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Impact of different chestnut coppice managements on root reinforcement and shallow landslide susceptibility

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ABSTRACT

The abandonment of chestnut coppice management since the end of WWII has caused a general overaging of coppice stands leading to their inability to meet stand and soil stability standards. In view of the important role played by roots against the triggering of shallow landslides, we investigated root systems and their contribution to slope stability in chestnut coppices. In particular, we looked at possible different root regrowth dynamics and their effects on root reinforcement as function of different sylvicultural treatments. To this purpose we selected young (managed and unmanaged) and an old unmanaged coppice stands in two sites (Gerra and Bedano) in the southern Swiss Alps. We collected data on root distribution and root tensile force in the field and then applied the RBMw (Root Bundle Model Weibull) to estimate the degree of root reinforcement provided by the different silvicultural options.

Results highlight the chestnut tree's ability to renew the root system each time a stool is subject to a coppicing again. This implies there are important differences in terms of root regeneration, distribution and contribution to soil stability between young and overaged coppices. No significant differences in terms of root distribution and related soil reinforcement could be detected as a function of the different management options in young trees. Whenever possible, long-term silvicultural strategies in areas prone to shallow landslides should aim to convert pure chestnut coppices into mixed high forest stands.

1. Introduction

The prevention or mitigation of gravitative natural hazards such as landslides, snow avalanches, debris flows, and rockfall is an important ecosystem service provided by forests in mountainous areas (Dorren et al., 2004; Dupire et al., 2016a; Vacchiano et al., 2016; Mina et al., 2017). The characteristics and attributes that make a forest stand effective in terms of protection vary considerably depending on the natural hazard under consideration (e.g., Dorren et al., 2005; Jancke et al., 2009; Teich et al., 2012; Fidej et al. 2015; Dupire et al., 2016b; Schwarz et al., 2016). In the case of shallow landslides and related soil stability, for instance, two primary vegetation effects are involved: the hydrological regulation and mechanical root reinforcement of soil. The first consists in water regulation by trees (e.g., precipitation interception, effects of evapotranspiration on soil water content) and mostly acts at the catchment scale (Forbes and Broadhead, 2013; Sidle and Bogaard, 2016). The second is represented by the reinforcement effect that trees provide through root systems (Stokes et al., 2009; Ghestem et al., 2011) and is considered to be the factor with the most influence for shallow landslides at the hillslope scale (Schmidt et al., 2001; Docker and Hubble, 2008; Schwarz et al., 2010a).

Root reinforcement depends on the distribution and mechanical properties of roots, and is thus a function of the tree species in question, stand origin (i.e., gamic vs agamic), structure, and health conditions (Schwarz et al., 2012, Phillips et al., 2014; Vergani et al., 2014). Root regeneration after disturbance, however, highly differs among tree species. Most European coniferous species do not resprout form stool and do not regenerate the roots, whereas deciduous species display a very different resprouting and root regeneration capacity, that usually decrease with increasing tree age (Bond and Midgley, 2001). Root reinforcement may thus be heavily influenced by disturbances such as silvicultural treatments (Vergani et al., 2016) or forest fires (e.g., Vergani et al., 2017a).

Among possible silvicultural treatments, coppicing is probably the most intriguing in this respect, mainly because of the (mostly) unknown dynamics of root system regrowth and the role roots play in stand regeneration (see Vergani et al., 2017b for a review). Generally, stools regenerate from vegetative adventive buds, which implies that part of

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the root system remains alive or regenerates very quickly (Giudici and Zingg, 2005). Furthermore, stool regeneration strategies may vary greatly among species and coppicing techniques (e.g., Bedeneau and Pagès, 1984; Aymard and Fredon, 1986; Bedeneau and Auclair, 1989; Montagnoli et al., 2012; Di Iorio et al., 2013).

Coppice woodlands are widespread in Central and Southern Europe, covering about 23 million ha of broadleaved forests (Nicolescu et al., 2014). In recent times, however, coppice management has progressively been abandoned due to low economic value (in the context of widely available fossil fuels starting at the end of WWII, Müllerova et al., 2015). As a result, present day coppice woodlands consist in a mosaic of different silvicultural treatments ranging from short-rotation, intensively managed patches to overaged abandoned stands devoid of any culturing input (Campetella et al., 2011; Chauchard et al., 2013). Such abandoned coppices overage, become rich in aerial biomass, and tend to uproot and disrupt over time (Vogt et al., 2006), thus likely causing problems in mountain protection forests (Conedera et al., 2010).

In order to guarantee protection over the long term, forest management should aim at increasing the protection function of the forest and its continuity. In the case of natural disturbances, the resistance and engineering resilience of the forest system may be strongly influenced by the type of management, which, in turn, can influence the temporal dynamics of the protection forest effect (e.g., Kulakowski et al., 2017). Such forest disturbances impact also on the root system, what may open in turn window of increased landslide probability as function of the species involved and the environmental conditions of the area (soil characteristics, rainfall regime, etc. (Ziemer, 1981, Sidle, 2008).

