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Anthropogenic impact on fluvisols in German Floodplains. Ecological processes in soils and methods of investigation

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A b s t r a c t. The region of the Leipzig floodplain areas (Germany) is one of the most beautiful floodplain forests in Europe with partly degradated soils. The Weisse Elster and Pleisse rivers and their catchments are examples of very strong human impact on the wetland ecosystems in Germany. The open cast lignite coal mining in the south of Leipzig as well as the chemical industries were the source of millions of tons of toxic organic and inorganic contaminants of which some have been accumulated in the floodplains of the Weisse Elster and Pleisse rivers and their floodplains. In recent years, international investigation on the ecological problems of the region has been undertaken.

This paper considers some examples of soil investigation carried out at the Geographical Department of the Leipzig University. First of all, questions related to soil matter flows (mobilization, complexing) of nutrients and harmful substances (e.g., heavy metals) will be discussed here.

K e y w o r d s: Leipzig floodplain, forests, anthropogenic impact on soils

INTRODUCTION

Floodplains and their forests are important retention areas for flora and fauna that are in danger of extinction. Special character of floodplains and floodplain biotops is described by their morphology and vegetation and as well as by the soils of these ecosystems.

The fluvisols of floodplain wetlands are characterised by seasonal hydrological dynamics and strong influence of the tree stand. In the last century, hydrological system of seasonal flooding of flood plains has been influenced intensively by man in the form of riversides regulation utilisation of parts of the floodplain wetlands for agricultural purposes and drying up wetland areas and soils. Most important soils perform an ecological function of accumulating and fixing airborne and fluvially transported nutrients and contaminants.

A geo-ecological team of the Department of Geography of the Leipzig University have been investigating central German floodplain wetlands very intensively for a couple of years. Since soils are good contamination indicators of floodplain ecosystems, they have been the object of research on the soil characteristics and dynamics.

As a consequence of river regulation in the beginning of our century the East-German floodplains of the Weisse Elster and Pleisse (Fig. 1) have been drying up, soils and forests have been changing.

The re-development and closure of large powerplants in the surroundings of Leipzig was followed by decreasing levels of sulphate and calcium in the atmosphere. The acidity of the precipitation was decreasing up untill 1996 [Haase *et al.*, 1998a, b; Kulhavý *et al.*, 1998; Neumeister *et al.*, 1997] to the pH level of 4.6. Nowadays, the pH of the precipitation was found to be 4.8.

Moreover, lignite coal based heating emitted heavy metals into atmosphere which were partly deposited in the fluvisols (which belong mostly to the group of *Umbric Fluvisols*) of the floodplains.

The danger of mobilising heavy metals, considerable damages to the sensetive soil edaphon and the vegetation as well as migration of contaminants into the water saturated zone varies according to the soil conditions but may occur even when the original concentration in the soil was not very high. Increases in the soil acidity will fasten these migration processes.

