Soil porosity along a gradient from forest edge to field

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Bodenporosität an Wald-Feld-Grenzen

Zusammenfassung

Der Beitrag analysiert zwei hydrologisch relevante Bodenmerkmale – Gesamtporosität und die Versickerungsrate zwischen dem Waldrand und dem angrenzenden Acker (100 m von der Grenze). Die Studie wurde in der zentralböhmischen Region in der Tschechischen Republik auf fünf Untersuchungstransekten zwischen März 1999 und September 2000 durchgeführt. Das Experiment war darauf angelegt, folgende Hauptfragen zu beantworten: (1) Existiert ein Einfluß der Entfernung vom Waldrand auf dynamische Veränderungen beim Wasserrückhalt? Und (2): Gibt es einen Gradienten der Gesamtporosität in den Bodendichten an der Oberfläche 0–10 cm, in 10–20 cm und 20–30 cm Krumentiefe? Wir fanden eine Abnahme der Gesamtporosität in der Zone vom Waldrand bis 10 m innerhalb des Ackers. Die Tendenz einer Zunahme bei beiden Merkmalen war in Zonen von 10 m bis 25 m oder 50 m zu beobachten. Zwischen 25 oder 50 und 100 m sanken die Werte beider Merkmale wiederum. Es gab keine signifikanten Differenzen beim Gradienten der zwei Bodenmerkmale in den oben erwähnten Krumenschichten. Wir schließen, daß die Bodenporosität zunimmt dank der steigenden Dichte der Bodenlebewelt. Die höhere Aktivität von strukturbildenden Bodentieren (z.B. Regenwürmer) zeigt einen „Randeffekt“ an. Die geringe Porosität und Versickerungsrate im Acker nahe beim Waldrand (0–10 m) sind wahrscheinlich hauptsächlich durch das häufigere Befahren mit Landmaschinen (Bodenverdichtungen) und ebenso durch höhere Bodenfeuchte (Versickerungsrate) verursacht.

Schlagworte: Randeffekt, Ökotone, Wasserrückhalt, Porosität, Versickerung, Landschaftsstruktur.

Summary

This paper analyses two hydrologically relevant soil characteristics – total porosity and the infiltration rate between the forest edge and the abutting crop field (100 m from the edges). The study was conducted in the Central Bohemian region of the Czech Republic in five study transects between March 1999 and September 2000. The experiment was carried out to answer the following main questions: (1) Is there an influence of the distance from the forest edge on dynamic changes in water retention? and (2) Is there a gradient of total porosity in the surface topsoil layers 0–10 cm, 10–20 cm and 20–30 cm of depth? We found a decrease in total porosity in the zone from the forest edge to 10 m inside the crop field. The tendency toward an increase in both characteristics has been observed in zones from 10 m to 25 or 50 m. Between 25 or 50 and 100 m, the values of both characteristics decrease again. There were no significant differences in the lateral gradient of the two soil characteristics in the three topsoil layers mentioned above. We conclude that soil porosity is increased due to increased density of edaphon. The higher activity of structure-forming soil animals (e.g., earthworms) indicates an “edge effect”. The low porosity and infiltration rate in the crop field near the forest edge (0–10 m) are probably caused mainly by higher frequency of agricultural machinery traffic (compacted soil) and also by higher soil moisture (infiltration rate).

Key words: edge effect, ecotone, retention, porosity, infiltration, landscape pattern.

1. Introduction

1.1 Edges

Boundaries where two distinct vegetation types abut are known as edges (JOHNSTON, 1947; GILES, 1978; THOMAS et al., 1979). These overlap zones are also called ecotones (FORMAN and GODRON, 1993). Edges are strips of activity where interactions and flows are concentrated (FORMAN, 1995). Where vegetation types are distinct, the edge appears as a line (e.g., between forest and crop field). However, abutting populations usually influence and grade into one another, resulting in an edge that is not a line but a transition zone overlapping each ecosystem (YAHNER, 1988). Recognizing the importance of edges for wildlife, LEOPOLD (1933) presented the concept of an "edge effect". ODUM (1971) defines the edge effect as the tendency for increased variety and density at community junctions. Organisms which occur primarily or most abundantly or spend the greatest amount of time in junctions between communities are often called "edge species" (MILNE and FORMAN, 1986; LUCZAJ, 1994; SARLÖV- HERLIN, 1999). Wooded edge zones in agricultural landscapes, such as forest edges and hedgerows, have been the focus of many empirical and conceptual landscape studies exploring their functions as corridors, as sources and habitats for a wide range of plants and animal species, as windbreaks, in preventing erosion, and in their contribution to social and aesthetic values (DE MERS et al., 1995; SARLÖV-HERLIN and FRY, 1999). Temporal changes of edge portions provide a better idea of the development of a landscape pattern than statistical land-use data alone (SKLENICKA, 2002).

