Catena 116 (2014) 173–184

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Use of soil profile truncation to estimate influence of accelerated erosion on soil cover transformation in young morainic landscapes, North-Eastern Poland

Marcin Świtoniak *

Department of Soil Science and Landscape Management, Faculty of Earth Sciences, Nicolaus Copernicus University, Lwowska str. 1., 87-100 Torun, Poland

ARTICLE INFO

Article history:
Received 27 March 2013
Received in revised form 20 December 2013
Accepted 24 December 2013

Keywords:
Accelerated erosion
Eroded soil
Soil truncation
Vertical texture contrast
Slope processes

ABSTRACT

Human-induced erosion is one of the key factors leading to the soil degradation. Agricultural, undulating or hilly morainic areas of North-Eastern Poland are exposed to this negative process. This paper elucidates the influence of accelerated soil erosion on soil cover in young morainic landscapes of North-Eastern Poland (Brodnica Lake District). Detailed pedological investigation (21 soil pits and 375 augerholes) were carried out within two study sites (forest and agricultural). A comparison of fully developed forest reference soil pedons with arable soil has been made. Five classes of soil truncation have been distinguished. According to the identified degrees of truncation, maps of soil cover transformation, caused by accelerated erosion, were generated and overlapped on Digital Elevation Models (DEMs). Eroded soils overlap 39.5% of agricultural area and 2.5% of forest site. The widespread occurrence of strongly and completely eroded pedons (respectively 7.4% and 5.4%), only in the agricultural areas, provides intense anthropogenic impact on soil cover in the agriculture areas of North-Eastern Poland. The average values of soil reduction are about 40–50 cm. In the case of completely eroded soils it exceeds even 100 cm. Truncation of pedons with abrupt textural change due to the slope processes leads to the disappearance of vertical textural contrasts and the formation of new soil units. The evidence of erosion from the topsoils is mainly the decrease in the content of organic matter and calcium carbonate enrichment. The effect of intensive slope processes is widespread occurrence of thick (up to 3 m) colluvial deposits.

1. Introduction

Soil erosion is a natural phenomenon and has occurred throughout geological history. Human activities have increased erosion rates. This human influenced process is termed accelerated erosion. Land use conversion modified soil morphological properties along the slope due to soil material redistribution (De Alba et al., 2004; Marcinek and Komisarek, 2004; Papendick and Miller, 1977; Van Oost et al., 2003). Surface soil horizon loss (truncation) occurs on convex parts of slopes and colluvial material deposition (accretion) takes place on concave areas (Dotterweich, 2008; Dreibrodt et al., 2010; Lang, 2003; Leopold and Völkel, 2007; Phillips et al., 1999).

Today in many parts of south-eastern Europe the soil cover was significantly damaged by erosion processes (Lang and Bork, 2006). The oldest colluvial sediments found in Central Europe were deposited in early Neolithic times (Bork and Lang, 2003). Much more significant erosion influence on soil cover due to human impact started in medieval times (Bork, 1989). Deforestation during the 12th and 13th centuries was the first important impulse that triggered slope processes in moraine plateau of the North European Plain (Böse and Brande, 2010). The most evident phases appeared in the first half of the 14th century (Dotterweich, 2008; Dreibrodt et al., 2010) and in the mid-18th to the early 19th centuries (Bork and Lang, 2003; Dotterweich, 2008). Many examples of case studies on historical records of soil erosion during Medieval Times in Western and Central Europe were given by Dotterweich (2013). Nevertheless, in the high fertile loess regions the oldest phase of colluvium formation was already in Neolithic times, too (Dreibrodt et al., 2010; Lang, 2003; Lang and Hönscheidt, 1999). During that period and the Bronze Age only minor erosion occurred in less productive areas of Central Europe (Böse and Brande, 2010; Zolitschka, 1998). Intensive agricultural activities and the associated risk of soil erosion in Lithuania began during the 12th century (Jankauskas and Fullen, 2002). In a sparsely populated hilly area of western Slovakia at the time of High Middle Ages, the oldest period of possible occurrence of accelerated soil erosion was the 14th century (Dotterweich et al., 2013; Stankoviansky, 2003). Due to current accelerated erosion, soil losses in Lithuanian Albeluvisols can reach up to 116 t ha^{-1} yr^{-1} (Jankauskas et al., 2003). On arable lands of European Russia, the mean calculated rate of sheet erosion is about 5 t ha^{-1} yr^{-1} (Sidorchuk et al., 2006). In some cases, human-induced slope processes are very intensive in nature. In southern Germany an accumulation of thick colluvium (0.8 m) during a single heavy rainfall event was reported (Leopold and Völkel, 2007).

