STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ÉTUDE DE L'ÉNERGIE NUCLÉAIRE

Book of Abstracts

SCK•CEN-BA-14

Topical day on

Biogeochemical response of forest vegetation to chronic pollution : processes, dynamics and modelling.

This activity is supported by NIRAS-ONDRAF

ONDRAF/NIRAS

Mol, Belgium, October 17, 2006

SCK•CEN, Boeretang 200, 2400 Mol, Belgium

http://www.sckcen.be

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Mol, Belgium, October 17, 2006

SCK•CEN, Boeretang 200, B-2400 Mol, Belgium

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Stichting van Openbaar Nut – Fondation d'Utilité Publique - Foundation of Public Utility

Registered Office: Avenue Herrmann Debroux 40 – B-1160 Brussel

Operational Office: Boeretang 200 – B-2400 Mol

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Contents

Introduction

Radionuclides, heavy metals or organic pollutants of various origins and ecological characteristics can enter and redistribute in terrestrial ecosystems from many routes (athmospheric fallout, underground water, waste repository, industrial relics,…). Forest ecosystems are usually long lived and over time accumulate large amounts of biomass, and thereby can act as a biospheric sink for numerous pollutants. In the long term, the biogeochemical cycling of element involves recurrent transfers of the pollutants between and within the forest ecosystem boundaries with strong interactions between geologic, hydrologic and meteorologic aspects as well as biologic features. There is now increasing demand for large scale and for long term studies and modelling of forest-site-climate interactions (effect of CO_2, climate changes, hydrological problematics, erosion, deforestation, phytostabilisation, …). At contaminated sites or for minimizing consequences of a possible radioactive leakage, the longevity of many radioactive isotopes requires similarly that safety assessments must also consider long time scales. Besides, dynamic ecosystem modelling is becoming essential for continuous (chronic) release situations and changing environments. An integrated understanding of the forest ecosystem functioning is a prerequisite to predictive modelling. Ecosystem studies are now at the stage to propose quantitative description of forest ecosystem functions and provide an opportunity to learn more about the long term recycling of various pollutants in a forest ecosystem.

Topics to be covered at this workshop include:

- biogeochemical cycling of major and trace element in forest ecosystem with emphasis on the processes involved
- localization of water and element uptake
- tree response to underground water contamination
- integrated and process-based forest modelling

Programme

08.30	Welcome	
08.50	Introduction	
09.00	Dr. U. Kautsky	*(SKB, Sweden)*
	Fluxes of carbon, nutrients, trace elements and radionuclides, in terrestrial and aquatic ecosystems for long time assessment of high level waste radionuclide repositories.	
09.40	Prof. G. Öberg	*(IRES, UBC, Canada)*
	The biogeochemistry of chlorine in soil.	
10.20	**Coffee break**	
10.40	Prof. F-R. Meng	*(UNB, Canada)*
	Modelling forest biomass growth and nutrient cycling at different time and spatial scale.	
11.20	Prof. G. Shaw	*(Nottingham University, UK)*
	Estimating long term, steady state balances in forest following inputs from atmosphere or geosphere.	
12.00	Dr. Y. Thiry	*(SCK•CEN, Belgium)*
	Impact of forest vegetation on long term recycling of trace elements and radionuclides.	
12.30	Lunch	

14.00	Dr. C. Vincke	(SCK•CEN, Belgium)
	Interactions between evapotranspiration fluxes and water table in a Scots pine stand: implications for element cycling modelling	
14.30	Dr. R. Avila	(Facilia, Sweden)
	Model of the long-term transfer of radionuclides in forests.	
15.00	Prof. M. Aubinet	(FUSAGx, Belgium)
	10 years assessment of measurements and analysis of CO_2 fluxes on the Vielsalm's site.	
15.30	**Coffee break**	
15.50	Prof. I. Janssens	(UA, Belgium)
	The carbon balance of a mixed pine-oak forest in the Flemish Campine region.	
16.20	Prof. M. Carnol	(ULg, Belgium)
	Canopy-atmosphere interaction in forests: a key process in nutrient cycling and pollution interception.	
16.40	Prof. M. Javaux	*(Forschungszentrum Juelich, DE/ Departement of environmental sciences, UCL, Belgium)*
	Modelling 3-D root water uptake at different scales.	
17.00	Dr. D. Jacques	(SCK•CEN, Belgium)
	Integration of biogeochemical processes in soil-vegetation models: A perspective from different scales.	
17.20	**General discussion and conclusion**	

Fluxes of carbon, nutrients, trace elements & radionuclides, in terrestrial & aquatic ecosystems for long time assessment of high level waste radionuclide repositories.