1.2 Soil structure-forming activities of soil animals

Unlike soil texture and specific surface, which are more or less constant for a given soil, soil structure is highly dynamic and may change greatly from time to time in response to a change in natural conditions, biological activity, and soil management practices (HILLEL, 1973).

Soil structure is defined as the size and arrangement of particles and pores in soil (OADES, 1984), the following aspects of faunal influence on soil structure can be distinguished (DIDDEN, 1990):

1. Influence on pore structure through:
   - enlargement, by applying pressure or transporting soil material;
   - reduction, by filling pores with materials from elsewhere, or as an effect of external pressure;
   - formation of new pores by burrowing.
2. Influence on soil aggregates through:
   - mechanical reduction in size;
   - joining particles or aggregates as part of the formation of fecal pellets;
   - changing the stability of aggregates, for instance by physiological processes in digestion or secretion of mucilages.

Numerous authors have noted that changes in the structure of topsoil by soil fauna activity increase the hydraulic conductivity of the unsaturated soil matrix (e.g., SPRINGETT, 1970; PAWLUK, 1987; TOMPSON et al., 1990; LIGTHART, 1996). Soil animals create burrows, supply organic matter to soil, transport mineral particles (O'CONNOR, 1967; BABEL, 1968) and generally alter the structure of the soil matrix. This influences water infiltration, drainage, water retention and aeration of the soil. The interaction between soil organisms and soil structure was investigated as a part of the Dutch Programme on Soil Ecology of Arable Farming Systems (BRUSSAARD et al., 1988).

For earthworms in particular, many studies have been devoted to the influence of soil fauna on soil structure. A correlation between earthworm activity and soil properties is commonly found, but cause and effect are hard to separate. LIGTHART (1996) chose an approach that studied the chronosequences of earthworm burrow systems and associated earthworm-affected soil properties. The density and architecture of the burrow systems changed quickly and responded strongly to changes in the biomass of the earthworm communities (HAUKKA, 1991; LIGTHART et al., 1993).

2. Site description and methods

2.1 Experimental design

The study was conducted between March 1999 and September 2000. The study sites are located around Kostelec nad Černymi lesy, in the Central Bohemian region of the Czech Republic. The soil in the study sites is Cambisol, classified as clay-loam. The average rainfall ranges from 550 to 700 mm per year. Five experimental transects were established in three sites (Figure 1). All sites were maintained under an annual crop – maize; *Zea mays* L. (1999) and wheat; *Triticum aestivum* L. (2000). The management practices that were applied included cultivation by ploughing in October each year. Data were collected each year immediately after harvesting.

The selection of the study sites was determined by the following criteria:

- the edge between forest and crop field is sharply defined as a line;
- the minimum width of the sites is 200 m;
- the maximum slope of the sites is 3%;
- the soil cover (soil type) of each site is homogeneous.

The study sites are parts of a landscape mosaic of arable land (matrix), woodlands, meadows and pastures. The height of

