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Soil and vegetation transformation in abandoned vineyards of the Tokaj Nagy-Hill, Hungary

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ABSTRACT

Two chronosequences, one south (S-sequence) and one southwest (SW-sequence) with differing times since their abandonment (193, 142, 101, 63, 39 and 14 years), were studied on Tokaj Nagy-Hill. The sites were investigated in respect of vegetation characteristics, soil physico-chemical characteristics, total organic carbon stocks (TOC stocks), accumulation rates of total organic carbon (TOC accumulation rates), and soil profiles, which were classified according to the World Reference Base (WRB) 2007. The S-sequence was 25–35% sloped and strongly eroded, and the SW-sequence was 17–25% sloped and moderately eroded.

Vegetation development at the S-sequence resulted in shrub-grassland mosaics, supplemented by protected herb species and forest development at the earliest abandonment. The SW-sequence was predominantly covered by forest vegetation, and trees were absent at the 63 and 14 year old abandonment sites.

Soils of the S-sequence show shallow remnants of loess cover with redeposited soil materials containing 15–65% skeletal volcanic rock of weathering products coated by secondary calcium carbonates. The SW-sequence profiles are developed on deep loess or loess derivatives. The calcium-carbonate content was higher in profiles of the S-sequence (18.1 ± 10.4%) than in the SW-sequence (6.7 ± 2.7%); consequently, the pH of the topsoil was higher in the S-sequence, and correlated significantly negatively with the age of abandonment in both sequences ($r = -0.893$; $p = 0.01$ in S, and $r = -0.739$; $p = 0.05$ in SW). TOC stocks of the top 6 cm soil layers were higher in the S slope (1.82 ± 0.71 kg m^{-2}) than in the SW-sequence (0.95 ± 0.49 kg m^{-2}), and correlated significantly positively with the duration of abandonment. When calculated for the whole profile, TOC stocks were similar in both S- and SW-sequences (S: 8.21 ± 3.31 kg m^{-2}; SW: 8.24 ± 6.01 kg m^{-2}). The TOC accumulation rates of the top 6 cm soil layers exhibited 18.9 ± 10.0 g C m^{-2} y^{-1} in the S and 7.0 ± 4.2 g C m^{-2} y^{-1} in the SW-sequence. Sites with the same age of abandonment showed different vegetation and soil features in both chronosequences, indicating that time is not the most decisive factor in soil transformation processes after abandonment of viticulture on Tokaj Nagy-Hill. Additional directing factors were slope steepness and exposition.

1. Introduction

Similarly to other hilly and mountainous areas in many European countries (García-Ruiz, 2010), the extension of vineyard plantations also decreased in the late nineteenth and twentieth centuries in Hungary. Economic difficulties during the first decades of the last century, the “Phylloxera disaster” at the end of 19th century (Balassa, 1975, 1991), the changes in cultivation techniques in the middle of 20th century and socio-economic transformations in the region (Boros, 2008; Szabó, 2001) at the end of 20th century led to multiple spatial reorganization and the abandonment of vine plantations. The Unesco World Heritage Tokaj-Hegyalja Vine Region did not escape these changes. Especially remote vineyards s

ituated at the highest elevation and the steepest, often terraced slopes were the first to be abandoned. Consequently, secondary succession processes started (Sendtko, 1997, 1999). The increasing coverage and root development of vegetation either moderated or stopped the loss of soil by water erosion, allowing the re-accumulation of organic material, and therefore facilitated soil development. On the other hand, retaining walls frequently collapsed and slopes were subjected to progressive decay due to areal erosion and slope failures (Schmitt et al., 2003), which is a still ongoing process on Tokaj Nagy-Hill (Nyizsalovszki and Fórián, 2007). Hence Kiss et al. (2005) and

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Nyizsalovszki and Fórián (2007) assessed generating changes of geomorphology for Tokaj-Hegyalja Vine region which might interfere with soil regeneration processes.

Studies on abandoned soils from Mediterranean and temperate regions show that abandonment of arable soils generally shifted soil and vegetation development towards the natural configuration and led to increased carbon stocks (Arnaez et al., 2010; Boix-Fayos et al., 2009; Kalinina et al., 2011; Leeschen et al., 2008; McLauchlan et al., 2006; Mensah et al., 2003; Novara et al., 2013).

The Tokaj Nagy-Hill was studied in detail in respect of phytocenological changes and plant dispersion in secondary succession processes following abandonment (Sendtko, 1997, 1999). The abandonment of Tokaj Nagy-Hill was also the focus of a recent microbiological study which revealed that the legacy effect of former cultivation significantly influences the microbial communities and soil nutrient availability (Spohn et al., submitted for publication). Nevertheless pedological studies of abandoned vineyard soils are still lacking. The aim of this study is to investigate soil transformation in relation to the vegetation development and carbon stocks dynamics of the abandoned vineyard soils on the Tokaj Nagy-Hill. The latter is of particular interest because it is well known that vineyard cultivation causes carbon losses (Bargon, 1956; Zakosek, 1967). Accordingly carbon stocks of cultivated vineyard soils are generally the lowest in comparison with other land uses (Chiti et al., 2012; Gerzabek et al., 2005).

In this study we hypotheses:

1. After abandonment of the vineyards soils develop towards their natural properties.
2. The diversity and complexity of vegetation increase with time after abandonment, developing towards the supposed climax associations (*Quercus pubescens–Quercetalia pubescenti–petraeae*).
3. Similarly to converting cultivated land to grassland (McLauchlan et al., 2006) or cultivated land to secondary forest (Guo and Gifford, 2002) the carbon stocks increase due to the input by net primary production during secondary succession.
4. Time is the most important factor affecting the development of soil and vegetation, but that it acts differently in the two chronosequences because of different exposition and slope grade.

