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Impact of land use and soil properties on piping in Belgium

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Abstract: Field observations and literature reveal that land use and soil characteristics play an important role in the development of piping. In this study, the hypothesis is tested that discontinuities in the soil profile favour piping erosion in loess-derived soils in a temperate humid climate. Abiotic characteristics (clay content, bulk density, K_{sat}, penetration resistance) and the biological activity in the soil were measured for each soil horizon until a depth of at least 40 cm below the pipes (ca. 1.30 m) for 12 representative soil profiles with different land use (pasture with and without collapsed pipes, arable land and forest). No clear discontinuities in abiotic characteristics were observed at soil depths where subsurface pipes occurred, but pastures with piping had significantly more earthworm channels and mole burrows at larger depths than pastures without piping, arable land or forest.

Keywords: soil piping, subsurface erosion, biological activity, earthworm

Introduction

Soil piping refers to the formation of linear voids by concentrated flowing water in soils or unconsolidated sediments, which can cause collapse of the soil surface and formation of discontinuous gullies (Jones 2004, Fig. 1).

Subsurface erosion (piping, tunnel erosion) in non-karstic landscapes has for a long time been considered of little importance compared to sheet and gully erosion, but nowadays, piping is considered to be a critically important soil erosion process in a wide range of European environments (Faulkner 2006). Gully development, mass movements and collapse can be significant secondary consequences of pipe enlargement, inducing high soil losses (Bocco 1991, Faulkner 2006).

The main factors responsible for piping are well understood, but there is still uncertainty about the precise critical thresholds of climate, soil and regolith properties that trigger subsurface pipe development (Bryan & Jones 1997). An inventory of collapsed pipes (137 parcels with 560 collapsed pipes) in the Flemish Ardennes (Belgium; study area of 236 km^2) revealed that zones with soil profiles developed on loess covering homogeneous massive clays (Tertiary, Aalbeke Member) were most prone to piping (Verachtert et al. 2010). Furthermore, land use played an important role as 97% of the parcels with piping are found under pasture. As there is still uncertainty about the soil properties contributing to pipe development in collapsible soils in temperate climate, this study aims at better understanding the influence of land use and soil properties on pipe development in the loess-derived soils of the Flemish Ardennes (Belgium).

Study area

The 236 km^2 study area for this research is situated in the Flemish Ardennes (Belgium; Fig. 2). It corresponds to a maritime temperate humid climate with mild winters and an average annual rainfall of about 800 mm, well distributed over the year. It is a hilly region with altitudes ranging from 10 m a.s.l. in the valley of the river Scheldt to 150 m a.s.l. on the hills. Less than 0.5% of the area has a slope gradient


Fig. 1. Collapsed pipes in Kluisbergen (left) and Ronse (right), Belgium

steeper than 20%. Most valleys are asymmetric with the steepest slope sections located on slopes facing south to northwest (Vanmaercke-Gottigny 1995).

The Tertiary lithology consists of an alternation of sands and less permeable clays, covered by Quaternary loess (Jacobs et al. 1999). Weathering of the loess resulted in loamy soils (i.e. Luvisols and Albeluvisols). Many springs and a high drainage density characterize the hydrology of the region. Cropland is located on the loess-covered plateaus of the lower hills, and pastures dominate on gentle and moderately sloping hillslopes. The Tertiary hills and the steepest hillslopes are forested.

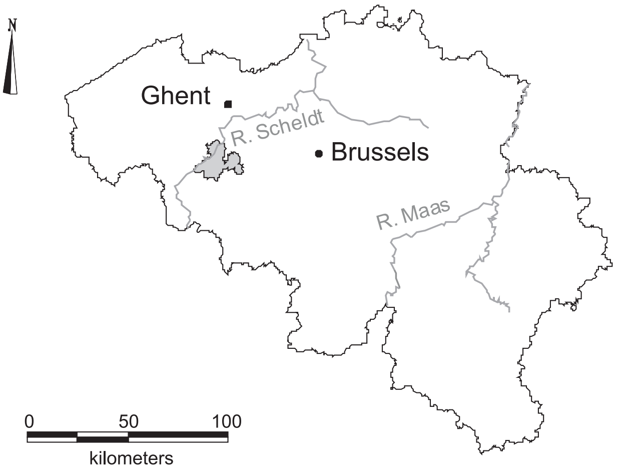

Fig. 2. Location of the study area in Belgium

Material and methods

Twelve representative sites (with a potential for piping erosion concerning topographical and geological situation) were selected in the study area: 4 pastures with collapsed pipes, 4 pastures without collapsed pipes, 2 sites under arable land without collapsed pipes and 2 sites under forest without collapsed pipes (Table 1).