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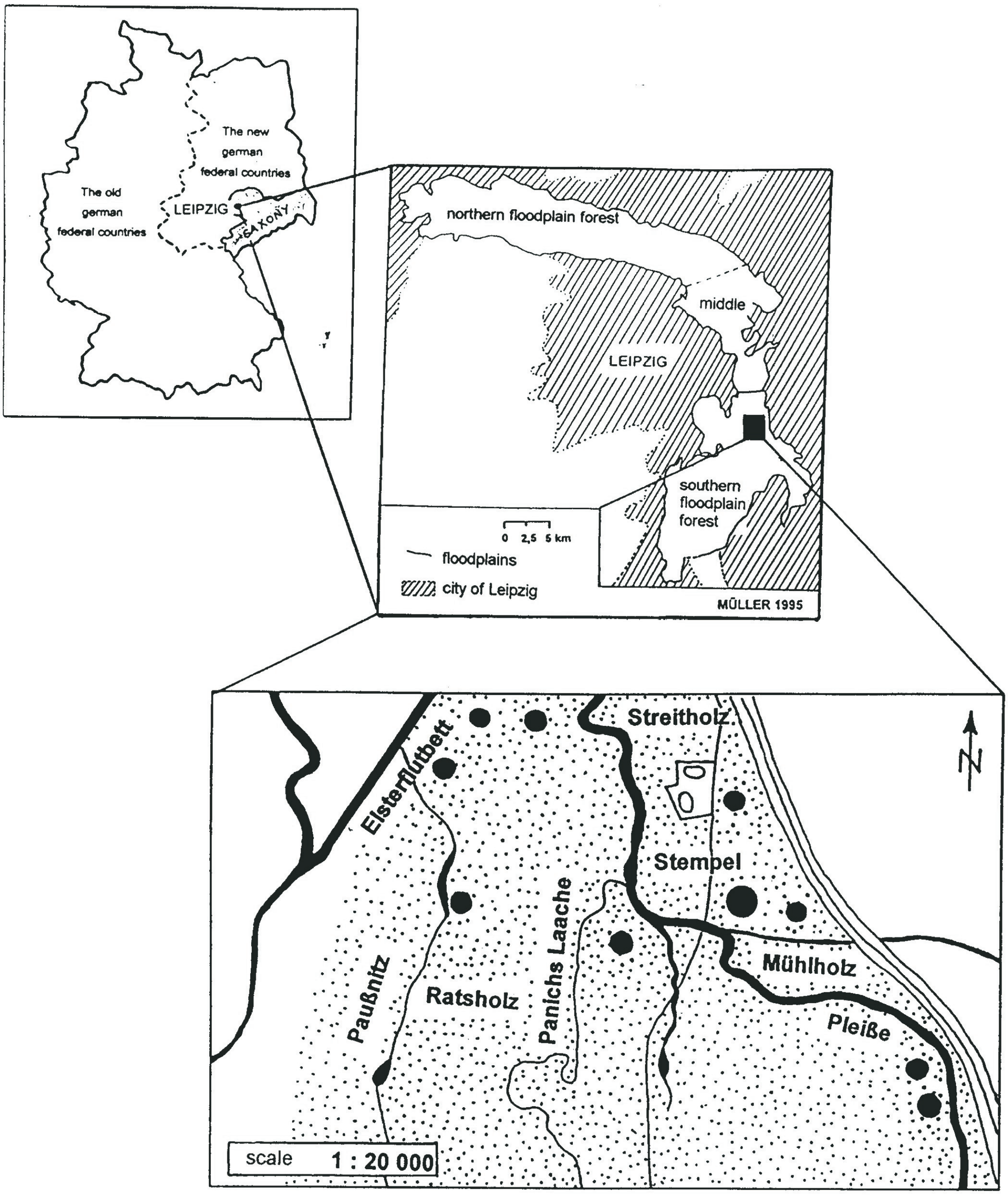

Fig. 1. Situation of the investigation area (• investigation area).

INVESTIGATION PROGRAMME

The main points of the research on the floodplain wetlands concentrate on the contents of toxic contaminants in the water saturated and unsaturated soil zone in general. Simulating of further acidification or alcalination of the precipitation by means of pH-titration experiments [Haase *et al.*, 1998a, b; Krüger *et al.*, 1997; Krüger *et al.*, 1998; Meiwes, 1984; Schneider *et al.*, 1997] gave an idea of possible migration or fixing processes in the humic and mineral soil layers.

Due to the ecological importance of contaminant bonding in the soils sequential leaching procedures [Zeien and Brümmer, 1989] indicated not only the mobility of various elements but also the importance of the DOM and SOM (Dissolved and Soil Organic Matter) for fixing and mobilizing inorganic and organic contaminants. Exchangeable fractions of heavy metals indicate their availibility for plants and soil fauna.

Re-naturation measures, such as artificial flooding of some parts of the wetlands with fresh water, will change geochemistry of the soils as the basis for flora and fauna. Even today, contents of nutrients of the flooded and non-flooded areas differ considerably [Hasse *et al*., 1998a, b].

The influence of forest vegetation and surface and groundwater in the floodplains has also been investigated because soils and their characteristics can be only understood by comparing them with their surrounding ecosystem compounds. It was proven that mostly airborne contaminants cause chemical enrichment and structural changing before accumulation in the upper soil.

New methological aspects of the in-situ measurement was developed for the spatial pattern of the soil-pH in the wetland floodplain ecosystem [Neumeister *et al*., 1997]. Special maps show soil reaction, and vegetation with inorganic and organic acids produced in the forest stand.

ISSUES

The main points in the investigation of the fluvisols of the Leipzig floodplains have been:
– developing a measuring system which can show the impact of decreasing pH on the precipitation on the soils;
– role of the wood stand in the nutrient and metal circulation in the soil body;
– finding out posible changes in the buffering system of the soils to answer questions related to mobilization of harmful toxic elements (e.g., heavy metals).

