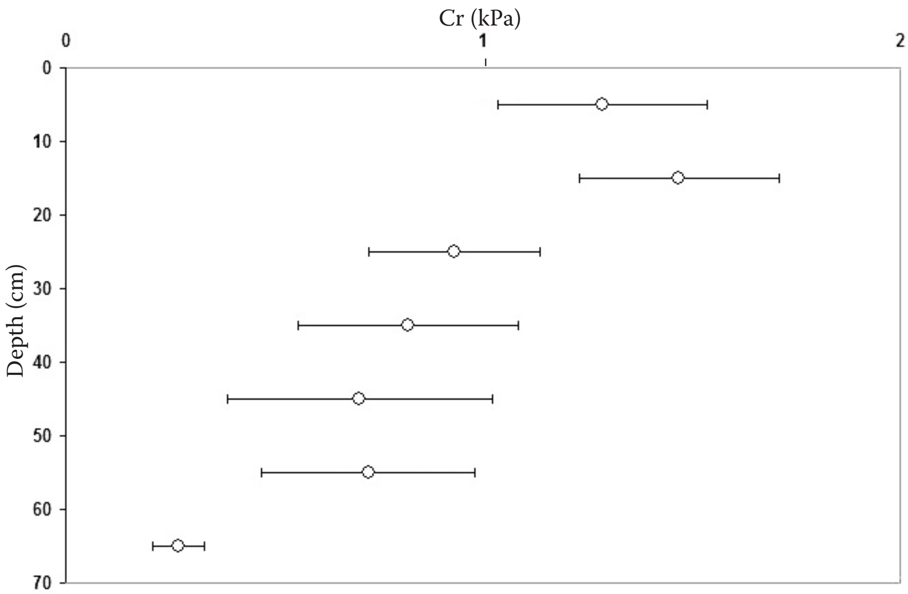

Fig. 4. Increased soil shear strength at different soil depths (data are mean ± SE)

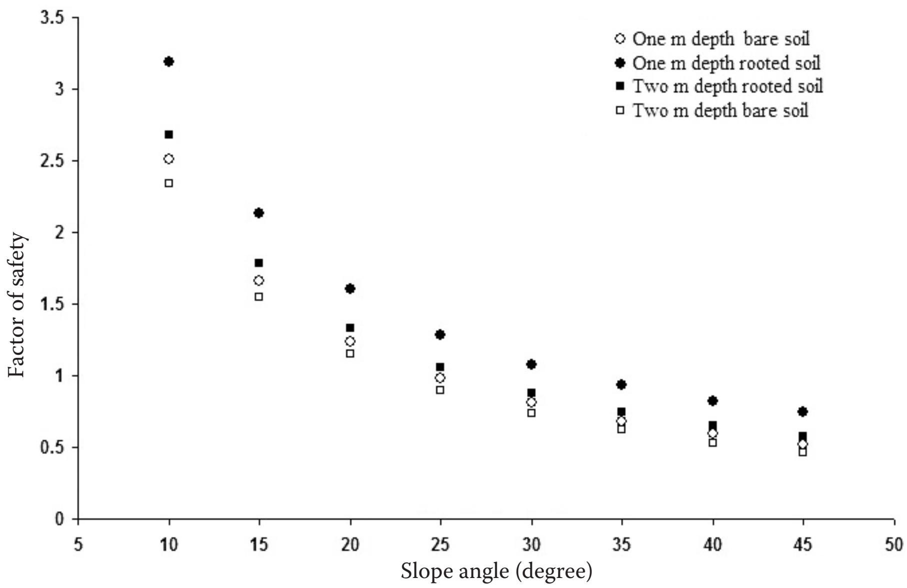

Fig. 5. Factor of safety versus slope gradient for the bare soil

samples and the diameter range tested. The root tensile strength values showed that the smallest roots were the most resistant and that the root strength decreases with increasing diameter, following a power equation (regarding R square and standard error of estimation) as found by many other authors (e.g. Bischetti et al. 2005; Genet et al. 2005; de Baets et al. 2008; Vergani et al. 2012). Bischetti et al. (2005) suggested that the exponent of the power law equation (β) controls the rate of strength decay with diameter, whereas α can be considered as a scale factor. Therefore a low scale factor (α) and a high exponent (β) mean a less resistant species. From our results we recognize that the value of β is relatively low, suggesting that the strength decay should be low in this species. Regarding the values of the parameters of the power law (α and β) obtained for the considered species, only α falls in the range that have already been suggested for hardwood roots (between 29.1 and 87.0 for α and between –0.8 and –0.4 for β; Nilaweera 1994). The values for β in some other studies did not fall in the range either (Bischetti et al. 2005; Mattia et al. 2005; de Beats et al. 2008; Abdi et al. 2010) and maybe that the range needs to be reconsidered and modified based on the results of new researches or classified based on forest zones or environmental conditions.

