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# Impacts of Deforestation and Land Cover Change on Mountain Soils in Hrazdan, Armenia

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*The impacts of deforestation and land cover change upon underlying soils were examined on one hillside in central Armenia. Soil characteristics in three land cover areas—forest, coppice, and pasture—were recorded and soil samples were analyzed. Deforestation and land cover change were found to increase erosion rates. From soil horizon and structural characteristics, it can be estimated that 40 cm of soil have been lost in the pasture and 20 cm have been lost in the coppice compared to the forest. Soil organic carbon was also affected by deforestation and land cover change. Compared to the forest (4.7% organic carbon), both the coppice (3.7%) and the pasture (3.4%) had lower values. Phosphorus, potassium, and nitrogen content varied and may have been affected by erosion, animal deposition, differing amounts of vegetative residues present, differing organic matter decomposition rates, and differing hydrological processes. Deforestation was also found to change the species composition of seedlings and saplings in the coppice in comparison to the forest, reducing oak numbers and increasing hornbeam recruitment.*

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## INTRODUCTION

Located in the Caucuses, Armenia is one of the smallest of the former Soviet Republics (Central Intelligence Agency [CIA], 2008; Figure 1). Recent estimates place the current forest cover within Armenia between 8–10%, roughly 283,000 ha (Moreno-Sanchez & Sayadyan, 2005; Boudjikanian, 2006). Armenia's forests are an important resource for the country as a whole and the local forest communities, providing timber, fuelwood, and other forest products such as fruits, herbs, and nuts; creating habitat for potential game animals; maintaining soil, water, and air quality; and offering a place for recreation (Hunter, 1990; Fetter, 1994; United Nations Environmental Program [UNEP]/Grid-Arendal, 2000; Ministry of Nature Protection [MNP], 2002; Xiubin, Zhanbin, Mingde, Keli, & Fengli, 2003; Abbasi & Rasool, 2005; Moreno-Sanchez & Sayadyan, 2005; Boudjikanian, 2006; Sayadyan & Moreno-Sanchez, 2006). With high levels of biodiversity and endemism in both plants and animals, Armenia's forests are also of importance to the world at large (MNP, 2002; Sayadyan & Moreno-Sanchez, 2006; CIA, 2008). Unfortunately, a long and complex history has resulted in extensive losses in forest cover and current pressures, especially illegal logging, threaten to further reduce this resource (Moreno-Sanchez & Sayadyan, 2005; Boudjikanian, 2006; Sayadyan & Moreno-Sanchez, 2006). Given the erodible nature of Armenia's mountain soils, the continued deforestation may have


**FIGURE 1** Map of Armenia showing the study site, Hrazdan, and surrounding countries.

long-term impacts upon them (MNP, 2002; Moreno-Sanchez & Sayadyan, 2005; Boudjikanian, 2006).

Deforestation can impact soils in multiple ways including reducing organic carbon, nitrogen, and exchangeable potassium (Mroz, Jurgensen, & Frederick, 1985; Pennock & van Kessel, 1997; Glaser, Turrion, Solomon, Ni, & Zech, 2000; Fu et al., 2003; Zheng, He, Gao, Zhang, & Tang, 2005; Abbasi & Rasool, 2005; Abbasi, Zafar, & Khan, 2007). These impacts can be accelerated when regeneration following the cut is suppressed (Bormann, Likens, Fisher, & Pierce, 1968). Deforestation and regeneration suppression can increase soil erodibility and erosion (Bormann, Likens, Siccama, Pierce, & Eaton, 1974; Sanchez, Ataroff, & Lopez, 2002; Cebecauer & Hofierka, 2008). It has also been shown to reduce the cation exchange capacity of the soil and the levels of soil nutrients such as calcium, magnesium, potassium, sodium, aluminum, nitrogen, chlorine, iron, and phosphorus (Likens, Bormann, Johnson, Fisher, & Pierce, 1970; Dominski, 1971; Bormann et al., 1974; Eden, Furley, McGregor, Milliken, & Ratter, 1991; Khresat, Al-Bakri, & Al-Tahhan, 2008). Additionally, deforestation and conversion to pastureland can increase bulk density (Eden et al., 1991; Desjardins, Barros, Sarrazin, Girardin, & Mariotti, 2004).

Within the Armenian highland (comprising eastern Turkey, Armenia, northern Iran, and the surrounding area), investigators have identified similar changes to soils from deforestation and land cover change. The conversion of native woodlands and grasslands to plantations, recreation land, and cropland had an impact upon soil organic carbon, bulk density, and pH in Indagi Mountain Pass, Cankiri, Turkey (Basaran, Erpul, Tercan, & Canga, 2008). In the Taurus Mountains of Turkey, cultivated soils had a higher bulk density and lower levels of soil organic matter compared to adjacent forests (Celik, 2005). To the south of Armenia, in the Lordegan area of Iran, cutting the native oak forests and subsequent tillage of these soils resulted in increased bulk density and decreases in organic matter, total nitrogen, and soluble ions (Hajabbasi, Jalalian, & Karimzadeh, 1997). In central Iran, soil organic carbon and microbial respiration decreased following cutting of native oak forests (Nael, Khademi, & Hajabbasi, 2004).

