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Effects of land use-induced vegetation and topography changes on soil chemistry in the Southern Alps (Ticino, Switzerland)

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Abstract: Effects of land use changes on chemical soil properties were studied in a southern alpine valley of Ticino, Switzerland by analysing three different land cover-topography units: (*i*) natural forested slopes (NFS); (*ii*) deforested, cultivated terraces (DCT), and (*iii*) reforested, abandoned terraces (RAT). Whereas NFS represents the natural reference state with negligible anthropogenic influence, DCT corresponds to intense agricultural utilization, and RAT refers to a post-cultural natural evolution after terrace cultivation. Land use-induced changes in vegetation cover and topography (i.e., terracing) had a clear influence on chemical soil properties. The presence or absence of the European chestnut (*Castanea sativa* Mill.), one of the main soil acidifying agents in the study area, clearly affected soil acidity, soil organic matter (SOM), and nutrient status. Compared to the vegetation change, terracing has a less obvious effect on soil chemistry. A greater effective rooting depth and a flat microtopography on terraces lead to a rapidly increased SOM accumulation due to better growing conditions for trees. Thus, the reforested, abandoned terraces develop peculiar soil chemistry conditions after 36 to 46 years of abandonment only.

Keywords: acidification; biodegradability; reforestation; agricultural terraces

In the past, the existence of rural communities highly depended on on-site agricultural production. However, in mountain regions, the availability of arable land was often limited due to the steepness of the terrain and related geomorphodynamic processes. As a consequence, in many alpine valleys, terracing hillslopes has most often been the only way to create a stable topographic basis for soil conservation and erosion control when doing arable farming (Sandor and Eash 1991, Crosta et al. 2003).

Measures of agricultural establishment and production, such as the initial clearance of the natural vegetation, terrace construction, mechanical soil tillage, application of fertilisers, as well as crop cultivation and harvesting, have a significant impact on soils. Besides causing soil physical (e.g., Layton et al. 1993, Huwe 2002, Bronick and Lal 2005) and biological modifications (e.g., Zelles et al. 1992, Marschner et al. 2003, Romaniuk et al. 2011, 2016), they can considerably alter the chemical composition in terms of concentration, distribution and quality of soil organic matter (SOM) (e.g., Reeves 1997, Angers et al. 1997, Angers and Eriksen-Hamel 2008, Paulino et al. 2014), soil acidity (e.g., Bolan and Hedley 2003, Goulding 2016), or nutrient balance (e.g., Paredes et al. 2016, Schröder et al. 2016). On the other hand, inverse effects are observed after the abandonment of cultivation consisting of successive restoring of altered soil properties (e.g., Ihori et al. 1993, Shang et al. 2012, Deng et al. 2013, Zhang et al. 2016).

The objective of the present study is to test the hypothesis that land use changes (i.e., agriculture

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initiation and cessation) have a distinct effect on soil properties. Special emphasize was laid on the influence of land use-induced changes in vegetation cover and topography (i.e., terracing) on soil chemistry. To this purpose, we analysed the chemical soil properties in the southern Alpine Onsernone valley (Switzerland).

MATERIAL AND METHODS

Research area. The research area is located in the territory of Loco (Municipality of Onsernone) in the east-west trending Onsernone valley near Lago Maggiore, in the southern Swiss Alps (Figure 1). Mean annual precipitation is about 2 000 mm with dry winters and a nearly bimodal regime with peaks in spring and fall. The mean annual temperature is 11 °C (1961–2003; Meteo Swiss 2004).

The valley is v-shaped and deeply incised with slopes between 30° and 50°. The bedrock consists of gneiss rich in plagioclase, quartz, biotite, and muscovite, which in many places is covered by a mixture of colluvium and glacial deposits (Blaser 1973). The soil cover consists mainly of podzols and cambisols depending on vegetation, microclimate and agricultural use (Blaser 1973, Blaser et al. 1987, 1997, 1999).

North-facing slopes are covered by extended European beech (*Fagus sylvatica* L.) forests (Muster et al. 2007), whereas settled south-facing slopes are poorer in forests characterised by mixed hardwood stands dominated by European chestnut (*Castanea sativa* Mill.), deciduous oaks (*Quercus* spp.), alder (*Alnus glutinosa* (L.) Gaertn) and lime (*Tilia cordata* Mill.) in differing composition according to site characteristics and forest management.