The influences of roots on soil shear strength have generally been related to the root area (Waldron 1977) and to the relationships between TS and root-soil bond strength (Waldron and Dakessian, 1981). The increment of the soil shear strength due to the presence of roots is difficult to quantify, because during landsliding, roots can stretch, slip or break in the soil. The model of Wu

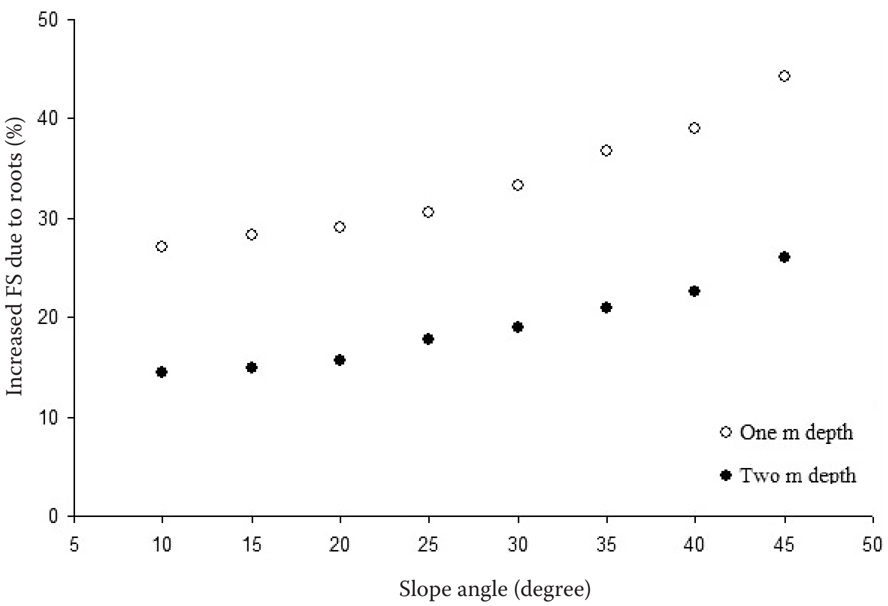

Fig. 6. Increased factor of safety due to the presence of roots versus slope gradient for the soil

(1976) is a simple model that is widely used in the evaluation of vegetated hillslope stability (Gray, Sotir 1996; Schmidt et al. 2001) and estimates additional cohesion due to the root presence (Tosi 2007; Ji et al. 2012). Using this model the reinforcement effect of Oriental beech was calculated and used in the slope stability analysis. The slope stability analysis showed that the influence of the root reinforcement on the factor of safety is an increase of 27–44% if the soil thickness is one metre and 15–26% if two meters. It should be noted that only roots smaller than 20 mm (Wu 1995) were included in the Wu model and this may justify the relatively lower increase in FS in this study compared to previous ones (e.g. Greenway 1987; de Baets et al. 2008).

CONCLUSION

For Oriental beech the increase in soil shear strength due to the presence of roots (C_r) was calculated from the Wu model. The slope stability analysis has shown that the influence of the root reinforcement on the factor of safety is large if the soil thickness is shallow and roots can improve stability up to 44%. In conclusion, the results presented in the paper serve to expand the understanding of biotechnical characteristics of the root systems of one of the most important species of deciduous Hyrcanian forest. This is a major issue in research, as the present lack of knowledge of the behaviour of root systems of typical species has been a limiting factor in using soil bioengineering techniques in *Hyrcanian* environments.

References

Abdi E., Majnounian B., Rahimi H., Zobeiri M. (2009). Distribution and tensile strength of Hornbeam (*Carpinus betulus*) roots growing on slopes of Caspian Forests, Iran. Journal of Forestry Research, ***20***: 105–110.

Abdi E., Majnounian B., Genet M., Rahimi H. (2010): Quantifying the effects of root reinforcement of Persian Ironwood (*Parrotia persica*) on slope stability. Ecological Engineering, ***36***: 1409–1416.

Abernethy B., Rutherfurd I.D. (2000): The effect of riparian tree roots on the mass-stability of riverbanks. Earth Surface Processes and Landforms, ***25***: 921– 937.

Bischetti G.B., Chiaradia E.A., Simonato T., Speziali B., Vitali B., Vullo P., Zocco A. (2005): Root strength and root area ratio of forest species in Lombardy (Northern Italy). Plant and Soil, ***278***: 11–22.

Cazzuffi D., Coreneo A., Cripra E. (2006): Slope stabilisation by perennial 'gramineae' in Southern Italy: plant growth and temporal performance. Geotechnical and Geological Engineering, ***24***: 429–447.

Cofie P., Koolen A.J. (2001): Test speed and other factors affecting the measurements of tree root properties used in soil reinforcement models. Soil and Tillage Research, ***63***: 51–56.

Danjon F., Bert D., Godin C. Trichet P. (1999): Structural root architecture of 5-year-old *Pinus pinaster* measured by 3D digitising and analysed with AMAPmod. Plant and Soil, ***217***, 49–63.

de Baets S., Poeson J., Reubens B., Wemans K., de Baerdemaeker J. Muys B. (2008): Root tensile strength and root distribution of typical Mediterranean plant species and their contribution to soil shear strength. Plant and Soil, ***307***: 207–226.

