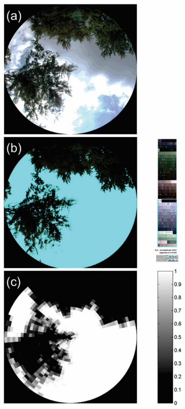

Conversion from coppice to high stand increase soil erosion in steep forestland of European beech

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Abstract

In forestlands on steep slopes, where the shallow soil can be considered a non-renewable resource, erosion is of special concern. The vegetation covers, at both soil and canopy level, provides essential protection to the soil against the rainfall erosivity and reduces considerably the water erosion rate. Consequently vegetation management may affect soil erosion. We focused our attention on old coppice beech forest growing on a steep slope (28-32°) and subjected to conversion to high stand. With the aim of obtaining information on surface water flow and the mineral soil loss, three runoff-erosion plots (10 m long × 3 m wide) were installed in catchments in Lombardy Alps (Intelvi Valley, Como) at three stands: a coppice 40 years old (CpS 1968) and two conversions from coppice to high forest respectively cut in 1994 (CvS 1994) and 2004 (CvS 2004). Water run-off and sediment losses were collected from June to October 2008 and from May to October 2009 together with stand characteristics, LAI, soil surface cover, canopy cover and fine-root traits. Our results showed that the conversion practices significantly affect the water runoff and soil erosion with the younger conversion CvS 2004 showing the highest erosivity. This was due to the lower values of tree density, canopy cover, soil surface cover and fine-root biomass and length. The old coppice stand (CpS 1968) together with the older conversion stand (CvS 1994) showed comparable values of soil erosion. Therefore, the major role in protecting soil from erosion played by old coppice stand is recovered by the conversion stand after a number of years since harvesting. Our study highlights that abandoned old coppice stand plays an important role in protecting soil from erosion and claims consideration in forest management of steep forestland stands.

Keywords

Steep forestland; Beech; Erosion control; Coppice forest; Stand conversion

Contents

1 Introduction

1.1 Coppice stands and conversion to high forest

In mountain regions, forests play an important role in the mitigation of risks due to natural hazards such as landslides, rock fall, floods and avalanches (Zingari and Fiebiger 2002). Coppicing is one of the oldest forestry systems known to many countries worldwide (Evans 1992; Fujimori 2001). Coppices were usually used as a source of firewood until the second half of the 19th century (Buckley 1992; Peterken 1993) and for this reason in the southern side of the Alps, forests were often managed as coppice systems. In Italy, starting from when there was a high demand for small timber, firewood and charcoal, forestland classified as coppice encompasses almost 35% of the national forest cover (Mairota et al. 2016). Although the recent interest in the potential renewal of coppicing biomass for energy production, coppice stands are considered inadequate to meet fully the societal demands of multiple functions forests (Mairota et al. 2016). Thus, even if coppicing today remains a common forest management system in countries of southeastern Europe (Vacik et al. 2009; Velichkov et al. 2009; Maděra et al. 2014) to provide firewood at the local scale, the conversion to high forests represents the principal trend required for higher-quality timber (Hédl et al. 2010). This conversion entails the transition from a condition where a number of stems grow contemporaneously on a single stool, to a condition where only one stem is left to continue its growth to a larger dimension (Terzaghi et al. 2013). In particular, these practices routinely involve thinning operations modifying stand characteristics (i.e. tree density, canopy cover, stand basal area) and related environmental variables (i.e. soil moisture and temperature, irradiance) (Liechty et al., 1992; Carlson and Groot 1997; Hashimoto and Suzuki 2004; Montagnoli et al. 2012; Di Iorio et al. 2013) leading to changes in the ecophysiological behavior of trees (Aussenac 2000; Terzaghi et al. 2016). Forest harvesting will determine the partial or complete death of the root systems of harvested trees and in turn changes in root density and production (Montagnoli et al. 2012; Di Iorio et al. 2013; Terzaghi et al. 2016). Furthermore, the conversion results in considerable alteration of almost all micro-environmental factors that characterize a coppice stand.