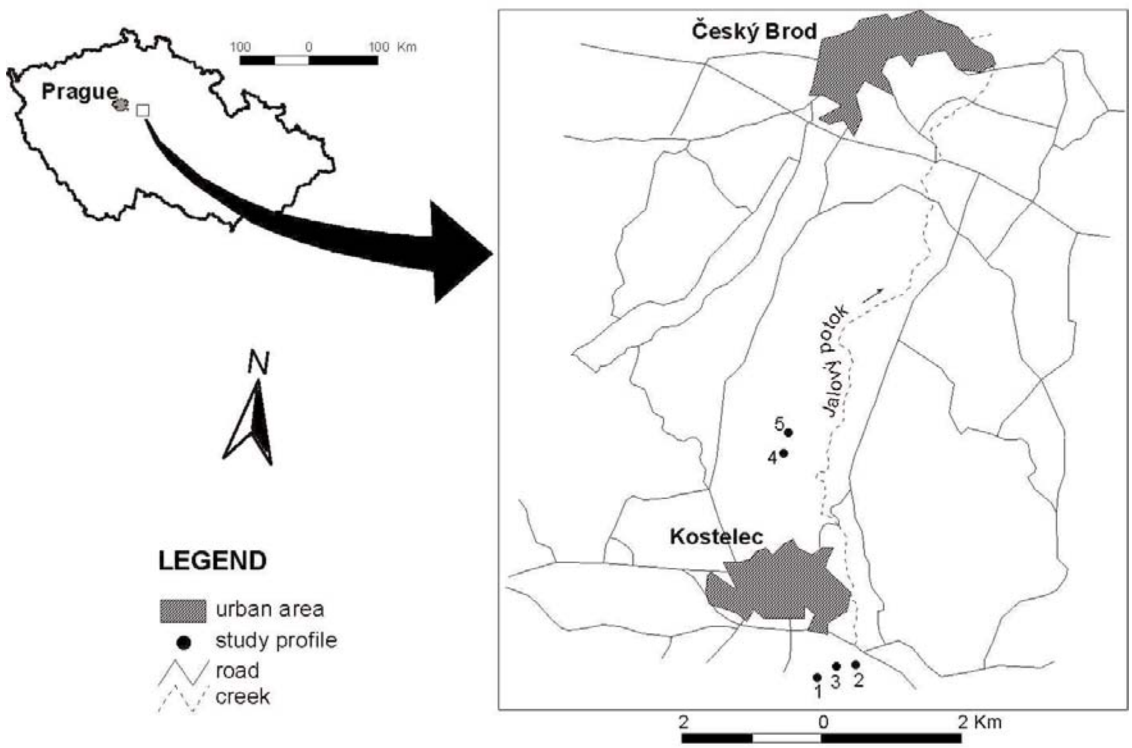

Figure 1: Localisation of the study sites
Abbildung 1: Lage der Untersuchungsstandorte

the forest edges investigated is between 20 and 25 m. The forest edges without shrub strip are composed of common forest species – oak (*Quercus robur* L.), pine (*Pinus sylvestris* L.), ash (*Fraxinus excelsior* L.), beech (*Fagus sylvatica* L.) and birch (*Betula pendula* Roth.). The edge orientation is N (site 1, transect 1), NNW (site 2, transects 2, and 3) and W (site 3, transects 4, and 5). A scheme of the transects is shown in Figure 2.

2.2 Methods

The three study sites were divided into five transects and tested separately. Our methods consisted of standard field procedures used in soil research. Data for porosity, infiltration rate, and soil moisture were collected in 5 transects 100 m in length, perpendicular to the forest edge. Total porosity P (%) was inferred from an analysis of undisturbed soil

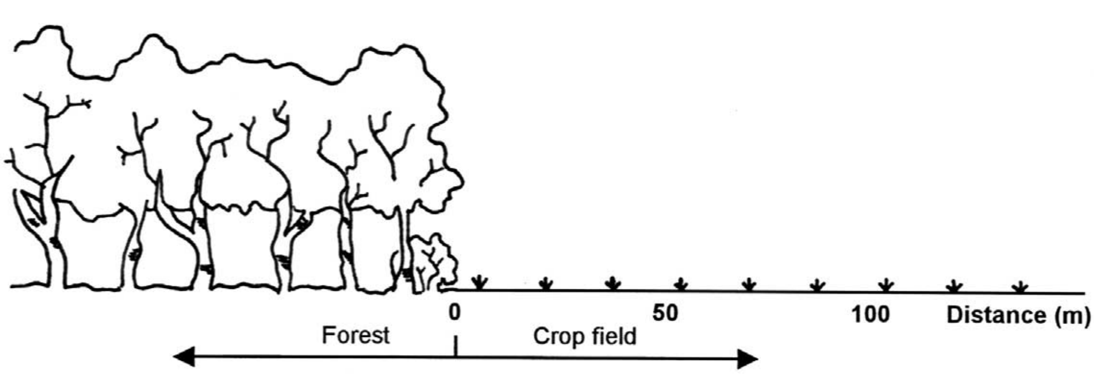

Figure 2: Scheme of the transects
Abbildung 2: Schematische Darstellung der Transekte

