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Pioneer shrub reinforcement on clayey hillslopes. A case history from the Northern Apennines (Italy).

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In Italian Northern Apennines the seasonal frequency of soil removal due to shallow landsliding is a limiting condition for clayey slope stabilization with vegetation. Only when the shrubs have the time to integrate or substitute the seasonal grass covering, steep (20-40˚) clayey slopes become generally stable. In this study, the mechanical reinforcement (Δs) provided by the roots of three pioneer shrub species, evaluated following the model proposed by Wu *et al.* (1979), was incorporated in the infinite slope stability model to show the increase of the factor of safety due to the presence of vegetation. In the test site, a 14˚ steep hillslope, located in the Centonara Creek catchment area (Bologna-Italy), the root systems of *Rosa canina* (L.) (16 years), *Inula viscosa* (L.) (15 years) and *Spartium junceum* (L.) (12 years) were exposed digging 0.8 m deep vertical trenches around shrubs (at 0.5 m from the root crown). For every species, lateral and basal root area ratio (R_{rl} and R_{rb}) was measured respectively on all four sides of trenches (R_{rl}) and at 0.25 and 0.50 m depth below ground surface (R_{rb}). R_{rb} was not calculated on *Rosa c.* (L.) because of its shallow root system without taproot. Root pull-out strength (*PS*) was measured manually in field and fifty samples of every species were tested in a root diameter range comprised between 0.4 and 12.5 mm.

Rosa c. (L.) shows the highest values of R_{rl} (1.53e-3) followed by *Inula v.* (L.) (3.8e-4) and *Spartium j.* (L.) (1.32e-4). On *Spartium j.* (L.) and *Rosa canina* (L.), R_{rl} varies with depth following a gamma distribution function, while on *Inula v.* (L.) R_{rl} can be best approximated using a normal distribution function. Below ground surface (0.25 and 0.5 m depth), R_{rb} varies between 2.84e-3 up to 1.35e-3 for *Inula v.* (L.) and between 1.94e-3 and 1.33e-3 for *Spartium j.*. *Spartium j.* (L.) shows the highest

mean value of *PS* (95.6 N) followed by *Rosa c.* (L.) (76.3 N) and *Inula v.* (L.) (67.5 N). For every species the best fit of *PS* increases with root diameter follows second-order polynomial regression curve. Tensile strength decreases with root diameter following power law curves. Lateral root reinforcement (Δs_l), calculated using *PS* and R_{rl},ranges between 17.4 kPa [*Rosa c.* (L.)] and 3.5 kPa [*Spartium j.* (L.)]. Basal root reinforcement (Δs_b) always decreases with increasing depth and varies between 39 and 27 kPa for *Spartium j.* (L.) and between 17 and 10 kPa for *Inula v.* (L.). The highest values of Δs_b provided by *Spartium j.* (L.) are consistent with the presence of a large tap-root (diameter $>$1 cm at 0.5 m depth) that characterizes this species. The above Δs_b values were used to calculate the factor of safety (F_s) for a slope with a topographic gradient ranging between 10 and 40° and assuming: c' = 0.5 kPa, φ' = 14°, γ_{soil} = 18 kN/m^3, a soil depth = 0.5 m, γ_{water} = 9.8 kN/m^3, a water table elevation half the height of the soil column. Slopes without roots show F_s values always smaller than 1 for topographic gradient $>$ 20°. Introducing Δs_b provided by *Inula v.* (L.) and *Spartium j.* (L.),F_s becomes larger than 1 for every topographic gradient.

References

Wu, T.H., McKinnell, W.P., Swanston, D.N., 1979. Strength of tree roots and landslide on Prince of Wales Island, Alaska. Canadian Geotechnical Journal 16, 19-33.