
**Geographia Polonica**
2016, Volume 89, Issue 3, pp. 323-343
http://dx.doi.org/10.7163/GPol.0060

INSTITUTE OF GEOGRAPHY AND SPATIAL ORGANIZATION
POLISH ACADEMY OF SCIENCES
www.igipz.pan.pl

**www.geographiapolonica.pl**

# THE USE OF KETTLE HOLES FOR RECONSTRUCTING FORMER SOIL COVER IN DIFFERENT TYPES OF LAND USE

**Bogusława Kruczkowska**

Institute of Geography and Spatial Organization
Polish Academy of Sciences
Twarda 51/55, 00-818 Warsaw: Poland
e-mail: b.przewozna@twarda.pan.pl

## Abstract

The aim of the study was to identify and examine main directions of soil patterns, typology, SOC (Soil Organic Carbon) and $N_t$ (Total Nitrogen) content in the topsoil changes that have occurred in kettle holes as an effect of soil erosion and anthropogenic denudation. Varied in the type of land use, three closed basins located in young glacial landscape in north-western Poland were investigated. According to the type of land use, the total area of soils with untransformed or moderately transformed morphology is different. Significant modifications have been taking place not only in mineral soils, which are located on slopes, but especially in soils of the bottom of sedimentary basins. In fact, most of primary soil properties and morphology have been replaced by new characteristics. The most intensive modifications of soil morphology and soil chemical properties occurs within croplands. Total area of colluvial soils can be treated as indicator of soil erosion processes intensity.

## Key words

kettle holes • soil cover evolution • soil redistribution • soil morphology • soil chemical properties

## Introduction

Closed basins are numerous, but particularly small land forms, which occur mainly within young glacial landscape not only in Poland. The contemporary soil cover of closed basins in north-western Poland formed in the course of pedological processes after the last melting of the ice sheet in the Late Pleistocene period, within the range of the Pomeranian phase of the last Weischselian/Würm glaciation. The term 'former soil cover' refers to soils which were developed completely after the last glaciation in Poland and non-transformed or slightly transformed by anthropogenic factors. In fact it is difficult to find natural soils, in view of pervasive human impact. Additionally the former soils should be developed from parent material, which had never been converted by soil-forming processes. It is almost impossible to recognize, because glacial deposits could be partly pediments. After the onset of human activity, soils were transformed, especially in undulated landscapes. To understand the relationships between soils and past slope processes, it is necessary to conduct paleopedologic research, which serves to reconstruct past environments (Karasiewicz et al. 2014; Mendyk et al. 2015). In agricultural lands, long-term tillage and strong natural slope processes cause runoff and infilling of depressions with sediments. An originally superficial soil profile is buried under deposited material. The properties of these new layers are related to the characteristics of the soils located upslope (Świtoniak 2015). Soil redistribution by tillage also modifies landscape topography (e.g. De Alba et al. 2004; Van Oost et al. 2005; Li et al. 2009; Vieira & Dabney 2011; Su et al. 2012; Rodzik et al. 2014). Knowledge of past events and current agricultural landscapes makes it possible to prevent their further degradation and peneplanation of Quaternary landscapes. Slope evolution is related to the duration of tillage, technological conditions, soil texture and morphometry of slopes. Previous studies of soil redistribution and modifications of geomorphology as a result of tillage (Lindstrom et al. 1992; Govers et al. 1994; De Alba et al. 2004; Świtoniak et al. 2016) confirm peneplanation of undulated agricultural areas. For this reason, closed basins are especially endangered land forms. Contemporary research proves that high soil redistribution is characteristic not only of modern tillage. Old cultivation methods, particularly at the beginning of human agricultural activity, were invasive and protective measures were not taken into account; therefore, the highest soil losses in the area investigated in the present study are characteristic of the past rather than the present. This phenomenon has also been confirmed in other studies (Quine et al. 1999; Thapa et al. 1999).

Closed basins are characterized by specific conditions of water circulation. To identify the basic types of kettle holes, a division proposed by Drwal (1975) was used. It is based on differences in the water cycle mechanism caused by the geological structure and distinguishes closed evapotranspiration basins and closed absorptive ones. The kettle holes examined in the present study represented the first type. The catchments of closed evapotranspiration basins are generally concave landforms without surface runoff with kettle ponds in the bottom (Major 2008). These specific land forms are numerous in young glacial landscapes around the world (Frielinghaus & Vahrson 1998; Kochanowska et al. 1998; Nichol 2001; Gaudig et al. 2006; Gerke et al. 2010; Corti et al. 2012), which makes them a universal tool for environmental reconstructions not only in Poland.

While we possess considerable knowledge about soil erosion and anthropogenic denudation, these processes have rarely been studied in relation to closed basins and submoraine depressions by Sinkiewicz (1998), Piaścik et al. (2001), Orzechowski et al. (2004), Sowiński et al. (2004), Lemkowska and Sowiński (2009), Sowiński and Lemkowska (2009, 2010) and Major (2010). Most studies focusing on large areas have concerned geomorphology and history of their evolution. Comprehensive study of the processes occurring within sedimentary basins enables their identification on a local scale. The reason for undertaking the present study of kettle holes was insufficient characterization of soil erosion and anthropogenic denudation within objects with closed water circulation and of transformations of soil morphology resulting from these processes.

The aim of the study was to identify and examine soil typology changes that have occurred in kettle holes as an effect of natural (soil erosion) and anthropogenic (anthropogenic denudation) processes. Transformations of the former soil cover created as a result of listed phenomenons can be irreversibly saved especially in soil morphology and basic physical properties. It indicates the perfect soil memory. Based on Targulian's and Goryachkin's (2004, 2011) observations, soil memory is 'in situ' by nature, which makes it the perfect tool for reconstructions on a local scale. Furthermore, soil as a complex unconsolidated mixture of inorganic, organic and living material is characterized by unique properties which are much more useful for landscape restorations than information included in sediments. Soils located within closed basins are preserved to different degrees, but all variations of soil properties reflect the influence of natural and anthropogenic processes.

## Materials and methods

The study was conducted in 2011 in three kettle holes located in a young glacial landscape within a morainic plateau near Czaplinek (Fig. 1). The study area is located within the Drawsko Lakeland, which is a part of the West Pomeranian Lakeland in north-western Poland. The kettle holes are characterized by various degrees of slope inclination, ranging from 13° to more than 35°, with relatively flat bottoms (0-2°). The stand *Drawsko* with a catchment area of 20.4 ha is used as a forest (*Galio-Fagetum*), *Siemczyno I* (catchment area of 5.8 ha) comprises a grassland (plant communities of *Arrhenatherion* with dominant *Arrhenatherum elatius*) with a small area of a crop field and a spruce forest (*Picea abies*) with single specimens of *Betula pendula*, while *Siemczyno II* (catchment area of 6.5 ha) covers with a crop field with grassland (*Magnocaricion*) in the bottom of the closed basin. In the *Drawsko* closed basin, only the east part, with a total area of about 10.0 ha, was selected for detailed research. Based on historical maps: 1618 – E. Lubinus, *Novo illustrissimi principatus Pomeraniae descriptis*... (average map scale 1:227,000), 1789 – D. Gilly, *Karte des Königl. Preuss. Herzogthum Vor- und Hinter- Pommern*... (map scale 1:180,000), 1850 – G.D. Reymann, *Topographische Specialkarte des Preussischen Staats und der angrenzenden Länder* (map scale 1:200,000) and 1893 – *Karte des Deutschen Reiches* (map scale 1:100,000), it can be concluded that the soils at *Drawsko* was not tilled in the past and is, accordingly, relatively natural and furthermore *Siemczyno II* and partially *Siemczyno I* have been cultivated for at least 400 years ago. Nowadays in *Siemczyno I* only the west slope is still tilled. Animal-pulled tillage and human-powered hoes were the dominant farming system until about 20 years ago, what was identified from direct interviews with owners of surveyed fields.

The reconstruction of the former soil cover was based on investigations of morphology and grain size analysis of 200 cm deep soil profiles and 300 cm deep soil drillings.

In each of the sedimentary basins, transects were made, generally in the N-S and E-W direction. The total number of soil profiles collected was 43 (6 to 8 soil profiles per transect) – Figure 1. The profiles represent both mineral and organic soils from every part of the slopes. The study area is relatively lithologically homogeneous, covered by glacial and fluvioglacial deposits, with a predominance of loamy sand, sandy, sandy loamy and loamy texture. The primary range of each soil type was reconstructed on the basis of data obtained from soil profiles and auger holes drilled to a depth of 3 m.

The soils were documented and sampled in a standard manner (FAO 2006). Soils were classified according to the WRB soil classification system (2015). Texture was determined by combined sieve and Bouyoucos (1951) hydrometer method. Organic carbon (SOC) content was measured by wet dichromate oxidation method, and total nitrogen ($N_t$) content by Kjeldahl method. Uncalibrated radiocarbon dating of soil samples was made at Poznan Radiocarbon Laboratory. Statistical analysis were made using SPSS Statistics 17.0.