samples (100 cm^3), which were sampled separately from the 3 layers of topsoil (0-10 cm, 10-20 cm, and 20-30 cm). Changes in total porosity were monitored as a function of distance from the forest edge – L (m), and depth – D (cm). This soil characteristic was analysed in four of the five study transects (transects 1, 3, 4 and 5). Each transect is represented by 36 undisturbed soil samples.

Infiltration rate – v_i ($mm.min^{-1}$) was measured by the field pipe method. At each measuring point of the transect, 10 pipes (length = 13 cm, calibre 6 cm) were located. After uncovering a 5-cm layer of topsoil the pipes were hammered 3 cm into the soil. The distances apart must be at least 15 cm. We measured the time (min) needed for infiltration of 100 ml of water in each of the pipes separately. A detailed description of this method is given in VADJUNINA and KORCAGINA (1961).

Soil moisture (by volume) – Q (%) of the surface layer of topsoil (0–5 cm) was measured simultaneously using a Thetameter HH1 soil moisture meter (Eijkelkamp). Changes in infiltration rate were monitored as a function of distance from the forest edge – L (m). The infiltration rate was measured at four of the five study transects (transects 1,2, 3, and 5) at 30 points of each study transect.

Only the soil characteristics of crop fields were observed. The data were compared with "background values", which are the reference values of the soil characteristics under study for a distance of 100 m from the forest edge in each transect. The data were analysed statistically by the non-parametric technique (Kruskal-Wallis one-way analysis of variance). This analysis of variance was used to test whether the two soil characteristics varied with distance from the forest edge.

3. Results

3.1 Total porosity

Figure 3 presents the changes in total porosity in study transects 1, 3, 4 and 5. The results show a significant decrease in total porosity values in the zone from the forest edge to 5 m in three of the four study transects. In the zone from 10 to 25 or 50 m we found a tendency toward increasing total porosity values (transects 1, 3 and 4), while in the distance interval from 25 or 50 to 100 m there was a tendency to decrease (transects 1, 3 and 4). The total porosity varied significantly. The course of the values of transect 5 is not consistent with the three other transects.

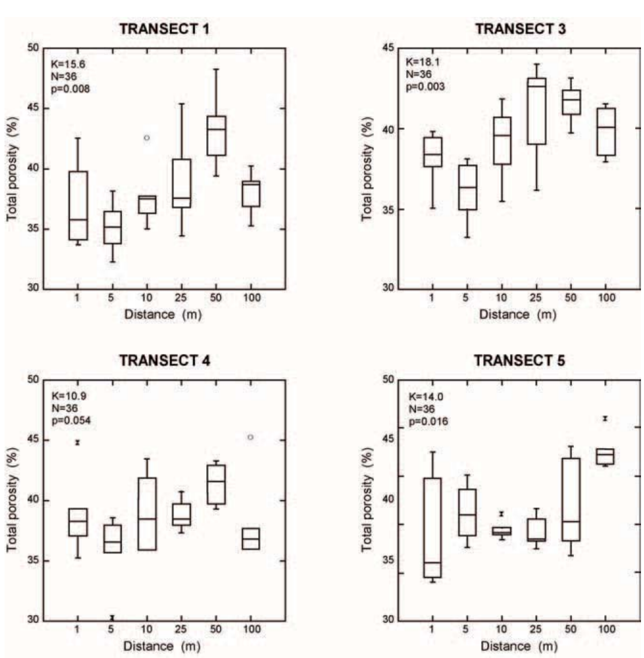

Figure 3: Changes in total porosity in four study transects. The boxplots give median ± 25% quartiles and ranges. The outliers are indicated by circles

Abbildung 3: Änderungen der Gesamtporosität bei vier Untersuchungstransekten. Die Boxplots geben den Median ± 25 % Quartile und Varianzen wieder. Ausreißer sind durch Kreise kenntlich gemacht.