With only 8–10% of the country covered by already fragmented forest, the importance of Armenia's forests, the erodibility of Armenia's mountain soils, and the estimated rate of logging (600,000 $m^3$ $yr^{-1}$)—both legal and illegal—make deforestation and soil degradation issues of major concern within the Republic of Armenia (MNP, 2002; Moreno-Sanchez & Sayadyan, 2005; Boudjikanian, 2006). Despite this concern, few studies have examined the effect deforestation has on the soils. With quantitative data and an accurate forest inventory, Armenia could begin to develop silvicultural management plans that allow for some legal, regulated logging in areas of the country. This study looks at the impacts of deforestation and subsequent land use upon the underlying soils on one hillside in central Armenia.

## SITE DESCRIPTION

The study site was located 45 km north of the capital city of Yerevan, Armenia in the town of Hrazdan, in Kotayk Marz (N 40° 32′ 36.8″, E 44° 44′ 53.0″; Figure 1). The site is on the northern aspect (20°) of a ridge with a 28% slope that is situated at the easternmost extent of the Tsaghkunyats Mountain Range and at the edge of the Hankavan Valley. The highest elevation within the study site was 1,890 m. The soils were formed from basalt colluvium parent material (Edilyan & Petrosyan, 1976). The soils in the immediate area are Ustepts, Ustolls, and Ustorthents. As in much of Armenia, the climate of the study site is semi-arid and prone to desertification (MNP, 2002). The average rainfall is between 600 and 800 mm $yr^{-1}$ with May and June being the rainiest months. In the winter, up to 2 m of snow can accumulate. Temperatures rise above 20°C in the summer and fall below −10°C in the winter (S. Babaxanyan, personal communication, 2008). The study site was situated at the easternmost edge of a natural Georgian oak/Caucasian hornbeam (*Querícus iberica* and *Carpinus caucasica*) forest that extended into the mountains west of Hrazdan, along the Hankavan Valley. The area of the study site was approximately 190 ha.

While the study site currently has three distinct areas of vegetative cover, within the past two centuries the entire north face of the hill was covered in the same natural oak/hornbeam forest (S. Margaryan, personal communication, 2008). At the farthest eastern edge of the hill, the forest was cut and the land was converted to pasture by local shepherds to graze their sheep, goats, and cows. The clearing of the forest and its conversion to pastureland probably began about 200 yr ago with the arrival of settlers in the immediate area (H. Alexanyan, personal communication, 2008). The land is still used for grazing livestock today. It is owned by the state and the villagers are allowed to pasture their animals on it without regulation (S. Margaryan, personal communication, 2008). The current land area under pasture cover is approximately 40 ha.

At the western edge of the pasture begins the natural oak/hornbeam forest. This forest was last heavily logged about 87 yr ago and then allowed to naturally regenerate (S. Margaryan, personal communication, 2008). Presently, it has a well-developed overstory of Georgian oak, Caucasian hornbeam, European ash (*Fraxinus excelsior*), Norway maple (*Acer platanoides*), and apple (*Malus*); with an understory comprised of Georgian oak, Caucasian hornbeam, European ash, Norway maple, European mountain ash (*Sorbus aucuparia*), Caucasian pear (*Pyrus caucasica)*, and wild cherry (*Prunus avarium*).

Adjacent to the 87-yr-old forest is a similar forest tract that was cut by local residents for fuelwood during an energy crisis in the early 1990s. From 1992 to 1994, the unplanned and unregulated harvest resulted in a clearcut of the area (S. Margaryan, personal communication, 2008). The forest was allowed to naturally regenerate following the cut and oaks and hornbeams have since stump-sprouted but have been left untended, resulting in bushy coppice regeneration. There is also prolific hornbeam regeneration in areas of the coppice receiving more light. The area of coppice forest is approximately 110 ha.

The portion of forest that went unlogged during the energy crisis was spared because a church and cemetery lie at the bottom of the hill and the villagers did not want to disturb those sites. This area of unlogged forest covers approximately 40 ha. Both forest stands are owned by the state and managed by Hayantar, the federal agency in charge of managing Armenia's forestland. As in the rest of Armenia, the only logging permitted is sanitary cutting, but some small-scale illegal logging does occur in the form of high grading. No forest inventories have been conducted since the 1989 National Forest Inventory, but the local branch of Hayantar hopes to begin surveying again within the next few years. Hayantar also plans to thin the coppice forest stand within the next 4 yr but has no other management plans for either stand (S. Margaryan, personal communication, 2008).

