Biological control of pedological and hydro-geomorphological processes in a deciduous forest ecosystem

Cammeraat, E.L.H.; Kooijman, A.M.

Published in:
Biologia

DOI:
10.2478/s11756-009-0075-x

Citation for published version (APA):
Cammeraat, E. L. H., & Kooijman, A. M. (2009). Biological control of pedological and hydro-geomorphological processes in a deciduous forest ecosystem. *Biologia*, *64*(3), 428-432. https://doi.org/10.2478/s11756-009-0075-x

Biologia **64**/3: 428—432, 2009
Section Botany
DOI: 10.2478/s11756-009-0075-x

Biological control of pedological and hydro-geomorphological processes in a deciduous forest ecosystem

Erik L.H. Cammeraat & Annemieke M. Kooijman

Institite for Biodiversity and Ecosystem Dynamics, University of Amsterdam, Nieuwe Achtergracht 166, 1018 WV Amsterdam, The Netherlands, e-mail: l.h.cammeraat@uva.nl

Abstract: This study describes the effect of soil fauna and vegetation on the development of landscapes and how these actually control soil formation, geomorphological development and hydrological response. The study area is located in a semi-natural deciduous forest on marl in Luxembourg, with a strong texture contrast in the soil at 15–25 cm depth (luvic planosols).

The methodology applied is both based on hydrological and geomorphological field measurements on runoff, sediment yield, perched water table dynamics, geomorphological survey, pedological survey and measurements related to in situ ectorganic horizon dynamics and litter decay, soil animal activity, as well as measurements of dynamic soil properties such as soil moisture and swelling and shrinkage.

The results show that there is a positive feedback between tree type, soil fauna activity and the development of pipes, partial areas, soils and geomorphology. The landscape can be divided into two main types: Areas where Stellario-Carpinetum vegetation and partial areas are common and areas with Milio-Fagetum vegetation on dry slopes, which are differentiating more and more over time as a result of ongoing geo-ecosystem processes, and which also reflected in their sediment yield. The hydrological response is highly different for both landscape compartments as they are dominated by matrix (Beech) and pipe flow (Hornbeam) respectively. Soil fauna and tree type drive both soil and geomorphological evolution and they both can be considered as important ecosystem engineers.

Key words: ecosystem engineers; faunal activity; forest hydrology; matrix through flow; partial areas; pipe flow; soil shrinkage

Introduction

It is well known that there is a strong interaction between biological, geomorphological, soil and hydrological processes on hillslopes (e.g. Nayler et al. 2002; Stallings 2006), however the biological control over these processes is still underrated. This study describes the effect of soil fauna and vegetation on the development of landscapes and their positive feedback relationships and how these actually control hydrological response, soil formation and geomorphological development. Main research questions addressed are: How do different tree species types affect the hydrological processes in a temperate deciduous forest system and can trees be considered as ecosystem engineers.

Material and methods

The field site

The area of study is located within the Schrondweilerbaach catchment, with gentle slopes up to 8° and rolling a landscape in the Gutland region of Luxembourg (S of Diekirch) and which is being studied in detail since the 1970's as summarized in (Cammeraat 2006).

The field site is situated in a micro-catchment of about 4 hectares (location: 49°49′04 N, 6°11′00 E) underlain by Mesozoic dolomitic marls and it is drained by a first order tributary of the Schrondweilerbaach. The area is covered with Oak (*Quercus robur*)–Hornbeam (*Carpinus betulus*)–Beech (*Fagus sylvatica*) forest, with locally shrubby undergrowth of mainly Hawthorn (*Crataegus leavigata*) and Ash (*Fraxinus excelsior*). Hornbeam is found at more damp locations [Stellario-Carpinetum (R.Tüxen 1937 pp.) Oberdorfer 1957], whereas the dryer parts are dominated by Beech (Milio-Fagetum Hesmer et Schroeder 1962 non Frehner, 1963; or Melico-Fagetum Lohmeyer et Seibert 1954). We consider the forest to be semi-natural as it is forested, with minimal human interference, at least since the late 18th century, which can be seen on the maps of Ferraris (1777). Rainfall is about 780 mm yr^{-1}, and annual mean temperature is 9.1 °C (Duijsings 1985). The soil profile is developed on weathered marl. The soil is characterized by an abrupt textural change at 12–18 cm depth, at the interface of the silty AEh/EAh horizons (containing approx. 20% clay) with the clayey and dense Bg horizon (approx. 50% clay) and is classified as an Aquic Distric Eutrochrept following the USDA classification (Broek 1989) or a Luvic or Vertic Planosol (FAO 2006). The top soils are generally very porous due to high biological activity (Hendriks 1993). The soil has a very characteristic hydrological behaviour. Due to the high macro-porosity of the topsoil and the very dense Bg horizon, lateral through flow over this horizon is common, resulting in the presence of a seasonal perched water table, local presence of saturation excess overland flow and a fast reaction of the perched water table and runoff to rainfall events (Bonell et al. 1984). Preferential flow paths of water through macropores (Germann & Beven 1981) and their spatial distribution play an important role in the hydrological response of the area.