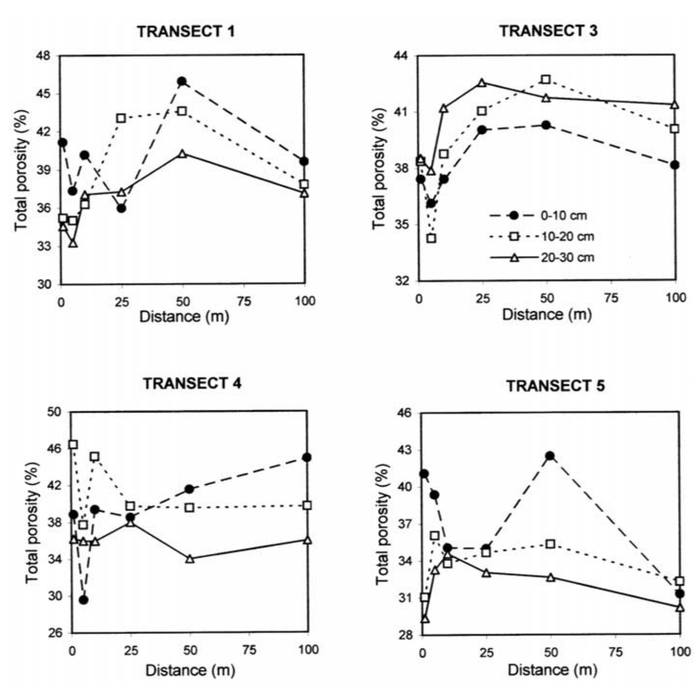

Figure 4: Changes in total porosity analysed separately in each of three topsoil layers

Abbildung 4: Veränderungen der Gesamtporosität, separat analysiert in jeder der drei Krumenschichten

Figure 4 shows the changes of total porosity separately in each of three topsoil layers. There were no remarkable differences in the courses of total porosity among the layers 0-10 cm, 10-20 cm, and 20-30 cm.

Table 1: Results of median values analysis of total porosity relative to the background values (for L = 100m) for the whole depth of topsoil (0–30 cm). Values are computed for strip 1m wide and 100 m long, perpendicular to the edge.

Tabelle 1: Ergebnisse der Mediananalyse der Gesamtporosität in Bezug zu den Hintergrundwerten (für L = 100 m) für die gesamte Krumentiefe (0–30 cm). Werte sind für einen 1 m breiten und 100 m langen (rechtwinkelig zum Waldrand) Streifen berechnet.

study site	Total porosity			
	Soil layer	Increase	Decrease	Final effect
	(cm)	(m^3)	(m^3)	(m^3)
Transsect 1	0-30	+1.8703	-0.3067	+1.5636
Transsect 2	0-30	+1.4486	-0.2456	+1.2030
Transsect 3	0-30	+3.1164	-0.0017	+3.1147
Transsect 4	0-30	Values were not computed		

Table 1 summarises the results of the analysis of median values of total porosity relative to the background value (for L = 100 m) for the whole depth of topsoil (0–30 cm). Three of the four study transects (transects 1, 3 and 4) show a positive total influence of forest edges, i.e., an increase in total porosity, as a result of negative and positive trends.