## METHODS

This study looked at soil characteristics and nutrient levels within the pasture, the forest, and the coppice. While it would be desirable to have multiple areas of each land cover type from which to sample and analyze and thereby avoid the problem of pseudoreplication, it would be difficult to find other hillsides with similar conditions and infeasible to try to artificially replicate the land cover areas. Experiments and studies with pseudoreplication can still yield valuable results as long as the implications of inferential statistics performed on the data are not overstated (Oksanen, 2001, 2004).

An area measuring 140 m across by 125 m down the slope was established in each of the three land cover areas—pasture, forest, and coppice. Three transects were randomly located within each land cover area. Transects ran down the slope. Sampling sites were located along the transects at 25-m intervals beginning 25 m from the top of the slope. Four sampling sites were located on each transect yielding 12 sampling sites in each land cover area. Overstory, understory, and herbaceous vegetation were surveyed. Soil profiles were dug, soil morphology was recorded, and composite soil samples were taken to a depth of 24 cm. Bulk density samples were taken using a bulk density sampler.

The soil samples were air dried, then sent to the soil laboratories at the State Agricultural Institute (SAI) in the capital city of Yerevan and to the University of Applied Sciences–Weihenstephan in Freising, Germany for analysis. Finally, another transect was run in each land cover area and four deep pits were dug on each transect to provide more observations of soil development and characteristics.

At the SAI laboratory in Yerevan, the soil samples were analyzed for percent soil organic carbon using a modification of the Tyurin method (USSR Science Academy, 1960). Electrical conductivity and total dissolvable salts were determined on an Ultrameter manufactured by the Myron L Company (Carlsbad CA, USA). Determination of pH was done on a Milwaukee SM 802 pH/EC/TDS meter (Milwaukee Instruments, Sales and Support, Rocky Mount, NC, USA; Sparks, 1996). Total nitrogen was found using the Ginsburg extraction and Kjeldahl distillation methods (Bremner & Mulvaney, 1982), phosphorus with the Ginsburg extraction and color development by an acid ammonium molybdate reagent (Bray & Kurtz, 1945), and total potassium using a propane flame spectrophotometer (USSR Science Academy, 1960). Texture was determined by sieving. Finally, the bulk density was recorded by dividing the weight of the samples by the volume of the bulk density sampler (63.68 $cm^3$) (Blake & Hartge, 1986). At the laboratory in Germany, thermogravimetry was used to analyze the soil samples for percent soil organic carbon, percent total nitrogen, and percent clay (Siewert, 2004).

SAS 9.1.3 service pack 4 software was used to test the laboratory results for normality, correlation, ANOVA, and Tukey's test for honestly significant difference (Steele & Torrie, 1960). (SAS 9.1.3 service pack 4 is copyright © 2008 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA.) Results of the statistical analysis are shown in Table 1. No statistically significant differences were found between slope positions or between the interactions of land cover type and slope position in the statistical analysis (Rhoades, 2009).



**TABLE 1** Laboratory Results: Mean Value (± 1 *SE*) of Quantitative Soil Nutrients and Characteristics in the Three Land Cover Areas ($n = 36$)

| | Quantitative soil properties | | |
|---|---|---|---|
| | Forest | Coppice | Pasture |
| % organic carbon | 4.74 ± 0.28 a | 3.65 ± 0.24 b | 3.39 ± 0.27 b |
| % organic carbon—Thermo | 6.7 ± 0.31 a | 5.4 ± 0.33 b | 4.3 ± 0.29 c |
| pH | 6.9 ± 0.03 a | 6.8 ± 0.05 a | 7.0 ± 0.04 a |
| Salts | 0.03 ± 0.002 a | 0.03 ± 0.003 a | 0.03 ± 0.003 a |
| Electrical conductivity | 80.97 ± 4.9 a | 78.83 ± 5.8 a | 79.63 ± 7.47 a |
| % nitrogen | 0.46 ± 0.03 a | 0.32 ± 0.02 b | 0.40 ± 0.04 a, b |
| % nitrogen—Thermo | 0.58 ± 0.03 a | 0.46 ± 0.03 b | 0.38 ± 0.02 b |
| % $P_2O_5$ | 0.19 ± 0.01 a, b | 0.16 ± 0.01 a | 0.20 ± 0.01 b |
| % $K_2O$ | 3.04 ± 0.13 a | 2.12 ± 0.18 b | 3.16 ± 0.13 a |
| C:N | 10.5 ± 0.47 a | 12.1 ± 0.89 a | 9.4 ± 0.99 a |
| Bulk density (g $cm^{-3}$) | 0.87 ± 0.02 a | 0.93 ± 0.02 b | 1.153 ± 0.02 c |

*Note*. The same letter for each value indicates no significant difference between land cover areas using Tukey's test for honestly significant difference ($\alpha = .05$).