Genet M., Stokes A., Salin F., Mickovski S.B., Fourcaud T., Dumail J.F., Vanbeek R. (2005): The influence of cellulose content on tensile strength in tree roots. Plant and Soil, ***258***: 1–9.

Genet M., Kokutse N., Stokes A., Fourcaud T., Cai X., Ji J., Mickovski S. (2008): Root reinforcement in plantations of *Cryptomeria japonica* D. Don: effect of tree age and stand structure on slope stability. Forest Ecology and Management, ***256***: 1517–1526.

Gray D.H., Barker D. (2004): X. In: Bennett J.J., Simon A. (eds): Riparian Vegetation and Fluvial Geomorphology. New York, American Geophyisical Union: 113–123.

Gray D.H., Sotir R.B. (1996): Biotechnical and Soil Bioengineering Slope Stabilization: a Practical Guide for Erosion Control. Toronto, John Wiley & Sons: 365.

Greenway D.R. (1987): Vegetation and slope stability. In: Anderson M.F., Richards K.S. (eds): Slope Stability. New York, John Wiley & Sons: 240.

Greenwood J. (2006): SLIP4EX – A program for routine slope stability analysis to include the effects of vegetation, reinforcement and hydrological changes. Geotechnical and Geological Engineering, ***24***: 449–465.

Jackson R.B., Canadell J., Ehleringer J.R., Mooney H.A., Sala O.E., Schulze E.D. (1996): A global analysis of root distributions for terrestrial biomes. Oecologia, ***108***: 389–411.

Ji J., Kokutse N., Genet M., Fourcaud T., Zhang Z. (2012): Effect of spatial variation of tree root characteristics on slope stability. A case study on Black Locust (*Robinia pseudoacacia*) and Arborvitae (*Platycladus orientalis*) stands on the Loess Plateau, China. Catena, ***92***: 139–154.

Mao Z., Saint-Andre L., Genet M., Mine F.X., Jourdan C., Rey H., Courbaud B., Stokes A. (2012): Engineering ecological protection against landslides in diverse mountain forests: choosing cohesion models. Ecological Engineering, ***45***: 55–69.

Mattia C., Bischetti G.B., Gentile F. (2005): Biotechnical characteristics of root system of typical Mediterranean species. Plant and Soil, ***278***: 23–32.

Naghdi R., Maliki S., Abdi E., Mousa R., Nikkoy M. (2013): Assessing the effect of Alnus roots on hillslope stability in order to use in soil bioengineering. Journal of Forest Science, ***59***: 417–423.

Nilaweera N.S. (1994): Effects of Tree Roots on Slope Stability: The Case of Khao Luang Mountain Area, So Thailand. [Ph.D. Thesis.] Bangkok, Asian Institute of Technology: 184.

Simon A., Collison A.J.C. (2002): Quantifying the mechanical and hydrologic effects of riparian vegetation on streambank stability. Earth Surface Processes and Landforms, ***27***: 527–546

Stokes A., Norris J., Greenwood J. (2008): Introduction to ecotechnological solutions. In: Norris J.E., Stokes A., Mickovski S.B., Cammeraat E., van Beek R., Nicoll B.C., Achim A. (eds): Slope Stability and Erosion Control: Ecotechnological Solutions. Dordrecht, Springer: 1–8.

Stokes A. (2002): Biomechanics of tree root anchorage. In: Waisel Y., Eshel A., Kafkafi U. (eds): Plant Roots: The Hidden Half. New York, Marcel Dekker: 175–186.

Sun H.L., Li S.C., Xiong W.L., Yang Z.R., Cui B.S., Yang T. (2008): Influence of slope on root system anchorage of *Pinus yunnanensis*. Ecological Engineering, ***32***: 60–67.

Tosi M. (2007): Root tensile strength relationships and their slope stability implications of three shrub species in the Northern Apennines (Italy). Geomorphology, ***87***: 268–283.

Vergani C., Chiaradia E., Bischetti G. (2012): Variability in the tensile resistance of roots in Alpine forest tree species. Ecological Engineering, ***46***: 43–56.

Waldron L.J. (1977): The shear resistance of root-permeated homogeneous and stratified soil. Soil Science Society of America Journal, ***41***: 843–849.

Waldron L.J., Dakessian S. (1981): Soil reinforcement by roots: calculation of increased soil shear resistance from root properties. Soil Science, ***132***: 427–435.

Wu T.H. (1976): Investigation of landslides on Prince of Wales Island, Alaska. Columbus, Ohio State University: 94.

Wu T.H. (1995): Slope stabilization. In: Morgan R.P., Rickson R.J. (eds): Slope Stabilization and Erosion Control – a Bioengineering Approach. London, Spon: 221–264.

Wu T.H., Mckinnell W.P., Swanston D.N. (1979): Strength of tree root and landslides on Prince of Wales Island. Canadian Geotechnical Journal, ***16***: 19–33.

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