Methods

The distribution and variation of litter cover was studied both in time and space. Five sites of 3.92 m^2 were selected under different types of vegetation. The litter cover, mineral surface, crack surface, and vegetation cover were mapped on a 1:10 scale on a monthly interval. Before the annual litter fall in autumn, the soil surface litter cover was mapped over the whole catchment at 1:500.

The origin and development of shrinkage cracks and macro-pores was studied at a monthly interval at 5 sites during two years (non-destructive). Size and origin of the macro-pores were determined. Also cross-sections of cracks were made by cutting small slices of soil along cracks and drawing of cross sections of cracks with a marker on overhead sheet.

Soil moisture was measured in a destructive way using metal 100 cm^3 cylinders, allowing the determination of soil moisture contents and the bulk density of the soil.

Shrinkage properties of the soil were established following Brasher et al. (1966) and was determined at both natural clods and tablets made from crushed soil samples.

Organic carbon was determined using wet oxidation following Allison (1935).

Hill slope processes were studied at a 100 × 100 m sized hill slope section. Capacitive water table sensors that were connected to a datalogger were installed on wet (8), intermediate (3) and dry places (3) of the test slope and rainfall was measured using a tipping bucket.

Water samples were taken during runoff events both manually and with an automatic sampler and were analyzed for sediment and corrected for the total amount of dissolved solids.

Results

Biological activity and soil cover were studied at 5 plots under different geomorphological and vegetation conditions. Under Beech almost no litter was removed or decomposed, keeping the forest floor completely covered, and a thin complete ectorganic soil profile [Mormoder; (Green et al. 1993)] was commonly observed. Under other types of vegetation (Oak, Hornbeam and Hawthorn) only a litter layer was present and other ectorganic horizons were not encountered [Vermimull; (Green et al. 1993)] with a litter forest floor cover ranging from 42% to only 4% in August.

The seasonal variation in in-situ litter cover under Hornbeam is shown in Fig. 1. In late summer the litter cover was strongly reduced. The arrows in the figure indicate an increase of litter cover, caused by the transportation of litter by overland flow during high rainfall events. The percentage litter cover changed from complete cover in November/December for the entire catchment to a very heterogeneous pattern in late summer. The spatial patterns observed were related to shallow elongated depressions, damp areas and forest roads and tree cover type and for two years this pattern appeared to be the same.

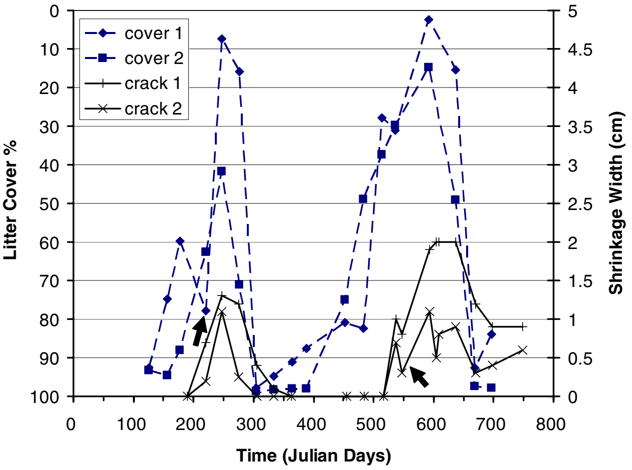

Fig. 1. Two yearly variations in surface litter cover and shrinkage crack width.