## RESULTS AND DISCUSSION

The unplanned and unregulated forest cuttings and land cover changes within the study area have had an impact on the soils. Erosion rates appear to have increased in both the pasture and the coppice compared to the forest. The increased erosion then acted as an important driver, which affected other soil characteristics and nutrient levels. In addition, the changes in vegetative cover between the three areas and the introduction of grazing animals in the pasture led to different inputs being added to the soils in each of the land cover areas and possibly to differing rates of organic matter decomposition. These changes of input levels and decomposition rates may have further affected soil characteristics and nutrient levels. This section first describes the evidence for the varying erosion rates, then the significant variations in soil nutrients and characteristics will be discussed, followed by a general conclusion looking at the impacts of deforestation and land cover change in the study area as a whole.



### Erosion

The horizon development, soil structure, and percentage of coarse fragments as observed in soil profiles in each land cover area indicate that more erosion has taken place in both the pasture and the coppice compared to the forest. The A horizon in the forest had an average depth of 34.5 cm. In the coppice, the A horizon is only 13.5 cm on average (Figure 2). As slope, aspect, and parent material are the same in the forest and the coppice, increased erosion in the coppice due to the unplanned and unregulated clear-cut is the clearest explanation of this difference.

Also, in all three land cover areas, the percent of coarse fragments rose sharply with depth, often from 20 or 30% to 55 or 60%. This rise usually coincided with the upper boundary of a transitional C horizon (usually AC in the pasture and usually BC in the forest and coppice) and is marking the transition from soil to the underlying unweathered basalt colluvium. In the forest, this coarse fragment-rich transitional C horizon was found at an average depth of 62.75 cm. In the coppice, it was found at an average depth of 34.5 cm. This would indicate that about 20 cm or more of soil has been lost as a result of the one clear-cut.

The transitional C horizon indicates that even more erosion has occurred in the pasture. The transitional horizon was found at an average depth of 21.75 cm, 41 cm shallower than the forest. Unlike the coppice and the forest, which generally have an A horizon above a B horizon, three of the four deep profiles dug in the pasture did not have a B horizon and only contained an A horizon, 21.75 cm deep on average, over an AC horizon (Figure 2). If 40 cm of soil have been eroded from the pasture compared to the forest, this would mean that the entire A horizon that may have once been present in

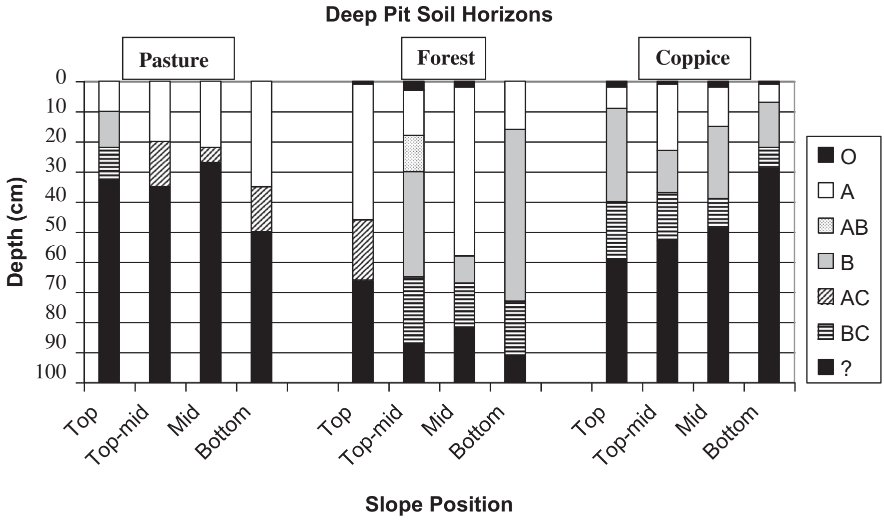


**FIGURE 2** Soil horizons for the soil profiles in the deep profile transects. The ? horizon colored black denotes an area below the maximum depth of pit and so of unknown characteristics.



the pasture soils (an average of 34.5 cm deep in the forest) has been eroded. The soils now located at the surface would have once been the B horizon when the pasture was under forest cover. The A horizon in the pasture, with a characteristic dark brown color (Munsell 10YR 3/3 was recorded most frequently in the pasture A horizon), is due to recent organic matter additions over the past 200 yr (Soil Survey Staff, 1951; Singer & Munns, 1987; Munsell Corporation, 1994; Vidic & Lobnik, 1997; Brady & Weil, 2002).

The structure of the soils in the forest, pasture, and coppice is also consistent with the pattern of erosion. In the forest and the coppice, a granular structure, 13.5 and 10.5 cm deep, respectively, before the soil structure changes to subangular blocky, is associated with the A horizon and the change to subangular blocky generally occurs where the A horizon transitions to a B horizon. In the pasture only one of the profiles had a layer of granular structure (10 cm deep) and the other profiles either began as subangular blocky or had a shallow layer (7 cm deep) of granular/subangular blocky soil before becoming subangular blocky. The subangular blocky structure is generally associated with the B horizon in the forest and coppice but is found in the pasture A horizon, supporting the idea that the current pasture A horizon was, in fact, once a B horizon that has been uncovered by erosion and has had recent additions of organic matter.

