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AGE04-P01 Room:Convention Hall Time:May 20 17:15-18:30

Geothermal property and groundwater flow estimated from the lithology in the late Pleistocene terrace area, Tokyo, Japan

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Introduction

The ground source heat pump (GSHP) is a highly efficient and renewable energy technology for space heating and cooling, with benefits including energy conservation and reduction in greenhouse gases emission. After the Great Japan Earthquake and following nuclear disasters, GSHP is getting noticed by media and some local governments are introducing GSHP.

On the other hand, the GSHP installation under the ground might enhance pollutions in geo- heat environment or change groundwater flow due to thermal disturbance released from GSHP. In this study, the effect of the GSHP was estimated based on the 3D geological model in the Su Tokyo.

Geological model

The Tokyo metropolitan area is surrounded by the Late Pleistocene terraces called Musashino uplands. These areas are densely populated residential area. The Shimosueyohi surface is one of these terraces, which was formed along the Tama River, during the last deglacial period.

The CRE-NUCHS-1 core (Funabiki et al., 2011) was obtained from this area to know the lithology, heat transfer coefficiency and chemical characteristics of the sediments. In this study, we collected borehole data logs within 5km square surrounding the core site, and created the 3 dimensional geological model. The lithology of this area consists of the Pleistocene Kazusa Group, terrace gravels, and volcanic ash layer called Kanto loam, in ascending order. The terrace gravel layer is located mainly beneath the Kanda, Kitazawa, and Karasuyama Rivers. These rivers flow parallel with the Tama River. At the center of the terraces, Kanto loam covered the Kazusa Group without terrace gravel.

Geothemal disturbance and groundwater flow

Using the geological model, heat transfer coefficiency and groundwater flow velocity was calculated. In areas with thick terrace gravels, the heat transfer coefficient is high and groundwater flow is relatively fast. Since the terrace gravel is located at relatively shallower level (8-20m in depth), its thickness is one of the elements to affect the geothermal disturbance and groundwater flow in this area.

Acknowledgement

This work was supported by the Core Research Evolutional Science and Technology (CREST) project of Japan Science and Technology Agency (JST).

Reference

Funabiki et al., (2011) Sedimentary facies and physical properties of the sediment core CRE-NUCHS-1 in Setagaya district, Tokyo, central Japan. Abstracts (Section B) for 2011 joint annual meeting of Japan Association of Mineralogical Sciences and the Geological Society of Japan.

Keywords: Geothermal disturbance, Groundwater, Heat transfer coefficient, Terrace gravel

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Numerical Analysis of Changes in Ground Temperature Caused by Ground Source Heat Pump System using HYDRUS

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Ground source heat pump systems (GSHP) that use ground or groundwater as a heat source can achieve much higher coefficient of performance (COP) than conventional air source heat pump systems because the temperature of the ground is generally much more stable than that of the air. Heat energy in the ground is then viewed as one of the renewable energy sources. GSHP has been receiving great interests among countries in North America and Western Europe, as well as some developed countries in Asia because it can potentially reduce energy consumption and greenhouse gas emission. While GSHP can inject heat from the buildings to the ground for cooling during the summer, it can pump heat stored in the ground for heating during the winter. Although it is rarely considered, installing too many GSHP systems nearby and/or running GSHP systems for long time may disturb the ground heat source. As some physical, chemical, and biological properties of the ground and groundwater are temperature dependent, this can eventually affect groundwater quality.

The effect of heat injection and pumping on the ground and groundwater temperatures therefore needs to be accurately quantified for assessing environmental impacts. Although there have been a number of studies predicting GSHP heat injection and pumping rates, their goals were usually to design optimum GSHP systems. The main objective of this study was to develop a model that allows predicting not only ground and groundwater temperatures but also changes in physical, chemical, and biological properties with GSHP under operation.