The sites with piping had a considerable higher upslope contributing area compared to the other selected study sites. The slope gradient was measured in the field, while the contributing area was calculated from from LiDAR data (Light Detection And Ranging; DEM of Flanders 2004) using routines from the spatially distributed soil erosion and sediment delivery model, WaTEM/SEDEM.

Table 1. Characteristics of the selected sites

Land use	Slope (%)	Contributing area (ha)	Spring upslope*
Pasture with piping n=4	10 ± 5.6	2.4 ± 0.6	yes**
Pasture without piping n=4	16 ± 6.9	0.33 ± 0.3	no
Arable land n=2	10 ± 0.7	1.2 ± 1.5	1 yes**, 1 no
Forest n=2	12 ± 0	0.28 ± 0.05	1 yes, 1 no

*Field observations; **one site with drainage water from road

Detailed descriptions of the model are provided in Verstraeten et al. (2002). Representative soil profile pits were dug at the selected sites and the following parameters were studied for the different horizons: saturated hydraulic conductivity (with double ring infiltrometer), biological activity (channels from earthworms (*Lumbricus terrestris* L.) and burrows from moles (*Talpa europaea* L.) evaluated on horizontal sections of 1 m^2), soil penetration resistance (horizontal resistance with manual penetrometer, Eijkelkamp© type IB, and vertical resistance with digital penetrologger, Eijkelkamp© type 06.15.SA), texture and moisture content.

Results and discussion

The objective of this study was to test whether soil piping preferentially occurs at soil depths with a clear discontinuity in the soil profile resulting from a abrupt change of one or more soil parameters values like those from texture, saturated hydraulic conductivity, penetration resistance or bulk density. However, at the depth of the pipes, no such discontinuities in the soil profiles were observed.

Soil pipes of the 4 studied profiles were observed, on average, at 114 cm depth (i.e. 70, 124, 130, 132 cm respectively) for the centre of the pipes. At soil depths of 80–120 cm (Fig. 3), the biological activity in terms of earthworm channels per m^2, on the other hand, was