Soil physical properties: At the same plots soil shrinkage cracks were monitored. In general shrinkage cracks are common in damp places from late summer until late autumn. In Fig. 1 the seasonal change in crack width in the field is also indicated. This change in width is a reflection of the seasonal dynamics of the water balance and physical aspects of the topsoil. In Fig. 2 a detailed spatial configuration of a shrinkage crack is shown, as present in relative wet, del-like areas. Several observations could be made: Along the crack at the surface of the forest soil the litter is removed into the cracks by earthworms (*Lumbricus terrestris*). The cracks are discontinuous in nature and connectivity for water flow is not always present. The cracks tend to widen towards the boundary of AEh and EAh horizons, and at the EAh-Bg horizon boundaries hollows are present in the EAh horizon. The cracks hardly penetrate into the Bg horizon, although the Bg horizon material had a higher shrinkage capacity than the two upper horizons. In general the shrinkage cracks showed a hexagonal surface pattern.

The shrinkage capacity of the different soil horizons showed that the Bg horizon had the strongest shrinkage properties, followed by the C horizon. The AEh horizon appeared to have soil shrinkage properties dependent on organic matter content. The higher the organic matter contents of the AEh and EAh samples, the stronger the shrinkage properties were found to be, reaching similar values as those of the Bg-horizon. After removal of organic matter from the soil by treatment with peroxide, the pastes of AEh material showed a considerably reduced shrinkage capacity, when compared to the non-treated pastes. Material from the deeper horizons did not show such behaviour.

The gravimetric soil water loss (θg) under normal shrinkage (θg at swelling limit – θg at shrinkage limit) in relation to organic carbon content is given in Fig. 3. With low organic carbon (e.g. Bg and C horizon), the amount of water stored is much larger than for the soils

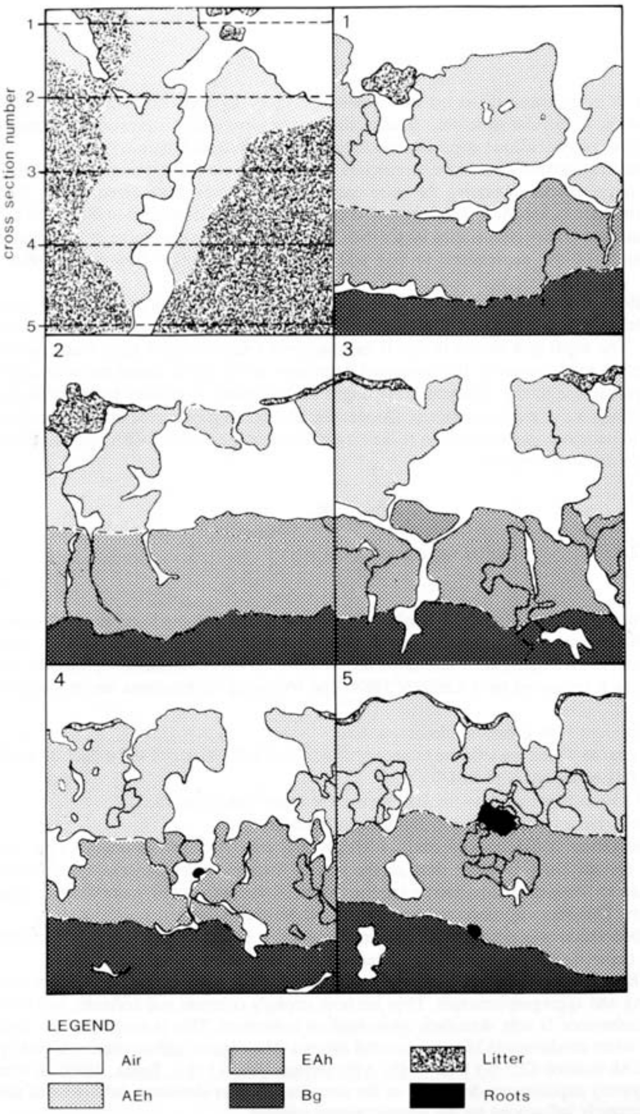

Fig. 2. Cross sections trough topsoil with a natural crack system as observed in October. The top-left figure gives a planar view of the crack with location of cross sections 1–5. The base of each image 1–5, as well as the cross section has a length of 20 cm.