In this particular study, we used HYDRUS software to simulate heat exchange and transfer processes in the ground for a vertical-loop closed GSHP system. HYDRUS allows one to simulate variably-saturated water flow and solute and heat transport in porous media numerically in two- and three-dimensional domains with great flexibility in defining boundary conditions. At first, for model verification, changes in ground temperatures measured at every 5-m in the 50-m observation well installed 3.7 m from the 50-m long heat exchange boreholes, in which polyethylene heat exchanger tubes had been installed, were predicted in response to Thermal Response Test (TRT) conducted at our study site. Then, heat exchange and transfer processes for the vertical closed-loop GSHP systems were simulated to predict changes in ground and groundwater temperatures using three-dimensional domains. In this simulation, inside the polyethylene heat exchanger tube and the tube itself were assumed to be porous media. Very high hydraulic conductivity was assigned to the former, while very low hydraulic conductivity was assigned for the latter so that there would be only negligible water exchange between the ground and the heat exchange tube. This study demonstrated that HYDRUS was a very effective tool to assess the environmental impact, especially the temperature changes, when GSHP systems were used for injecting heat to the ground and pumping heat from the ground.

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Thermal Properties of Non-aggregated and Aggregated Soils: Effects of Particle Size and Shape

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Thermal properties of soils including thermal conductivity and heat capacity are very important for understanding heat transport processes at landfill sites, hereunder promoting the site stabilization, and for optimizing heat treatment technique at polluted sites.

Previous studies have shown effects of soil conditions such as moisture content and degree of compaction on the thermal properties for differently-textured soils. However, there are few studies on the relations between the thermal properties and micro-scale soil information such as particle size and shape although the size and shape of soil particles highly affect soil packing configuration (solid-phase tortuosity and contact number).

In this study, non-aggregated and aggregated soils with different size fractions at variably-saturated conditions were used for measuring thermal properties. Micro-scale characterizations of soil-pore structure and soil particle configuration using a Xray-CT device were performed. Mineral composition such as quartz content was also measured for the samples. The relations between the obtained thermal properties for soils under different moisture conditions and their soil structure functions and mineral compositions were investigated.

Keywords: Thermal property, Thermal conductivity, Particles size, Particle shape, Soil-pore structure, Moisture condition

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Landfill Gases at an Abandoned Open Dump: A Case Study from Udapalatha/Gampola Site in the Central Province of Sri Lanka

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Haphazard dumping of the municipal solid waste mostly observed in developing countries, where the waste is dumped in an uncontrolled manner. Although landfill gas is an important factor which causes odor and firing and indicates stability of the waste, there are very limited studies on the uncontrolled open dumps. In this study, landfill gas samples at 1 m depth from an abandoned open dump in Udapalatha (N 7^o 09', E 80^o 35') in the Central Province of Sri Lanka were collected on the end of November 2011 and the typical landfill gas composition such as O_2, N_2, CH_4, CO_2, H_2, H_2S, and N_2O were measured. Buried waste samples at 1 m depth were also taken from the site and organic carbon and nitrogen contents in the residue (smaller than 2 mm) were measured. The samples were taken from some marked plots inside the dump with waste ages of around 0.5 and 7 years ($AOD_{0.5}$ and AOD_7) and outside intact. For comparison, landfill gas samples were also taken from another open dumping, Gohagoda (N 7^o 19', E 80^o 37') and an engineered landfill in Nuwara-Eliya (N 6^o 58', E 80^o 48'), those are under operation, in the same province.

Measured CH_4 concentration for $AOD_{0.5}$ and AOD_7 ranged in 19-58 % and 0-12 %, respectively, suggesting that the dumped waste at 1 m depth was in the process to be the 'stabilization phase', where the CH_4 concentration is normally less than 45 %, at least 7 years after dumping. This is likely to be a much shorter time period to reach the phase after dumping than those in mid-latitude regions (typically in several decades). Measured CH_4 concentration for both Gohagoda and Nuwara-Eliya ranged in 56-57 %, suggesting that the waste inside were not stabilized. The carbon contents in the waste residue in $AOD_{0.5}$ and AOD_7 were 151 and 29 mg g^{-1}, respectively, implying that high waste decomposition and leaching of organic compounds might be enhanced due to high temperature and precipitation at the site. A further study for the landfill gas and waste quality in the deeper layer is required to judge whether whole of the dumpsite had reached the stabilization phase rapidly. Besides, relatively high values of N_2O concentration were observed in some plots at AOD_7 (95 and 39 ppmv), suggesting that nitrification was stimulated due to time-dependent aerobic conditioning in the 1 m depth (measured O_2 concentration for the plots ranged in 13-18%). This indicates that nutrient leaching through runoff and surface water might give an impact to groundwater environment at open dump sites even in the stabilization phase.