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Abstract

The Swedish Nuclear Fuel and Waste Management Company (SKB), is responsible for taking care of Swedish nuclear fuel waste. One of the tasks is to plan a repository for long-lived spent fuel from nuclear power plants. This planning includes a safety assessment of the consequences of failure of the repository during one million year. One of the endpoints in the SA is to estimate risk to humans and ecosystems.

Traditionally, dose modelling for the environmental transfer utilises different types of uptake factors which are empirically estimated for some radionuclides. For a long term SA these factors are insufficient, since there are more than 40 potential radionuclides that can give risk and factors are not available for all of them. The uncertainty of factors is usually several orders of magnitude and includes both element specific behaviour but also generic ecosystem variation, e.g. evapotranspiration, runoff, water-turnover, primary production, biomass turnover. The ecosystem variation is usually measurable and scalable over time and contains low variation.

To be able to make meaningful prediction about future ecosystems and scale the variation from expected changes of the land sea distribution and climate change, SKB is developing alternative methods for estimating radionuclide dispersal in ecosystem.

First of all a process based ecosystem approach is utilised by studying and modelling the transfer of matter (carbon, nutrients, trace-elements), between different dominating organism in the ecosystem. The main routes for transfer of matter are water transport and food uptake. Other important parameters are primary production and metabolisation of matter.

The transfer of matter is studied and modelled in different scales from individual organism to entire landscapes and includes ecosystems like sea, lakes, mires, forest, streams and agricultural land.

In this talk several examples terrestrial ecosystems will be presented with the focus on process based radionuclide transfer from groundwater sources.

Keywords:

Dose, ecosystems, radionuclide waste, trace elements, hydrology, forest, process based modelling, climate.

The biogeochemistry of chlorine in soil

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Abstract

Chlorine is ubiquitous in the environment and is present as inorganic chloride (Cl_{in}) as well as in various forms of organically bound chlorine (Cl_{org}). The Cl_{in} in soil either originates from dry and wet-deposition (rain, snow, fog etc) or from below-ground sources, actively transported upward by roots or passively transported by up-ward moving water in periods of net-evaporation. The origin of Cl_{org} compounds in soil is more complex. It was previously believed that Cl_{org} compounds originated from anthropogenic activities only and that Cl_{in} was inert in soil moving unaffected with the soil water. This has led to that the mere presence of Cl_{org} compounds has been taken as a sign of industrial influence. Furthermore, based on its perceived inertness, Cl_{in} has been used as an internal tracer of other substances and water movement in biogeochemical, hydrochemical and hydrological studies.

In the early 1990s, it was revealed that large amounts of naturally produced Cl_{org} were present in soil. Later studies have shown that chlorine participates in a complex biogeochemical cycle in which the terrestrial environment appears to be a key-component. Recent studies suggest that a large portion of the Cl_{in} that is deposited on terrestrial environments is transformed to Cl_{org} in soil or in/on vegetation. The majority appears to become chlorinated organic matter. The process is not known, but there is strong evidence that the transformation is driven by biotic processes, although abiotic processes have been shown to exist.

In the temperate region, the chlorinated organic matter is subsequently transported to deeper soil layers with the soil water. It precipitates and is sooner or later mineralized leading to the release of Cl_{in} which is taken up as such by living organisms or transported to surface water by the movement of soil water. The general understanding since the 1950's is that Cl_{in} in surface water mirrors the chemical composition of precipitation. In contrast, recent chlorine research suggest that Cl_{in} in surface water to a large extent originates from decomposing organic matter, which may be years, decades or several thousand years old. Still, the input-output of Cl_{in} in most catchments are in balance. This situation, with a large storage in soil, complex biogeochemical transformation processes at hand and still balance in the relatively small in-put output may appear confusing. However, the same pattern is since long well documented for e.g. carbon, nitrogen and sulphur.

Although the knowledge that chlorine does participate in a complex biogeochemical cycle by now undoubtedly is accepted in the scientific community, it is still not generally known even among researchers. The field is very much still close to a virgin area and besides that fact that cycling of chlorine is at hand, several issues remain unclear. For example, it is known that chlorinated volatiles (VOCls) are formed naturally, and it appears as if both biotic and abiotic sources are involved but the magnitude, the underlying processes and the relation between VOCls and the formation of chlorinated organic matter remain unclear. Furthermore, it is known that plants take up Cl_{in} and that organochlorine compounds are formed in/or plant leaves but it is not known whether this formation is driven by the plants or by microbes in/on the leaves or to what extent various chlorine species are formed and transformed within and among the plant-soil system. Without doubt, in order to develop a wise policy for the management of anthropogenic chlorinated compounds, it is necessary to acquire a better understanding of the natural cycle.