Quantitative descriptions of such dynamics are strongly required in practice to support strategic decisions at regional scales. In this paper, with reference to the Sweet chestnut (*Castanea sativa* Mill.) in southern Switzerland, we analyze and quantify the root reinforcement of different silvicultural treatments and their effects on slope stability. The chestnut is a representative and valuable study case not only because it covers over 1.5 million hectares in Europe, but also because the species is managed in very different ways (e.g., simple coppicing, coppice-with-standards, pollarding, stored coppicing, seed-regenerated trees) and is often located on slopes of mountainous areas where the protection function is of great importance (Conedera et al., 2004a). Despite such importance, the root systems of chestnut and chestnut coppices in particular are poorly studied (e.g., Bedeneau and Pagès, 1984; Pividori et al., 2008) and little available data on their contribution to root reinforcement results from laboratory studies (Bassanelli et al., 2013). In light of these considerations, the research questions are:

– How does root distribution vary in chestnut trees subjected to different silvicultural treatments?
– How do such different root distributions contribute to overall root reinforcement and related slope stability?
– How can root reinforcement be influenced by silvicultural techniques in such stands?

2. Material and methods

2.1. Study area

The research was conducted in the chestnut forests (*Castanea sativa* Mill.) of Canton Ticino in the southern Swiss Alps (Fig. 1). The area is characterized by siliceous rocks generating well-drained and unmottled sandy haplic podzols or cryptopodzols with a consistent and highly stable organic matter component (Blaser et al., 2005). The mean annual precipitation ranges from 1800 to 2200 mm depending on the geographical position, with a rather high quantity of summer precipitation (June–September 800–1200 mm depending on annual variation). Both the mean annual temperature (12.4 °C) and the minimum mean monthly temperature (0.8 °C, January) are mild and thus well-suited to the chestnut tree (www.meteoswiss.ch, climate normal 1981–2010, Meteorological stations of Locarno-Monti and Lugano).

In this area, chestnuts was first introduced by the Romans (Conedera et al., 2004b) and its cultivation assumed for long time a central role for the local economy, both for fruit and timber production. The traditional silvicultural treatment of the chestnut stands devoted to timber production had for a long period of time consisted of short to mid-rotation (i.e., 15–25 years) simple coppicing for the production of small-sized poles and firewood (Merz, 1919). After WWII, the chestnut pole market crisis caused the progressive abandonment of coppice management, which resulted in a post-culturing natural evolution of stands that had become stored and overaged (Conedera et al., 2001). In recent years, the need to avoid large-scale uprooting in the abandoned coppice stands (Conedera et al., 2010), together with a new demand for larger-sized and high quality chestnut timber products, stimulated the resumption of coppicing activities in the area, including some experimental and innovative techniques for quality wood production (Amorini et al., 2000; Manetti et al., 2010, 2016).

2.2. Sampling design

Two study sites (Bedano and Gerra Gambarogno, hereafter referred to as “Gerra”, Fig. 1), located at similar altitudes but with different aspects (Table 1), were selected within the chestnut coppice management experiment sites of the WSL Swiss federal research institute for forest, snow and landscape (Manetti et al., 2010, 2014). Both stands are dominated by the chestnut tree (*Castanea sativa* Mill.) with isolated individuals of black alder (*Alnus glutinosa*), aspen (*Populus tremula*), ash (*Fraxinus excelsior*), sycamore (*Acer pseudoplatanus*), and birch (*Betula pendula*) at the site of Bedano and birch, sessile oak (*Quercus petraea*), black locust (*Robinia pseudacacia*), whitebeam (*Sorbus aria*), and wild cherry (*Prunus avium*) in Gerra.

Three different silvicultural treatments were considered (see also Table 2):

– A - managed (in rotation) simple coppice, but subject to single-tree-oriented silviculture consisting in the early (ca. 8–10 years after the self-thinning phase) selection of 100–150 evenly distributed, dominant, well-shaped, vigorous, and healthy target trees per hectare, with a subsequent and repeated freeing up of their crown by eliminating direct competitors. Depending on the local distribution of the best candidates, selected individuals may have originated from stools or seed. The first crown thinning (including the pruning of the stem up to 5 m in height) took place at the age of 8 years in Bedano and 10 years in Gerra, with a second treatment performed at the age of 12 and 14, respectively. We will refer to this silvicultural treatment hereafter as *tree-oriented silviculture - A*, with subcategories based on whether the origin of the target tree was from stools or seed (see Fig. X1 supplementary materials).
– C - managed (in rotation) simple coppices (same sites and ages as the tree-oriented silviculture) that never experienced any silvicultural treatment since the last coppice (17 years previously in Gerra and 18 previously years in Bedano, respectively), hereafter referred to as *untreated coppice in rotation - C* (Fig. X2 supplementary materials);
– O - unmanaged, overaged and stored stands originating from simple coppicing or a coppice with standards during or just after WWII and completely abandoned since then to its natural evolution, hereafter referred as *untreated overaged coppice - O* (Fig. X3 supplementary materials). Ages range from 50 to 90 years depending on the time of coppicing and the origin of the individual (resprout or standard).

Three sample trees were selected for each silvicultural treatment and site for a total of 18 individuals. Main selection criterion was the distance from the candidate sample tree to the next chestnut stool, so as to minimize possible confusion of root’s belonging when digging. All