## Results

### Transformations of soil cover at *Drawsko* (forest)

Compared with the reconstructions of former soils condition, present-day soil cover in the *Drawsko* sedimentary basin is more varied. Post-agricultural features are not present in the soils. For this reason the possibility of agricultural anthropogenic impact on soil

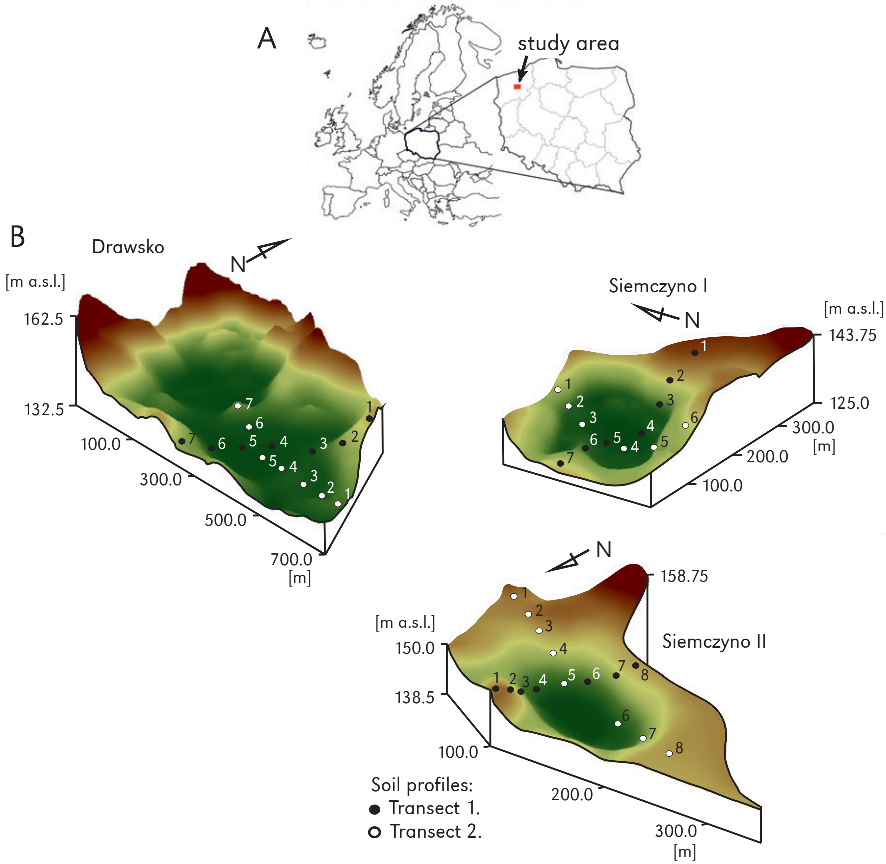


**Figure 1.** The study area: A – Localization, B – Location of soil profiles within research transects

cover formation in the *Drawsko* closed basin should be excluded. In spite of the effects of soil transforming factors such as erosion and other slope processes, undulated landscape and steep slopes, the contemporary soil profiles are practically natural (Fig. 2). The most transformations have occurred in the bottom of the *Drawsko* study area and they are connected with overdrying. Protection is primarily afforded by vegetation, which reduces the kinetic energy of precipitation and prevents rainwater from impacting on the sedimentary basin surface with the force which it exerts on exposed places.

The percentage of mineral soils in the original soil cover of both the slopes and the bottom was significant (about 90%). The main organic soil type in the lowest part of the basin was Fibric Histosols. From derivative Gleyic Luvisols (Loamic, Cutanic, Novic) features (ferrugineous mottling), it can be concluded that ground water levels in the past were higher than nowadays. The range of occurrence of these features in mineral soils in the sedimentary basin bottom leads to the conclusion that present-day groundwater levels are lower than in the past by up to about 50 cm. These significant fluctuations caused overdrying of superficial organic soil horizons, accelerating muck formation and their mineralization. The surface horizon of Hemic Drainic Histosols is built from loamy sand mineral material. As a result of water level lowering, organic layers composed of Fibric Soil Materials were transformed into Sapric and Hemic, which differ

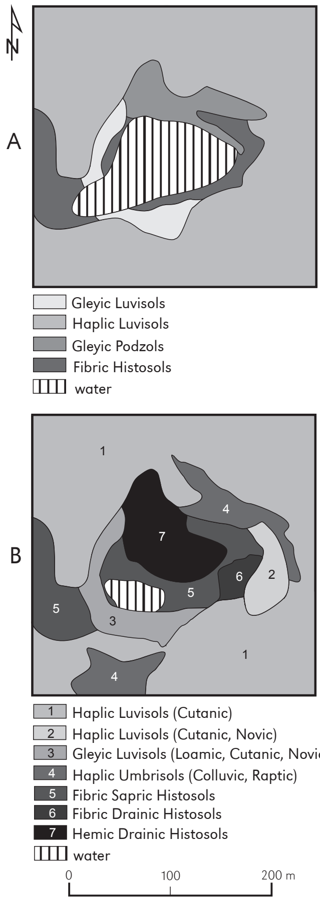


**Figure 2.** *Drawsko* soil cover: A – former (reconstruction at the base of terrain research), B – contemporary (according to IUSS Working Group WRB 2015)

mainly in the degree of peat decomposition (peat, mucky peat, muck) and water content. These transformations resulted from natural processes without a direct anthropogenic impact on the soil such as drainage or agricultural drainage. The main anthropogenic alternation behind ground water level lowering in the lowest parts of the *Drawsko* study area was deforestation of the surrounding areas. Organic material is also observed at the surface of Gleyic Luvisols, which means that peat was also formed after mineral soil formation in the bottom of the sedimentary basin.

The gradual transformation of buried soils as a result of soil erosion led to a reduction or inhibition of primary soil-forming processes and the formation of Haplic Umbrisols (Colluvic, Raptic). Even though slope gradients were about 6-25°, the intensity of sediment transport down the slopes must have been slight. There were no mineral sediments on the surface of all organic soils examined in the area. Colluvial deposits up to 10 cm thick were observed only locally in the area immediately adjacent to the slope bases. In the N-SW transect, certain morphological changes were observed in the top profiles. Humus horizons divided into two sub-horizons were of considerable thickness (60-65 cm). Probably during the construction of a forest road the mineral material which was deposited along the edge of the *Drawsko* study area was mechanically translocated. Colluvial horizon thickness of mineral soil profiles on the north slope is 9-35 cm, but on the east slope it reaches 20-75 cm.

## Transformations of soil cover at *Siemczyno I* (meadow)

On the basis of aforementioned historical maps analysis, the closed basin at *Siemczyno I* has been tilled for at least 400 years, but most of the study area is not cultivated at present. Only the west part of the study area is used for agricultural purposes. The remaining area comprises a meadow and a small stretch of a spruce forest on the north slope. In relation to the current condition, the potential primeval soil cover of the *Siemczyno I* closed basin was characterized by significantly lower typological diversity and increased ranges of certain soil types (Fig. 3).

The central part of the study area, as in the *Drawsko* sedimentary basin, was occupied by a water reservoir supplied with groundwater and originally with water melted from dead ice blocks deposited during ice sheet deglaciation in the Late Pleistocene. As a result of human settlement and intensification of tillage after the Roman period, the environment (including soils) was transformed

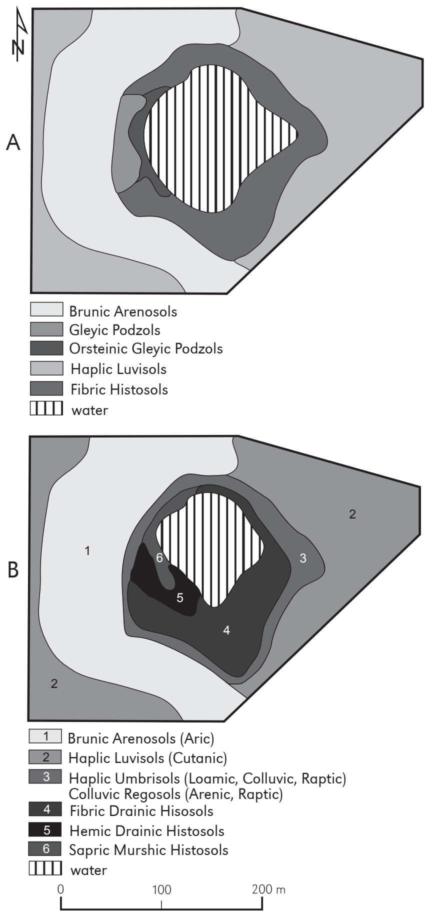


**Figure 3.** *Siemczyno I* soil cover: A – former (reconstruction at the base of terrain research), B – contemporary (according to IUSS Working Group WRB 2015)

by both natural and anthropogenic factors. Strong land drainage in the bottom of the *Siemczyno I* closed basin caused peatland overdrying. Fibric Histosols which originally occurred in the bottom of the closed basin were transformed into drier Sapric Drainic Histosols and Fibric Drainic Histosols. Overdrying of buried peat soils would have been initiated before the area was covered with deposits.

The soils of the middle parts of the slopes in the study area are not strongly transformed (Fig. 3). Profiles represented by Brunic Arenosols and Haplic Luvisols have a complete sequence of soil horizons. Agricultural use of Luvisols is common in Poland and changes of their physical and chemical properties occur with varying intensity (Przewoźna 2014). Haplic Luvisols (Cutanic) prevail in the study area. The natural sequence of soil horizons of these soils is as follows: Oi-A-Bw-E-Bt-C. As a result of deep plowing, material from the humus horizon is often mixed with the underlying horizons. Depending on type of tillage treatment, the range of influence of mechanical tools can be different. The characteristic feature of tilled humus horizons is the presence of a distinct transition separating them from deeper-lying horizons. This is the case with the *ochric* and *sideric* horizon in Brunic Arenosols and the *ochric* and E horizon (in Haplic Luvisols). The type of transition between soil horizons is an indicator of past agricultural use. In transformed Haplic Luvisols, the horizon sequence does not comprise a Bw and/or E horizon. Based on the loss of genetic horizons in natural morphology of Haplic Luvisols and Brunic Arenosols as an effect of erosion and anthropogenic denudation, Świtoniak (2014) created a 5-grade classification of vertical texture contrast (VTC)-soil (with and without *argic* horizon) truncation:

- Fully developed VTC-soils (natural soils with an intact sequence of genetic horizons),
- Slightly eroded VTC-soils (soils without *cambic* and *sideric* horizons),
- Moderately eroded VTC-soils – soils in which humus horizon composed of material from *luvic* (in Haplic Luvisols) or C horizon (in Brunic Arenosols) is retained in Bt horizons (in Haplic Luvisols) or 2C horizons of incomplete Brunic Arenosols,
- Strongly eroded VTC-soils – soils without a E horizon (Haplic Luvisols),
- Completely eroded VTC-soils (without diagnostic features characteristic for Brunic Arenosols or Haplic Luvisols).

