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INSIGHTS INTO HOW VEGETATION AND VEGETATION MANAGEMENT AFFECT SLOPE STABILITY

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There is wide recognition that vegetation cover enhances the stability of hillslopes, but specific ways in which such benefits are derived are less clear and vary depending on climate, biosphere, depth to failure plane, and type of landslide. As such, the effects of vegetation management on landslide susceptibility varies with geographic region and landslide type. In some cases, vegetation can exacerbate instability by increasing surcharge above cutslopes or streambanks, but this is generally not the case. Reinforcing contributions of vegetation occur primarily in the substrate, while the destabilizing aspects of vegetation occur via the above ground biomass.

Vegetation affects slope stability in the following ways: (a) modifying the soil moisture regime through the processes of evaporation; (b) altering the subsurface flow paths due to live and dead root systems; (c) adding surcharge to the hillslope at critical locations; (d) providing root reinforcement in the regolith; and (e) buttressing the regolith against downslope movement (1). Most of these mechanisms benefit slope stability, although surcharge and altered subsurface flow paths may marginally destabilize slopes. In general, vegetation plays a more significant role in enhancing stability of potential shallow landslides compared to deeper landslides.

Interactions of vegetation cover, soil moisture regime, and slope stability are complicated and depend on climate and potential landslide type. Tree canopies have been suggested to benefit stability of shallow soils by intercepting rainfall and buffering peak intensity pulses (2), but evidence in both tropical and coastal temperate forests suggests this plays only a minor role in modifying pore water pressure at depth (3,4). Evaporation from forest litter layers can also reduce throughfall inputs (5) and seasonal influences, especially in deciduous forests, play a role (6). In areas with snow packs, evaporation can be a major loss of water inputs to the soil depending on weather conditions and the time and amount of snow held in tree canopies. Transpiration may help reinforce shallow soils when rather deep-rooted woody species remove soil water near potential failure planes. Benefits of evaporation and transpiration are diminished in temperate regions where storms that trigger shallow landslides occur during fall and winter rainy seasons; however, in tropical regions where transpiration is more active year-round, some benefit may occur. The benefits of grass cover are much less than woody vegetation, as evapotranspiration from grasses is typically only about one-third that of woody vegetation.

Both live and dead root systems influence routing of subsurface flow and thus can affect slope stability depending on whether preferential flow concentrates or disperses drainage in the hillslope. Improved understanding of root architecture of different species and forest ecosystems can help assess whether root systems positively or negatively affect slope stability (7). The interaction of woody roots with bedrock fractures poses a challenge for slope stability assessment. Fractures can facilitate penetration of anchor roots into more stable substrate (8), but they may either concentrate or dissipate pore water pressures in regoliths (7).

In most cases, the increased surcharge due to weight of trees on steep slopes is more than offset by other benefits of root reinforcement and evapotranspiration. Exceptions include large trees at the crest of steep cutslopes or channels. Tree surcharge has a small destabilizing effect on hillslopes when slope gradient exceeds internal angle of friction (9). Windthrow of trees on unstable slopes is believed to cause shallow landslides due to wind-generated stresses in the soil mantle, however, evidence is anecdotal (10).

Reinforcement of shallow soil mantles by woody roots is generally recognized as the most significant benefit of vegetation on slope stability. Root systems reinforce soils by anchoring into stable substrate and by providing a membrane of strength within the soil – debate remains as to which of these mechanisms is more important, but root anchoring is certainly significant in reducing shallow landslides (9). The strength of root systems depends on tree or woody shrub species, age and density of trees and woody understory, root architecture and interaction with the soil matrix, root density, and depth of root penetration. Root reinforcement of deep regoliths (e.g., potential earthflows and slumps) by woody root systems is minimal. Grasses offer negligible contributions to slope reinforcement due to shallow rooting depths and individually weak roots (9). Individual tree trunks may act as buttresses to stabilize some hillslopes (11).

Vegetation management can affect landslide susceptibility in different ways. Forest cutting in steep terrain affects shallow landslide initiation by reducing root cohesion, typically from 3 to 15-20 years following clearcutting (1,9). The recovery of rooting strength is dependent on the regeneration techniques used at the site, available soil nutrients and moisture, and other site factors. Deep-seated slope failures, such as rotational slumps and earthflows, are typically less affected by timber harvesting because tree roots rarely penetrate deep into the unstable soil mantle. By modifying the soil moisture regime, timber harvesting has the potential to increase the “window” of susceptibility for a shallow landslides to occur or for deep-seated failures to initiate or activate for longer periods in the wet season. Forest conversion to pasture or weak-rooted plantations impart long-term consequences for landslides in most climatic environments.

Keywords: shallow landslides, deep-seated landslides, root strength, evapotranspiration, subsurface flow.

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