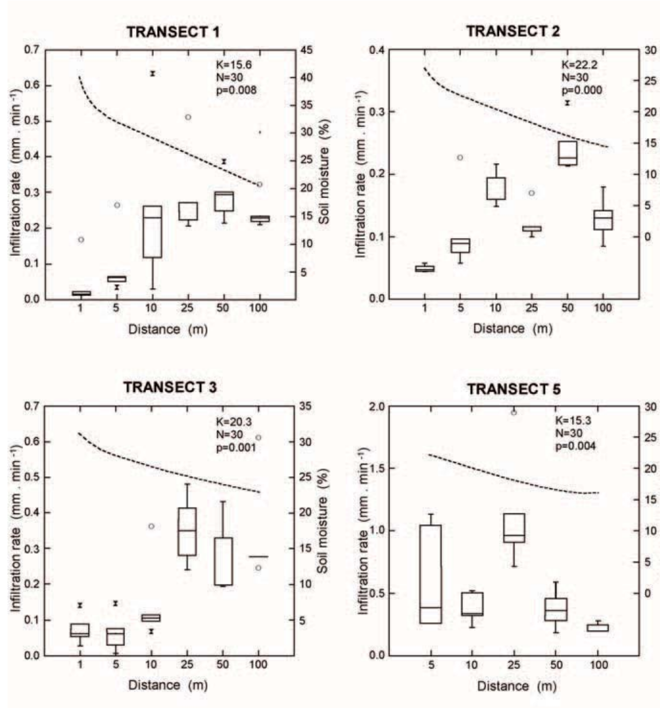

Figure 5: Influence of distance from forest edge on infiltration rate in four study transects. Descriptions of box-plots see Fig. 3. Dashed line presents changes in soil moisture (by volume) in the study transects.

Abbildung 5: Einfluss der Entfernung vom Waldrand auf die Versickerungsrate in den Untersuchungstransekten. Beschreibung der Boxplots vgl. Abb. 3; gestrichelte Linie stellt die Änderung der Bodenfeuchte (in Volumsprozent) in den Untersuchungstransekten dar.

3.2 Infiltration rate

Figure 5 shows the influence of distance from the forest edge on infiltration rate in four study transects (transects 1, 2, 3 and 5). The infiltration rate varied significantly among the zones.

No decreasing trend was observed in the zone from the forest edge to 5 or 10 m in any study transect, but the lowest infiltration rate values were found in this zone. The trend toward an increase in infiltration rate was observed in all four study transects. The highest values of infiltration rate were observed at a distance of 25 or 50 m from the forest edge. Between 25 or 50 and 100 m a decreasing trend was observed in each transect.

4. Discussion

The edge effect is mostly mentioned with reference to its positive influence on species diversity and population density. However, some authors also note some negative impacts of this phenomenon, e.g., increased predation at the edges (ANDREN, 1992; PATON, 1994; ANDREN, 1995) or competition of plant communities (TWOLAN-STRUTT and KEDDY, 1996). Major threats to the bio-diversity in European rural landscapes are due to homogenisation of the landscape pattern. During the second half of the 20th century, this transformation of cultural landscapes resulted in a reduction in patches, linear elements, and edges generally. The effect of these dramatic changes led not only to a decrease in bio-diversity and ecological stability, but also in a decrease in landscape retention. There are a number of indications, some of which have been mentioned above, that the soil structure-forming activities of soil animals contribute to rapid water movement and increased retention in ecotones. This study confirms the theory (SKLENICKA, 1998) that the retention potential of landscape can respond not only to the total area of ecologically valuable habitats but also to their number, shape and distribution inside the matrix (portion or length of edges).

We found characteristic gradients of soil porosity and infiltration rate, which are determined by distance in seven out of eight study transects (total porosity – three out of four transects; infiltration rate – all four transects). The typical gradients of these values give lowest values in the zone 0–10 m away from forest edges. In spite of the assumed higher density of soil animals, this decrease is probably caused by higher compaction of the soil, because these zones near field boundaries are very often used as a corridor for agricultural machinery traffic. We suggest that the factor of higher soil structure compression is dominant in the zone from forest edge to 10 m. For this reason there is a significant decrease in total porosity in that distance interval and, together with the higher values of soil moisture, these are the two main factors that determine the lowest values of infiltration rate in the zone from 0 to 10 m.

The highest values were found at a distance of 25 or 50 m. Beyond these culmination points the values decrease again to the background values (for L = 100 m). We suggest that the increasing values of these two characteristics are caused by the higher soil structure-forming activity of soil animals. The developments of total porosity and infiltration rate depending on distance from forest edges are very similar to each other.

This experiment contributes to the development of land use planning to formulate the principles of proposal size, form and distribution of the elements in the landscape pattern. The results of the study also can help to specify the role of landscape structure and of hydrophysical parameters of soil in hydrological modelling. Our recent results underline the need for long-term field experiments, and several of the effects that we have identified could only have been detected through an experiment lasting several years.

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