According to Świtoniak (2014) VTC-soils means units with an abrupt change in particle-size distribution. The types of soil cover transformation in *Siemczyno I* are presented on Figure 4.

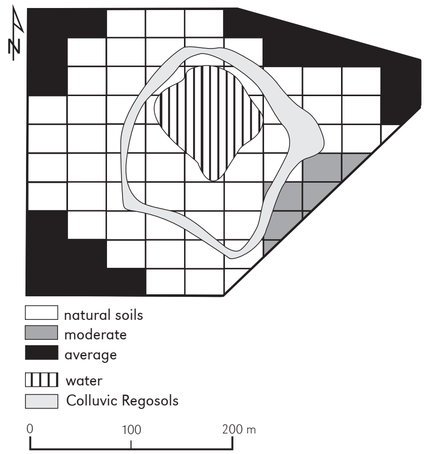


**Figure 4.** Degree of soil profile truncation at *Siemczyno I* study area, according to Świtoniak's division (2014)

Eroded sediments overlie the primaeval soil units located at the border between the slopes and the bottom of the basin without outlets. The thickness of allochthonous colluvial material in Haplic Umbrisols (Loamic, Colluvic, Raptic) which are located at the base of the slopes in the study area is about 65-90 cm. Despite the presence of slope sediments, significant soil loss is not observed in the higher parts of the slopes. It is difficult to state clearly what is the origin of these deposits and which factors (natural or anthropogenic) contributed to this redistribution.

## Transformations of soil cover at *Siemczyno II* (arable land)

Modifications of soil morphology in the *Siemczyno II* sedimentary basin are observed in almost all soil profiles studied (Fig. 5). This area has been tilled integrally for at least 400 years and for this reason it is especially subjected to degradation and erosion processes. Using soil sample radiocarbon dating, it has been estimated that the most intensive slope processes in the *Siemczyno II* sedimentary basin took place during the Middle Ages (ca 560±30 BP; uncal.), which indicates the beginning of anthropogenic denudation. The superficial peat soil horizons in the bottom of the *Siemczyno II* closed basin were formed during the Subatlantic period (ca 2390±35 BP; uncal.).

Generally, this field is tilled twice a year (before sowing and after the harvest) to loosen the soil surface and mix the remaining organic material with soil.

A significant modification of Haplic Luvisol morphology is the complete absence of E horizons. The *argic* horizon was located directly under the humus horizon in all studied profiles.

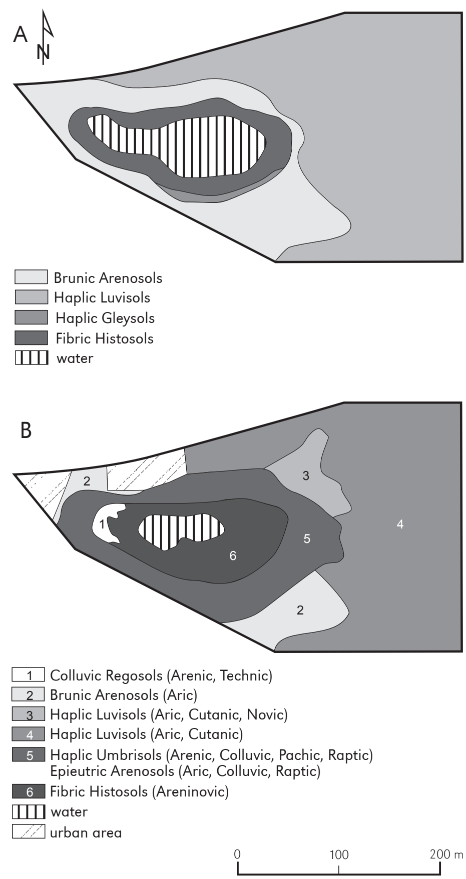


**Figure 5.** *Siemczyno II* soil cover: A – former (reconstruction at the base of terrain research), B – contemporary (according to IUSS Working Group WRB 2015)

Morphological transformations of tilled soils are also visible on ortophotomaps. The contours of soils which are moderately modified are a darker color than non-transformed areas. These dark-grey units represent Haplic Luvisols (Aric, Cutanic), in which wetter Bt horizons are located directly under A horizons. This phenomenon is more noticeable in *Siemczyno II* than in *Siemczyno I* (Fig. 6).

Based on Świtoniak's division (2014), soils in the *Siemczyno II* study area are slightly and moderately transformed (Fig. 7). The modified soil units cover almost the total area of the closed basin. The range of colluvial soils is larger than in *Siemczyno I* or *Drawsko*. The most modified soils are located on the north and east slopes of *Siemczyno II*, which are 15-20 m high and their inclination varies between 3-25°. Changes of soil morphology on the remaining, 2-5 m high, slopes (south, west), with slope reduction about 0-5° are mostly the result of backfilling due to accumulation of material over the surface horizon. The thickness of the humus horizon increases from 25-30 cm at the highest points of slopes tops to 50-120 cm at the border between slopes and the bottom of sedimentary basin. Buried soil profiles are characterized by distinct transitions between further humus horizons, demonstrating their continuous agricultural use. Colluvial sediments, occurring at the base of north and south slope, provide protection against the impact of plowing for deeper soil horizons, which confirms the complete morphology of buried Brunic Arenosols at this location. The west part of the *Siemczyno II* study area is strongly modified by slope denudation, caused by soil erosion, anthropogenic denudation and cultivation machinery impact. At the surface of buried Fibric Histosols are 120 cm thick colluvial sediments. The period and type of tillage, which indicates the intensity of slope processes in *Siemczyno II* are the


**Figure 6.** Contours of eroded soils areas visible on ortophotomaps: A – *Siemczyno I*, B – *Siemczyno II*

causative factors of eroded material displacement and their redeposition not only within slopes, but also in the bottom of closed basin. Original superficial Fibric Histosols become buried under 5-20 cm thick colluvial sediments over the entire surface of the bottom. Allochthonous material cover forms a continuous surface, with the boundary up to 5 m away from the slope base. Despite land drainage, peat soils are not overdried, because allochthonous deposits play a protective role against soil exsiccation. The contemporary ground water level varies between 15-40 cm below soil surface. In the central part of the closed basin, bottom water is on the surface throughout the year.

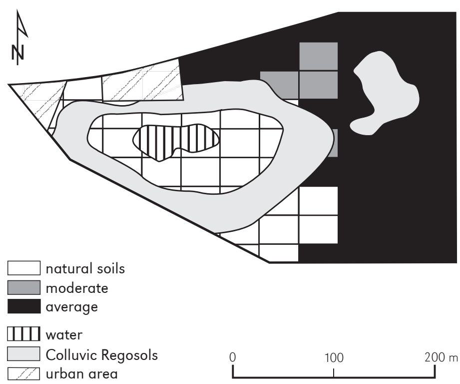


**Figure 7.** Degree of soil profile truncation at *Siemczyno II* study area, according to Świtoniak's division (2014)

## Topsoil texture, SOC and $N_t$ content

Depending on soil erosion intensity, these transformations may concern soil horizons located at different depths, however, the humus horizon is particularly exposed to this process. As a result of long-term cultivation, superficial horizons are transported down the slopes. Their redeposition is determined mainly by slope angle, plant cover, precipitation intensity and type of cultivation. The kettle holes in our study demonstrated some patterns of change in soil texture related to slope angle, which, however, were not statistically significant. Haplic Luvisols are the dominant soil type in the areas investigated in our study, which influences the distribution of soil texture. A moderate degree of erosion of these profiles with their former sequence of soil horizons leads to partial unveiling of the loamy Bt horizon and deposition of sandy material especially from the mixed A and E horizons at lower slope positions. Additional influence on the present condition of the soil cover, especially at the *Siemczyno II* stand, came from anthropogenic denudation, which led to the mixing of A and E material. Truncation of Haplic Luvisols is partially visible at the highest slope parts. On short slopes with a gradient of between 3° and 12°, translocation of sandy material is dominant (Tab. 1).