METHODS

The investigation methods included various elements of forest ecosystem research as well as soil investigation methods. To evaluate the processes in the soil as an interactive medium between biosphere, atmosphere and hydrosphere, only a complex compilation of methods can be applied.

Therefore, our plots in the Southern Floodplain Forest of Leipzig (hardwood stands) were chosen according to the layout below (Fig. 2).

One of the aspects was the relation between the soil pH-value and the forest stand. To achieve this we required a reference point for the actual deposition rates. Canopy precipitation, stemflow of various trees and soil solution of the upper soil was investigated over the period of 18 months.

A new field method of investigating acidity of the upper soil in the forest area was applied [Neumeister *et al*., 1997]. This method is based on the relation between the soil-pH-value on the canopy and stemflow (run-off paths of the trees). The measurement was carried out in-situ (Figs 3-5) and allowed to form an idea of the spatial variation of the actual soil-acidity.

With a carbon-nitrogen-analyser (made by Analytik Jena), contents of dissolved organic carbon and dissolved nitrogen of the stemflow, canopy precipitation and various soil layers have been determined.

Moreover, loamy riverside sediments, non saturated and water saturated soil zones, were analysed with respect to their inorganic compounds (nutrients, heavy metals, proton concentration), organic matter (orgC, DOC, humic acids) and their capacity to buffer acid and alcaline input from the atmosphere [Meiwes, 1984; Haase and Neumeister, 1998].

While studying soil content of nutrients and heavy metals not only the actual total and water soluble contaminant contents were determined. Using the method of sequential leaching procedures ([Zeien and Brümmer, 1989], Table 1), bonds between nutrients and heavy metals were determined to obtain an idea about the bounding mechanisms, reactivity and the resulting mobility of each element.

Mobile fractions of contaminants are able to migrate from the upper soil layers into the water saturated soil zone

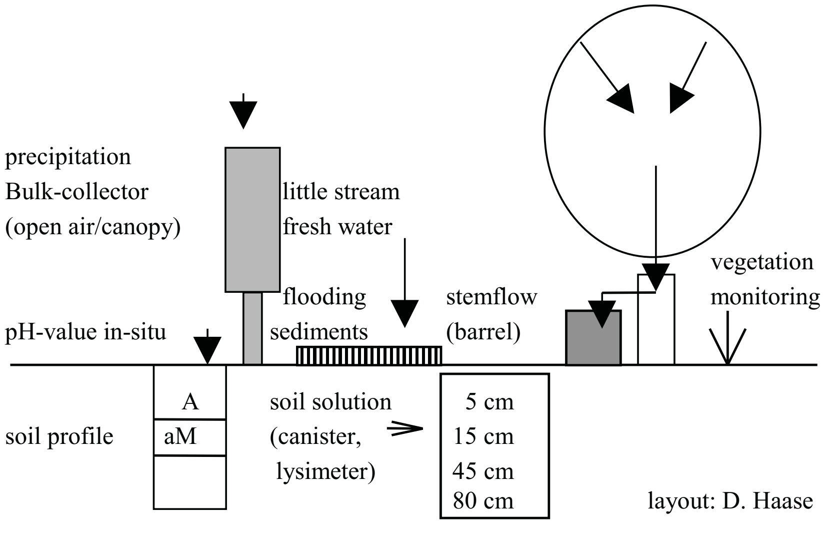

Fig. 2. Station for continiuous measurement in the Southern Leipzig floodplain forest.

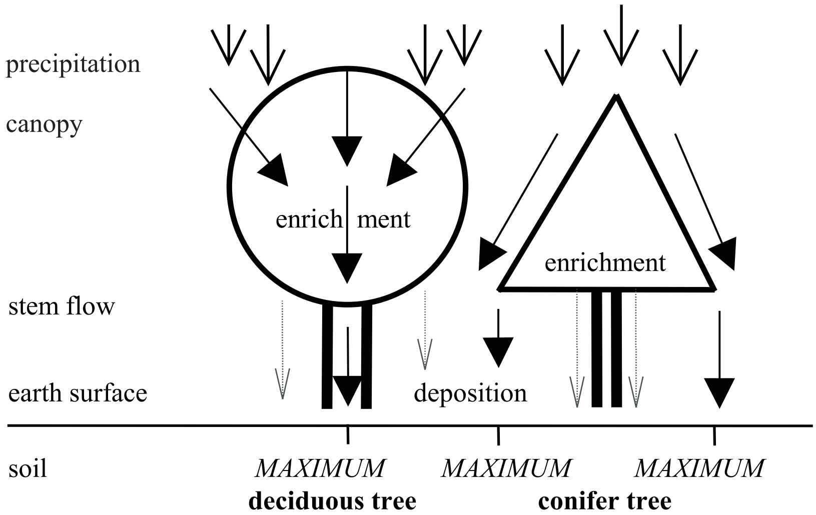

Fig. 3. Run off paths of the precipitation of deciduous and conifer trees [Otto, 1994].