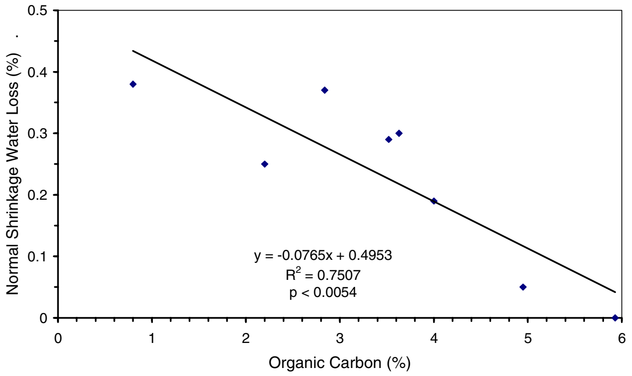

Fig. 3. Gravimetric water loss under normal shrinkage (between swelling and shrinking limit) in relation to organic carbon content.

with high organic matter levels, as expressed in the significant negative correlation. The shrinkage limits for natural clods showed a similar pattern. The shrinkage limit of natural soil clods for the AH, Bg and C was reached at θg levels of respectively 0.25 ± 0.06, 0.12 ± 0.04 and 0.08 ± 0.01 g g^{-1}, of which the differences between the first and the latter two was statistically significant ($p < 0.001$).

Hydrological findings: In Fig. 4 the dynamics of water flow through and over the soil are illustrated. It shows the fast response of the perched water table to rainfall events in a very wet period in May/June. Apart from rainfall, two curves are shown, one reflecting the perched water table in a wet area, reflecting a partial area (pipe-/overland flow dominated) with Hornbeam dominated vegetation, and one showing the perched water table in a nearby relative dry area under Beech cover. The wet area showed many shrinkage cracks in autumn, with semi-permanent pipe systems, whereas the dry area was devoid of shrinkage cracks. At this part of the slope, no large shrinkage cracks occur, and drainage has probably mainly taken place by matrix through flow. At many places pipe flow discharge

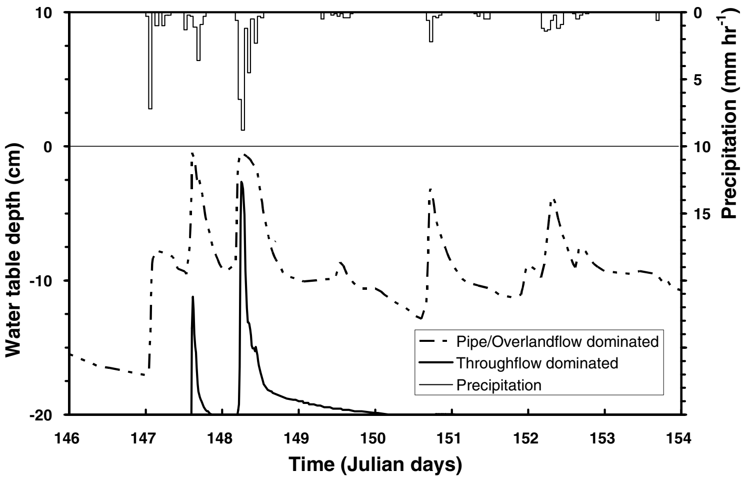

Fig. 4. Perched water table fluctuation as a response on rainfall.

was observed at the channel incision. These pipe outflow points are connected to larger pipe-systems that are situated in elongated shallow depressions draining the wetter areas.

At the upper hillslope water is concentrated in pipe and crack systems present in an area with increasing perched water table thicknesses. Saturation excess overland flow is occurring at the mid slope, in the area with the highest perched water tables. Further down slope, at lower water tables, the water infiltrates diffusely and concentrates in pipe-systems, leading towards the drainage ditch down-slope. The water table drops towards the drainage ditch. The test slope, discharged approx. 28% of the yearly output of the 4 ha sized subcatchment and the partial area (20% of the slope area) delivers at least 50% of the test slope discharge (Cammeraat 1992).

Discussion

The litter cover dynamics show that the turnover of litter under a Hornbeam dominated canopy is very fast, whereas the turnover under a Beech canopy was much lower, as reflected in the presence of well developed ectorganic horizon. The increased turnover of Hawthorn and Hornbeam litter was also found by Hooff (1983) and Hazelhoff et al. (1984) and attributed to the activity of earthworms (*Lumbricus terrestris*). Jungerius et al. (1989) reported that in this type of soil the A horizon was totally bioturbated within 10 years, indicating the importance of soil animals. Low accumulation of degradable Beech organic matter is also reported in Swift et al. (1979) and Aubert et al. (2003).