Modeling forest biomass growth and nutrient cycling at different time and spatial scale

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Abstract

Growth of forest is related to climate conditions and affected by the biogeochemical nutrient balance and related effects on soil nutrient availability. Forest biomass and nutrient cycling model (ForNBM) is a process based model being developed to simulate nutrient cycling and net primary productivity based on inputs of site and monthly mean weather conditions. A modular design was used to partition forest ecosystems into separate modules that address: (1) soil moisture and temperature in forest soil layers; (2) soil H-ion balance in the soil, in the context of atmospheric deposition, nutrient uptake, soil weathering, and soil-ion retention; (3) nutrient cycling of N, S, Ca, Mg, and K to estimate nutrient uptakes, mineralization, nitrification, immobilization, mineral soil weathering and nutrient leaching associated with atmospheric deposition; and (4) biomass to estimate net primary productivity and its allocation to foliage, wood, and root biomass, as well as litterfall and decomposition. The model is constructed to accept data at monthly to daily level and in conjunction with other GIS models, ForNBM can be used to determine the limiting nutrients of forest growth; to evaluate the effects of atmosphere acidic deposition on soil chemistry and forest growth at different time and spatial scales.

Key words:

Biogeochemistry, Nutrient Cycling, Forest Productivity, Ecosystem Model.

Estimating long term, steady state balances in forest following inputs from atmosphere or geosphere.

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Abstract:

Forests are a key long-term feature of the landscape in the temperate and boreal belts. The time period over which natural forest cover develops (hundreds to thousands of years) is similar to that over which radioactive waste assessments must be carried out. Leakage of long-lived radionuclides from waste repositories is not predicted to occur before at least 1,000 years after closure. After this time it is only the most mobile radionuclides such as Cl-36, Tc-99 and I-129 which have the migration potential to contaminate the biosphere. We have conducted a combination of laboratory and field studies, along with deterministic and probabilistic modelling based on measurement data, to 'predict' the likely long-term, steady state distributions of radioactive chlorine, iodine and technetium in forest ecosystems. Approximately equal inventories of chlorine were found in soils and the standing biomass of trees, which reflects the high degree of biological incorporation of this element. For iodine and technetium, the soil represents a substantially greater long-term reservoir than standing biomass within forest ecosystems. For each of these elements, some degree of interaction with humic substances appears to control the behaviour of the element. This is particularly relevant to iodine and technetium, but the role of humic-chlorine interaction in the long term behaviour of chlorine-36 may be more significant than previously recognised.

Key words:

Forest, radionuclide, radioactive waste disposal, technetium, chlorine, iodine.

Impact of forest vegetation on long term recycling of trace element and radionuclides.

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Abstract

A major challenge for biogeochemistry in the future deals with aspects of human-accelerated environmental changes which include the impact on ecosystem and biogeochemical processes of climate changes and toxification of the biosphere. Forest ecosystems are usually long lived and over time accumulate large amounts of biomass. Besides, forests are characterized by strong interactions between climate, hydrology and biological features: this makes forest ecosystems a relevant biogeochemical study model. The stabilization role of forests, in particular, has been illustrated from different environmental studies. They showed a reduction of water export from watersheds as well as of erosion and hydrological losses of chemicals or even of radionuclides. Forest area can thus act as a biospheric sink for numerous pollutants (atmospheric or underground) in steady-state conditions. Still, a remobilisation of the elements is likely in case of disruption of the vegetation-site-climate equilibrium. The reliability of predictive models is highly affected by our knowledge about processes and by the quality of available data. For various trace contaminants, a need exists for new integrated studies of contaminant transfer in forest zone to support the development of long term bioaccumulation-recycling models and to justify the necessary simplifications. In addition to semi-natural area impacted by current chronic atmospheric or underground pollution, many spoils and contaminated industrial soils will be probably afforested for a return to a better ecologically functional system. However, the ecosystem processes and functioning, i.e. involving the soil-tree system as a whole, are generally poorly known. In fact, the long-term impact of perennial vegetation on pollutant biogeochemistry is hardly considered in standard risk assessments. In particular, the role of biota in recycling and partitioning processes needs further attention for a complete long term and large scale assessment and modelling of the contamination dynamics.