Redistribution of SOC and $N_t$ along the line of the research transects is seen in zones located at the border between slopes and the bottom of the *Drawsko*, *Siemczyno I* and *Siemczyno II* study area. In the depositional landscape positions of the transects, concentration of these nutrients was higher than in the higher parts of the slopes by about 4.4-36.6 $g \cdot kg^{-1}$ (*Drawsko*), 1.1-9.7 $g \cdot kg^{-1}$ (*Siemczyno I*), 0.1-45.0 $g \cdot kg^{-1}$ (*Siemczyno II*) for SOC and 0.51-1.40 $g \cdot kg^{-1}$ (*Drawsko*), 0.11-0.48 $g \cdot kg^{-1}$ (*Siemczyno I*), 0.01 to 2.55 $g \cdot kg^{-1}$ (*Siemczyno II*) for $N_t$ (Tab. 1). Concentrations of these nutrients within colluvial humus horizons were related to slope gradient, soil type, texture, flora and, as a result of combination of these factors, intensity of soil erosion. Differences in SOC and $N_t$ content between eroded and colluvial soils at *Drawsko* are not much marked. However, erosion contributes to translocation of small amounts of soil material and results in partial maintenance of natural terrain morphology and soil cover condition and is also visible in SOC and $N_t$ content in soil humus horizons. Colluvic Regosols are characterized by better chemical properties and greater solum thickness than eroded soils. Mixed soil horizons consisting of material derived from A and E horizons are much poorer in nutrients than soils with natural morphology. Generally, subsoil is characterized by low nutrient content,

**Table 1.** Properties of superficial (O and A) horizons of investigated soils

| Horizon | Depth (cm) | Sand (%) | Silt (%) | Clay (%) | Texture | SOC ($g \cdot kg^{-1}$) | $N_t$ ($g \cdot kg^{-1}$) | C:N |
|---|---|---|---|---|---|---|---|---|
| *Drawsko* (forest) | | | | | | | | |
| Profile T1P1 Haplic Umbrisol (Colluvic, Raptic) | | | | | | | | |
| Oi | 2-0 | - | - | - | - | 46.5 | 13.00 | 36 |
| Acol1 | 0-25 | 76 | 20 | 4 | LS | 17.0 | 0.55 | 31 |
| Acol2 | 25-60 | 77 | 19 | 4 | LS | 16.5 | 0.52 | 32 |
| Profile T1P2 Haplic Umbrisol (Colluvic, Raptic) | | | | | | | | |
| Oi | 2-1 | - | - | - | - | 167.8 | 7.25 | 23 |
| Oe | 1-0 | - | - | - | - | 152.5 | 6.89 | 22 |
| Acol1 | 0-10 | 71 | 25 | 4 | SL | 43.5 | 1.95 | 22 |
| Acol2 | 10-35 | 69 | 26 | 5 | SL | 28.9 | 1.13 | 26 |
| Ab | 35-40 | 73 | 23 | 4 | SL | 112.4 | 4.20 | 27 |
| Profile T1P6 Gleyic Luvisol (Loamic, Cutanic, Novic) | | | | | | | | |
| Oi | 2-0 | - | - | - | - | 454.2 | 12.80 | 35 |
| Acol | 0-15 | 73 | 24 | 3 | LS | 64.8 | 2.92 | 22 |
| Profile T1P7 Haplic Umbrisol (Colluvic, Raptic) | | | | | | | | |
| Oi | 2-0 | - | - | - | - | 426.7 | 11.00 | 39 |
| Acol1 | 0-10 | 60 | 33 | 7 | SL | 47.5 | 2.41 | 20 |
| Acol2 | 10-65 | 59 | 29 | 12 | SL | 7.8 | 0.51 | 15 |
| Profile T2P1 Haplic Luvisol (Cutanic) | | | | | | | | |
| Oi | 2-1 | - | - | - | - | 491.2 | 12.00 | 41 |
| Oe | 1-0 | - | - | - | - | 333.0 | 12.50 | 27 |
| A1 | 0-7 | 70 | 26 | 4 | SL | 41.4 | 2.07 | 20 |
| A2 | 7-25 | 62 | 20 | 18 | SL | 6.2 | 0.29 | 21 |
| Profile T2P2 Haplic Umbrisol (Colluvic, Raptic) | | | | | | | | |
| Oi | 2-0 | - | - | - | - | 451.7 | 15.20 | 30 |
| Acol1 | 0-10 | 67 | 29 | 4 | SL | 32.6 | 1.95 | 17 |
| Acol2 | 10-75 | 59 | 32 | 9 | SL | 16.5 | 0.62 | 27 |
| 2Ab | 75-80 | 77 | 20 | 3 | LS | 42.1 | 1.71 | 25 |
| Profile T2P3 Haplic Luvisol (Novic) | | | | | | | | |
| Oi | 2-0 | - | - | - | - | 460.2 | 15.27 | 30 |
| Acol | 0-20 | 68 | 27 | 5 | SL | 37.0 | 1.83 | 20 |
| A1 | 20-22 | - | - | - | SL | - | - | - |
| 2Ab2 | 22-45 | 76 | 21 | 3 | LS | 33.0 | 1.30 | 25 |
| Profile T2P6 Gleyic Luvisol (Loamic, Cutanic, Novic) | | | | | | | | |
| Oi | 2-1 | - | - | - | - | 386.5 | 11.20 | 35 |
| Oe | 1-0 | - | - | - | - | 394.7 | 17.00 | 23 |
| Acol1 | 0-7 | 72 | 24 | 4 | SL | 115.0 | 4.84 | 24 |
| Acol2 | 7-9 | 64 | 19 | 17 | SL | 5.6 | 0.45 | 12 |
| Profile T2P7 Haplic Luvisol (Cutanic) | | | | | | | | |
| Oi | 2-1 | - | - | - | - | 435.7 | 11.80 | 37 |
| Oe | 1-0 | - | - | - | - | 348.5 | 12.40 | 28 |
| A | 0-10 | 67 | 28 | 5 | SL | 78.4 | 3.65 | 21 |

| Horizon | Depth | Sand | Silt | Clay | Texture | SOC | $N_t$ | C:N |
|---|---|---|---|---|---|---|---|---|
| | (cm) | (%) | (%) | (%) | | ($g \cdot kg^{-1}$) | ($g \cdot kg^{-1}$) | |
| *Siemczyno I* (meadow) | | | | | | | | |
| Profile T1P1 Haplic Luvisol (Cutanic) | | | | | | | | |
| Oi | 2-0 | - | - | - | - | 439.0 | 13.00 | 22 |
| Ap(E) | 0-15 | 89 | 10 | 1 | S | 8.9 | 0.83 | 11 |
| Profile T1P2 Haplic Luvisol (Cutanic) | | | | | | | | |
| Oi | 2-0 | - | - | - | - | 442.0 | 16.80 | 26 |
| A | 0-25 | 64 | 24 | 12 | SL | 11.8 | 1.20 | 10 |
| Profile T1P3 Haplic Umbrisol (Loamic, Colluvic, Raptic) | | | | | | | | |
| Oi | 2-0 | - | - | - | - | 438.0 | 19.80 | 22 |
| Acol1 | 0-40 | 69 | 26 | 5 | SL | 10.7 | 1.02 | 10 |
| Acol2 | 40-65 | 72 | 24 | 4 | SL | 11.1 | 1.01 | 11 |
| Profile T1P5 Hemic Drainic Histosol | | | | | | | | |
| Oi | 1-0 | - | - | - | - | 435.0 | 13.50 | 32 |
| A | 0-30 | 89 | 10 | 1 | S | 53.5 | 2.96 | 18 |
| Profile T1P6 Haplic Umbrisol (Loamic, Colluvic, Raptic) | | | | | | | | |
| Oi | 2-0 | - | - | - | - | 445.0 | 14.60 | 30 |
| Acol | 0-90 | 87 | 12 | 1 | S | 18.3 | 1.21 | 15 |
| Profile T1P7 Brunic Arenosol (Aric) | | | | | | | | |
| Ap | 0-20 | 89 | 9 | 2 | S | 8.6 | 0.73 | 12 |
| Profile T2P1 Brunic Arenosol (Aric) | | | | | | | | |
| Oi | 2-0 | - | - | - | - | 43.7 | 12.10 | 36 |
| A(p) | 0-30 | 76 | 20 | 4 | LS | 0.7 | 0.59 | 12 |
| Profile T2P2 Colluvic Regosol (Arenic, Raptic) | | | | | | | | |
| Oi | 2-0 | - | - | - | - | 439.0 | 14.10 | 31 |
| Acol | 0-70 | 77 | 19 | 4 | LS | 8.0 | 0.70 | 11 |
| Profile T2P3 Sapric Murshic Histosol | | | | | | | | |
| Oi | 2-0 | - | - | - | - | 435.0 | 13.50 | 32 |
| A | 0-15 | 89 | 9 | 2 | S | 118.0 | 6.04 | 20 |
| Profile T2P4 Fibric Drainic Histosol | | | | | | | | |
| Oi | 2-0 | - | - | - | - | 467.0 | 17.00 | 27 |
| A | 0-25 | 89 | 10 | 1 | S | 85.6 | 4.80 | 18 |
| Profile T2P5 Colluvic Regosol (Arenic, Raptic) | | | | | | | | |
| Oi | 2-0 | - | - | - | - | 441.0 | 19.70 | 22 |
| Acol | 0-85 | 76 | 18 | 6 | LS | 8.2 | 0.70 | 12 |
| Profile T2P6 Haplic Luvisol (Cutanic) | | | | | | | | |
| Oi | 2-0 | - | - | - | - | 442.0 | 19.60 | 23 |
| A(p) | 0-30 | 79 | 14 | 7 | LS | 5.7 | 0.53 | 11 |