   We tested these hypotheses with a chronosequence approach in which time is substituted by space (Bardgett et al., 2005; Walker et al., 2010).

2. Materials and Methods

2.1. Study area

The study sites are situated on Tokaj Nagy-Hill, which is a part of the Tokaj-Hegyalja Wine Region, one of Hungary's historic wine regions. Presumably viticulture started on the Nagy-Hill in the late Iron Age (1900–2100 years BP), but it has been the dominant type of land use since the 15th–16th Century (Balassa, 1991). The hill itself has been classified as a wine producing area since the early 18th Century. The geographically relatively isolated area of the Tokaj Nagy-Hill (21.08 km^2) rises from the alluvial plain (92–95 m) of the Hungarian Lowland reching 514 meters in the center of the hill (Fig. 1).

The hill is built from late Miocene pyroxene dacite lava flows and subordinate pyroxene dacite tuffs (Harangi, 2001). A significant part of the Nagy-Hill consists of the Amadévár Andesite and Tarcal Dacite Formations (Pécskay et al., 2006; Zelenka et al., 2004). Volcanic rocks are mostly covered by Pleistocene aeolian loess sediments and loess derivates. The thickness of loess sediments and loess derived layers ranges from a few centimeters to 20 meters (Pinczés, 1954), but on average reaches 3–5 m. The mean carbonate content of the loess is 5.4–6.8%(m/m) (Pinczés, 1954). Based on radiocarbon data, mollusk fauna (Sümegi, 1995; Sümegi and Hertelendi, 1998; Sümegi and Rudner, 2001) and species composition of fossil macrovertebrata fauna (Pinczés, 1954), the age of loess deposits is from the lower to the upper Weichselian Ice Age (70 000–12 000 years BP, Schatz et al., 2011). On the steepest slopes the erosion of the loess cover is rapid and intense as a result of both areal erosion and dense gully-forming processes. Due to translocation and the altering of erosion-sedimentation processes including leaching, these eroded sediments are partially decarbonated and contain interlayered colluvic materials (gravel, blocks, and redeposited soil). On the exposed, steepest slopes loess layers are completely eroded, and volcanic materials are at the surface.

To prevent intense soil erosion dry stone walls and terraces were constructed for viticulture. The age of terraces and terrace walls is unknown; they were first mentioned in a document dating from 1629 (Balassa, 1991). Terraced slopes extend for approximately 1.16 km^2 (5.5%) of the hill. After introducing modern technologies to cultivation during the 20th century the old terrace walls were no longer maintained. Similarly to other regions (Arnaez et al., 2010) abandonment of agricultural terraces and lack of continuous maintenance led to the collapse of dry stone walls. This also has consequences for mass movement processes and is a significant loss for the cultural landscape (Petit et al., 2012; Stanchi et al., 2012).

The climate of the area is temperate continental, with warm summers, and cold winters. The mean annual air temperature is 8.5 °C at the summit and reaches almost 10 °C at the base of the hill (January: −2 °C, July: 22 °C). The average annual sunshine duration is approximately 2000–2050 h. The frost-free period covers about 190 days (Dövényi, 2010). Justyák (1981) pointed out that slope sections between 300 m and 350 m elevations get the highest values of extra-heat, which decrease only in higher positions on the hill. This provides favorable conditions for vine cultivation also at higher elevations. The mean annual precipitation is between 580 mm (Tarcal) and 617 mm (Tokaj) (Justyák, 1981) of which 360 mm falls in the summer months, when heavy rains are frequent, causing significant erosion events on soils not covered by vegetation. The average duration of snow cover is 40 days and the mean thickness is less than 20 cm. The snow melting period is another critical period of the year in terms of soil erosion, causing both strong linear and gully erosion on the slopes of the hill (Boros, 2008). The soil temperature regime of the hill is mesic, and the soil moisture regime is ustic (Füleky et al., 2007) and potentially xeric.

The natural vegetation of the hill is a mosaic of different deciduous forest types (Zólyomi, 1989), such as *Quercetum petraeae*, dominated by sessile oak (*Quercus petraea*) at higher elevations. On exposed steep southern slopes in xerotherm habitats shrub forest and grasslands mosaics are native (Sendtko, 1999). Forest patches are dominated by *Quercetea pubescentis–petraeae* vegetation (Zólyomi, 1989), with downy oak (*Quercus pubescens*); in grassland patches feather grasses (*Stipa* spp.) and fescues (*Festuca* spp.) are most frequent. Agricultural activity started on the hill in the Neolithic age, and it became a significant land forming factor in the early medieval period. The major part of the hill, between 350 and 400 m elevations, has been cultivated since this time. Cultivated slopes were frequently transformed by the construction of terraces or later leveled by landscaping for vine cultivation. After abandonment of the higher vineyards several of them were used for grazing in the late 19th and early 20th centuries (Sendtko, 1999). Spontaneous reforestation and shrub development of abandoned vineyards resulted in valuable semi-natural grasslands, shrubs and forests (Sendtko, 1999), but following the most recent abandonments (<20 years) adventive plant species may also be present. On higher slope sections in the 1960s afforestation was carried out with black pine (*Pinus nigra*); most of plantations were later overgrown by native tree species, leaving pines in sparse frequency until the present time.

Because of its lithological diversity and large variability of landforms, high soil diversity could be observed. Former studies (Kerényi, 1994; Stefanovits et al., 1999) reported the so called "Ramann brown forest soils" and chernozems (WRB: Cambisols, Chernozems, Phaeozems). Due to the strong erosion processes, paleosoils could be exhumed and