Soil shrinkage width indicated a clear seasonality, as also reported by Imeson (1986), and was synchronous in time with litter cover dynamics (Fig. 1). Shrinkage was limited to the AEh and EAh horizon. Shrinkage crack dynamics were related to reduced water levels in summer and early autumn, resulting from evapotranspiration under summer conditions, depleting the topsoil of water and inducing soil shrinkage, whereas wet conditions in winter with strongly reduced evapotranspiration shows the importance of soil swelling. It was observed that Moles (*Talpa e.*) used the shrinkage cracks for their movement creating wider and continuous crack and pipe systems. Once by-pass flow had occurred in these connected cracks, they could survive winter wetting as semi-permanent subsurface pipes, being closed at the forest floor surface. An important observation was that in summer and autumn shrinkage cracks mainly appeared in the wetter areas, where also Hornbeam predominated. The development of shrinkage cracks was also related to the swelling characteristics of the parent material and the presence of organic material. Bronswijk & Evers-Vermeer (1990) and more recently Puppala et al. (2007) found comparable results with respect to the effect of organic matter on the shrinkage behaviour of clayey soils. Experimental removal of organic matter from the AEh material showed a strong decline in the swelling and shrinkage behaviour of that soil. It is speculated that *Lumbricus t.* plays an important role in organic matter turnover and that their excrements contain organic matter-clay mineral complexes increasing swelling and shrinkage properties of the AEh/EAh horizon in the wetter parts of the hill slopes. This is especially reflected in soils with higher organic carbon contents.

Soil water movement is highly dynamic and strongly influenced by the strong contrast in hydraulic conductivity between the AEh/EAh and B horizons, resulting from the abrupt textural change. This forces the soil water to flow over the top of the B horizon through the AEh and EAh horizons. However there is a clear heterogeneity in soil water flow. The dryer Beech covered hill slopes don't have pipes or shrinkage cracks, and the importance of lateral matrix through flow is most probable, although tracing techniques would be necessary for confirmation. Soil pH is lower under Beech (Kooijman & Cammeraat, subm.), and combined with the dominating matrix through flow, lateral eluviation of clay from the top of the B horizon (Broek 1989) must be dominant here, explaining thicker AEh/EAH horizons. Matrix through flow derived sediment yield was estimated to be 13–26 g m^{-2} yr^{-1} (Broek 1989), an order of magnitude lower than the sediment yield of pipes. In the damp areas, with dominating Hornbeam, water is more stagnating as reflected in Figure 4, and the accumulation of water into this area also keeps the water table high. Clearly seasonal variation in macro-porosity may affect the response of this wet system. Furthermore, as the mineral soil surface is not protected for a large part of the year, splash erosion is more prominent as well as erosion of pipe and macro-pore walls. Most water is conveyed through these pipes, and erosion is increased (200 and 145 g m^{-2} yr^{-1}) as reported by Hendriks & Imeson (1984) and Cammeraat (1992) respectively. This reinforces soil surface lowering and reduced thicknesses of the AEh/EAh horizons in the wetter Hornbeam covered places.

We can conclude that interaction of Beech and Hornbeam and their litter production with soil animal activity plays an important role in the development of the heterogeneity in hydrological processes. Moreover, there seems to be a strong feedback between the biological and hydrological processes. This results in the development of two landscape zones with a different geomorphology (dry zones vs wet partial areas) and different pedogenetic processes, resulting in differences in horizon thickness and development. Beech and Hornbeam could be considered as eco-system engineers, driving a feed-back loop involving dry slopes under Beech, with limited macro-porosity and increased matrix through flow and enhanced lateral eluviation of clay, whereas under Hornbeam higher soil macro fauna activity is present, leading to increased macro-porosity and shrinkage and swelling properties in the soil, that enforce pipe and macro-pore flow and increased erosion due to flow concentration and landscape lowering.

References

Allison L.H. 1935. Organic soil carbon reduction of chromic acid. Soil Sc. **40:** 311–320.