1.2 Soil erosion and the role of vegetation

Soil erosion is a critical environmental problem all over the world's terrestrial ecosystems. Indeed erosion leads to multiple, serious damages in managed ecosystems such as crops, pastures, or forests as well as in natural ecosystems (Zuazo and Pleguezuelo 2008). Each year, almost 75 billion tons of soil, mainly used for agriculture, is eroded from the world's terrestrial ecosystems. Because soil is formed very slowly, it has been hypnotized that the rate of loss is 13–40 higher than the rate of renewal and sustainability (Zuazo and Pleguezuelo 2008 and reference herein). In forestlands on steep slopes, where the shallow soil can be considered a non-renewable resource, erosion is of special concern (Edeso et al. 1999). Soil erosion is a two-phase process involving the detachment of soil particles from the soil mass and their transport by erosive agents such as running water runoff (Morgan 2005). Rainfall energy is the prime cause of erosion from tilled or bare land, occurring when the soil lacks protective vegetative cover. The increase in heavy precipitation episodes, contribute progressively more to the total amount of precipitation occurring during the year (Brunetti et al. 2000; Fischer and Knutti 2015). Runoff and soil erosion are closely linked to vegetation cover. Indeed it provides essential protection to the soil against the erosivity of rainfall and considerably reduces the water erosion rate. Several studies in different environments have demonstrated that vegetation positively reduce soil erosion (Zuazo and Pleguezuelo 2008). The role of vegetation in mitigation of soil erosion may be due to three main effects: 1) the mechanical protection of the soil surface by the canopy and litter covers that intercept rainfall, reduce the impact of the raindrop and therefore reduce the detachment of soil particles (Bochet et al. 1998) 2) the improvement of the soils physical and chemical properties (Auerswald et al. 2003; Tejada and Gonzalez 2007; Jien and Wang 2013) 3) the direct and indirect contribution of plant roots in altering the soil erodibility over the enhancement of soil aggregation and the reinforcement through mechanical and hydrological mechanisms (Ola et al. 2015). From another point of view, climate may strongly influence morpho-physiology of plant species as in the case of the root system, which dynamics is driven, among the others, by the soil water availability and temperature (Zhong et al. 2009; Montagnoli et al. 2010, 2012, 2016). Indeed, mitigation of soil erosion may change as root morphological characteristics, such as diameter, change (Ola et al. 2015). Therefore, coppice stand characteristics such as high stem density, continuous canopy cover and high fine-root standing biomass, might be remarkably valuable in terms of protective function (Petzold et al. 2014). However, so far, the suitability of coppice as soil protection forests has been poorly investigated. Based on the above consideration concerning the abundance of coppice stands in mountain regions, these investigations become fundamental to understand the future management of these forestlands. Since the different type of forest management, harvesting practices and application age causes different morphologies at both tree (stems, branches and canopy) and stand level (soil cover, fine root biomass), we hypothesized a consequent relative change of efficiency in reducing water erosion on slopes. To test this hypothesis, we focused our attention on the forestland cover subjected to abandoned coppice stand and to conversion stands with different harvesting age, and measured tree density, canopy cover, soil surface cover and fine-root traits for each stand type. Moreover three plots were set up to measure soil erosion and water run-off.

2 Material and Methods

2.1 Site description

The study area is located in the catchments of the Telo stream in the Lombardy Alps (Intelvi Valley, NW Italy, 45°59'N, 9°07'E) approximately from 1,160 m to 1200 m above sea level between Lakes Como and Lugano. This area is characterized by a sub-continental climate, with a mean annual precipitation of 1,600 mm, occurring in two main periods (April-May and October-November) and a mean annual temperature of 10–11°C. Generally, the area is snow-covered from late October to late March. According to the World Reference Base for Soil Resources (FAO/ISRIC/ISSS 2006), soil type is Leptosol 40–50 cm deep. General characteristics of this area were already described in a previous work carried out on the same site (Montagnoli et al. 2012). Briefly, three beech stands were selected and labelled by ascending cutting age: two conversions thinning from coppice to high forest cut in 2004 (Conversion Stand [CvS] 2004) and 1994 (CvS 1994) respectively; a residual coppice stand cut in 1968 (CpS 1968) and then allowed to re-grow from stools. The three stands were adjacent to each other and located on the same slope facing south-west, with slope inclination averaging between 28 and 30°. Above ground stand characteristics (Table 1) such as biomass (Mg ha^{-1}), diameter at breast height (DBH, cm) and stand basal area (m^2 ha^{-1}), were evaluated on seven circular-shaped (20 m diameter) sampling plots per stand along a transect almost 120 m long for a total of 1,884 m^2 area per stand. In the case of CpS 1968, each stool was counted as a single tree.

Table 1. Above-ground characteristics and soil temperature of the three beech stands.

Forest stand	Density (trees ha^{-1})	Mean dbh (cm)	Mean tree height (m)	Above-ground biomass (Mg ha^{-1})	Soil temperature[b] (°C)
CpS	724 ± 35	17.2 ± 0.7	12.1 ± 0.3	248.5 ± 15.6	10.2 ± 0.3
CvS 1994	279 ± 24	22.6 ± 1.5	12.8 ± 0.7	123.7 ± 7.3	11.3 ± 0.3
CvS 2004	167 ± 20	31.9 ± 1.9	18.9 ± 0.8	91.8 ± 20.2	12.2 ± 0.4

Data shown are means ± SE. dbh, diameter at breast height. Beech above-ground biomass values are the mean of seven replicates. [b] Soil temperature (0–30 cm) is referred to the mean of three soil depths (5, 15 and 25 cm) and each value is the mean of four replicates for eight sampling dates (May 2008 - April 2009)

2.2 Soil surface and canopy cover, Leaf Area Index (LAI)

Soil cover was measured for each different stand by a quadrat method built of wooden frame (25 cm x 25 cm). The frame was randomly thrown for 50 times into the seven circular-shaped plots used for measurements of stand characteristics. Within the quadrat, the number of seedlings, the percentage of moss, grass, litter and bare soil were measured. In July 2008, in order to measure the canopy cover, including leaves, branches and stems, a number of 20 hemispherical photos (Figure 1) for each stand were taken every 20 m along a transect perpendicular to the slope line. Afterwards photos were analyzed by Can_Eye Software (Figure 2). Finally, during the fall of 2008 Leaf Area Index (LAI) was also measured by the litter trap method (Figure 3).