Other field observations support the argument that erosion has taken place at a higher rate in the pasture and, to a lesser degree, the coppice when compared to the forest. An O horizon was found in 15 of the 16 total profiles in the forest. O horizons were only present in 5 out of 16 profiles in the coppice and were not present in the pasture. Multiple factors may be influencing O horizon development such as varying rates of vegetative residue additions to the soils and varying decomposition rates for organic matter within each land cover area. The inconsistent presence of an O horizon may also indicate that greater erosion has taken place in the coppice and the pasture. Higher erosion rates in these areas compared to the forest would remove O horizons that were once present and subsequently prevent their regeneration (Dominski, 1971; Pennock & van Kessel, 1997; Abbasi & Rasool, 2005; Khresat et al., 2008).

The relative bulk density of the three land cover areas is another possible indicator of erosion. The differences in the bulk densities of the upper 10 cm of soil in each area were statistically significant; highest in the pasture (1.53 g $cm^{-3}$), lower in the coppice (0.93 g $cm^{-3}$), and lowest in the forest (0.87 g $cm^{-3}$) ($p = < .0001$). Erosion could have increased the bulk density of the pasture and coppice soils by removing the less dense upper level soils and thereby bringing the denser lower level soils to the surface (Brady & Weil, 2002). It is important to note, however, that compaction by livestock in the pasture and potentially lower amounts of vegetative residue inputs into the soil leading to lower levels of soil organic matter in both the pasture and the coppice as compared to the forest could also have contributed in creating the differences in the soils' relative bulk densities (Eden et al., 1991; Koutika et al., 1997; Brady & Weil, 2002; Abbasi & Rasool, 2005; Abbasi et al., 2007; Khresat et al., 2008).

Although multiple factors affect soil consistency, it can also be used to compare the relative amounts of erosion that may have taken place. Pasture soils tended to be more firm, while forest soils tended to be more friable, with coppice soils falling in between (Table 2). Considering that the three areas are adjacent, from the same parent material, and subject to the same environmental conditions, the clearest explanation of the differences in consistency is that the upper levels of soil have been eroded to a greater extent in pasture and coppice compared to the forest, uncovering the denser subsoils that were once located lower in the soil profile.

Finally, the impacts of recent erosion were visible in parts of the pasture and coppice. This set of field observations indicate a consistent picture that erosion has occurred as a result of deforestation and land cover change. The

**TABLE 2** Upper Horizon Soil Consistency in All Profiles

| | Soil consistency | | |
|---|---|---|---|
| | Very friable | Friable | Firm |
| Pasture | 0 | 9 | 7 |
| Forest | 6 | 10 | 0 |
| Coppice | 0 | 16 | 0 |

relative amount of erosion occurring in each land cover area is an important factor in explaining the other changes that have occurred in the study area due to deforestation and land cover change.

Other studies have also recorded similar increases in erosion due to land cover change. Erosion rates increased in the Venezuelan Andes (Sanchez et al., 2002), the Hubbard Brook watershed experiments in New Hampshire, USA (Bormann et al., 1974), and the Taurus Mountains of Turkey (Celik, 2005). Other studies have also found bulk density to be higher in pastures, grasslands, and disturbed sites compared to natural forests, especially in highly degraded or overgrazed pasturelands (Eden et al., 1991; Hajabbasi et al., 1997; Koutika et al., 1997; Abril & Bucher, 2001; Desjardins et al., 2004; Celik, 2005; Abbasi et al., 2007; Zou, Wang, Wang, & Xu, 2007; Basaran et al., 2008).



## Organic Carbon and Organic Matter

The Tyurin method showed the difference in the levels of organic carbon in the forest (4.7%) compared to the coppice (3.7%) and the pasture (3.4%) to be statistically significant ($p = < .0001$). The thermogravimetric results showed all the land cover areas—forest (6.7%), coppice (5.4%), and pasture (4.3%)—as having statistically significant differences in organic carbon content ($p = .0001$). The higher levels of organic carbon in the forest compared to the coppice could be attributed to the interaction of factors. First, the unplanned and unregulated clear-cutting of the coppice and the harvest of woody biomass for use as fuelwood removed organic material high in carbon and other nutrients (Boyle, Phillips, & Ek, 1973; Harvey, Larsen, & Jurgensen. 1980; Mroz et al., 1985; Pennock & van Kessel, 1997; Schwendenmann & Pendall, 2006; Yimer, Ledin, & Abdelkair, 2007; Khresat et al., 2008). Therefore, following the cut, the coppice soils would have had fewer inputs of vegetative residues than the forest soils. Higher erosion rates after the removal of the overstory in the coppice could also have removed decomposable vegetative material as well as the upper levels of soil where organic matter and organic carbon would accumulate. The proportionally lower abundance of an O horizon in the coppice (5 out of 16 profiles) when compared to the forest (15 out of 16 profiles) also indicates higher erosion rates in the coppice. The removal of the overstory vegetation when the coppice was cut could also have increased the solar radiation reaching the soil surface and raised daytime temperatures. This would decrease organic matter by increasing organic matter mineralization rates in the soil (Dominski, 1971; Anderson & Coleman, 1985; Pennock & van Kessel, 1997; Abbasi & Rasool, 2005; Schwendenmann & Pendall, 2006; Zou et al., 2007).