Aubert M., Hedde M., Decaens T., Bureau F., Margerie P. & Alard D. 2003. Effects of tree canopy on earthworms and other macro-invertebrates in beech forests of Upper Normandy (France). Pedobiologia **47:** 904–912.

Bonell M., Hendriks M.R., Imeson A.C. & Hazelhoff L. 1984. The generation of storm runoff in a forested clayey drainage basin in Luxembourg. J. Hydrol. **71:** 53–77.

Brasher B.R., Franzmeier D.P., Valassis V. & Davidson,S.E. 1966. Use of SARAN resin to coat natural clods for bulk density and water retention measurements. Soil Sc. **101:** 108.

Broek T.M.W.v.d. 1989. Clay dispersion and pedogensis of soils with an abrubt contrast in texture. PhD Thesis, University of Amsterdam, Amsterdam, 109 pp.

Bronswijk J.J.W. & Evers-Vermeer J.J. 1990. Shrinkage of Dutch clay soil aggregates. Neth. J. Agric. Sc. **38:** 175–194.

Cammeraat L.H. 1992. Hydro-geomorphological processes in a small forested catchment: Preferred flow paths of water. PhD-thesis, Amsterdam, 146 pp.

Cammeraat L.H. 2006. Luxembourg, pp. 427–438. In: Boardman J. & Poesen J. (eds), Soil Erosion in Europe, John Wiley & Sons, Chichester,.

Duijsings J.J.H.M. 1985. Streambank contribution to the sediment budget of a forest stream. PhD Thesis, University of Amsterdam, Amsterdam, 190 pp.

FAO 2006. World Reference Base for Soil Resources. World Soil Resources Reports, 103. Food and Agriculture Organization of the United Nations, Rome.

Ferraris C.d. 1777. Carte de cabinet Pais Bas Autrichiens. (Reprint 1965–1970) Bibliotheque Royal de Belgique, Bruxelles.

Germann P. & Beven K. 1981. Water flow in soil macropores I. An experimental approach. J. Soil Sci. **32:** 1–13.

Green R.N., Trowbridge R.L. & Klinka K. 1993. Towards a taxonomic classification of humus forms. Forest Science Monograph 29. Society of American Foresters, Bethesda, MD, 50 pp.

Hazelhoff H., Hooff P. v., Imeson A.C., & Kwaad, F. J. P. M. 1981. The exposure of forest soil to erosion by earthworms. Earth Surf. Proc. & Landforms **6:** 235–250.

Hendriks M.R. 1993. Effects of lithology and land use on storm run-off in East Luxembourg. Hydrol. Proces. **7:** 213–226.

Hendriks M.R. & Imeson A.C.1984. Non-channel strom period sediment supply from a topographical depression under forest in the Keuper region of Luxembourg. Z.Geomorph.N.F. Suppl.-Bd. **49:** 51–58.

Hooff P. v. 1983. Earthworm activity as a cause of splash erosion in Luxembourg forest. Geoderma **31:** 195–204.

Imeson A.C. 1986. Investigating volumetric changes in clayey soils related to subsurface water movement and piping. Z.Geom.N.F.Suppl.-Bd. **60:** 115–130.

Jungerius P.D., Ancker H.v.d. & Zon H.J.M.v. 1989. Long term measurement of forest soil exposure and creep in Luxembourg. Catena **16:** 437–447.

Kooijman A.M. & Cammeraat L.H. Hornbeam and Beech as ecosystem engineers: short and long-term effects on habitat conditions in oldgrowth mixed forests on decalcified marl. Submitted to Oecologia

Naylor L.A., Viles H.A. & Carter N.E.A. 2002. Biogeomorphology revisited: looking towards the future. Geomorphology **47:** 3–14.

Puppala A.J., Pokala S.P., Intharasombat N. & Williammee R. 2007. Effects of Organic Matter on Physical, Strength, and Volume Change Properties of Compost Amended Expansive Clay. J. Geotechnical & Geoenvironmental Eng. **113:** 1449–1461.

Stallins J. A. 2006. Geomorphology and ecology: Unifying themes for complex systems in biogeomorphology. Geomorphology **77:** 207–216.

Swift M.J., Heal O.W. & Anderson J.M. 1979. Decomposition in terrestrial ecosystems. University of California Press, Berkeley.

Received January 23, 2009
Accepted February 16, 2009