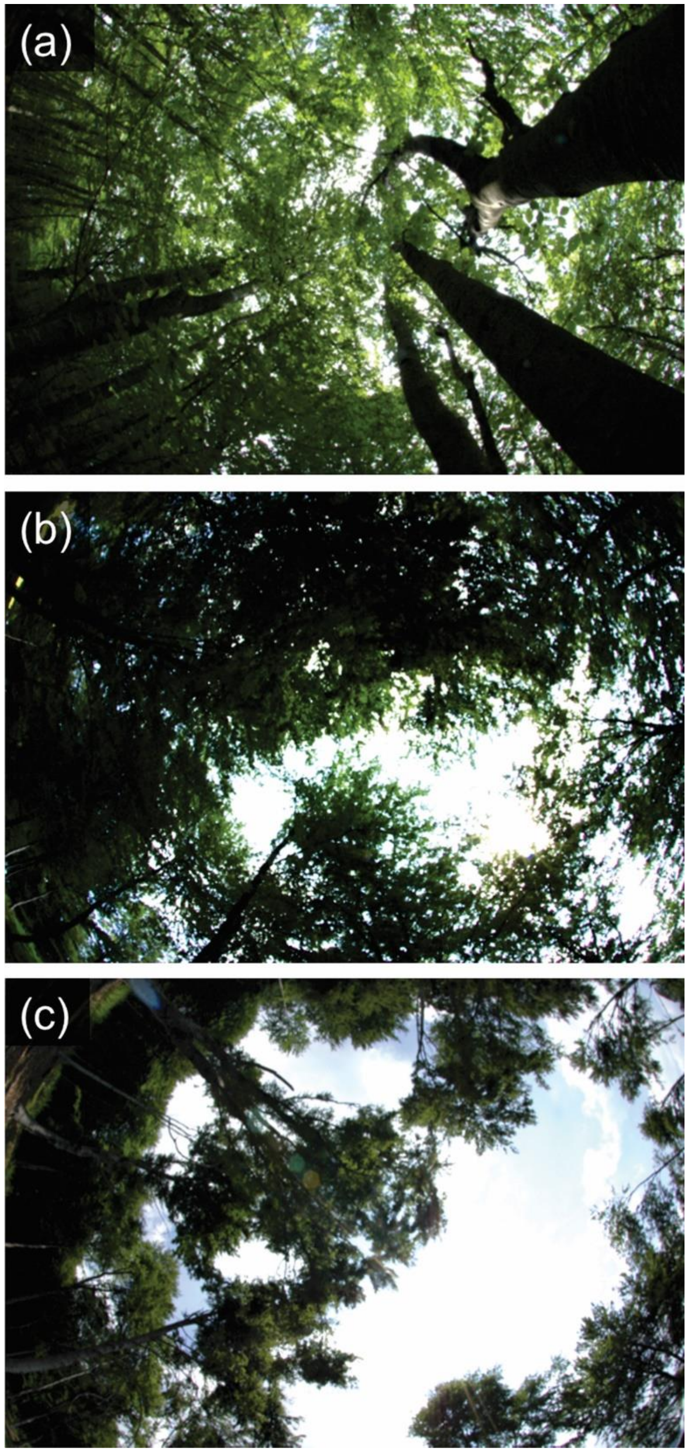

Figure 1. Hemispherical photos of the canopy cover. Example of photos hemispherical taken by Fisheye Nikon Objective for estimation of canopy cover (leaves, branches and stems) in different stands (CpS 1968 (a), CvS 1994 (b) and CvS 2004 (c)).