Keywords: landfill gas, nutrient leaching, open dump, organic carbon, Sri Lanka, waste decomposition

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Effects of soil-water retention hysteresis on gas and heat transport parameters

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Knowledge of soil-gas and heat transport parameters is essential for understanding and simulating behaviors of greenhouse/toxic gases and changes in soil temperature at landfill sites. Degree of water-saturation at different water potentials (i.e., water retention characteristic) highly affects these gas and heat transport parameters. In this study, the effects of water retention hysteresis on the soil-gas diffusion coefficient (D_p), air permeability (k_a), and thermal conductivity (K_T) were investigated. Different sand particle size fractions with different particle shapes were used for measuring gas and heat transport parameters. The soil-water retention hysteresis highly affected the gas transport parameters, showing higher D_p and k_a values for the wetting processes than those for drying processes at the same air content. This suggests that the more continuous air-filled pore-networks in the wetting processes enhanced diffusive and advective gas transport. As compared to gas transport parameters, the effect of soil water retention hysteresis on the K_T was insignificant for all sand materials.

Keywords: soil-water retention hysteresis, gas transport parameter, heat transport parameter

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Estimation of Water Flux in Variably Saturated Soil with a Penta-Needle Heat Pulse Probe

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The penta-needle heat pulse probe (PHPP) employs a central heater needle surrounded by an orthogonal arrangement of four thermistor needles. By inversely fitting an analytical solution for two-dimensional heat transport with an infinite line source, both components of the flux in a plane normal to the axis of the PHPP needles, Jx and Jy, thermal conductivity, and thermal diffusivity can be estimated. Using estimated Jx and Jy, water flux magnitude and direction can also be calculated. In this study, the applicability of PHPP estimations was tested in both of saturated and unsaturated water flows in sand. Laboratory column experiments under steady-state saturated (flux range of 180-430 cm/d) and unsaturated (1.9-130 cm/d) water flow conditions were conducted. Two PHPPs were installed with orientations to yield water flow directions of 30^o and 45^o. In case of saturated flow condition, estimated Jx and Jy agreed well with measured water fluxes (less than 25 % relative errors), resulting in good estimations of water flow magnitudes and directions. In case of unsaturated flow condition, water fluxes estimated by PHPP with 30^o agreed well with measured flux. However, one component (Jx) from PHPP with 45^o showed a constant discrepancy (-55 cm/d) in any flow rates. This result indicates that differences of constant resistance between sand and needle, heterogeneity of the sand-water-air system, and heterogeneity of microscopic unsaturated flow in measurement area resulting from water content changes (0.38 cm^3/cm^3 for saturated flow to 0.10 cm^3/cm^3 for unsaturated flow) affect PHPP estimations.

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Numerical simulation of wetting zones generated by artificial macropores

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Introduction

Soil macropores have been recognized historically (e.g., Schumacher, 1864). Water retention characteristics of the macropores have been described quantitatively by using capillary pressure (e.g., Nelson & Baver, 1940), while transport phenomena through macroporous soils are still a research topic in geological science. Laminar flows in macroporous soils have been estimated by the dual-porosity model (Gerke & van Genuchten, 1993). Rapid flows in macroporous soils have also been characterized with non-destructive techniques for visualization of soil macropores (e.g., Capowiez et al., 2011), quantification of macropore volume (e.g. Nakashima & Kamiya, 2007), and quantitative evaluation of transport parameters for macropores (Elliot et al., 2010). As the tools for the assessment of soil macroporosity being developed, various efforts to utilize the natural processes generated by macropores are being carried out. Shipitalo and Gibbs (2000) suggested a method to dispose wastewater to soils through the network of earthworm burrows. Hirth et al. (2005) developed artificial biopores to introduce seedlings of ryegrass into soils. The authors developed an artificial macropore system to promote flows in subsurface soils. The artificial macropore has narrow (c.a. 1 cm) auger-holes filled with coarse fibrous materials (Mori, 2009). By filling the fibrous materials, erosion of the macropore walls is expected to be reduced. Rapid flows in macropores are moderated by the fillings to extend flow regions in the subsurface layers. The extended flow regions would be effective in leaching of soil contaminants, bioremediation, carbon sequestration, etc. To evaluate the wetting zones generated by the artificial macropores, a numerical simulation with Hydrus2D (PC-Progress, s.r.o.) was conducted at two types of rainfall intensity (2, 20 mm/hr) and three types of inclination (0, 5, 10 degree).