This workshop will give us an opportunity to illustrate the importance of the forest biological cycling in the redistribution of different trace contaminants with emphasis on the processes involved. We will envisaged at least three study cases:

- A vast pine forest highly contaminated with radiocaesium originating from the Chernobyl atmospheric fallout,
- A coniferous stand established on uranium-mining debris for stabilization purpose,
- A new forest in the Chernobyl exclusion zone growing after decline of the irradiated vegetation and the burial of radioactive matter into trenches trenches.

Key words:

Biogeochemistry, radionuclides, forest, biological cycling, ecosystem contamination.

Interactions between evapotranspiration fluxes and water table in a Scots pine stand : implications for element cycling modelling.

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Abstract

The forest tree vegetation, because of its longevity, high biomass turnover and high evaporative capacity, has a great influence on the water and element cycling: it can transpire about 80% of the potential evapotranspiration (PET) under high evaporative demand. Forest vegetation can also absorb and recycle a considerable amount of nutrients as well as of radionuclides (Thiry *et al*., 2000 ; Goor and Thiry, 2004) when compared to the soil bioavailable pool. On that basis, and to contribute to the construction of a lumped biosphere model for large scale performance assessment in a deep disposal scenario, we measured the water fluxes and ecophysiological variables (roots density, Leaf Area Index) in a Scots pine stand during the 2005 growing season. One particular task was to identify the sources of water used by trees, *i.e.* precipitation *vs* groundwater. Effectively, the stand was installed on a podzol with a shallow water table (60 cm deep in winter) which demonstrated seasonal fluctuations within the rooted zone. The stand evapotranspiration (ET) was measured from mid-April to mid-November and reached 540 mm, which represented 75% of PET. Pine trees transpiration (T) contributed to 20% of ET. This was calculated from sap flow monitored every 30-min. By the use of a closed chamber, understorey evapotranspiration (ETu) was estimated to contribute to 33% of stand ET. From soil volumetric water content and water table measurements, the water uptake from the different soil horizons was calculated and compared to the transpiration results. From mid-April to mid-November, the water table contributed to 26% of the stand transpiration (during a 3-weeks drought period in June, it contributed to 99% of the water used by the forest) and a correlation between hourly pines sap flow and water table variations was observed. Those results will be used to implement a coupled water-elements-biomass model for further radionuclides uptake estimation in a deep disposal scenario. An example of valorization will be showed with the calculation of the stable chloride uptake by the forest through the 2005 growing season.

Key words:

Forest ecophysiology, hydrology, water cycle, modeling, elements cycle.

Model of the long-term transfer of radionuclides in forests.

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Abstract

In my presentation I will describe a model of the long-term behaviour in forests of radionuclides entering the ecosystem with subsurface water. The model can be applied for most radionuclides that are of relevance in safety assessment of repositories for high-level radioactive waste. The model assumes that biomass growth, precipitation and evapotranspiration drive the radionuclide cycling in the system by influencing the uptake of radionuclides by vegetation and their export from the system via runoff. The mathematical model of radionuclide transfer consists of a system of ordinary differential equations describing the mass balance in different forest compartments, taking into account the fluxes in and out from the compartments and the radioactive decay. The model assumes that the fluxes of radionuclides are driven by fluxes of water and nutrients and hence the transfer coefficients between compartments are expressed as functions of ecological parameters, such as the biomass production and the evapotranspiration rate.

The model includes there alternative approaches to describe the transfer from soil to plants. In the simpler approach, applicable when soil to plant Concentration Ratios (CR) are available, the root uptake rates are calculated by multiplying the concentration in the plant, obtained with the help of the *CR*, by the biomass production. A second approach is based on the assumption that some elements are taken-up passively with the transpiration flux. For them, the total flux from soil to plants can be expressed as a function of the transpiration rate and the radionuclide concentration in the pore water. The third approach, which is applicable to analogues of plant macronutrients, is based on the assumption that the radionuclide uptake by plants is modulated by the uptake of the analogue macronutrient. This means that the radionuclide and its corresponding analogue nutrient are taken up by plants in an identical manner via the same carrier molecules.

Transfer factors to forest wild animals are lacking for many of the relevant radionuclides. Hence, these were calculated with an equation that relates the radionuclide concentration in the animal diet to the radionuclide concentration in the animal body. This equation was derived by combining allometric relationships and biokinetic modelling.