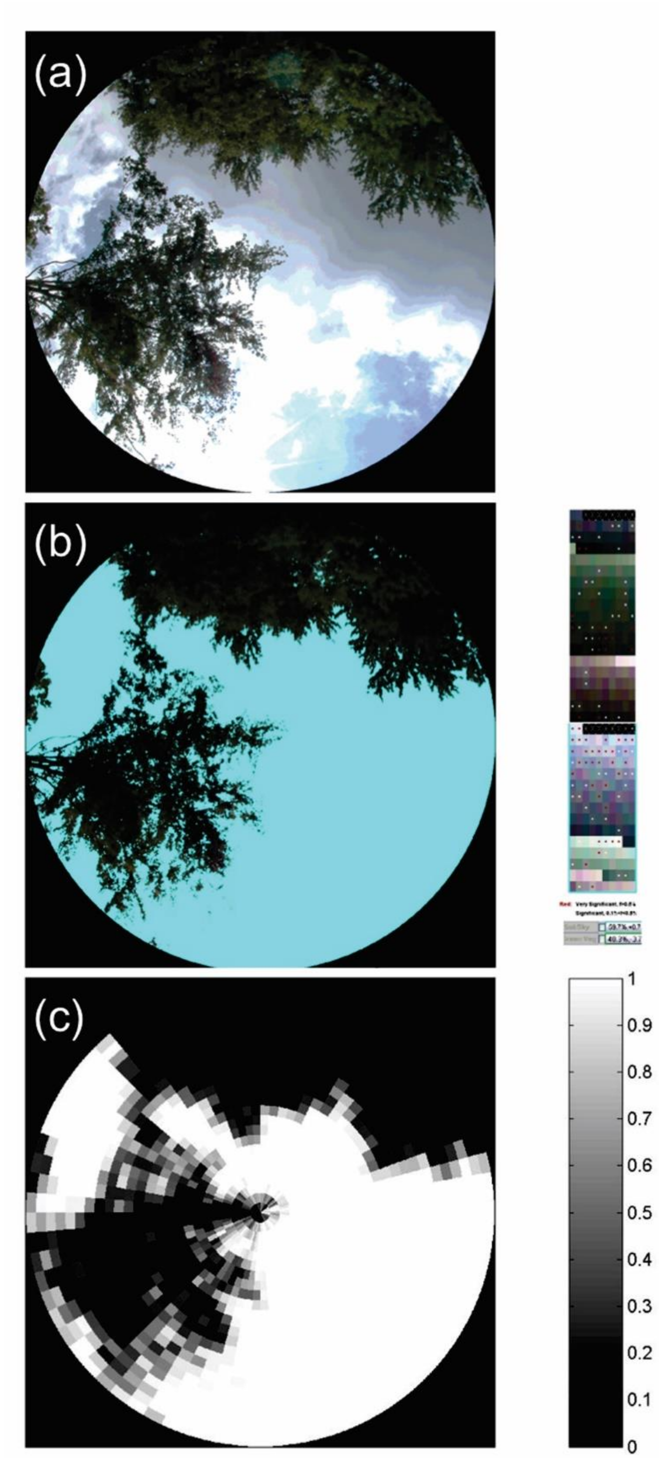

Figure 2. Hemispherical photo analysis. Example of analysis performed by the software Can_Eye on the hemispherical photo of the canopy cover taken in CvS 2004. a) The software use only a certain angle of the entire photo for the analysis; b) color analysis performed automatically by the software and then manually adjusted by the user; c) mean fraction for class 'Sky'.

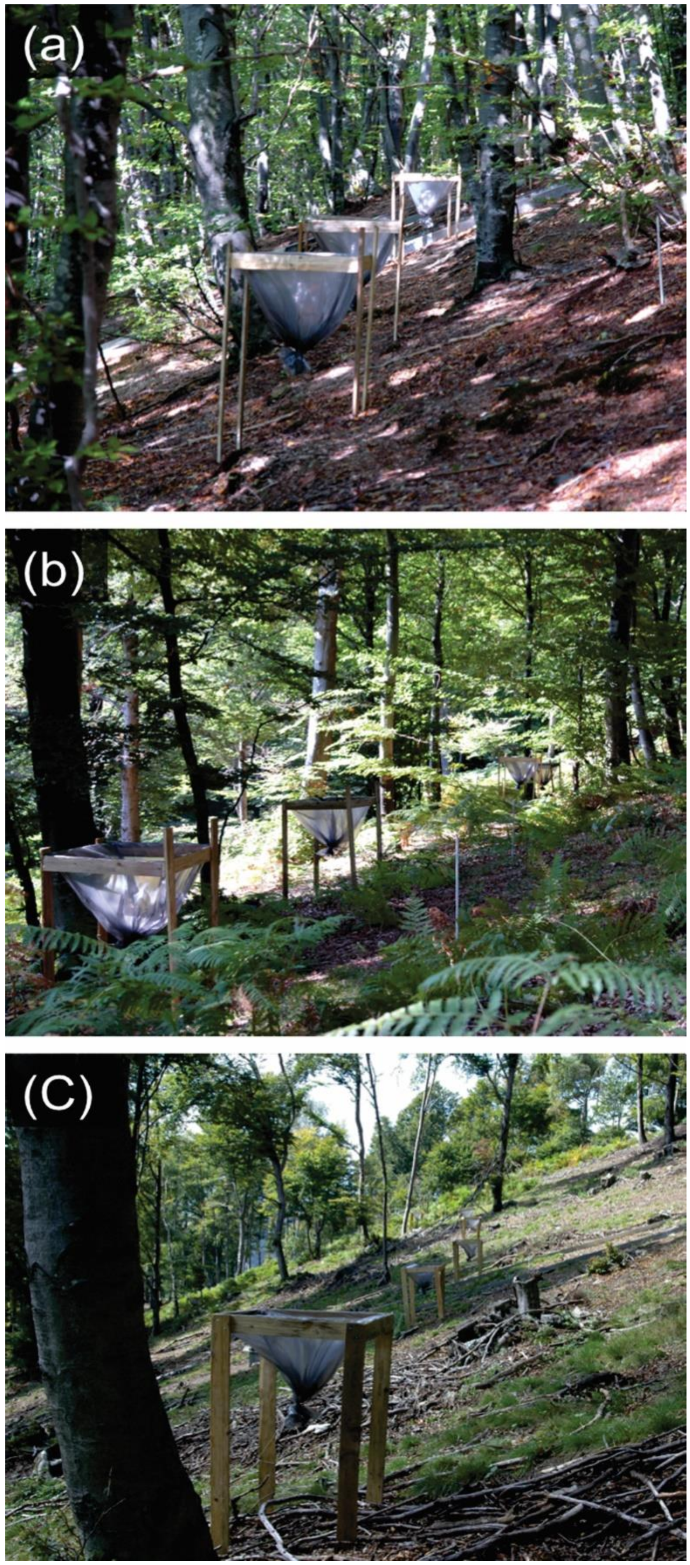

Figure 3. Litter traps for LAI measurements. Wooden litter traps placed along a transect perpendicular to the slope in CpS 1968 (a), CvS 1994 (b) and CvS 2004 (c).