| Horizon | Depth (cm) | Sand (%) | Silt (%) | Clay (%) | Texture | SOC ($g \cdot kg^{-1}$) | $N_t$ ($g \cdot kg^{-1}$) | C:N |
|---|---|---|---|---|---|---|---|---|
| *Siemczyno II* (arable land) | | | | | | | | |
| Profile T1P1 Haplic Luvisol (Aric, Cutanic) | | | | | | | | |
| ApE | 0-25 | 66 | 21 | 13 | SL | 7.6 | 0.69 | 11 |
| Profile T1P2 Haplic Luvisol (Aric, Cutanic) | | | | | | | | |
| ApE | 0-30 | 70 | 22 | 8 | SL | 10.5 | 0.95 | 11 |
| Profile T1P3 Epieutric Arenosol (Aric, Colluvic, Raptic) | | | | | | | | |
| Acolp | 0-25 | 78 | 15 | 7 | LS | 9.1 | 0.81 | 11 |
| Acol(p) | 25-50 | 86 | 11 | 3 | LS | 7.9 | 0.74 | 11 |
| Acol | 50-60 | 86 | 12 | 2 | S | 2.8 | 0.23 | 12 |
| Ab | 60-85 | 79 | 15 | 6 | LS | 3.2 | 0.25 | 13 |
| Profile T1P4 Haplic Umbrisol (Arenic, Colluvic, Pachic, Raptic) | | | | | | | | |
| Oi | 2-0 | - | - | - | - | 426.0 | 11.40 | 37 |
| Acol | 0-40 | 75 | 24 | 1 | LS | 36.6 | 2.16 | 17 |
| A | 40-80 | 74 | 25 | 1 | LS | 33.6 | 1.98 | 17 |
| Profile T1P5 Fibric Histosol (Areninovic) | | | | | | | | |
| Oi | 2-0 | - | - | - | - | 448.0 | 13.50 | 33 |
| Acol | 0-30 | 78 | 17 | 5 | LS | 69.4 | 4.37 | 16 |
| Profile T1P6 Fibric Histosol (Areninovic) | | | | | | | | |
| Oi | 2-0 | - | - | - | - | 464.0 | 12.20 | 38 |
| Acol | 0-30 | 81 | 17 | 2 | LS | 58.3 | 3.79 | 15 |
| Profile T1P7 Haplic Umbrisol (Arenic, Colluvic, Pachic, Raptic) | | | | | | | | |
| Oi | 2-0 | - | - | - | - | 429.8 | 12.55 | 34 |
| Acol1 | 0-60 | 84 | 15 | 1 | LS | 13.3 | 1.24 | 11 |
| Acol2 | 60-100 | 78 | 19 | 3 | LS | 9.7 | 0.69 | 14 |
| Profile T1P8 Epieutric Arenosol (Aric, Colluvic, Raptic) | | | | | | | | |
| Acolp | 0-40 | 90 | 7 | 3 | S | 7.2 | 0.58 | 12 |
| Acol | 40-55 | 92 | 4 | 4 | S | 2.3 | 0.22 | 10 |
| Ab | 55-90 | 86 | 13 | 1 | S | 3.5 | 0.29 | 12 |
| Profile T2P1 Haplic Luvisol (Aric, Cutanic) | | | | | | | | |
| ApE | 0-25 | 60 | 30 | 10 | SL | 7.4 | 0.80 | 9 |
| Profile T2P2 Haplic Luvisol (Aric, Cutanic, Novic) | | | | | | | | |
| Ap | 0-30 | 70 | 23 | 7 | SL | 8.2 | 0.81 | 10 |
| Acol | 30-60 | 71 | 25 | 4 | SL | 6.9 | 0.72 | 10 |
| Profile T2P3 Haplic Luvisol (Aric, Cutanic, Novic) | | | | | | | | |
| Acolp | 0-40 | 70 | 23 | 7 | SL | 8.3 | 0.83 | 10 |
| Profile T2P4 Haplic Umbrisol (Colluvic, Raptic) | | | | | | | | |
| Acol | 0-50 | 78 | 19 | 3 | LS | 452.0 | 14.00 | 32 |
| Profile T2P5 Fibric Histosol (Areninovic) | | | | | | | | |
| Oi | 2-0 | - | - | - | - | 448.0 | 13.50 | 33 |
| Acol | 0-30 | 78 | 17 | 5 | LS | 69.4 | 4.37 | 16 |
| Profile T2P6 Fibric Histosol (Areninovic) | | | | | | | | |
| Oi | 2-0 | - | - | - | - | 453.5 | 13.65 | 34 |
| Acol | 0-30 | 82 | 17 | 1 | LS | 62.7 | 4.82 | 13 |

| Horizon | Depth (cm) | Sand (%) | Silt (%) | Clay (%) | Texture | SOC ($g·kg^{-1}$) | $N_t$ ($g·kg^{-1}$) | C:N |
|---|---|---|---|---|---|---|---|---|
| *Siemczyno II* (arable land) | | | | | | | | |
| Profile T2P7 Colluvic Regosol (Arenic, Technic) | | | | | | | | |
| Oi | 2-0 | - | - | - | - | 452.0 | 13.98 | 32 |
| Acol1 | 0-25 | 86 | 14 | 0 | S | 42.9 | 3.73 | 12 |
| Acol2 | 25-30 | 91 | 7 | 2 | S | 10.7 | 0.80 | 13 |
| Acol3 | 30-40 | 76 | 23 | 1 | LS | 34.7 | 2.47 | 14 |
| Profile T2P8 Epieutric Arenosol (Aric, Colluvic, Raptic) | | | | | | | | |
| Acolp | 0-80 | 87 | 12 | 1 | S | 8.7 | 0.62 | 14 |
| Acol | 80-120 | 77 | 20 | 3 | LS | 28.1 | 1.86 | 15 |

which results in diminution especially of SOC in topsoil as a result of the soil material being stirred during tillage. Disproportions in SOC and $N_t$ content in the A horizons of eroded and colluvial soils at *Siemczyno II* are considerable and the highest among all of the study areas. Average SOC content in the A horizons of non-tilled colluvial soils at this area was 33.5 $g·kg^{-1}$, compared to 8.4 $g·kg^{-1}$ in tilled colluvial soils. The highest average content of SOC from superficial horizons (65.0 $g·kg^{-1}$) was seen in allochthonous sediments deposited on the surface of peat, within the sedimentary basin bottom. It is dependent not only on soil nutrient concentration in the lowest-lying area of the catchment, but also on the influence of a high groundwater level, dense plant cover and the presence of peat. A strong correlation is observed between the slope gradient, location on a slope and SOC and $N_t$ content in topsoil (Figs. 8, 9). Regardless of land use, the concentrations of these nutrients are higher at lower slope positions (Figs. 10, 11), which is additionally directly related to the land being used as a meadow at these positions. However, increasing content of SOC and $N_t$ is also visible in the topsoil of tilled profiles located at lower slope positions.

The average C:N ratio in forest soils is higher than in tilled or meadow soils (Tab. 1). In A horizons of Haplic Umbrisols (Colluvic, Raptic) located within both research transects of *Drawsko*, the values of this indicator varied from 17 to 31, compared to 20-24 in other types of soils. This study area, especially on slopes, is characterized by a relatively homogeneous plant cover, local texture and water conditions, which has

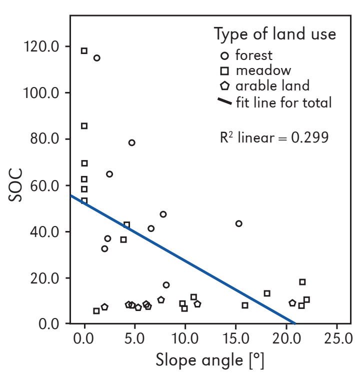


**Figure 8.** Scatter plot of relationships between SOC ($g·kg^{-1}$) content, slope angle (°) and type of land use

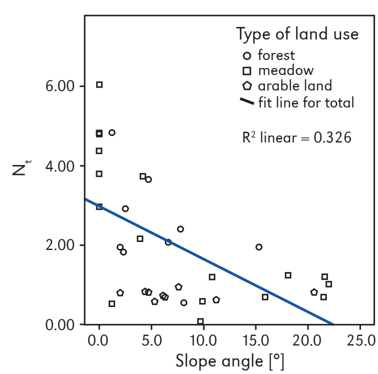


**Figure 9.** Scatter plot of relationships between $N_t$ ($g·kg^{-1}$) content, slope angle (°) and type of land use

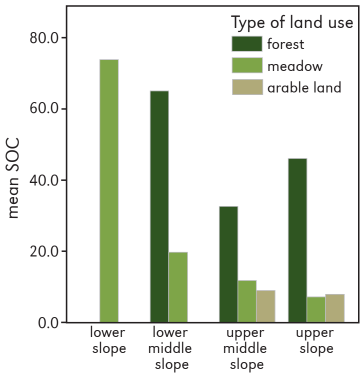


**Figure 10.** Chart of relationships between SOC (g·kg$^{-1}$) content, location on the slope and type of land use

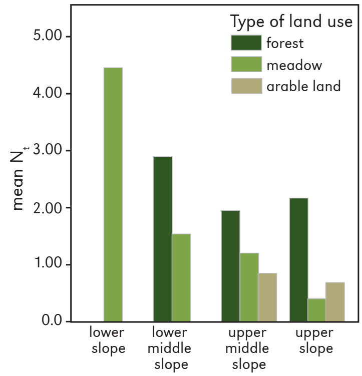


**Figure 11.** Chart of relationships between $N_t$ (g·kg$^{-1}$) content, location on the slope and type of land use

an impact on the distribution of the biological activity index of soils. The C:N ratio of eroded and deposited A horizons at *Siemczyno I* was fairly uniform, varying from 10 to 15. Slight disproportions may result from the blurring of differences between soil properties of truncated and superstructure soils. Cessation of agricultural use and the development of a dense vegetation cover on the *Siemczyno I* slopes has resulted in neutralization of differences and is promoting homogenization of the superficial soil horizons. Disproportions are still strongly marked at the border between tilled and non-tilled soils, where the type of land use plays a key role in sediment and mineral distribution. The C:N ratio in colluvial A horizons at *Siemczyno II* ranged from 10 to 17, compared to 9-11 in eroded soils.