* Tel.: +48 56 6112555.
E-mail address: swit@umk.pl.

0341-8162/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.catena.2013.12.015

Soil erosion is one of the key threats to soil in Poland. A comprehensive review of the literature related to this issue was recently presented by Rejman and Rodzik (2006). According to earliest studies of soil erosion in Poland (Bac, 1928), the average soil loss on cultivated slopes was about 5 mm annually. Some authors estimated that almost 30% of the total area of the country is considerably degraded by this process (Józefaciuk and Józefaciuk, 1992). The area undergoing most devastative erosion covers about 7.1% of the country's area (Wawer and Nowocień, 2007). The highest soil losses — nearly 40 t ha^{-1} yr^{-1}, was recorded at runoff plots located within loess slopes (Rejman and Rodzik, 2006). The most vulnerable to erosion are mountain regions (Carpathians, Sudetes) and Polish Uplands. The impact of past agricultural use on formation of colluvium within the small catchments in the eastern and central parts of the Sudetes Mountains was described by Latocha (2012). Recent research on accelerated erosion in Carpathian Foothills confirmed significant susceptibility of Luvisols to water erosion (Święchowicz, 2012). According to the result of these studies, in the summer half-year of 2007 hydrological year there were several slope wash events. The total amount of the transported soil depended on land use and ranged from 27 $kg \cdot ha^{-1}$ to 42 $kg \cdot ha^{-1}$. Human-induced erosion led to substantial truncation of soils developed from loess in south-eastern Poland (Klimowicz and Uziak, 2001; Paluszek, 2010, 2013), deposition of thick colluvium (Zgłobicki, 2013) and development of gullies (Dotterweich et al., 2012; Schmidt and Heinrich, 2011; Schmitt et al., 2006). On the basis of studies conducted near Chroberz (loess plateau in south Poland), the earliest severe soil erosion was probably related to agricultural activity of the Neolithic cultures. The oldest colluvium was dated 5890 $\pm$ 100 BP (Szwarczewski, 2009). Several phases of human-induced erosion were distinguished on the basis of research on the gully system in the Nałęczów Plateau (Dotterweich et al., 2012). The earliest period of gully formation was dated to the Bronze Age. The first strong erosion and sedimentation processes occurred during the 15th–17th centuries. Until the end of the 20th century periods with high activity of slope processes had appeared a few times. Present-day intensive erosion in loess areas has also been noted by Schmidt and Heinrich (2011). One heavy rainfall event in 2001 eroded approximately 4800 m^3 of loess deposits near Słaboszyce. Loess erosion led to truncation of former soils and excavation of Mesozoic marlstones. On the other hand, the exposures in gully walls, cutting through the loess cover in the central part of the Roztocze, consist of colluvial sediments with a thickness of up to 5 m (Schmitt et al., 2006). The first phase of rapid filling of the gully began in the 15th or 16th century. Nevertheless, gully and soil erosion in this area had already started earlier — in the 14th century after deforestation of the surroundings.

Accelerated soil erosion in the hilly young morainic agricultural landscapes of North-Eastern Poland is also a particularly important problem (Uggla et al., 1968). Since the end of the 10th century, this area is strongly influenced by anthropic pressure and has suffered heavy soil erosion, aggravated by agriculture and deforestation (Sinkiewicz, 1998). The strongest transformations occur in regard to arable soils developed on ground moraine deposits in hummocky moraine plateau landscapes (Smólczyński and Orzechowski, 2010). The most intensive soil profile truncation occurred during the last decades under the influence of intensive agriculture, land drainage and modern agricultural machinery.