Between the 13th and the 16th century, the small-scale topography of the settled south-facing valley side has been modified by largely deforesting and terracing the slopes to establish agriculture. The climax of terracing in the Onsernone valley was reached during the 16th century when the terraces were used to grow rye for straw plaiting (Bonstetten

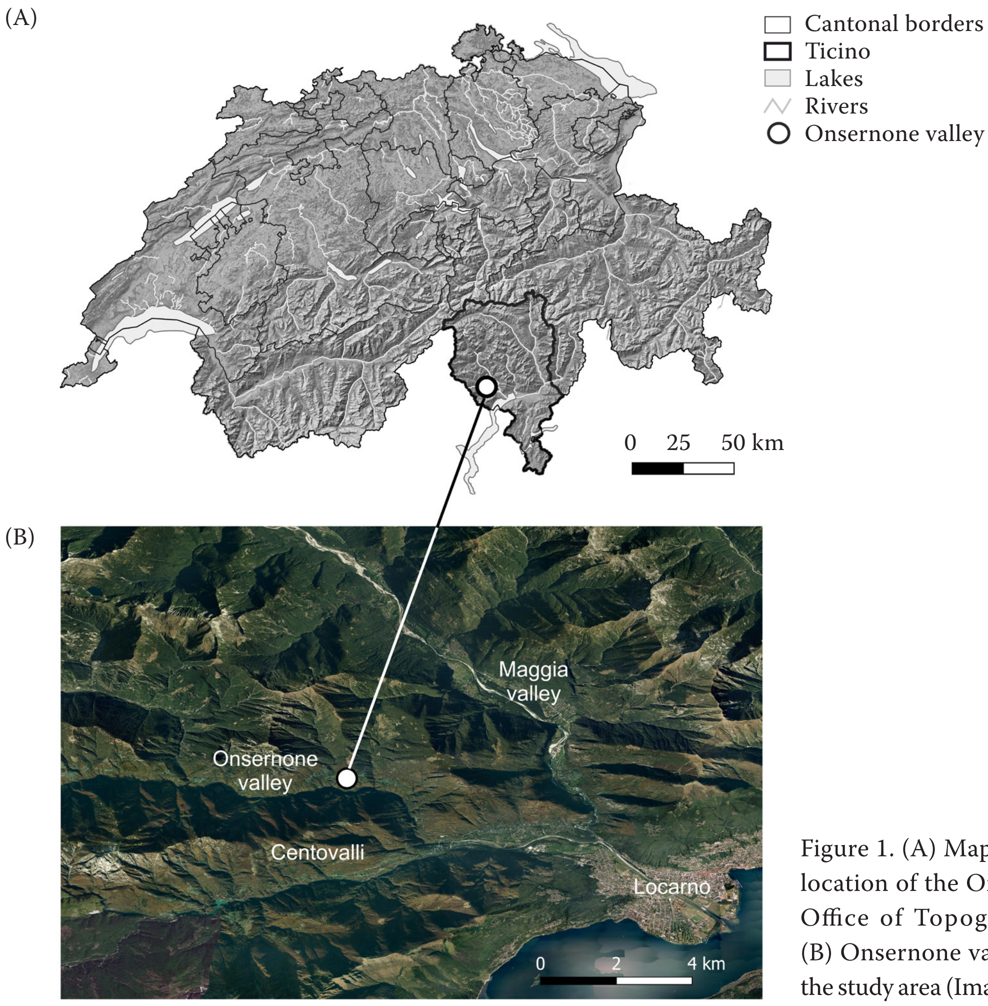

Figure 1. (A) Map of Switzerland with the location of the Onsernone valley (Federal Office of Topography, swisstopo) and (B) Onsernone valley with the location of the study area (Image: Google|DigitalGlobe)

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1795, Zoller 1960, Wähli 1967). After centuries of cultivation, a large amount of terraces was abandoned at the end of the 19^{th} century with the decline of straw plaiting and the latest with the cessation of marginal alpine farming in the 1950s. This led to progressive reforestation of the terraces and the present-day land cover (Vogel 2005, Muster et al. 2007). Terraces that are still under cultivation today are either used for viticulture or meadow which is cut once a year.