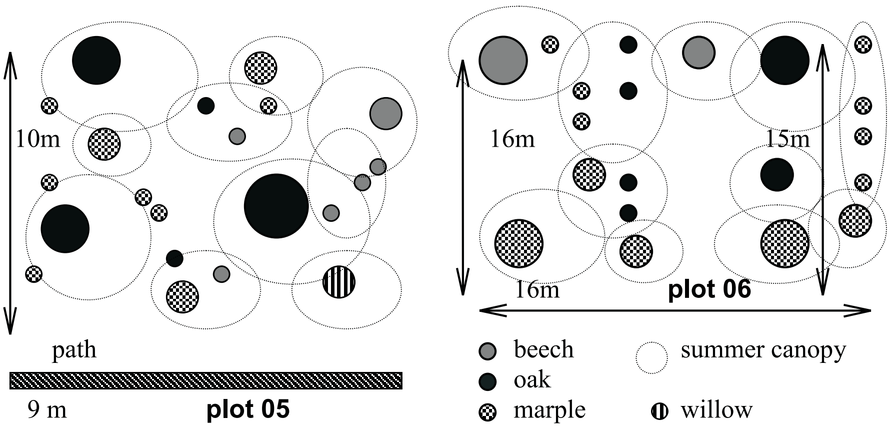

Fig. 4. Examples of 2 plots in the floodplain forests: spatial distribution of trees and determination of the input into the soils.

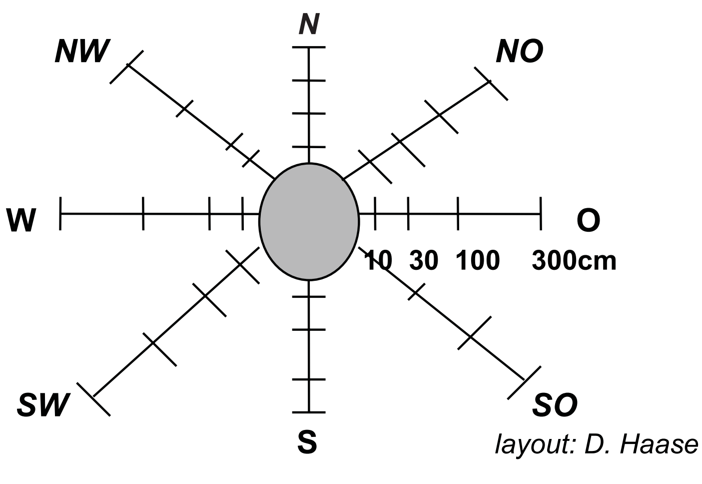

Fig. 5. In-situ-measurement of pH-values of the upper soil layers (0-10 cm) around the trees [after Neumeister *et al.*, 1997].

T a b l e 1. Sequential leaching procedure after Zeien and Brümmer, 1989

Fraction	Extraction reagent	Speciation	Ecological meaning
I	aqua dest.	water soluble fraction	very important, because water is the most frequent solvent
II	1 M NH_4NO_3	mobile fraction, exchangeable bonds	mobilisation is given by acid input
III	1 M NH_4Ac (pH 6)	exchangeable fraction	input of acids and bases; soil-carbonate-buffer (after Ulrich)
IV	0.1M NH_2OH-HCl (pH 6), 1 M NH_4Ac	Mn-oxides fixed fraction	soluble during more acid input (strong acids)
V	0.025 M NH_4-EDTA (pH 4.6)	organic fixed fraction	soluble with solution or precipitation of humic substances
VI	0.2 M NH_4-oxalate (pH 3.25)	poor crystallised Fe-oxides fixed	poor soluble fraction, Al-Fe-soil-buffer (after Ulrich)
VII	0.1 M ascorbic acid in 0.2 M oxalate buffer	crystallised Fe-oxides fixed	
VIII	(HCl, H_2O_2, HNO_3)	residual fraction	not very relevant for natural ecosystems (insoluble fraction)

accelerated by changing of the acidification or alcalination conditions in the soil body.