A common feature of untruncated soils in young glacial areas is the presence of a coarse-over-fine vertical texture contrast (VTC) with an abrupt textural change. A multiple causality model of VTC as a result of pedo- and geogenesis has been presented by Phillips (2001, 2004, 2007). The VTC in investigated soils is inherited from the parent material: a sandy ablation and fluvioglacial layer (thickness about tenths of centimeters) covering the heavier lodgment till (Bednarek and Szrejder, 2004; Niewiarowski, 1986; Niewiarowski and Wysota, 1986). The VTC-soils have generally two different sequences of the genetic horizons. Different soil-forming processes were determined by an initially heterogeneous content of clay fraction in sandy cover. In the majority of soils, geological VTC was increased by an eluviation–illuviation (*lessivage*) process. The *lessivage* process occurred in rocks where ablation or fluvioglacial layer was primarily relatively rich in clay fraction. The effect of an illuvial accumulation of clay in subsoil is the development of *argic* Bt horizon. In some cases, when sandy cover primarily contained a low amount of clay fraction, the features characteristic for clay illuviation were not present (Świtoniak, 2006, 2008).

Because of complicated genetic horizon sequences, undisturbed VTC-soils can be useful as reference pedons to determine the degree of arable soil transformation by erosion (Olson et al., 1994; Podlasiński, 2013). Luvisols developed from loess deposits were interpreted as reference pedons in recognition of human-induced soil erosion in western Slovakia (Dotterweich et al., 2013). The occurrence of a few well-preserved Luvisols enabled an estimation of several soil loss-classes in loess landscape in Saxony (Wolf and Faust, 2013). The variance in solum thickness of Alfisols and Mollisols was used as an indicator of the degree of erosion in north-central United States (Mokma et al., 1996). The estimates of soil losses were based on the depth to the lower boundary of a Bt horizon or a fragipan. An absence of eluvial horizons between Ap and B horizons was interpreted as moderate or severe stage of soil truncation. In the studied area the problem has not yet received sufficient attention (Bednarek and Szrejder, 2004; Karasiewicz et al., in press; Sinkiewicz, 1998).

The aim of the present paper is to define several classes of VTC-soil truncation and to test their applicability in the estimation of soil cover erosion spatial range.

2. Material and methods

The vertical contrast texture is a common feature of soils in Brodnica Lake District (Fig. 1). Most VTC-soils in this region are developed from ground moraine deposits. Forest Arenosols and Podzols determine the extent of Brodnica outwash plains (sandurs).

In order to compare the influence of land use on the intensity of erosion, soil cover of two study sites (1 km square each site) were mapped in detail. The first site (A) represents the mixed forest area and a natural stage of a soil cover development (Fig. 2). The canopy layer is dominated by pines (*Pinus sylvestris*). Species typical for hornbeam forest (*Carpinus betulus*, *Tilia cordata*, and *Quercus sp*) predominates in understory, herb layer and forest floor. The second site (B) is mostly an agricultural area with strong modifications of soils due to erosion.

The relief of both studied sites is typical for hummocky moraine plateau landscapes. The topography of the investigated area is characterized by a large inclination of the slopes and the denivelations up to 20 m. The differences in terrain heights are associated with numerous kettles, irregular and elongate or roundish in shape. Lakes in the south-west (Site A) and north-west (Site B) parts of the study sites are located at the bottom of the subglacial channels.

Twenty profiles developed on ground moraine deposits located within hummocky morainic plateau were described and sampled. Parent materials of these soils — the glacial tills were formed during the Poznań phase of the Vistulian (Weichselian) glaciation (Niewiarowski and Wysota, 1986). One pedon was situated on subglacial channel slope (profile A1) and derived from fluvioglacial sands. In terms of use twelve pedons were located under mixed forests (Site A), and nine were situated in arable areas (Site B). Apart from soil pits, 375 augerholes were made (Fig. 2).

Two Digital Elevation Models (DEM) of the study sites were derived. DEMs were constructed at a 10 m resolution by interpolation from the spot heights and digitized contours with a 1.25 m interval of the 1:10,000 topographic map. Interpolation was fitted using a kriging method, incorporated in the Grid tool of SURFER 8 (Golden Software, Inc., 1999). Digital Elevation Models were used as a background for maps of soil cover transformation and for the morphometric analyzes