Land use reconstruction and study design. The land cover dynamics in the study area was first reconstructed by analysing topographical maps (starting in 1895) and aerial photographs (starting in 1933) to identify the three land cover-topography units (LCTU) of interest:

(*i.*) natural forested slopes (NFS), which are considered in the present study as the natural reference state where, today, the anthropogenic influence is negligible;

(*ii.*) deforested cultivated terraces (DCT), corresponding to the situation of past agricultural utilization (only present-day meadow sites were selected);

(*iii.*) reforested abandoned terraces (RAT), which usually originate from the abandonment of cultivation at the latest with the cessation of alpine farming in the 1950s and results in natural forest re-growth. RAT represents the post-cultural soil evolution in our study.

On RAT, additional dendrochronological analyses on trees were carried out in order to accurately estimate the time since terrace abandonment. The final study design consisted of three sites for each LCTU (Figure 2) covering an altitudinal range from 450 to 865 m a.s.l. on the south-facing slope of the Valley Onsernone.

Field survey and soil analyses. Each of the nine selected study sites (three repetitions for each LCTU) was characterised in terms of topography and dominant vegetation before digging a soil profile down to the parent material. The nine soil profiles were described in the field, and soil samples for further laboratory analyses were taken in accordance with macroscopically visible soil horizons as well as in 10 cm intervals within soil horizons by taking at least five subsamples at each depth interval in order to gain representative composite samples.

The collected soil samples were oven-dried and passed through a 2 mm sieve to obtain the fine earth fraction for the soil chemical analyses. The following standard soil chemical properties were analysed in three repetitions:

- soil pH value was measured in 0.01 mol/L $CaCl_2$ solution (DIN ISO 10390, 2005);
- total organic carbon (TOC) was examined by elementary analysis using the dry combustion reference method (DIN EN 13137, 2001);
- nitrogen (N) was analysed using the modified method of Kjeldahl (DIN ISO 11261, 1995);
- effective cation exchange capacity (CEC_{eff}) and the amount of exchangeable base cations were analysed by flame atomic absorption spectrometry (AAS) after treatment with unbuffered $BaCl_2$.

Data analysis. All soil samples were analysed in triplicates, and arithmetic means were calculated.

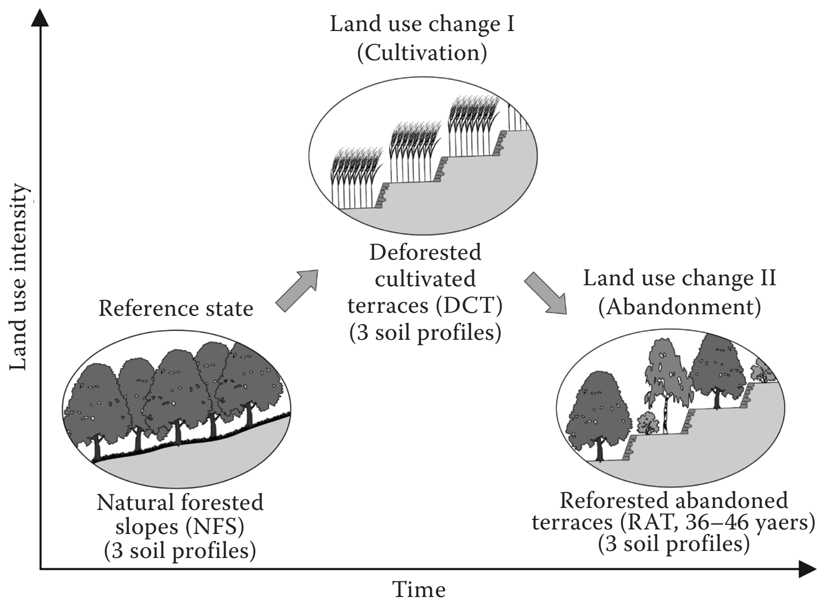

Figure 2. Research concept and design

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To compare the soil chemical properties of the three land cover-topography units, only the mineral soil of the topsoil horizons were considered as in general they are characterised by high SOM and nutrient turnover rates as well as by major soil chemical reactions due to plant roots, microorganisms and land use effects. Methods of descriptive and inferential statistics were applied using the free software environment for statistical computing and graphics R (version 3.6.1) (R Core Team 2018). Box-and-whisker plots were used for graphical examination of the data sets. To test for statistically significant differences (P-value < 0.05) in soil chemistry between the three LCTU, Wilcoxon rank-sum tests for non-normally distributed data were carried out. Linear discriminant analysis (*LDS*) was performed on normalised soil data to classify the sampling sites regarding their land use-related soil chemical characteristics and to detect similarities. This is done by finding a linear combination of the soil chemical parameters that best separates the three LCTU.