Keywords*:*

Modelling, radionuclides, forest

Ten years assessment of measurements and analysis of CO_2 fluxes on the Vielsam's site.

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Abstract

An overview of the measurements performed since ten years at the Vielsalm experimental site is presented. The site is situated in the Belgian Ardennes and is covered by a mixed forest (Beech, Douglas fir and Spruce). Measurements include net ecosystem fluxes of CO_2, water vapour and energy, micrometeorological variables, soil respiration and advection fluxes.

Measurements were initiated in 1996 in the frame of the European Euroflux project and developed in the further Carboeuroflux and CarboEurope IP projects with the help of the Belgian Fonds National de la Recherche Scientifique.

In the early years, much work was devoted to the elaboration of an eddy covariance flux measurement procedure. A methodology, common to all the Euroflux sites, was set up and largely spread. The problem of night flux measurements was also addressed. It was shown that a systematic CO_2 flux underestimation appears during quiet nights because the turbulent transport is challenged by other processes like storage or advection. Experiments were developed at the site in order to obtain an evaluation of the advection terms. Besides, standardised correction procedures were set up in order to provide defensible data sets.

The site was found to behave as a strong sink during day, between February and November, and as a moderate source in winter and in night time. In average, it behaves as a sink (about 0,4 - 0,6 $kgCm^{-2}yr^{-1}$), the carbon sequestration due to the assimilation exceeding the carbon emission due to respiration. Inter annual flux variations were found quite limited.

The ecosystem functional responses were described. The main climatic driving variables of the CO_2 flux were found to be radiation and water pressure deficit for the day flux and temperature and soil water content for the night flux.

One challenge is to discriminate the net flux measured by the eddy covariance system between its different components. On one hand the net ecosystem exchange results from two antagonist fluxes: the gross primary production and the respiration that should be estimated. On the other hand, in mixed forests, the contribution of each vegetation plot to the total flux should be identified.

For soil respiration measurements, specific devices were set up. The data analysis revealed a large sensitivity of soil respiration to temperature and a small dependency to soil water content and precipitation. A large spatial variability was also observed at the site that was mainly driven by the litter depth variations.

Contribution of the different vegetation plots were estimated using an original model that was run on the eight year data set. The model showed that the beech ecosystem was the most efficient for carbon assimilation but is active on a shorter period than conifers. Douglas fir was most efficient than Spruce. These results also allowed some evaluation of footprint models.

Keywords:

Eddy covariance, CO_2 fluxes, forest, soil respiration, net ecosystem exchange.

The carbon balance of a mixed pine-oak forest in the Flemish Campine region.

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Abstract

Since 1995, we combined ecological – and micrometeorological measurements with empirical – and mechanistic models to study the carbon balance of a mixed pine-oak forest in Brasschaat. We observed that during 2000-2001, despite being a net CO_2 sink, the carbon content of the forest decreased. We also observed very different behavior in the pines as compared to the oaks, and a substantial contribution of understorey vegetation to the carbon fluxes. In this presentation we will give an overview of the most striking results, highlight where methodological uncertainties remain problematic and indicate which processes are poorly understood and, hence, poorly modeled.

Key words:

Carbon budget, forest ecosystem, modeling, processes, uncertainties.

Canopy-atmosphere interaction in forests : a key process in nutrient cycling and pollution interception.

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Abstract

An efficient way for assessing the nutrient status of an ecosystem is the establishment of nutrient input-output mass balance budgets at the catchment scale. For example, outputs (i.e. losses in streamwater, through havesting etc.) greater than inputs (i.e. weathering, dry and wet deposition, fertiliser) indicate that a depletion of the given element is taking place. In forest ecosystems, element input via throughfall is an important pathway in nutrient cycling. Precipitation interacts with the stand canopy, resulting in increased/decreased solute inputs to the forest floor. For example, acid deposition (H, N) may be substantially increased through the filtering action of the tree canopy. Indeed, canopy throughfall chemical composition includes wet deposition (rainfall), dry deposition intercepted by the canopy and elements leached from the foliar tissue (canopy leaching). Moreover, interactions between canopy and atmosphere or precipitation depend on several factors such as: season, tree species and physiology, stand structure and health. However, canopy leaching results from an internal nutrient cycling process. Ignoring this component in throughfall measurements thus leads to an overestimation of the inputs to the ecosystem.