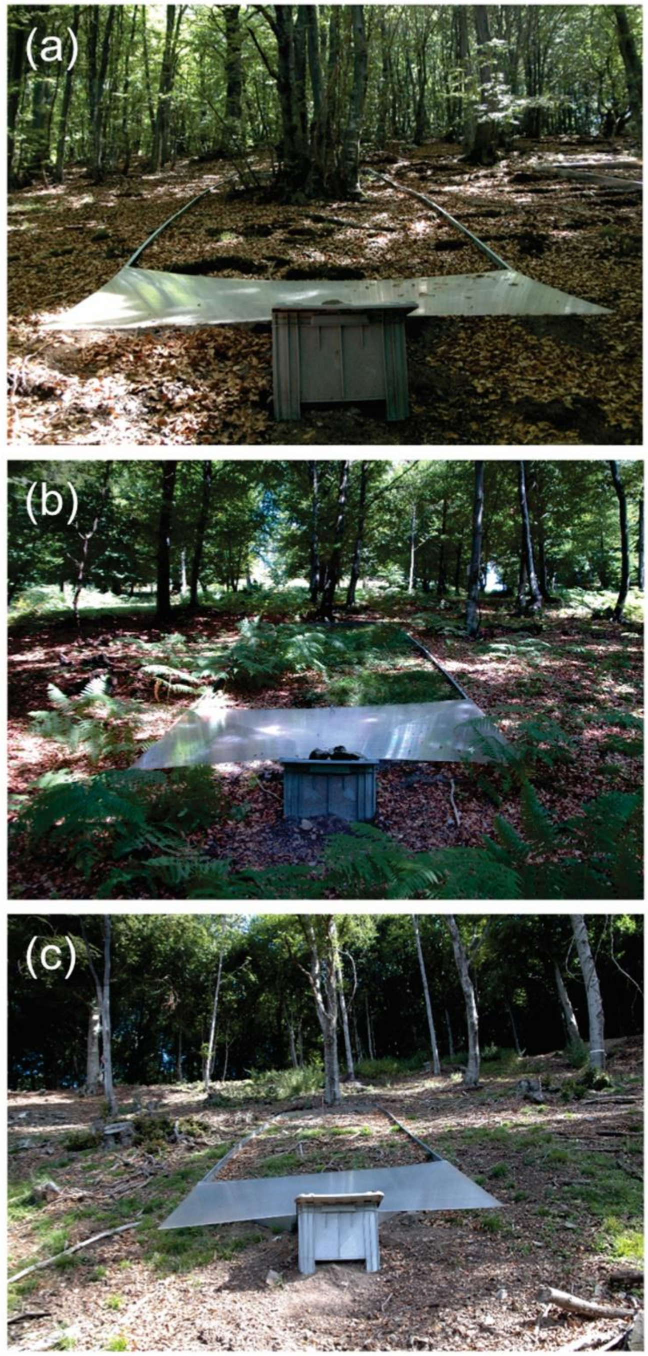

Figure 4. Soil erosion plots. Plots for soil erosion and water runoff measurements in CpS 1968 (a), CvS 1994 (b) and CvS 2004 (c).

2.3 Fine-root collection and measurements

Soil cores were harvested sequentially every 40-60 days from April to October 2008 and 2009. In each stand, four smaller permanent 10 m^2 replicated plots were set within four out of the previously described seven larger plots and used for fine-root measurements. Two soil cores (4 cm diameter 30 cm deep) were randomly collected in each plot at each sampling date and successively divided into 10 cm depth increments. For the present study only the upper soil layer (0–10 cm including the first 2–3 cm of a humus layer), was considered. Soil-free roots were sorted into color, texture, and shape under a 10× stereomicroscope (Vogt and Persson, 1991). Live fine roots were scanned at resolution of 400 dpi by using WinRhizo Pro V. 2007d (Regent Instruments Inc., Quebec) and analyzed in order to obtain length and diameter. Samples were then oven-dried and weighed to obtain dry mass.

2.4 Soil erosion plots layout and material

Three experimental soil erosion and water run-off plots (10 m long × 3 m wide; 30 m^2 area), one each forest stand, Figure 4) were installed in May 2008 along the max slope line. In order to be representative of the whole stand characteristics, plots were placed in relation to stem density. For that reason referring to the coppice stand, we included within the plot a multi-stemmed tree. Plots were bordered by a solid strip of stainless steel sheets (8 mm tick and 30 cm height) cut into two halves along the length. In order to avoid water run-off and soil erosion from outside the plot moving inside, border sheets were buried for 10 cm of height. At the bottom of the plot a sort of funnel of 3 m length (the width of the plots) was made by a triangular stainless steel sheet and covered by an alveolar Plexiglas® sheet. The funnel convoyed water run-off and soil eroded into a plastic tank partially buried. Runoff and sediment losses were collected from June to October 2008 and from May to November 2009 every 15 days and after every heavy rainfall. The soil loss samples were oven dried and weighed.