RESULTS

Table 1 reports the characteristics of the nine study sites. The natural forested slopes (NFS) are situated between 450 and 865 m a.s.l. and dominated by European chestnut (*Castanea sativa* Mill.), oak (*Quercus* spec. L.), alder (*Alnus glutinosa* (L.) Gaertn), and lime (*Tilia cordata* Mill.). The forest floor has nearly no vegetation ground cover and is overlain by an organic surface layer of up to 11 cm. It consists of an uppermost litter layer of undecomposed chestnut leaves (L horizon) and subjacent layers of partly to strongly decomposed organic material (O horizon) (Table 1). The sites are south-easterly to south-westerly exposed and show inclinations of 33° to 49°. The deforested cultivated terraces (DCT) are located in elevation of 565 to 815 m a.s.l., show slope angles of 8° to 19°, and aspects towards the south to south-west. The reforested abandoned terraces (RAT) have elevations of 470 to 780 m a.s.l. and southern aspects. According to the dendrochronological data, the time since cultivation abandonment ranged from 36 to 46 years. Hence, European chestnut, hazel (*Corylus avellana* L.), oak and lime have established. Moreover, an organic surface layer of up to 7 cm has formed.

Figure 3 highlights the significant differences between the three land cover-topography units from descriptive statistics and Wilcoxon rank-sum tests. It is noticeable that the most distinct disparities lie between NFS and DCT, whereas RAT occupies a rather intermediate position.

Soils at NFS show the lowest pH values being extremely acidic, whereas, at deforested cultivated terraces (DCT), the pH values are highest, i.e., very strongly acidic. At reforested abandoned terraces, the pH takes an intermediate position between NFS and DCT. In contrast to the pH value, total organic carbon shows an inversed behaviour being highest on NFS and lowest on DCT. On RAT, TOC has intermediate values showing no statistical significance. The C/N ratio has a distinct maximum at NFS and minimum at DCT. Even though the C/N ratio at RAT is again in between, it is significantly higher compared to DCT. The effective cation exchange capacity is significantly lower on NFS compared to DCT and RAT. In that regard, base saturation and soil acidity are lower and higher on NFS in comparison to DCT and RAT, respectively.

The linear discriminant analysis (LDA) reveals that the three LCTU can be clearly separated based on their

Table 1. Location characteristics of the study sites

No.	Land cover-topography unit	Exposition	Slope (°)	Elevation (m a.s.l.)	Organic layer thickness (cm)	Years since abandonment
1	natural forested slopes (NFS)	S	33	865	L: 5, O1: 1, O2: 2	–
2		SE	49	520	L: 6, O1: 3, O2: 2	–
3		SW	41	450	L: 1, O1: 1, O2: 3	–
4	deforested cultivated terraces (DCT)	SW	9	815	–	–
5		SW	19	690	–	–
6		S	8	565	–	–
7	reforested abandoned terraces (RAT)	S	9	780	L: 3, O1: 1, O2: 1	46
8		S	20	735	L: 1, O1: 1, O2: 1	36
9		S	20	470	L: 4, O1: 2, O2: 1	40