Therefore, together with sequential leaching procedures, titration experiments were done simulating various conceivable immission or input situations (Fig. 6).

RESULTS

Since 1990 untill 1996, a decreasing pH-value of the precipitation was found [Neumeister *et al*., 1997]. This resulted in a very acidic stemflows of hardwood forest species like esh or oak (Table 2), in which high contents of sulphate and DOC (dissolved organic carbon) was found.

With the help of High Performance Liquid Chromatography (reversed phase, RP-HPLC; [Krüger *et al*., 1998; Haase *et al*., 1998a, b]), organic compounds of the stem flows as well as of the upper soil layers of the fluvisols were determined as humic acids (HA). They showed very similar structures in the chromatograms (Fig. 7). Since the HA contents of the stemflows are higher than in the soil, it can be supposed that parts of the humic acids are produced in the stem and bark. What influence is exerted by these humic acids on further acidification of the soils, cannot as yet be discussed.

The in-situ-measurements of various plots in the floodplain forests show a strong dependency of the upper-soil -pH-value on the trees and their stemflows (Fig. 8). The pH-values between the trees differ up to pH 2.0 in very short distances of less than 2 m. Every rainfall provokes a sudden

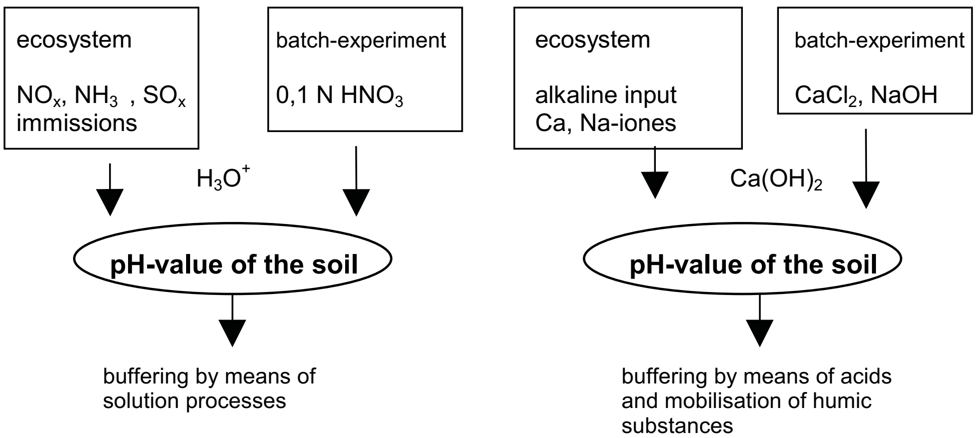

Fig. 6. Experiments on acidification and alkalination by means of atmospheric input after Meiwes, 1984.

T a b l e 2. Acidity and organic carbon content of the stem flows of oak and ash trees

Stemflow	(H^+)	pH-value	DOC
Quercus 1	$10^{-3.3}$	3.30	92.71
Quercus 2	$10^{-3.52}$	3.52	79.77
Quercus 3	$10^{-3.22}$	3.22	206.80
Fraxinus 1	$10^{-3.75}$	3.75	60.88
Fraxinus 2	$10^{-3.94}$	3.94	90.81
Farxinus 3	$10^{-4.09}$	4.09	113.60