## Discussion

The presence of closed basins in a young glacial landscape in north-western Poland has a significant impact on soil cover diversity. The studied kettle holes were formed during the same period (about 12,000 years ago) as a result of slow melting of blocks of buried dead ice and have been subjected to similar processes. Despite these similarities, nowadays they are differently transformed. On the basis of previous research (Borówka 1992; Hulisz et al. 2012; Karasiewicz et al. 2014) in northern Poland, it is possible to determine the main stages of closed basin development in a young glacial landscape. The presence of mineral sediments in the bottom of the sedimentary basin indicates the existence of a water reservoir after ice sheet deglaciation probably in Late Glacial. Changing environmental conditions resulted in gradual overgrowth of closed basin areas and the appearance of a peat cover. The deposition of colluvial sediments as an effect of erosion and slope processes was the next phase of evolution. Ground water level fluctuations caused overdrying of organic material and muck formation. Terrain peneplanation with soil cover modifications, anthropogenic impact and climate change were the main factors which contributed to the contemporary condition of the closed basins. The main stage in the formation of peat within the Drawsko Lakeland during Holocene took place in the Atlantic and Subboreal period. It is also confirmed by palynological analysis of samples taken from peatlands located near Czaplinek (Nita 2006; Lewandowski & Nita 2008). Pedological processes due to climate and flora changes in these periods were intensive and led to the generation of a continuous organic soil cover in the bottom of the *Drawsko* closed basin.

The soil cover in *Siemczyno I* sedimentary basin is currently moderately transformed in relation to the former. The new soils have been developed by intense translocation and erosive effects due to manual tillage and land drainage. The part of the closed basin which is not used for agricultural purposes was probably tilled for a short time in the Middle Ages in view of its disadvantageous diversified relief. The intensification of tillage results in initiation of anthropogenic denudation and colluvial soil formation. The impact of tillage on soils in undulated landscapes is significant. In contrast to a common belief, strong soil translocation rates have been documented not only for modern tillage. Using animal power in land cultivation can also be dangerous, as it intensifies soil erosion and anthropogenic denudation. This phenomenon has also been confirmed by other researchers (e.g. Quine et al. 1999; Thapa et al. 1999; Turkenbloom et al. 1999). At *Siemczyno I* eroded sediments overlie the original soil units located at the border between the slopes and the bottom of the basin without outlets. It can be assumed that the presence of fully developed soil profiles in degradation areas is the result of strong, but monotonous slope processes, which are related to tillage or/and multiple redeposition of eroded material before its final accumulation within contact zone between slopes and kettle hole bottom. This phenomenon is also evidenced by Świtoniak (2011). In most colluvial covers, clear stratification is not observed, which further confirms this thesis. Significant changes in the near-surface soil properties depend on the length of the no-till period. Cessation of agricultural use results e.g. in better air conditions and increased soil porosity (VandenBygaart et al. 1999).

Long-term effects of soil erosion on slope profiles of closed basins are particularly significant in tilled areas, also at *Siemczyno II*. Tillage depth, direction and speed generally show considerable within-field variations (Van Muysen et al. 2006). The evolution of slopes and the rate of peneplanation of undulated areas in a young glacial landscape depend largely on human impact. Soil slope stability modifications due to soil erosion and accumulation processes can increase the risk of surface mass movement (Schumacher et al. 1999; Kosmas et al. 2001; De Alba et al. 2004). Tillage erosion smoothens the landscape and reduces slope angles by moving soil material (Van Oost et al. 2005; Zhang et al. 2008). The downslope direction of soil movement is characteristic of hoe and animal-power tillage. In mechanized agriculture areas, the soil is tilled in opposing directions, resulting in not only downslope soil deposition (Su et al. 2012). Soil variability of undulated areas changes according to tillage depth. The most noticeable alterations of soils are seen in the summit and toe positions. The impact of soil erosion and anthropogenic denudation is visible also in soil depth, which increases from the top to the slope base. Radiocarbon age of analyzed soil samples at *Siemczyno II* refers to results of palynological analysis of peat samples collected at Drawsko Lakeland by other researchers (Nita 2006; Lewandowski & Nita 2008).

Truncated profiles of Haplic Luvisols with the following sequence of soil genetic horizons: Ap-Bt-Ck, are commonly found in tilled areas of Poland (Sinkiewicz 1998; Szrejder 1998; Marcinek & Komisarek 2004; Stasik & Szafrański 2005; Kobierski 2013; Podlasiński 2013; Świtoniak 2014). That morphology is similar to Cambisols and therefore these type of soils are often confused with each other during field works (Świtoniak 2014; Świtoniak et al. 2016). Laboratory research reveals that topsoil horizons of Haplic Luvisols are built from a loamy sand soil material, while superficial horizons of Cambisols usually have a loamy texture, what is also confirmed at *Siemczyno II*. The stratification of allochthonous sediments at *Siemczyno II* is not clearly marked, which shows that their redeposition may have been the result of anthropogenic denudation (Paluszek 2010). Indirectly, it can also indicate a slow and long-term accumulation with the predominant influence of rill-wash or multiple sediment translocation before final deposition in the contact zone between slopes and the sedimentary basin bottom (De Ploey 1985; Smolska 2005).

Soil movement by tillage results in soil material displacement from convex slope positions and soil accumulation in concave slope positions (e.g. Govers et al. 1994; Lobb et al. 1995; Papiernik et al. 2007). Long-term tillage effects result in transformation of the mineral and organic soil profiles and the natural configuration of soil cover (Tsara et al. 2001). However transformations of organic soils are related not only to tillage, but also to groundwater level fluctuations. Tillage plays a significant role in soil redistribution on agricultural land (e.g. Frielinghaus & Vahrson 1998; Thapa et al. 1999; Van Muysen et al. 1999, 2000, 2006; Kosmas et al. 2001; Van Muysen & Govers 2002; Heckrath et al. 2005; Su et al. 2012). Anthropogenic denudation initiated by tillage leads to closed basin backfilling and contributes to the creation of colluvial sediment cover. Based on the range of allochthonous sediments it is possible to define the relative duration of tillage and intensity of the impact of the use of mechanical or/and animal power in land cultivation. It is also possible to make reconstructions of the original extent of sedimentary basins bottoms. Tillage erosion may be responsible for reductions of soil profiles (especially topsoil). Peneplanation of sedimentary basins causes reduction of geodiversity of young glacial landscapes.

According to our results, three main groups of transformation factors have a significant impact on soil cover condition: soil erosion, anthropogenic denudation and influence of groundwater level fluctuations. In combination with plant cover, soil texture, slope angle, precipitation and type of land use, these factors create unique conditions preventing or enhancing changes of soil cover. The intensity of their impact on soils was severe in the past but is highly limited nowadays.

Eroded soil mass movement determined by natural or anthropogenic factors is related to changes of soil texture (e.g. Chodak et al. 2005; Smolska 2008). Mahaney and Sanmugadas (1989), Szpikowski (2003), Baužienė et al. (2008) and others have stated that soil material washed during erosion is fine-grained and well-sorted. However at studied kettle holes the movement of the sand fraction down the slopes is also observed.

Loss of SOC and total nitrogen is characteristic especially of tilled areas, which is related to the destruction of macroaggregates by soil material redeposition resulting from soil erosion. In well drained soils located within a wet footslope zone, the translocation of nutrients within the soil profile is more intense than in other parts of slopes (Gregorich et al. 1998). Soils located in upper slope parts have lower SOC and $N_t$ content than those at footslope positions, which is the result of loss of soil material, especially smaller and lighter particles enriched with nutrients (Lal 2004; Ritchie et al. 2007). This phenomenon also has an important influence on soil structure and texture of colluvial sediments (VandenBygaart 2001). Research results shows that SOC and $N_t$ concentration is observed in colluvial soils. A similar correlation has been confirmed by numerous studies (Gregorich et al. 1998; Lal 2003; Polyakov & Lal 2004; Zhang et al. 2006; Ritchie et al. 2007; Martinez et al. 2010). The relatively low C:N ratio of humus horizons of higher located soil units results from their rejuvenation (Baužienė et al. 2008).

Moreover, the landscape topography of closed basins determines the deposition of nearly all eroded soil material within their catchments. Insignificant or absent discharge of material enables complete reconstruction of past topography changes in basins without outlets and also sediment genesis with processes which they were subjected to. According to research data, mainly long-term conventional tillage practices in the past have a significant impact on soils in sedimentary basin bottoms. Disparities between contemporary mechanized and previous non-mechanized agriculture are significant and concern all soil properties. Despite appearances, the main backfilling period of sedimentary basins took place in the Middle Ages. Contemporary soil redistribution is initiated principally by water erosion and less by anthropogenic denudation.

Soil erosion proceeds at various rates, depending, among others, on soil texture.

Despite the presence of steep slopes (slope angles greater than 20°), a dense vegetation cover is a factor which inhibits runoff and soil material deposition. A good condition of today's closed basins results from appropriate agricultural practices and high resistance of cultivated soils to erosion. Steep slope parts are the most transformed and microrelief plays an important role in the process of soil material redeposition.

## Conclusions

The modifications of contemporary soil cover in the kettle holes investigated in this study can be regarded as moderate. The type of land use intensifies or inhibits erosion and is, therefore, a main factor of superficial soil horizon transformations, what is visible on all studied kettle holes. Most soil cover changes, especially the formation of thick colluvial horizons, took place in the Middle Ages as a result of improper agricultural purposes. The type of land use strongly diversifies the intensity of soil cover modeling. Differences between the kind of modifications in particular research areas are significant and concern the range of colluvial sediments, overdrying of organic soils and initiation of new soil-forming processes. Changes of the former soil cover of closed basins are inevitable and strongly related to the type of land use. Preservation of the original sequence of genetic horizons in each type of soils is rare in the natural environment. The degree of transformation in soil morphology is an indicator of slope processes resulting from natural and anthropogenic events. No-till areas are characterized by the presence of a colluvial material cover created as a result of natural processes. These objects are moderately transformed, preserving a percentage of natural soils. Characteristic of tilled areas, besides thick allochthonous sediments, are distinct transitions between genetic horizons and soil compaction. The effects of human influence on soils are clearly visible, even long after cessation of tillage. The impact of soil erosion on soil cover in sedimentary basins is dependent on land use, agricultural practices, coverage by vegetation, slope angle, intensity of rainfall and soil moisture. The thickness of colluvial soils is diversified and depends on the intensity of soil erosion and anthropogenic denudation. In many cases, buried peat soils occur in their floor, indicating the extent of the former sedimentary basin bottoms. Shrinking of the area occupied by organic soils, an integral feature of post-glacial areas, significantly impoverishes soil cover diversity in hummocky young glacial landscapes. Patterns of SOC and $N_t$ translocation in individual types of land use are similar and confirm that the translocation of these nutrients is directed downslope.