Grassland and pasture soils often have levels of organic carbon and organic matter comparable to forest ecosystems as a result of the vegetative biomass usually found in them and the rate of decomposition (Lugo, Sanchez, & Brown, 1986; Koutika et al., 1997; Saviozzi, Levi-Minzi, Cardelli,

& Riffaldi, 2001; Murty, Kirschbaum, McMurtrie, & McGilvary, 2002; Conant, Six, & Paustian, 2004; Desjardins et al., 2004; Schwendenmann & Pendall, 2006). Overgrazing, however, can lead to significant losses in organic matter and organic carbon by altering aboveground and belowground biomass, plant litter, and soil respiration and temperature (Parton, Schimel, Cole, & Ojima, 1987; Abril & Bucher, 2001; Murty et al., 2002; Zou et al., 2007). The comparatively low levels of organic carbon in the pasture at the study site illustrate the overgrazed and degraded nature of the pasture. Reduced aboveground and belowground biomass, due to grazing, would also leave the steep (28%) pasture soils more exposed and prone to erosion which would remove surface soil where organic matter would be accumulating in an undisturbed pasture (Eden et al., 1991). Other studies, with conditions similar to the pasture in this study, often involving a steep slope or overgrazing, showed decreases in organic carbon or organic matter of 26% or more (Glaser et al., 2000; Abril & Bucher, 2001; Sanchez et al., 2002; Nael et al., 2004; Abbasi et al., 2007). In Mongolia, highly degraded pastures had less organic carbon than protected pastures (Zou et al., 2007).

## Phosphorus

The difference in total phosphorus levels between the pasture (0.20%) and the coppice (0.16%) was statistically significant ($p = .0271$). Phosphorus values in the forest (0.19%) were in between and no statistically significant differences were reported between the forest and the pasture or coppice. The higher levels of phosphorus in the forest compared to the coppice are, in part, probably attributable to the higher levels of organic matter in the forest (Singer & Munns, 1987; Abbasi et al., 2007; Brady & Weil, 2002). The pasture, in contrast to the low levels of organic matter found there, however, had the highest levels of phosphorus. This may be explained by the high concentrations of phosphorus being added to the pasture soils in the form of animal urine and manure deposition which could offset the limited inputs from vegetative residues and the amount lost to erosion (Wolton, 1955; Watkin, 1957; Saunders, 1984; Goland, 1993; Allison, Chiew, & McMahon, 1998; Turrion, Glaser, Solomon, Ni, & Zech, 2000; Xu & Hirata, 2005; Garg, Yadav, Sheoran, Chand, & Kaushik, 2006). Other studies have reported various changes in phosphorus content resulting from deforestation, land cover change, overgrazing, and manure additions to the soil. Zheng et al. (2005), Abbasi et al. (2007), and Hajabbasi et al. (1997) report higher levels of phosphorus in forests than pasture, while Turrion et al. (2000) report higher levels in pastures due to animal deposition.

## Potassium

The total potassium in the coppice (2.1%) was less than the content in the pasture (3.1%) and the forest (3.0%) ($p = < .0001$). The levels of potassium found in the three land cover areas are difficult to explain, but the mobility of potassium ions within soil and the inputs of weathering minerals may partially be responsible (Mroz et al., 1985; Brady & Weil, 2002; Alfaro, Gregory, & Jarvis 2004a; Alfaro, Jarvis, & Gregory, 2004b). The unplanned and unregulated clear-cutting of the forest, which resulted in the coppice, could have increased both lateral and vertical movement of water and resulted in leaching of potassium from the upper levels of the soil (Pennock & van Kessel, 1997). The hydrological processes in the pasture may also be similar to those in the coppice following the clear-cut. Over the past 200 yr, however, the erosion in the pasture appears to have been so extreme that the soil surface of the pasture is closer to the relatively unweathered parent material, which may provide a ready source of potassium for nutrient cycling. The soil samples were taken to a depth of 24 cm. Within the pasture, the depth at which coarse fragments reached a minimum of 50% was found within 10 cm of the soil surface. Therefore, many of the pasture soil samples analyzed at the SAI laboratory were partially collected from the area of the soil profile having a high percentage of coarse fragments. This was not true of the soil samples in the forest or the coppice. The weathering of the rocks, releasing potassium, in this layer would be an input into all the land cover area soils. However, the relative depth of this layer in the three land cover areas could result in higher concentrations of potassium in the pasture samples. Animal deposition in the pasture may also be contributing to the potassium levels in the pasture (Wolton, 1955; Watkin, 1957; Richards & Wolton, 1976; Saunders, 1984; Sakadevan, Mackay, & Hedley, 1993; Alfaro et al., 2004b).