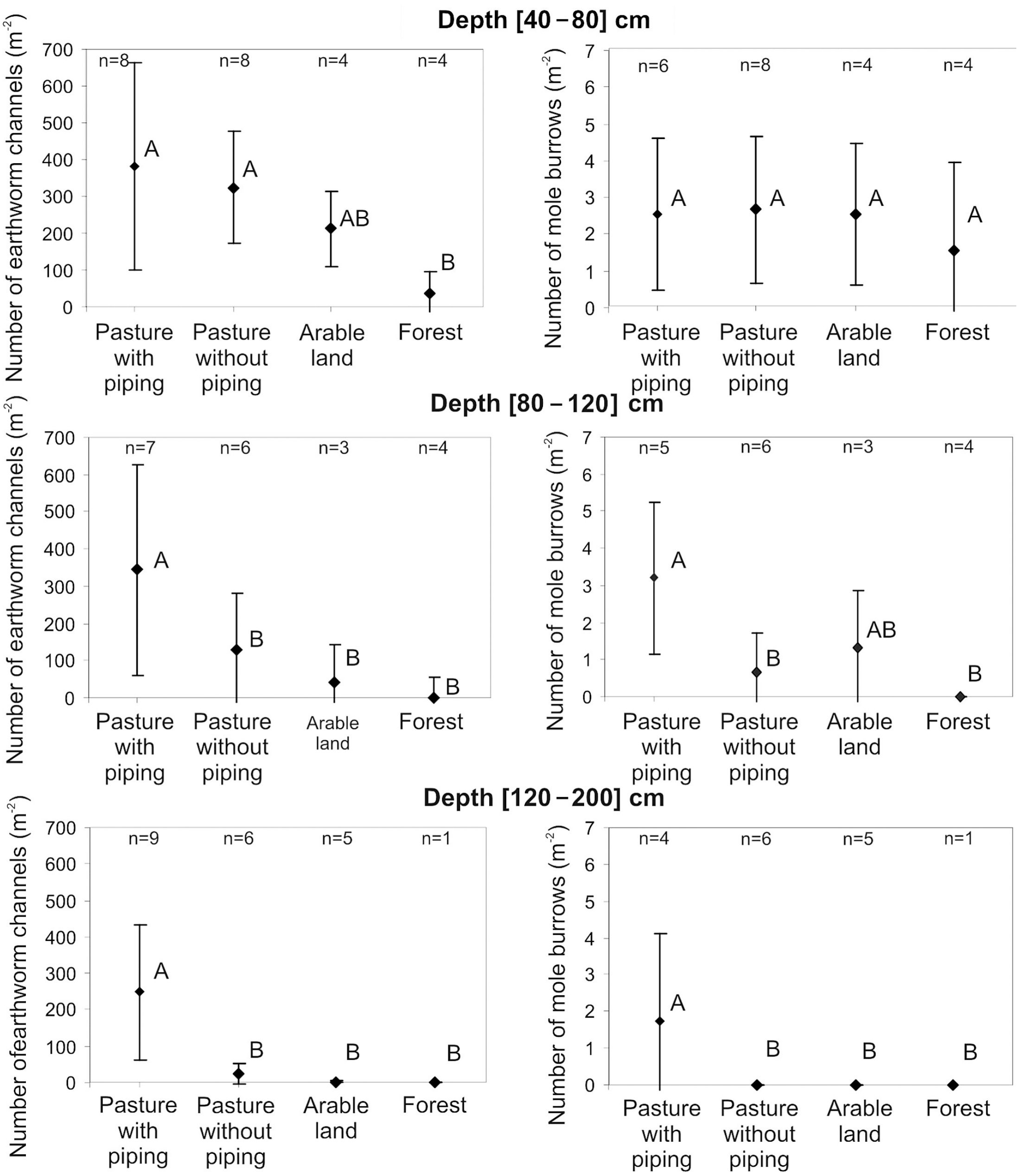

Fig. 3. Relation between land use and biological activity resulting from earthworms (open and closed earthworm channels; left) and moles (open and closed mole burrows; right) at different soil depths. *Error bars indicate ± standard deviation; Means with a different letter differ significantly at P < 0.05; n = number of soil cross-sections studied*

significantly higher for pastures with piping (mean 309 m^{-2}, max 531 m^{-2}) than for pasture, arable land and forest without piping (mean 78, 17 and 0 m^{-2} resp.).

At smaller soil depths (40–80 cm), earthworm activity was only significantly lower for forest (mean 6 m^{-2}) compared to all pastures (mean 335 m^{-2}). At larger depths (120–200 cm), no earthworm channels were observed for arable land and forest, and only a few were observed for pastures without piping (mean 11 m^{-2}) which is in clear contrast with the pastures with piping (mean 264 m^{-2}).

Although the small horizontal surface area (1 m^2) studied, the same trend was observed for mole burrows. The presence of moles is related to the abundance of earthworms, being their major food. Throughout the soil profiles, the saturated hydraulic conductivity was generally low (median of 0.12 mm h^{-1} and 0.23 mm h^{-1} for all pastures with and without piping resp.) but highly variable. The highest values (maximum 275, 174 and 1710 mm h^{-1} for pasture, arable land and forest resp.) observed are explained by macropore flow (e.g. earthworm channels). Earthworm activity favours rapid vertical infiltration through macropore flow and mole burrows may favour lateral flow in the soil profile (during rising water tables) which may lead to piping. Other authors pointed to the role of animal burrows in the formation of pipes as well (e.g. Carroll 1949, Czeppe 1960, Botschek et al. 2002).

End of the summer, the water table was higher (on average more than 1 m) in the pastures with piping than those without piping, arable land or forest. It can therefore be hypothesized that piping is triggered by high temporary water tables together with important biological activity (earthworms, moles) in pastures if other conditions in terms of topography and lithology are met. Although no textural discontinuity was observed at the depth of the pipes, the deeper clay layers below the loess layer may have an indirect influence by creating temporary water tables and springs on hillslopes.

Conclusions

Unlike the expectations, no clear discontinuities in texture, saturated hydraulic conductivity, penetration resistance or bulk density were found at soil depths where soil pipes occurred in collapsible loess-derived soils in Belgium. Pasture, the land use where almost all collapsed pipes were observed, is the land use with the highest density of earthworm channels and mole burrows compared to forest and arable land.

A high biological activity was found at larger soil depths in pastures with piping (average of more than 200 earthworm channels m^{-2} at >120 cm depth) than in pastures without piping (few earthworm channels left at >120 cm depth).

It can therefore be hypothesized that the biological activity, in combination with sufficiently high water tables, plays an important role in the development of soil pipes. Nevertheless, this research should be extended to more than 12 soil profiles to confirm the role of the water table depth and the biological activity.

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