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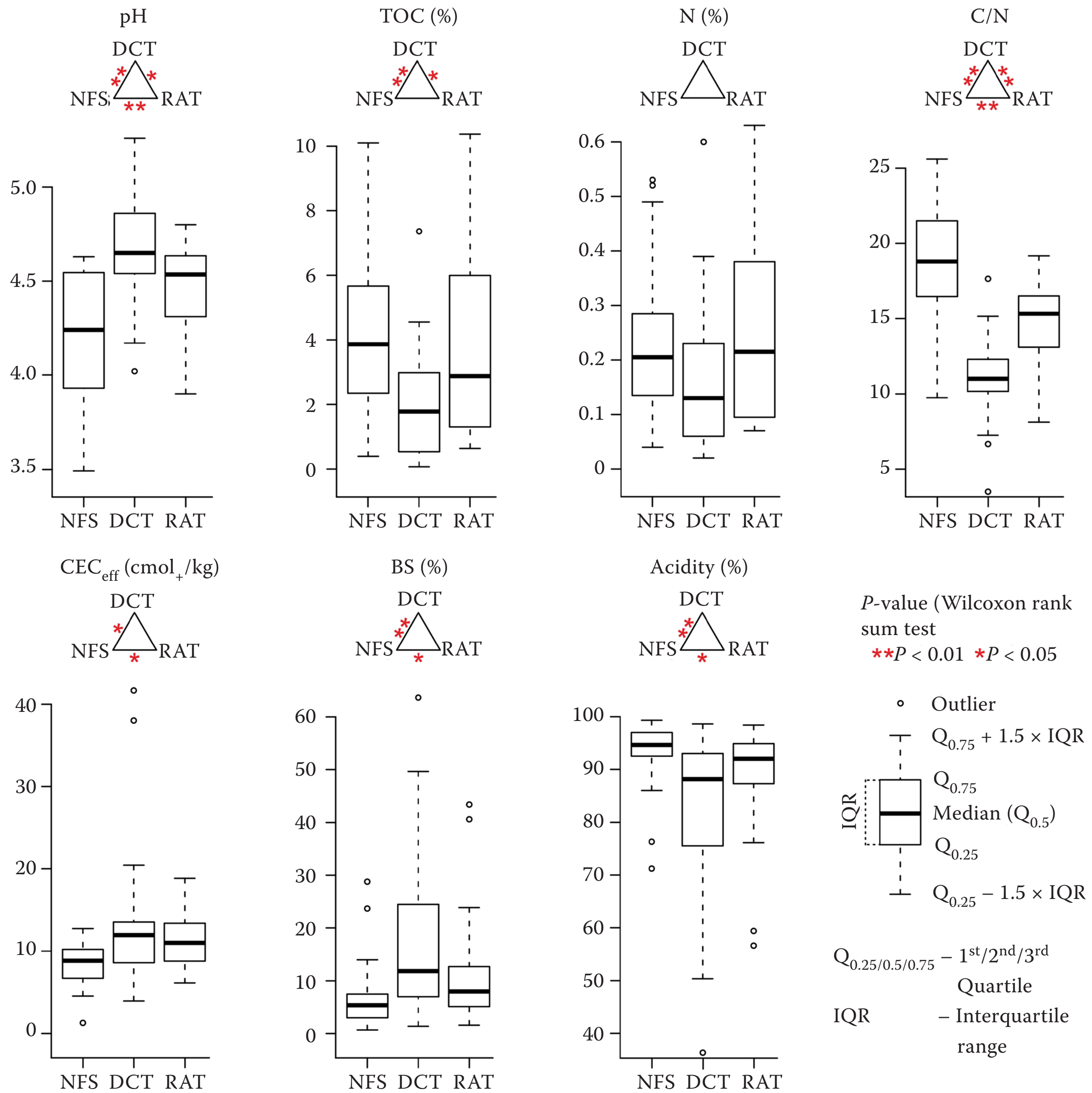

Figure 3. Box-and-whisker-plots of chemical soil properties. Triangles with asterisks indicate statistically significant differences between the three land cover-topography units (LCTU); NFS – natural forested slopes (*n* = 20); DCT – deforested cultivated terraces (*n* = 25); RAT – reforested abandoned terraces (*n* = 24); TOC – total organic carbon; CEC_{eff} – effective cation exchange capacity; BS – base saturation

soil chemical characteristics (Figure 4). Even though the scatter (Figure 4A) and density (Figure 4B) plots highlight that the three LCTU have developed their own soil chemical classification, a certain overlap can be observed between them. This overlap is greatest between DCT and RAT. Along the sequence of land use-induced vegetation and topography change, NFS and DCT represent the two extremes, whereas RAT displays an intermediate state. This is in line with the predicted classifications of LCTU during the LDA (Figure 4C). No NFS sample was erroneously classified as a DCT sample or *vice versa*. In contrast, 20% and 28% of NFS and DCT samples were, by mistake, classified as RAT samples. Nevertheless, it has to be emphasised that the vast majority of 79% of RAT samples were correctly classified as RAT which leads to the conclusion that RAT has already established its own soil chemical characteristic after 36 to 46 years of forest ingrowth.