## Nitrogen

The Ginsburg extraction and Kjeldahl distillation methods indicated a statistically significant difference between total nitrogen levels in the forest (0.46%) and the coppice (0.31%) ($p = .0176$). Pasture levels (0.40%) were not statistically different from either the forest or coppice. Thermogravimetric analysis showed the difference in total nitrogen levels in the forest (0.58%) to be statistically significant when compared to both the coppice (0.46%) and the pasture (0.38%; $p = < .0001$). The higher levels of total nitrogen in the forest compared to the coppice and the pasture can be explained by the higher amounts of organic matter in the forest soils (Dominski, 1971; Brady & Weil, 2002; Wachendorf, Lampe, Taube, & Dittert, 2008). In addition, removing the overstory in the coppice and the pasture could have caused increased organic matter decomposition and nitrogen transformation rates followed by higher rates of nitrogen leaching (Dominski, 1971; Harvey et al., 1980; Mroz et al., 1985; Pennock & van Kessel, 1997; Khresat et al., 2008). Despite possible nitrogen additions from the higher percentage of nitrogen fixing plants in the coppice (6.1% of total ground cover) compared to the forest (1.7% of total ground cover), these factors could have combined to result in less nitrogen in the coppice than the forest. Comparatively low total nitrogen levels in the pasture due to erosion, overgrazing, increased decomposition rates, and leaching, however, may also be partially compensated for by nitrogen fixing plants (5.9% ground cover) and by nitrogen inputs through urine and manure deposition by grazing animals on the pasture (Wolton, 1955; Watkin, 1957; Richards & Wolton, 1976; Saunders, 1984; Sakadevan et al., 1993; De Klein & Van Logtestijn, 1994; Flessa, Dorsch, Beese, Konig, & Bouwman, 1996; Somda, Powell, & Bationo, 1997; Ma et al., 2007; Wachendorf et al., 2008). The additional inputs of nitrogen from animal deposition in the pasture could explain the proportionally higher nitrogen to organic carbon ratio in the pasture compared to the coppice.

## Regeneration and Species Composition

In addition to changes in soil nutrients and characteristics, the unplanned and unregulated clear-cut in the coppice has also affected the species composition of seedlings and saplings. The regeneration, in terms of saplings and seedlings, in the forest is 48% oak, 31% hornbeam, with maple and other species taking up 21%. The clear-cut in the coppice has increased the numbers of hornbeam seedlings and saplings in the coppice compared to the forest (from 256 to 1723 seedlings and 184 to 1038 saplings) and now the regeneration in the coppice is 80% hornbeam (Figure 3). This means, as the coppice eventually grows into a mature forest, it will have a different species composition that it did before the cut. This could have negative effects on wildlife as some species may be better adapted to the original oak/hornbeam forest species composition and have a more difficult time in a predominantly hornbeam forest. This could be especially true as the

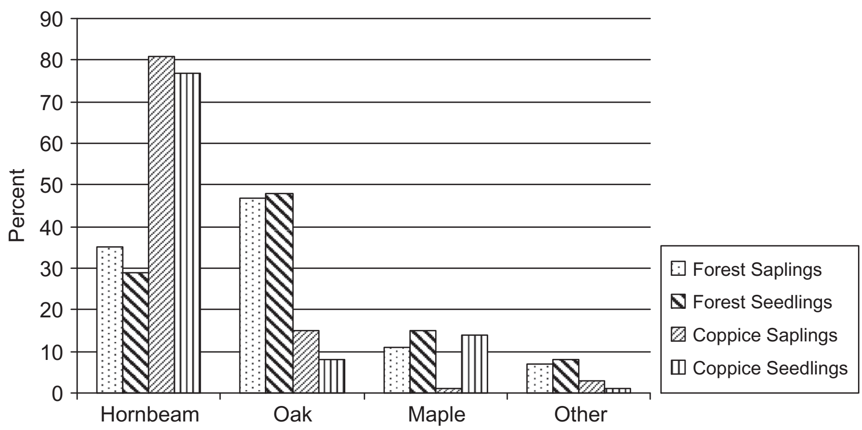


**FIGURE 3** Percentage of saplings and seedlings by species in forest and coppice. Hornbeam is the dominant species in the coppice stand while the forest is mixed oak and hornbeam.

mast of oak trees is an important food source for many wildlife species (Van Dersal, 1940).