3 Results and discussion

3.1 Soil surface and canopy cover, LAI

The canopy cover measured by hemispherical photo analysis showed the highest value in the CpS 1968 (Table 2; 94.2%), the lowest in the recent conversion stand (CvS 2004) and the intermediate value in the older conversion stand (CvS 1994). In the case of the leaf area index (LAI), the highest value was measured in CvS 1994, with intermediate values in CpS 1968 and the lowest in CvS 2004. According to Cutini et al. (2009) the canopy cover data are probably due to the stand tree density on the vegetation cover, while the LAI may be connected to the growth habit of converted trees that showed a more developed canopy 14 years after cutting. Indeed, although the canopy cover was the highest in CpS 1968 with an almost fully covered stand, LAI value was the highest in the older conversion stand (CvS 1994). This result highlights the prompt response of beech to thinning cycles with a higher canopy production in converted stands than in the old coppice one (Cutini et al. 2009, 2010). Leaves and fine roots are active organs with the primary function of plant resource acquisition and are often associated in their dynamics (Wardle et al. 2004; Huang et al. 2010; Mommer and Weemstra 2012; Osnas et al. 2013). Thus, also in our case, findings about leaves are in accordance with the highest values of fine-root production found in beech stand subject to conversion to high forest (Montagnoli et al. 2012). Soil cover data resulted in almost 20% of mosses in CpS 1968 while in the younger conversion (CvS 2004) mosses were not detectable. This might be due to the differences in air temperature directly connected to the deeply shaded microsite such as old forests

(D'Amato et al. 2009; Montagnoli et al. 2012, 2014; Glime 2015a). Soil cover by grass species was almost null in CpS 1968 (1.3%) with intermediate values in CvS 2004 and highest in CvS 1994 (Table 2). The coverage of seedlings was almost null in CpS 1968 (0.2%) since coppice stands have mainly a vegetative reproduction with a low production of seedlings (Lust and Mohammady 1973) (Table 2). Finally, while in CpS 1968 and CvS 2004 the bare soil represented almost 20%, this data fall to 2% circa in the case of CvS 1994.

Table 2. Stand measurements of canopy cover, soil cover, Very fine and Fine roots mass and length.

Forest management	**CpS 1968**	**CvS 1994**	**CvS 2004**
Canopy cover			
Vegetation (%)	94.2 ± 0.4	74.2 ± 4.3	54.3 ± 4.8
LAI (m^2 m^{-2})	4.12 ± 0.1	5.29 ± 0.5	2.20 ± 1.1
Soil cover			
Moss (%)	19.6 ± 4.1	8.3 ± 2.8	0
Grass (%)	1.3 ± 0.6	17.9 ± 3.1	9.7 ± 2.3
Litter (%)	60.4 ± 4.2	66.5 ± 3.8	62.5 ± 4.6
Seedlings (%)	0.2 ± 0.2	5.1 ± 1.9	3.8 ± 1.7
Bare soil (%)	18.5 ± 2.9	2.2 ± 1.5	24.0 ± 4.1
Very Fine root (d < 0.3 mm)			
Dry mass (g m^{-2})	6.2 ± 1.0	7.5 ± 0.7	4.1 ± 0.5
Length (m m^{-2})	627 ± 55	800 ± 116	426 ± 80
Fine root (d < 2.0 mm)			
Dry Mass (g m^{-2})	86.6 ± 5.9	72.9 ± 7.0	50.9 ± 5.8
Length (m m^{-2})	1229 ± 145	1385 ± 119	787 ± 87

3.2 Soil erosion and water run-off

Harvesting practices significantly affected water runoff and soil loss with marked differences among the plots (Figure 5). Mean data obtained from 2008 and 2009 sampling season, showed that the coppice (CpS 1968) and the older conversion stands (CvS 1994) have almost five fold lower values of soil loss than the young conversion stand (CvS 2004). The latter was also characterized by the lowest values of mosses and the highest value of bare soil (Table 2). Regarding to water runoff, CvS 2004 showed the highest value (Figure 5) while the lowest value was found in CvS 1994. Although, CpS 1968 showed high runoff value probably due to the multi-layer canopy and the multi-stemmed trees that convoy into the plot a higher amount of rainfall, the low soil loss values confirmed its soil protection rule (Zuazo and Pleguezuelo 2008; Petzold et al. 2014). Moreover, data from the two conversions to high forest stands showed that soil loss decrease with the increase of harvest age (Figure 5). This might be explained with the smaller canopy cover due to the lower tree density and branches pruning (Table 1) occurring in CvS 2004. Moreover, although the CpS 1968 had values of water runoff similar to the CvS 2004 the amount of eroded soil was quite lower. In this case the low energy of water dropping (Edeso et al. 1999; Descroix et al. 2001; Hartanto et al. 2003) associated to the canopy interception as well as to the high cover of mosses, which have high water retention potential, may have played a role in soil protection from excessive erosion (Glime 2015b). Finally, both the amount of water run-off and eroded soil was the lowest in the older conversion stand (CvS 1994).