Methods

A surface-crusted loam soil was supposed for remediation with the artificial macropore. Hydraulic conductivity of the crust was set at $5.56*10^{-7}$ m/s (ca. 2 mm/hr). We supposed to use a blasted bamboo for the permeable filling. Saturated hydraulic conductivity of the filling was set at $7.00*10^{-3}$ m/s (obtained by the constant head method). To simulate overland flows with Hydrus2D, two types of approach were employed.

(1) Introducing a virtual layer for ponding water storage in Hydrus2D simulation

A virtual surface layer (Rassam et al., 2003) was set above the real soil surface. Saturated hydraulic conductivity of the layer was set at 5 m/s to avoid retardation of flows. A valley-like geometry was selected as an ideal site for the artificial macropore.

(2) Overland flow calculation with Hydrus2D

The overland flow module for Hydrus2D (Simunek, 2003; Kohne et al., 2011) utilizes the kinematic wave approximation of ponding water change with the empirical Manning hydraulic resistance. The Mannings roughness coefficient was set at 0.030 for forests with sufficient understory vegetation. Geometry of the system was simplified to a single slope for this approach. The hydraulic parameters were re-optimized to maintain water content at positive pressure values.

Results & Discussion

At 20 mm/hr rainfall intensity, the artificial macropore generated a wetting zone around the macropore (Figure 1). For both of the valley system and the single slope system, the width of the wetting zones were ca.140 cm in the inclined (5 and 10 degree) lands. The artificial macropore system was less effective in the horizontal lands. No significant difference was given by installing the artificial macropore at 2 mm/hr rainfall intensity. Base on the results, appropriate spacing of the artificial macropores should be less than 140 cm for the crusted loam soils with moderate inclinations. Inclination enhanced infiltration through the artificial macropores, but precise estimation for more realistic geometries will be conducted with COMSOL software package.

Keywords: artificial macropore, Hydrus, carbon sequestration, leaching, wetting zone, numerical simulation

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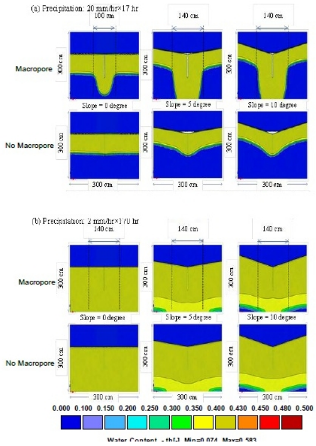

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The Effect of Artificial Macropores on the Amount of Organic Matters in soils

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I. Introduction

Reclamation of impervious soils is desirable, because soil erosion by surface runoff may have unfavorable effects on environments (e.g. nutrient loss from soils, eutrophication of downstream lakes). In this study, we scrutinized the effect of an artificial macropore system, i.e., a technique for permeability control, on the amount of organic matters in soils.

II. Experimental method

We installed the artificial macropores at an inclined site with red-yellow soil in Matsue Experimental Station of Shimane University, Japan. The adjacent plot without the artificial macropores was also monitored as a control plot. Total carbon (TC) and water content of soil samples, and ion concentration of infiltrated water samples were measured for both plots.

III. Results and discussion

Temporal variation in TC of the soil showed a trend of slight reduction at the treated plot. Cumulative amount of NO_3^- in the infiltrated water was greater in the treated plot than the control, while that of NH_4^+ was high in the control. The scatter diagram of Cl^- concentration of the infiltrated water versus cumulative rainfall during the interval of sampling suggested three categories of chloride dynamics (A, B, and C). At high cumulative rainfall, data from both the plots were laid in the same area (A) of the diagram. In contrast, when there was little rainfall, data from the treated and the control plot were classified into B and C, respectively. The gradient in the scatter diagram for B is similar to that of A, which indicates high efficiency of infiltration by the artificial macropores. Based on the results, we concluded that the artificial macropore system had promoted digestion of soil organic matter and leaching of NO_3^- through nitrification.

Keywords: environmental restoration, macropore, infiltration

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Assessment of VOCs Bioremediation Considering Microbial Inhabitation and Soil Environmental Factors

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Volatile organic compounds (VOCs) like tetrachloroethene (PCE) and trichloroethene (TCE) spread throughout the fields in Japan, which causes significant problem of soil and water pollution. PCE and TCE are biotic or abiotic decomposable pollutant. In recent years, bioremediation, purification method utilizing microbial metabolism, has become a remarkable technique due to its low-cost and environmental friendly points.