## CONCLUSION

The clearing of the far eastern edge of the forest; the conversion of that area of land into pasture; and the subsequent unregulated grazing of cows, sheep, and goats have altered the erosion rate, nutrient levels, and soil characteristics in comparison with the adjacent native oak/hornbeam forest. Once the forest cover was removed and the growth of herbaceous plants in the pasture limited by unregulated grazing, 40 cm of soil may have been lost due to erosion in the pasture compared to the forest. While grazing animal deposition may have added some soil nutrients to the pasture, erosion and low levels of vegetative residue addition have in turn led to reduced levels of organic carbon and organic matter. The reduced levels of organic carbon and organic matter will only lead to further erosion and erodibility of the soil and reduce the nutrient and water holding capacities of the soil (Anderson & Coleman, 1985; Brady & Weil, 2002; Abbasi & Rasool, 2005; Abbasi et al., 2007). While this study was limited to only one hillside and therefore conclusions may not be extended to the conversion of forest to pasture in parts of Armenia, it is clear that the conversion of this forest to pasture and the continued unregulated grazing within the study area is an unsustainable practice.

The soils in the area adjacent to the forest on the western side—where the forest was nearly completely harvested without planning or regulation, allowed to regenerate, and thereby turned into a coppice forest—have been affected in a manner similar to that of the pasture but to a lesser degree. The more recent cutting of the coppice compared to the pasture and the natural regeneration within the coppice area, the estimated erosion that has occurred falls between that of the forest and the pasture. Similarly, with the intermediate levels of erosion, and intermediate amounts of vegetative residue additions to contribute to the soil in relation to the forest and pasture, the organic carbon level in the coppice falls between the levels of the forest and the pasture. With lower levels of organic carbon and organic matter and a higher erosion rate than the forest, the coppice also had significantly less nitrogen, phosphorus, and potassium than the forest. Again, while this study is limited to just one hillside, and therefore the potential impacts of cutting in other areas are unknown, it is clear that just the one unplanned and unregulated clear-cutting immediately followed by natural regeneration had negative impacts on the underlying soils within this study area. While forest cover has returned, it is premature to speculate if and to what degree a forest similar to the more mature oak forest will return.

While this study was limited to one hillside and so does not have replicates, the findings are consistent with other studies on deforestation and land cover change from a variety of locations around the world (Table 3).

**TABLE 3** Comparison of Impacts of Deforestation and Land Cover Change Between This Study and Similar Studies

| Study | Location | Erosion | OM/OC | P | K | N | Bulk density |
|---|---|---|---|---|---|---|---|
| Hrazdan study | Hrazdan, Armenia | ▲ | ▼ | O | O | ▼ | ▲ |
| Mroz et al., 1985 | Michigan, USA | – | – | O | ▼ | ▼ | – |
| Sanchez et al., 2002 | Andes Mountains, Venezuela | ▲ | ▼ | – | – | – | – |
| Bormann et al., 1968, 1974 | New Hampshire, USA | ▲ | ▼ | – | ▼ | ▼ | ▲ |
| Celik, 2005 | Taurus Mountains, Turkey | ▲ | ▲ | – | – | – | ▲ |
| Hajabbasi et al., 1997 | Lordegan, Iran | – | ▼ | ▲ | ▼ | – | ▲ |
| Koutika et al., 1997 | Eastern Amazon, Brazil | – | ▲ | – | – | ▲ | ▲ |
| Abbasi et al., 2007 | Rawalakot Azad Jammu and Kashmir, Pakistan | – | ▼ | ▼ | ▼ | ▼ | ▲ |
| Zheng et al., 2005 | Loess Plateau, China | – | ▼ | ▼ | – | ▼ | – |
| Boyle et al., 1973 | Wisconsin, USA | – | – | O | O | O | – |

*Note*. OM/OC = organic matter/organic carbon, P = phosphorus, K = potassium, N = nitrogen. Arrows indicate trends in the property of varying degrees: ▲ indicates an increase in the property due to land cover change, ▼ indicates a decrease in the property due to land cover change, O indicates no trend, – indicates that no data were recorded for this property in the study. Studies have been included in the Table that measure the impacts upon multiple properties due to land cover change.

Therefore, it is reasonable to expect that the impacts found within this study, and the other studies mentioned, would also be occurring in other locations within Armenia where deforestation and land cover change have occurred. Until more studies are conducted, it would be prudent to assume that deforestation and land cover change may be having significant and long-term impacts on soils throughout Armenia.

Further studies need to be conducted to investigate the impacts grazing has on native mountain pastures and other forest areas that have been converted into pastures within Armenia, how the impacts of grazing are affected by slope and soil type, and to compare how differing levels of grazing intensity may affect pasture vegetation and soils. Additional studies should focus on looking at the impacts that different types of forest cuts (i.e., planned and regulated clear-cuts, shelterwood cuts, and selective harvesting) involving different rotations and basal areas have on soils, stand dynamics and vegetative cover. These studies should also investigate the role various soil types, slopes, and climates may play in the impacts those cuts may have on soils, stand dynamics, and general vegetative cover throughout Armenia. Until further research is conducted within Armenia and the impacts of various logging methods are known in regard to various soils, slopes, and climates, and an accurate forest inventory is conducted from which informed management decisions can be made, forest management decisions should be made with caution to avoid causing long-term damage to this important resource.



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