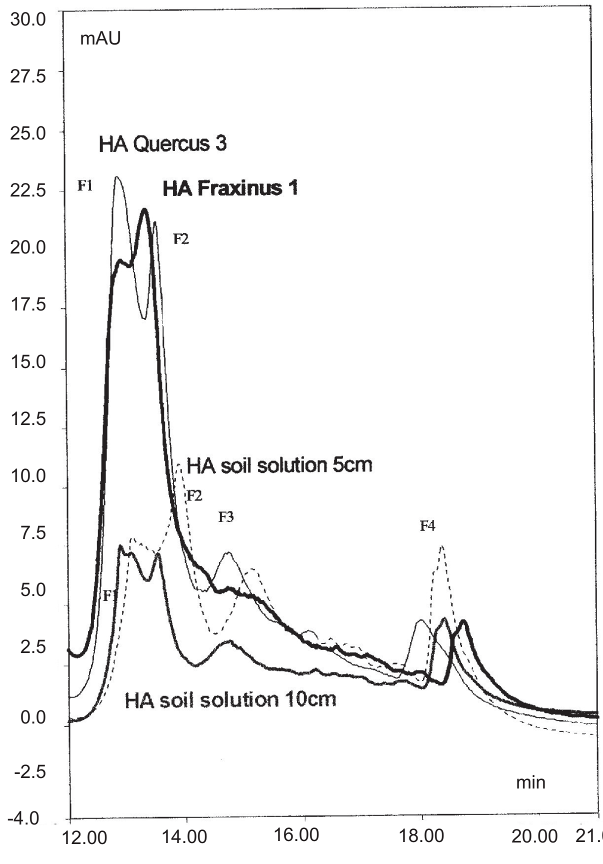

Fig. 7. Humic acids (HA) of stemflow (Fraxinus; Quercus) and soil solution (depth: 5 and 10 cm).

decrease of the soil-pH and neutralization reactions which lead to the wash-out-processes of nutrients such as calcium (Ca) observed in the upper soil near the stems (Fig. 8).

Furthermore, an input of acids by precipitation, leads not only to a transfer of essential nutrients into the groundwater zone. Harmful effects like the mobilization and migration of mobile and exchangable heavy metals and aluminium (Al) in the fluvisols are also provoked.

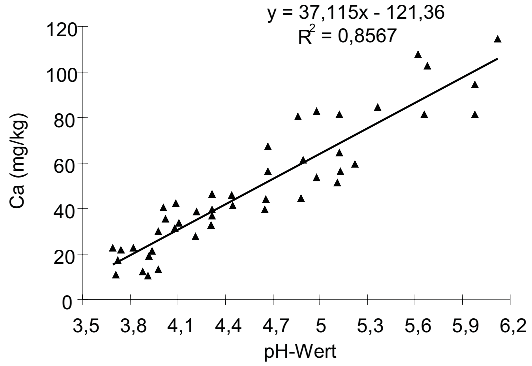

Fig. 8. Regression and correlation between the calcium-content (mg kg^{-1}) and the pH-values of upper soil samples of the Southern Floodplain Forest of Leipzig.

Experiments with the sequential leaching procedures (Fig. 9) and the titration experiments (Fig. 10) show that most of all the positively charged elements, i.e., cadmium (Cd) and zinc (Zn), will be re-soluted from the adsorption surfaces (of the clay minerals). Elements like copper (Cu) or lead (Pb) often form metal-humic-complexes and will be soluted more under increasing alcaline conditions (Fig. 10). This could occur during neutralization measures taken according to the forestry conservation requirement.

The presented results clearly underline, that factors like acidity of the floodplain forest mediums (precipitation, stemflow, soil) and contents of organic matter (dissolved,

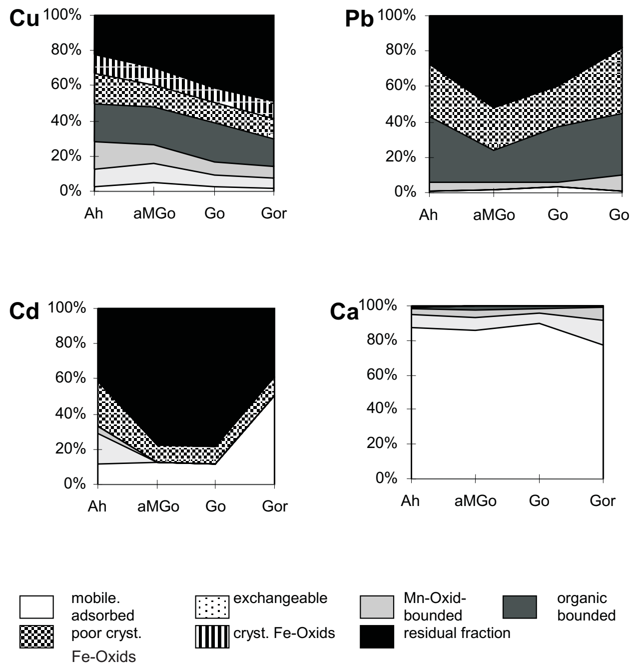

Fig. 9. Bonds of metals in several horizons (Ah, aM, Go and Gor) of the fluvisols in the Leipzig Floodplain Forest.