PCE and TCE can be entirely decomposed to ethen only by *Dehalococcoides*, through dichloroethene (DCE) and vinyl chloride (VC); *Dehalococcoides* is key microbes for the bioremediation. Inhabitation of *Dehalococcoides* in polluted sites is essential for in-situ bioremediation, especially biostimulation, while the distribution of the microbes and the environmental factors constraining microbial activities have not been elucidated.

To investigate the *Dehalococcoides* inhabitation and environmental factors like soil organic carbon, undisturbed cores including sandy and clayey soils were taken from several polluted sites. The cores were divided by soil texture, and the microbes and the factor items in the divided samples were analyzed.

The factor items were categorized into some groups related to anaerobic conditions, energy source, nutrients, osmotic pressure, and so forth. As an example, soil organic carbon was considered to affect appropriate anaerobic conditions, energy source, and nutrients during reductive bioremediation. The feasibility of the bioremediation was assessed based on a series of experimental data and considerable affecting items.

Keywords: VOCs, *Dehalococcoides*, Bioremediation, Environmental factor, Soil organic carbon

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Advances in and Limitations Associated with In-Situ Bioremediation of Chlorinated Solvents

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Chlorinated solvents, like perchloroethene (PCE) and trichloroethene (TCE), have been widely used by many industries, especially in developed countries like Japan. Because of their wide applications, lack of proper regulation, poor handing, storage and disposal practices in the past, chlorinated solvents have become a type of the most prevalent contaminants for soil and groundwater pollution. In recent years, the environmental concern and interest is growing for bioremediation of such chlorinated solvents, commonly called VOCs in Japan, in soil and groundwater including aquatards. Research works in the recent decades have demonstrated 3 types of biodegradation resulting in degradation of VOCs.

In this presentation, the 3 types of bioremediation, specifically reductive dechlorination, cometabolism and direct oxidation together with some recent advances in bioremediation are overviewed. The overview presented the current research trend in understanding the mechanisms of biodegradation with regard to in situ applications, including potential application to aquatards. Limiting factors in bioremediation are examined from biochemical, geochemical and hydro-geological aspects. In addition, the fusion of technologies that could be used to enhance or accelerate the bioremediation are discussed and proposed.

Keywords: Biodegradation, VOCs, Reductive Dechlorination, Cometabolism, Direct Oxidation, Limiting Factors

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Development of evaluation method on soil pollution by luminous bacteria -Effects of elution components of soil-

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Recently, a lot of soil pollutions with heavy metals or volatile organic compounds have been found in many parts of the world. The soil pollution survey and the countermeasure are required socially. The bioassay with luminous bacteria is becoming the center of attention as a simplified detection technique or an acute toxicity evaluation method on pollutants.

However, the constituents of the soils other than the pollutants shall be dissolved in the extracts. Therefore the evaluating the influence of elution components of soil is essential for applying adequately the bioassay method.

In this study, it focuses attention on alkali metal, alkali earth metal, general anions and Al, Si, Fe dissolved components as main components which will elute from soils. We report the effects of the above components on the luminescence intensity of luminous bacteria.

Keywords: bioassay, luminous bacteria, soil pollution evaluation method, soil elution components

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Heavy Metal Removal in Landfill Leachate Using Agricultural Waste Materials: A Case Study in Sri Lanka

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Heavy Metal Removal in Landfill Leachate Using Agricultural Waste Materials: A Case Study in Sri Lanka

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Abstract

Open dumping of Municipal Solid Waste (MSW) is a common practice and identified as a source of pollution for surface and groundwater resources in Sri Lanka. The objective of this study was to identify the heavy metals in leachate and soils in the vicinity of MSW dump site and to assess locally available agricultural waste materials to use as adsorbents to remediate heavy metals from polluted water. Coconut husk (CH) and saw dust (SD) was used as the adsorbents in the column and field experiments. The influent solutions were introduced from the bottom of the column using a submersible pump. Field experiment was carried out in the selected MSW landfill using concrete cylinders with 0.3 and 3 m in diameter and length, respectively. These were filled with CH and SD. Cadmium and Lead concentrations were measured in influent and effluent with time. Cadmium and Lead was found to be the most critical heavy metals in landfill leachate which possess quality rating scales of 620% and 108% based on the general standards for portable water. Removal efficiencies of both Cd and Pb by CH and SD were $>$85% at the beginning and decreased with time until the equilibrium is achieved in column experiment. In contrast, at the field, average removal efficiencies of them were $>$50% which could be due to the presence of other ions, and large particle size and variable concentration of heavy metal in the field. Hence, these agricultural wastes have potential to mitigate heavy metal pollution and more studies are needed to optimise the effective removal and to increase the efficiency of CH and SD.