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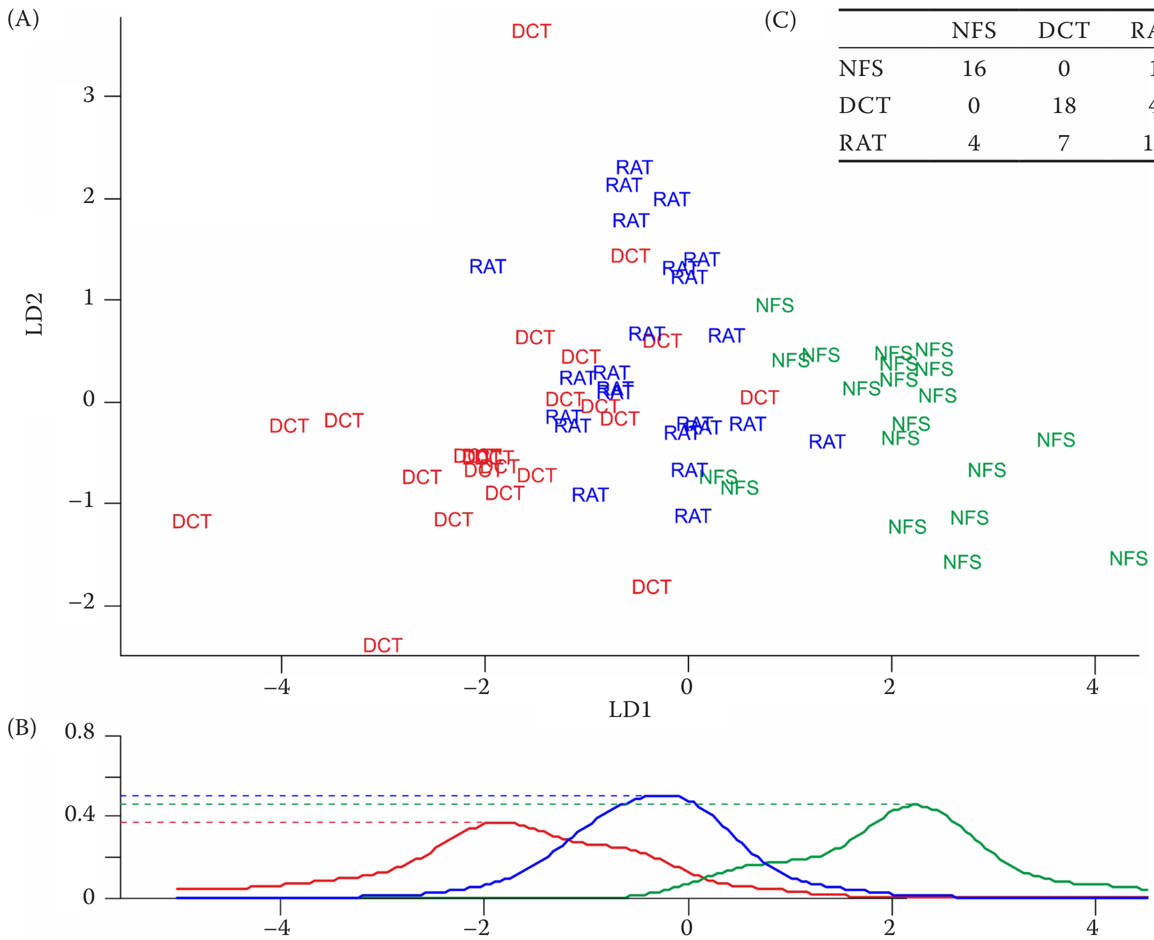

(C)

	NFS	DCT	RAT
NFS	16	0	1
DCT	0	18	4
RAT	4	7	19

Figure 4. Results of the linear discriminant analysis (LDA). (A) Scatterplots; (B) density plots and (C) comparison between predicted and real classification of land cover-topography units (LCTU); NFS – natural forested slopes; DCT – deforested cultivated terraces; RAT – reforested abandoned terraces

DISCUSSION

The soils in the study area are characterised by a more or less strong acidification level as a consequence of (*i*) the low base cation content of the gneissic bedrock; (*ii*) the low buffer capacity and the high permeability of the sandy substrate, and (*iii*) the high amounts of very intense precipitation leading to strong nutrient washout (Vogel 2005). This results in very low pH values in all investigated soils ranging between 3.5 and 5.3. However, on natural forested slopes, additional soil acidification derives from the forest vegetation, especially European chestnut that contains a lot of badly biodegradable tannins. Hence, soil organic matter (SOM) decomposes very slowly and fragmentarily forming low-molecular-weight organic acids, predominantly fulvic acids (Blaser 1973, Rehfuess 1990) that reduce the pH values. Consequently, the pH on the investigated forested sites is deepest in the study area. Moreover, the high amount and bad biodegradability of organic material eventually resulted in the formation of an organic surface layer of up to 11 cm and an accumulation of SOM within the upper part of the soil profile. The described relationship between SOM and pH can be seen in their inverse linkage in the sense that high amounts of TOC and therefore availability of organic acids correspond to low pH values. Because of the low pH, the mineralisation rate of N in forests is also slower (Rehfuess 1990), leading to low amounts of N within the soil and eventually to very high C/N ratios. That results in a scarce nutrient status in the soil as represented by the lowest effective cation exchange capacity and base saturation as well as the highest soil acidity with respect to DCT and RAT.