Editors' note:
Unless otherwise stated, the sources of tables and figures are the authors', on the basis of their own research.

## References

BAUŽIENĖ I., ŚWITONIAK M., CHARZYŃSKI P., 2008. *Properties of deluvial soils in Poland and Lithuania and propositions of their classification*. Žemės Ûkio Mokslai, vol. 15, no. 3, pp. 29-35.

BORÓWKA R.K., 1992. *Przebieg i rozmiary denudacji w obrębie śródwysoczyznowych basenów sedymentacyjnych podczas późnego vistulianu i holocenu*, ser. Geografia, vol. 54, Poznań: Wydawnictwo Naukowe UAM.

BOUYOUCOS G.M., 1951. *Particle analysis by hydrometer method*. Agronomy Journal, no. 43, pp. 434-438.

CHODAK T., KASZUBKIEWICZ J., TASZ W., 2005. *Skład granulometryczny i zawartość makroskładników w materiale glebowym zmywanym w wyniku erozji powierzchniowej.* Acta Agrophysica, vol. 5, no. 3, pp. 577-587.

CORTI G., COCCO S., BASILI M., CIOCI C., WARBURTON J., AGNELLI A., 2012. *Soil formation in kettle* *holes from high altitudes in central Apennines, Italy.* Geoderma, vol. 170, pp. 280-294.

De Alba S., Lindstrom M.J., Schumacher T.E., Malo D.D., 2004. *Soil landscape evolution due to soil redistribution by tillage: A new conceptual model of soil catena evolution in agricultural landscapes.* Catena, vol. 58, no. 1, pp. 77-100.

De Ploey J., 1985. *The origin of modern and old colluvium in the light of a colluviation model* [in:] M. Van Molle, L. Peeters (eds.), Recent trends in physical geography in Belgium. Study series of the Vrije Universiteit Brussel, New Series, vol. 20, pp. 157-171.

Drwal J., 1975. *Zagadnienia bezodpływowości na obszarach młodoglacjalnych.* Zeszyty Naukowe Wydziału Biologii i Nauk o Ziemi, ser. Geografia, vol. 3, pp. 7-26.

FAO, 2006. *Guidelines for Soil Description.* Rome: Food and Agriculture Organization of the United Nations.

Frielinghaus M., Vahrson W.-G., 1998. *Soil translocation by water erosion from agricultural cropland into wet depressions (morainic kettle holes).* Soil and Tillage Research, vol. 46, no. 1-2, pp. 23-30.

Gaudig G., Couwenberg J., Joosten H., 2006. *Peat accumulation in kettle holes: bottom up or top down?* Mires and Peat, no. 1, pp. 1-16.

Gerke H., Koszinski S., Kalettka T., Sommer M., 2010. *Structures and hydrologic function of soil landscapes with kettle holes using an integrated hydropedological approach.* Journal of Hydrology, vol. 393, no. 1-2, pp. 123-132.

Govers G., Vandaele K., Desmet P., Poesen J., Bunte K., 1994. *The role of tillage in soil redistribution on hillslopes*. European Journal of Soil Science, vol. 45, no. 4, pp. 469-478.

Gregorich E.G., Greer K.J., Anderson D.W., Liang B.C., 1998. *Carbon distribution and losses: erosion and deposition effects*. Soil and Tillage Research, vol. 47, no. 3-4, pp. 291-302.

Heckrath G., Djurhuus J., Quine T.A., Van Oost K., Govers G., Zhang Y., 2005. *Tillage erosion and its effect on soil properties and crop yield in Denmark*. Journal of Environmental Quality, vol. 34, no. 1, pp. 312-324.

Hulisz P., Karasiewicz M.T., Dąbrowski M., Michalski M., 2012. *Zmiany fizykochemicznych i chemicznych właściwości osadów w odniesieniu do etapów rozwoju zagłębienia w rezerwacie Retno* [in:] M.T. Karasiewicz, P. Hulisz, M. Świtoniak (eds.), Postglacjalna historia zagłębienia bezodpływowego w rezerwacie Retno (Pojezierze Brodnickie), Toruń: Wydawnictwo Naukowe UMK, pp. 131-143.

IUSS Working Group WRB, 2015. *World reference base for soil resources 2014.* World Soil Resources Report No. 106, Rome: FAO.

Karasiewicz M.T., Hulisz P., Noryśkiewicz A.M., Krześlak I., Świtoniak M., 2014. *The record of hydroclimatic changes in the sediments of a kettle-hole in a young glacial landscape (north-central Poland).* Quaternary International, vol. 328-329, pp. 264-276.

Kobierski M., 2013. *Morfologia, właściwości oraz skład mineralny gleb płowych zerodowanych w wybranych obszarach morenowych województwa kujawsko-pomorskiego*, ser. Rozprawy, 166, Bydgoszcz: Uniwersytet Technologiczno-Przyrodniczy.

Kochanowska R., Pienkowski P., Wolejko L., 1998. *Characteristics of intrafield water holes in Western Pomerania in relation to differentiation of the young-glacial landscape and human impact.* Journal of Water and Land Development, vol. 2, pp. 85-101.

Kosmas C., Gerontidis St., Marathianou M., Detsis B., Zafiriou Th., Nan Muysen W., Govers G., Quine T., Vanoost K., 2001. *The effect of tillage displaced soil on soil properties and wheat biomass.* Soil and Tillage Research, vol. 58, no. 1-2, pp. 31-44.

Lal R., 2003. *Soil erosion and global carbon budget.* Environment International, vol. 29, no. 4, pp. 437-450.

Lal R., 2004. *Soil carbon sequestration impacts on global climate change and food security.* Science, vol. 304, no. 5677, pp. 1623-1627.

Lemkowska B., Sowiński P., 2009. *Mikroelementy w glebach obniżeń pojeziornych Pojezierza Olsztyńskiego.* Zeszyty Problemowe Postępów Nauk Rolniczych, vol. 540, pp. 237-245.

Lewandowski J., Nita M., 2008. *Ewolucja systemu hydrograficznego i szaty roślinnej dorzecza górnej Piławy i górnej Drawy (Pomorze Środkowe).* Przegląd Geologiczny, vol. 56, no. 5, pp. 380-390.

Li S., Lobb D.A., Tiessen K.H.D., 2009. *Modeling tillage-induced morphological features in cultivated landscapes.* Soil and Tillage Research, vol. 103, no. 1, pp. 33-45.

LINDSTROM M.J., NELSON W.W., SCHUMACHER T.E., 1992. *Quantifying tillage erosion rates due to moldboard plowing.* Soil and Tillage Research, vol. 24, no. 3, pp. 243-255.

LOBB D.A., KACHANOSKI R.G., MILLER M.H., 1995. *Tillage translocation and tillage erosion on shoulder slope landscape positions measured using* [137]*Cs as a tracer.* Canadian Journal of Soil Science, vol. 75, no. 2, pp. 211-218.

MAHANEY W.C., SANMUGADAS K., 1989. *Late-Holocene soil toposequence in Stroud Basin, Central Wind River Mountains, western Wyoming.* Geografisk Tidsskrift, vol. 89, pp. 58-65.

MAJOR M., 2010. *Charakter i funkcjonowanie zagłębień bezodpływowych w krajobrazie strefy młodoglacjalnej (Pomorze Zachodnie, górna Parsęta).* Poznań: Poznańskie Towarzystwo Przyjaciół Nauk.

MAJOR M., 2008. *Morphometric differences among basins without outlets in the southern and central parts of the Parsęta catchment.* Limnological Review, vol. 8, no. 1-2, pp. 43-49.

MARCINEK J., KOMISAREK J., 2004. *Antropogeniczne przekształcenia gleb Pojezierza Poznańskiego na skutek intensywnego użytkowania rolniczego.* Poznań: Wydawnictwo Akademii Rolniczej.

MARTINEZ C., HANCOCK G.R., KALMA J.D., 2010. *Relationships between* [137]*Cs and soil organic carbon (SOC) in cultivated and never-cultivated soils: An Australian example*. Geoderma, vol. 158, no. 3-4, pp. 137-147.

MENDYK Ł., MARKIEWICZ M., BEDNAREK R., ŚWITONIAK M., GAMRAT W.W., KRZEŚLAK I., SYKUŁA M., GERSZTYN L., KUPNIEWSKA A., 2015. *Environmental changes of a shallow kettle lake catchment in a young glacial landscape (Sumowskie Lake catchment), North-Central Poland*. Quaternary International (in press).

NICHOL D., 2001. *Environmental changes within kettle holes at Borras Bog triggered by construction of the A5156 Llanypwll Link Road, North Wales.* Engineering Geology, vol. 59, no. 1-2, pp. 73-82.

NITA M., 2006. *Wyniki analizy pyłkowej osadów organicznych. Szczegółowa mapa geologiczna Polski 1:50 000, ark. Czaplinek (196).* Warszawa: Centralne Archiwum Geologiczne Państwowego Instytutu Geologicznego.

ORZECHOWSKI M., SMÓLCZYŃSKI S., SOWIŃSKI P., 2004. *Przekształcenia antropogeniczne gleb obniżeń śródmorenowych Pojezierza Mazurskiego.* Roczniki Gleboznawcze, vol. 55, no. 2, pp. 311-320.