In this paper, main results of studies performed in the Belgian Ardennes at the watershed (80 ha) and plot scale are summarised. The aim of this research was to quantify long-term nutrient budgets in a forested watershed, within a context of sustainable management. In this area, soils are naturally acidic and poor in magnesium, so that forest dieback symptoms reported from 1983 onwards were related to increased pollution exacerbating magnesium deficiency. There is concern that acid (S and N) deposition, together with sylvicultural management (harvesting, spruce monocultures etc.) could deplete the available cation pool and that soils would not be able to support intensive sylviculture on the long term.

We measured concentrations and fluxes of major ions in bulk deposition, throughfall and stream water over 13 years. Throughfall deposition under coniferous (*Picea abies* (L.) Karst.) and several deciduous tree species was also compared. A canopy budget method was used for distinguishing between external (dry deposition) and internal (canopy leaching) sources of ions in the throughfall flux. The contribution of canopy leaching in throughfall measurements and consequences for mass balance calculations will be

discussed. Furthermore, nutrient fluxes through the ecosystem will be examined with regard to the long term nutrient status of the system.

Keywords :

Canopy interactions, forest ecosystem, catchment, input-output budget, throughfall.

Modelling 3-D root water uptake at different scales.

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Abstract

Root water uptake is a dynamic and non-linear process, which interacts with the soil natural variability and boundary conditions to generate heterogeneous spatial distributions of soil water. Soil-root fluxes are spatially variable due to heterogeneous gradients and hydraulic connections between soil and roots. While 1-D effective representation of the root water uptake has been successfully applied to predict transpiration and average water content profiles, finer spatial characterization of the water distribution may be needed when dealing with solute transport. Indeed, root water uptake affects the water velocity field, which has an effect on solute velocity and dispersion. Although this variability originates from small-scale processes, these may still play an important role at larger scales. Therefore, in addition to investigate the variability of the soil hydraulic properties, experimental and numerical tools for characterizing root water uptake (and its effects on soil water distribution) from the pore to the field scales are needed to predict in a proper way the solute transport processes. Obviously, non-invasive and modeling techniques which are helpful to achieve this objective will evolve with the scale of interest.

At the pore scale, soil structure and root soil interface phenomena have to be investigated to understand the interactions between soil and roots. Magnetic resonance imaging may help to monitor water gradients and water content changes around roots while spectral induced polarization techniques may be used to characterize the structure of the pore space. At the column scale, complete root architecture of small plants and water content depletion around roots can be imaged by magnetic resonance. At that scale, models should explicitly take into account the three-dimensional gradient dependency of the root water uptake, to be able to predict solute transport. At larger scales however, simplified models, which implicitly take into account the heterogeneous root water uptake along roots, should be preferred given the complexity of the system. At such scales, electrical resistance tomography can be used to map the water content changes and derive effective parameters for predicting solute transport.

Integration of biogeochemical processes in soil-vegetation models : A perspective from different scales.

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Abstract

Process-based models for (groundwater)-soil-vegetation systems can include mechanistic descriptions for water flow, solute transport, biogeochemical reactions, uptake of water and solutes, plant growth,… The uptake of water from the soil by plants and the exchange of solutes from the soil solution to the plant (and vica-versa) is studied on different scales: (i) rhizosphere scale, (ii) lysimeter scale, and (iii) field-scale. For the latter two scales, some of the processes will contain lumped parameters integrating (microscopic) processes occurring at a smaller scale. This presentation illustrates some model tools and codes currently available at SCK to address problems related to the soil-vegetation interactions at different scales, with special attention to the incorporation of complex biogeochemical processes and reaction networks. For the rhizosphere scale, a coupled speciation-reactive transport model (PHREEQC) was evaluated for a simple rhizosphere model considering uptake of K or Ca (with linear adsorption) by a single cylindrical root. Extension of this model by including other biogeochemical reactions or root exudation products is straightforward. For the two other scales, the HP1 code (a recently developed reactive transport model coupling PHREEQC with HYDRUS-1D for simulating water flow, transport and biogeochemical reactions in environmental soil quality problems – www.sckcen.be/hp1) is a useful tool in which the uptake of water is described by macroscopic parameters. A main limitation is that plant growth is only considered implicitly by imposing constant or time-variable root growth and potential evaporation. The possibilities of HP1 are shortly illustrated by calibration of water content series under natural boundary conditions and a hypothetical simulation of U-transport in a field soil.

Keywords:

Coupled speciation-transport models, vadose zone, rhizosphere, modelling