The soil chemistry on deforested, cultivated terraces differs from that on NFS. Especially, the absence of *Castanea sativa* Mill. as an important soil acidifying agent results in the highest pH values within the study area. Furthermore, the absence of an organic surface

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layer reduces the SOM accumulation in the soil that leads to very low amounts of TOC and finally, a better remineralisation of the SOM to very low C/N ratios. Less intense acidification and better nutrient status are also indicated by a higher CEC_{eff} and base saturation as well as lower soil acidity compared to NFS.

Apart from the lack of forest vegetation, decreased amounts of TOC can also arise from regular tillage of the terraces leading to a better ventilation and aggregate destruction and by that to a higher SOM mineralisation rate (Rehfuess 1990). Barrett and Schaetzl (1998) state that the absence of vegetation that promotes soil genesis primarily results in a change of soil parameters closely linked to SOM. This could have been the case on DCT after clearing and terracing.

The abandonment and successive reforestation of formerly cultivated terraces cause a retrogressive trend towards the soil chemical situation on NFS. After 36 to 46 years of forest ingrowth, this results in the formation of an organic surface layer of up to 7 cm as well as higher SOM contents and C/N ratios. The pH value is significantly lower compared to DCT, indicating a higher production of organic acids. However, regarding the cation exchange characteristics, no significant difference is noticeable yet.

The results demonstrate that in the study area, the vegetation has a strong influence on pedogenesis in general and on soil chemistry in particular. This leads to a relatively fast response to land use changes especially among soil properties closely linked to SOM (i.e., TOC, N and pH; Barrett and Schaetzl 1998). Elsenbeer (1997) investigated the effect of vegetation changes on soil properties on a 100-year time series of European beech (*Fagus sylvatica* L.) forest regrowth on the north-facing slope of the same valley. He demonstrated that distinct changes in chemical soil properties could be detected already after 50 years of forest regrowth. Once again, the bad biodegradability of the produced forest litter (European beech in this case) induced an accumulation of SOM in the upper soil and a decreased pH value. Stronger eluviation of base cations decreased the base saturation and increased the soil acidity (Elsenbeer 1997). This all is in line with other studies demonstrating that vegetation changes can have at least an analytical effect on soil properties within a few decades (e.g., Certini et al. 1998, Stützer 1998, Reissenweber and Stützer 2001). Stützer (1998), in particular, states that in warm regions, pedogenetic processes can be more intense and/or rapid because plants grow faster, produce more litter as well as organic and other components that increase the speed of soil chemical reactions.

Compared to the vegetation change, terracing seems to have a less obvious effect on soil chemistry, as revealed by the linear discriminant analysis. The three LCTU can be clearly distinguished based on their soil chemical characteristics, with NFS and DCT representing the two extremes of the sequence of land use-induced vegetation and topography change and RAT taking an intermediate position. Although displaying greater similarity to DCT, the flat microtopography on terraces allowed the RAT sites to develop peculiar soil chemistry conditions after 36 to 46 years of abandonment only. On terraces, a greater effective rooting depth and a flat soil surface lead to higher water and nutrient availabilities and finally to better-growing conditions for trees what resulted in a rapidly increased SOM accumulation.

In summary, it can be stated that land use changes in the Onsernone valley had a clear effect on chemical soil properties. This is caused by both changes in the vegetation cover and changes in the topography in terms of terracing, respectively. The former is particularly induced by the presence or absence of the European chestnut (*Castanea sativa* Mill.), which acts as the main driver for soil acidification with distinct effects on soil acidity, soil organic matter and nutrient status. The flat soil surface on terraces, on the other hand, favoured tree growth and the accumulation of soil organic matter. Thus, the reforested, abandoned terraces have established their own soil chemical characteristics after 36 to 46 years of abandonment.

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