PALUSZEK J., 2010. *Zmiany pokrywy glebowej pod wpływem erozji.* Prace i Studia Geograficzne, vol. 45, pp. 279-294.

PAPIERNIK S.K., LINDSTROM M.J., SCHUMACHER T.E., SCHUMACHER J.A., MALO D.D., LOBB D.A., 2007. *Characterization of soil profiles in a landscape affected by long-term tillage.* Soil and Tillage Research, vol. 93, no. 2, pp. 335-345.

PIAŚCIK H., SOWIŃSKI P., ORZECHOWSKI M., SMÓLCZYŃSKI S., 2001. *Sekwencja gleb obniżeń śródmorenowych w krajobrazie młodoglacjalnym Pojezierza Mazurskiego.* Zeszyty Problemowe Postępów Nauk Rolniczych, vol. 476, pp. 491-496.

PODLASIŃSKI M., 2013. *Wpływ denudacji antropogenicznej na zróżnicowanie pokrywy glebowej i jej przestrzenną strukturę w rolniczym krajobrazie morenowym.* Szczecin: Wydawnictwo Uczelniane Zachodniopomorskiego Uniwersytetu Technologicznego.

POLYAKOV V., LAL R., 2004. *Modeling soil organic matter dynamics as affected by soil water erosion.* Environment International, vol. 30, no. 4, pp. 547-556.

PRZEWOŹNA B., 2014. *Change of bulk density, air-water properties and morphology of soils in basins without outlets as an effect of erosion and anthropogenic denudation (a study from northwestern Poland).* Soil Science and Plant Nutrition, vol. 60, no. 1, pp. 30-37.

RITCHIE J.C., MCCARTY G.W., VENTERIS E.R., KASPAR T.C., 2007. *Soil and soil organic carbon redistribution on the landscape*. Geomorphology, vol. 89, pp. 163-171.

RODZIK J., MROCZEK P., WIŚNIEWSKI T., 2014. *Pedological analysis as a key for reconstructing primary loess relief – A case study from the Magdalenian site in Klementowice (eastern Poland).* Catena, vol. 117, pp. 50-59.

QUINE T.A., WALLING D.E., CHAKELA Q.K., MANDIRINGANA O.T., ZHANG X., 1999. *Rates and patterns of tillage and water erosion on terraces and contour strips: evidence from caesium-137 measurements.* Catena, vol. 36, no. 1-2, pp. 115-142.

SCHUMACHER T.E., LINDSTROM M.J., SCHUMACHER J.A., LEMME G.D., 1999. *Modeling spatial variation in productivity due to tillage and* *water erosion.* Soil and Tillage Research, vol. 51, no. 3-4, pp. 331-339.

Sinkiewicz M., 1998. *Rozwój denudacji antropogenicznej w środkowej części Polski Północnej.* Toruń: Wydawnictwo UMK.

Smolska E., 2005. *Znaczenie spłukiwania w modelowaniu stoków młodoglacjalnych (na przykładzie Pojezierza Suwalskiego).* Warszawa: Wydział Geografii i Studiów Regionalnych UW.

Smolska E., 2008. *Badania sedymentologiczne współczesnych osadów deluwialnych i ich znaczenie w ocenie procesów dynamiki procesów erozji gleby na przykładzie Pojezierza Suwalskiego.* Przegląd Naukowy Inżynieria i Kształtowanie Środowiska, vol. 17, no. 2(40), pp. 202-212.

Sowiński P., Smólczyński S., Orzechowski M., 2004. *Wpływ rolniczego użytkowania na właściwości fizyczno-wodne gleb w katenie moreny dennej Pojezierza Mazurskiego.* Annales UMCS, Sec. E, Agricultura, vol. 59, no. 3, pp. 1057-1064.

Sowiński P., Lemkowska B., 2009. *Toposequence and soil properties in the landscape of ground moraine of Olsztyn Lakeland* [in:] B. Bieniek (ed.), Soils of chosen landscapes. Olsztyn: University of Warmia and Mazury, pp. 21-36.

Sowiński P., Lemkowska B., 2010. *Makroskładniki w glebach obniżeń pojeziernych na Pojezierzu Olsztyńskim.* Roczniki Gleboznawcze, vol. 61, no. 2, pp. 87-94.

Stasik R., Szafrański C., 2005. *Zmiany w pokrywie glebowej erodowanych terenów Pojezierza Gnieźnieńskiego.* Acta Agrophysica, vol. 5, no. 2, pp. 447-454.

Su Z.A., Zhang J.H., Qin F.C., Nie X.J., 2012. *Landform change due to soil redistribution by intense tillage based on high-resolution DEMs.* Geomorphology, vol. 175-176, pp. 190-198.

Szpikowski J., 2003. *Contemporary processes of soil erosion and the transformation of the morphology of slopes in agricultural use in the postglacial catchment of the Chwalimski Potok (upper Parseta, Drawskie Lakeland).* Quaestiones Geographicae, vol. 22, pp. 79-90.

Szrejder B., 1998. *Niektóre właściwości i pozycja systematyczna gleb powstałych w wyniku denudacji antropogenicznej w Koniczynce na Wysoczyźnie Chełmińskiej.* Zeszyty Problemowe Postępów Nauk Rolniczych, vol. 460, pp. 499-511.

Świtoniak M., 2011. *Przekształcenia pokrywy glebowej obszarów wysoczyznowych Pojezierza Brodnickiego w wyniku oddziaływania denudacji antropogenicznej* [in:] M. Jankowski (ed.), Wybrane problemy genezy, systematyki i ochrony gleb regionu kujawsko-pomorskiego. Wrocław-Warszawa: PTSH, PTG.

Świtoniak M., 2014. *Use of soil profile truncation to estimate influence of accelerated erosion on soil cover transformation in young morainic landscapes, North-Eastern Poland.* Catena, vol. 116, pp. 173-184.

Świtoniak M., 2015. *Issues relating to classification of colluvial soils in young morainic areas (Chełmno and Brodnica Lake District, northern Poland).* Soil Science Annual, vol. 66, no. 2, pp. 57-66.

Świtoniak M., Mroczek P., Bednarek R., 2016. *Luvisols or Cambisols? Micromorphological study of soil truncation in young morainic landscapes – Case study: Brodnica and Chełmno Lake Districts (North Poland).* Catena, vol. 137, pp. 583-595.

Targulian V.O., Goryachkin S.V., 2004. *Soil memory: Types of record, carriers, hierarchy and diversity.* Revista Mexicana Ciencias Geológicas, vol. 21, no. 1, pp. 1-8.

Targulian V.O., Goryachkin S.V., 2011. *Soil memory and environmental reconstructions.* Eurasian Soil Science, vol. 44, no. 4, pp. 464-465.

Thapa B.B., Cassel D.K., Garrity D.P., 1999. *Assessment of tillage erosion rates on steepland Oxisols in the humid tropics using granite rocks.* Soil and Tillage Research, vol. 51, no. 3-4, pp. 233-243.

Tsara M., Gerontidis S., Marathianou M., Kosmas C., 2001. *The long-term effect of tillage on soil displacement of hilly areas used for growing wheat in Greece.* Soil Use and Management, vol. 17, no. 2, pp. 113-120.

Turkelboom F., Poesen J., Ohler I., Ongprasert S., 1999. *Reassessment of tillage erosion rates by manual tillage on steep slopes in northern Thailand.* Soil and Tillage Research, vol. 51, no. 3-4, pp. 245-259.

VandenBygaart A.J., Protz R., Tomlin A.D., Miller J.J., 1999. *Tillage system effects on near-surface soil morphology: observations from the landscape to micro-scale in silt loam of* *southwestern Ontario*. Soil and Tillage Research, vol. 51, no. 1-2, pp. 139-149.

VandenBygaart A.J., 2001. *Erosion and deposition history derived by depth-stratigraphy of Cs-137 and soil organic carbon.* Soil and Tillage Research, vol. 61, no. 3-4, pp. 187-192.

Van Muysen W., Govers G., Bergkamp G., Roxo M., Poesen J., 1999. *Measurement and modelling of the effects of initial soil conditions and slope gradient on soil translocation by tillage.* Soil and Tillage Research, vol. 51, no. 3-4, pp. 303-316.

Van Muysen W., Govers G., Van Oost K., Van Rompaey A., 2000. *The effect of tillage depth, tillage speed, and soil condition on chisel tillage erosivity.* Journal of Soil and Water Conservation, vol. 55, no. 3, pp. 355-364.

Van Muysen W., Govers G., 2002. *Soil displacement and tillage erosion during secondary tillage operations: the case of rotary harrow and seeding equipment.* Soil and Tillage Research, vol. 65, no. 2, pp. 185-191.

Van Muysen W., Van Oost K., Govers G., 2006. *Soil translocation resulting from multiple passes of tillage under normal field operating conditions.* Soil and Tillage Research, vol. 87, no. 2, pp. 218-230.

Van Oost K., Van Muysen W., Govers G., Deckers J., Quine T.A., 2005. *From water to tillage erosion dominated landform evolution.* Geomorphology, vol. 72, no. 1-4, pp. 193-203.

Vieira D.A.N., Dabney S.M., 2011. *Modeling edge effects of tillage erosion.* Soil and Tillage Research, vol. 111, no. 2, pp. 197-207.

Zhang J., Quine T.A., Ni S., Ge F., 2006. *Stocks and dynamics of SOC in relation to soil redistribution by water and tillage erosion.* Global Change Biology, vol. 12, no. 10, pp. 1834-1841.

Zhang J.H., Nie X.J., Su Z.A., 2008. *Soil profile properties in relation to soil redistribution by intense tillage on a steep hillslope.* Soil Science Society of America Journal, vol. 72, no. 6, pp. 1767-1773.



Article first received • April 2016
Article accepted • June 2016