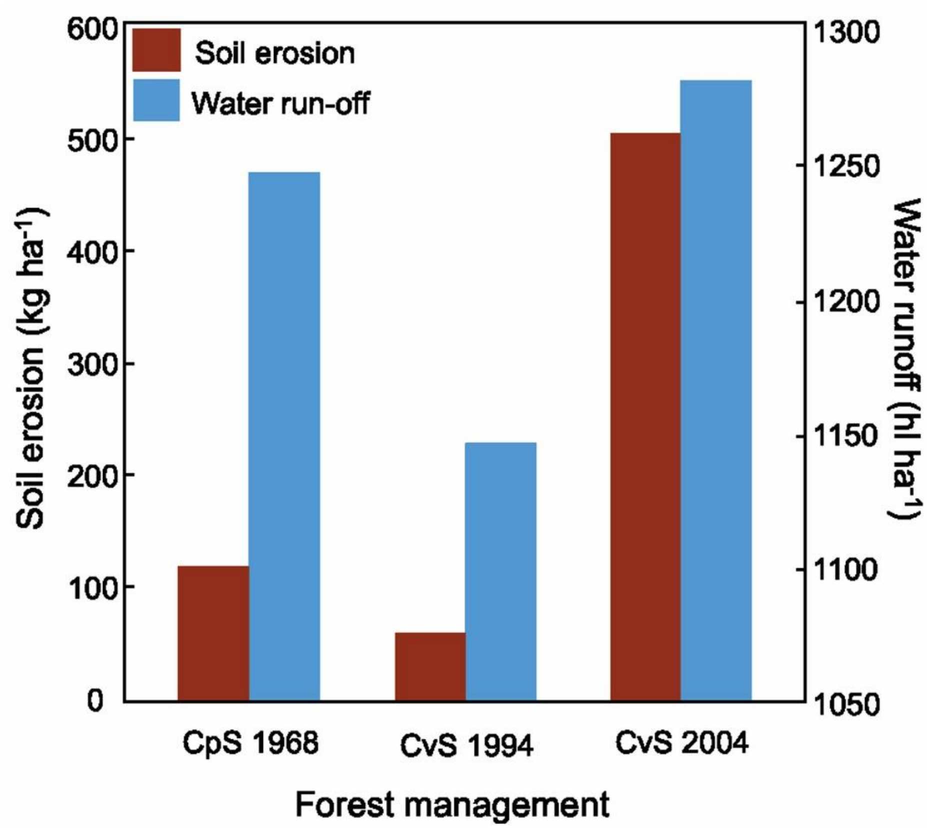

Figure 5. Soil erosion and water runoff. Mean values of soil erosion and water runoff measured during 2008 and 2009 in three different plots placed respectively in CpS 1968, CvS 1994 and CvS 2004.

3.3 Fine-root traits

The highest values of both mass and length of very fine roots (d < 0.3 mm) were found in CvS 1994 with lowest values in CpS 2004 (Table 2). When the totality of fine roots (d< 2 mm) was analyzed, the highest values of dry mass was found in CpS 1968 while the highest value of length in CvS 1994. Cutting operations showed to have a strong influence on both fine-root mass, length and diameter classes, with the lowest values found in the youngest conversion stand (CvS 2004) (Table 2). These findings are in line with what was previously found by Montagnoli et al. 2012. Indeed, the old coppice stand showed the highest fine-root standing biomass due to the lack of recent harvests of the above ground part. Moreover, CpS 1968 showed also a longer fine-root lifespan (Montagnoli et al. 2012) and this may justify the higher values of biomass when considering also the thicker fine-root fraction. Finally, fine-root results showed that 14 years after cutting the fine-root system might recover from harvestings and reach similar or higher values, as in the case of very fine roots, than those found in the old coppice forest.

3.4 Soil erosion versus above and belowground characteristics

Relationship between soil erosion and the measured stand characteristics well explained how they might influence the amount of eroded soil. In particular, when the entire soil surface was covered by seedlings, grass, moss and litter, soil erosion decreased with increasing of soil cover (Figure 6a). The impact of herbaceous and woody crop production on soil erosion is crucial. Perennial herbaceous stands provide year-round soil surface cover, limiting water runoff and sediment loss and favoring soil-development processes by improving the content of organic matter, the structure, the water and nutrient-holding capacity of the soil (Zuazo and Pleguezuelo 2008). In the long term, vegetation influences the fluxes of water and sediments by increasing the soil-aggregate stability and cohesion as well as by improving water infiltration. This complex relationship might explain the lower amount of eroded soil erosion measured in the conversion stand where harvesting was applied ten years ago. Moreover, as also demonstrated by Bochet et al. (1998) the highest value of bare soil inter-plant areas, observed in CvS 2004 due to intense tillage operations, give rise to higher soil loss rates. Canopy cover (%), which included also branches and stems, did not explain the differences in soil erosion measured between plots (Figure 6b). On the contrary, LAI was inversely related to soil erosion and well explained the differences between forest management stands (Figure 6c). Although it has been clearly stated that tree leaves and branches intercept and diminish rain and wind energy protecting the soil (Zuazo and Pleguezuelo 2008), little attention has been given on the singular influence of each feature. However, in the present study leaves area showed a higher influence on the mitigation of soil erosion instead of the more general trait of canopy cover. Fine-root biomass and length also showed to be very important in soil erosion mitigation. In particular, root mass showed a good relationship with soil erosion when very fine-root fraction (d< 0.3 mm) was considered (Figure 7a). This was not the case when the totality of fine roots (d < 2 mm) was analyzed (Figure 7b) probably because of the higher tensile strength that thinner fine roots plays (Mattia et al. 2007; Nyambane and Mwea 2011) and because fine-root mass is not a trait that sufficiently describes the effectiveness of mitigates soil erosion. On the contrary, in our study the amount of eroded soil decreased when both very fine and fine-root length increased (Figure 7c). Indeed, root length per unit of soil is a most frequently used root parameter, which provide information about the occupation of soil by roots (Bauhus and Messier 1999; De Baets et al. 2006; De Baets et al. 2007).