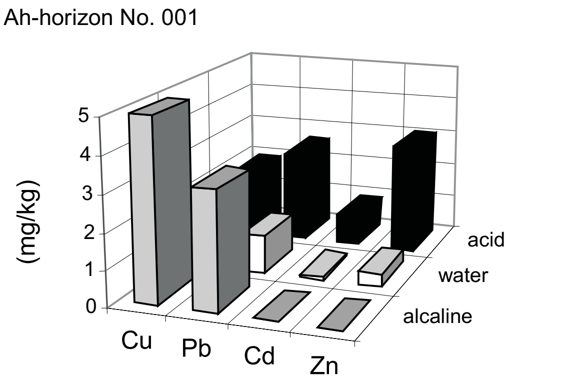

Fig. 10. Mobilization of metals after acid and alcaline input by means of precipitation.

total) must be observed regulary to get an idea of the solution, migration and pollution processes of the soil and groundwater. With the help of fixed plots and a monitoring programme, an efficient support for the landscape and regional planning processes could be achieved.

CONCLUSIONS

Acidity of the upper horizons of the fluvisols in the floodplain forests of Leipzig strongly depend on the spatial distribution of trees. Soil acidity depends also on the season, troughfall and kind of trees. With the tree run-off there occurs also an input of organic humic acids into the upper soil horizons. Within the soil body, the acid inputs lead to element specific mobilization and changing of the bonds.

Not only acid input is followed by the solution of nutrients and metals, but also alcaline deposition provokes leaching of heavy metal-humic-complexes (Cu, Pb).

The results of the investigation show that pH, measured in-situ, as well as the buffering qualities of the soil body can be considered as the main parameters (master variables) to describe the actual processes occuring in fluvisols.

This kind of results is urgently required for the construction of a long-time recording programme monitoring of the positive and harmful effects on soils in floodplain forests (Fig. 11) including both, regional fluctuations and a long time registration.

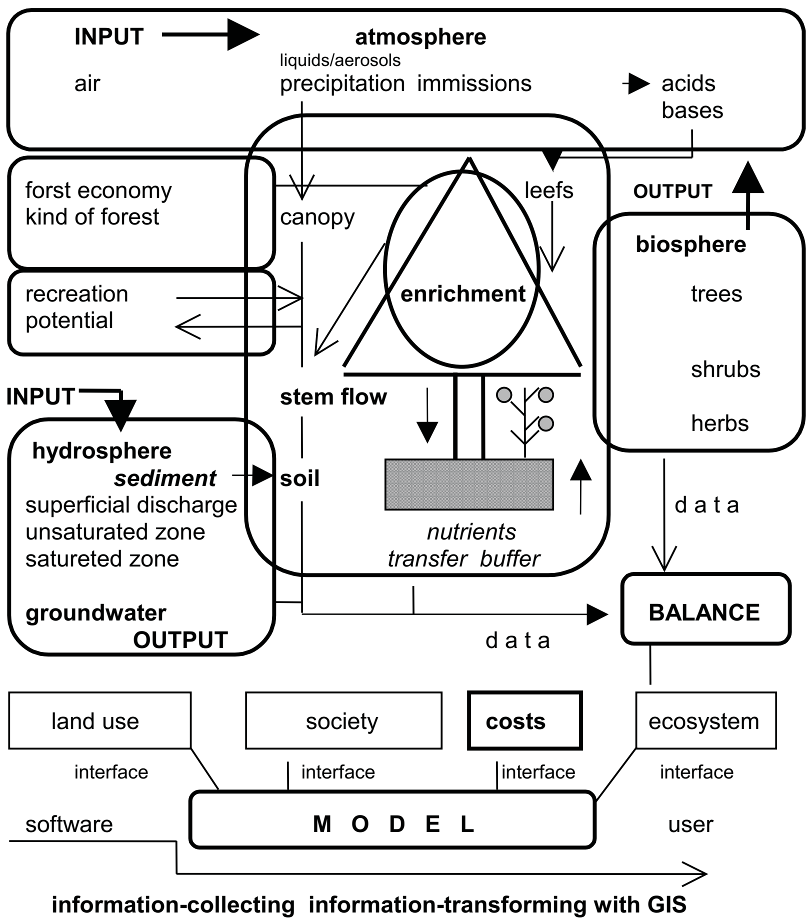

Fig. 11. Model for a computerized forest-monitoring system.

At least a database is needed for forest management and forest economy to build up a soil information system (SIS) of the floodplains, necessary for the decision making, to create or to enlarge environmental protection areas within the floodplain forests.

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