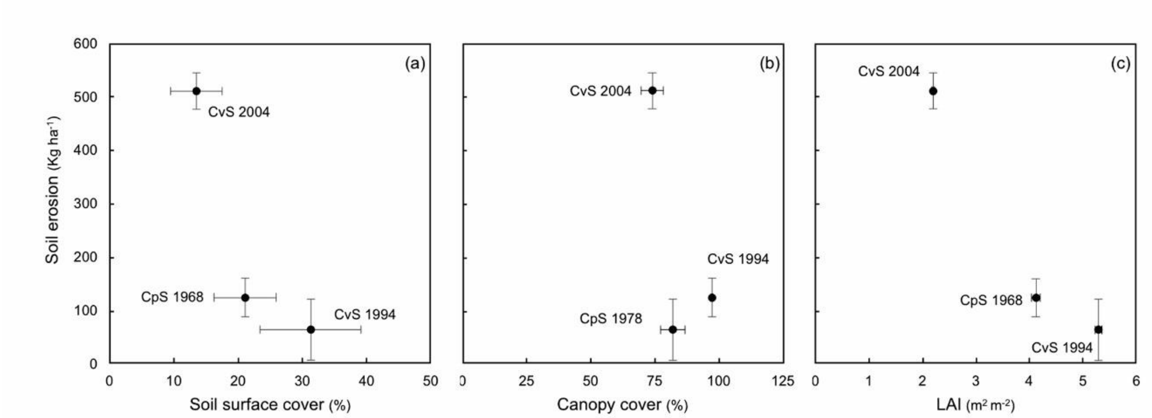

Figure 6. Relationship between soil erosion and soil surface cover, canopy cover and LAI. Graphs show relationships between soil erosion data and Soil surface cover (a), Canopy cover (leaves, stems and branches) (b) and Leaf area index (LAI)(c) for the three plots corresponding to CpS 1968, CvS 1994 and CvS 2004.

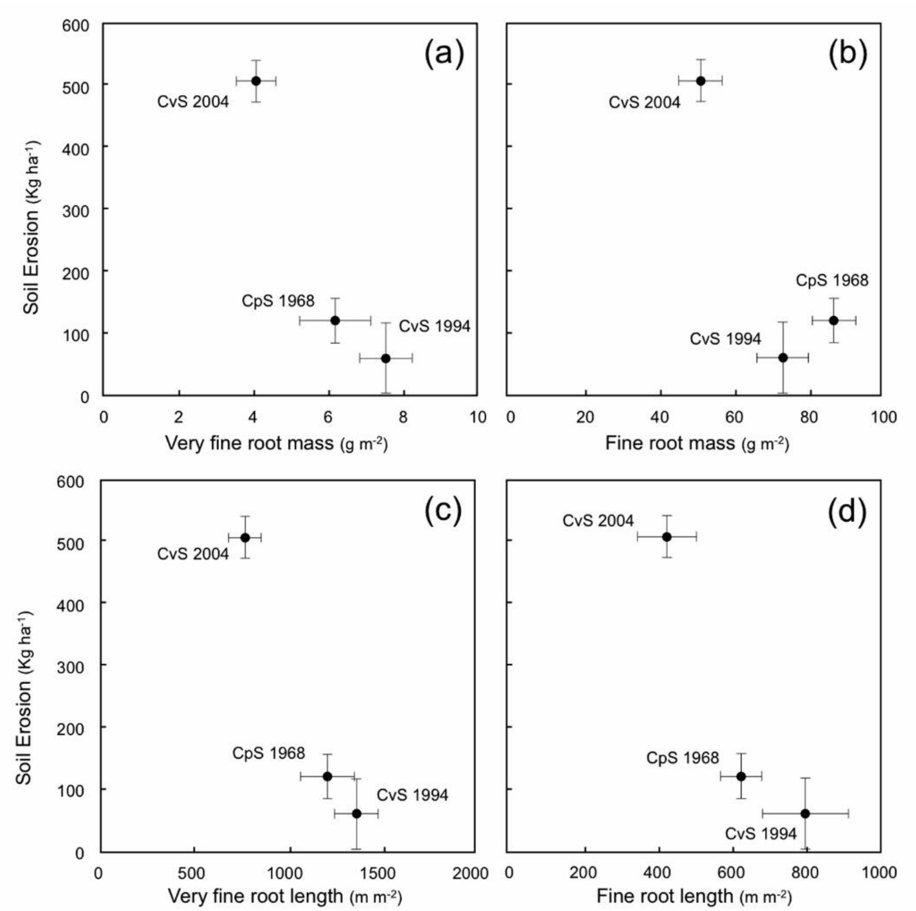

Figure 7. Relationship between soil erosion and fine root traits. Graphs show relationships between soil erosion data with very fine (d < 0.3 mm) (a) and fine root mass (d < 2 mm) (b), very fine (c) and fine root length (d) for the three plots corresponding to CpS 1968, CvS 1994 and CvS 2004.

4 Conclusions

The present study highlighted that the conversion to high forest practices cause a strong change in the forest aboveground structure (i.e. lower tree stem density, canopy cover, soil surface cover) and in fine-root traits (mass and length). These variations make the soil more vulnerable and subject to higher erosion Moreover, the higher amount of soil loss occurs in the first ten years after the harvest practices, because the ground vegetation canopy cover and fine-root traits increase so that the soil loss values became quite similar to the old coppice forest. Finally our study showed that abandoned old coppice stand plays an important role in protection soil resource from erosion. These findings should be taken into consideration if and when forest practitioners evaluate the future of old coppice forest stands growing on a steep slope.

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