Key words: coconut husk, dumping site, heavy metals, leachate, saw dust

Keywords: coconut husk, dumping site, heavy metals, leachate, saw dust

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Contamination of wetlands through transport of pollutants generated from the municipal solid waste open dumpsite, Kandy,

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Landfill leachate is well reported as a contaminant source polluting surface and ground water. Since the predominant waste disposal method still in Sri Lanka is open dumping which leads to generate significant amount of leachate mostly to nearby water sources. Gohagoda open dump site is one such location at the world heritage city, Kandy, in Sri Lanka. This leachate directly flows to the Mahaweli River which is the main water source for entire province due to absence of proper lining system or any treatment mechanism before disposal. Hence, this study was focused on characterization of leachate generated from Gohagoda dumpsite, assess their spatial and temporal variations, identify subsurface canals and perched water bodies in the wetland system affected by the leachate flow.

Leachate samples were collected monthly for one year from different points of the leachate drainage channel and tested for quality parameters as pH, temperature, EC, TDS, TS, VS, TSS, VSS, BOD5, COD, alkalinity, hardness, nitrates, phosphates, ammonium nitrogen, chloride and heavy metals (Fe, Mn, Zn, Cu, Pb, Ni and Cr). Moreover, 1D and 2D modes of resistivity data were collected from Vertical Electrical Sounding (VES) at the abandoned paddy field at the downstream of the dumpsite, towards the Mahaweli River.

Results demonstrated average values of pH 8.37, BOD5 380 mg/L and COD 1835 mg/L. Nitrate and phosphate seemed to range between 1-765 mg/L and 2-258 mg/L and high levels were observed towards wet season exceeding the allowable limits for wastewater discharge. Some heavy metals were reported in high concentrations such as Zn, Pb, Ni, Cu, Cd and Cr in average concentrations of 0.3710, 0.217, 0.207, 0.135, 0.092 and 0.061 mg/L respectivly. Concentrations were decreasing with the distance from the landfill. Leachate characteristics indicated that the leachate is in the methanogenic phase. VES results revealed that the depth to the bedrock is about 3-5m and bedrock is plunging towards the river with a gentle slope. Further, few subsurface canals were found in the abandoned paddy field area and the leachate flow is mainly confined to the near surface. In addition, no perched water pockets were observed and that may be due to the continuous flow in the subsurface. The results strongly suggest that the leachate generated from Gohogoda dumpsite may pollute the soils and waters in the close by wetland systems and the drinking water sources. The geophysical findings can be effectively used to obtain an understanding of the subsurface flow and transport of the leachate from open landfills without landfill liners.

Keywords: Landfill leachate, subsurface canals, Chemical oxygen Demand

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EFFECT OF SINGLE-SPECIES SALT SOLUTIONS ON GEOTECHNICAL PROPERTIES IN BENTONITE

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The importance of bentonite in engineered barrier systems is well recognized. This naturally occurring clay has unique properties of swelling on contact with water and very low hydraulic conductivity to liquids. In addition to these, its high cation exchange capacity (CEC), large specific surface area and ability of self-healing has made it a necessary component for the liner system of the modern engineered landfills. However, leachate produced in the landfill due to the biodegradation of waste can react with bentonite chemically and may affect its engineering characteristics. The increase in hydraulic conductivity can cause leachate to enter subsurface and pollute the subsurface environment including ground water table. On the other hand change in liquid limit is an indicative of change in other geotechnical properties including shear strength and swelling behavior of bentonite. Therefore, it is necessary to analyze the effect of chemicals present in landfill leachate on geotechnical properties in bentonite.

This study investigated the individual effect of such chemicals using single-species salt solutions of different cations, concentration and valance on the liquid limit and hydraulic performance of bentonite. A total of thirteen solutions including de-ionized water and three different solution concentrations (0.01M, 0.1M, and 1M) of four major exchangeable cations Na^{+}, K^{+}, Ca^{2+} and Mg^{2+} were used in this study.

Liquid limit tests were carried out using all the thirteen type of solutions on sodium bentonite. It was observed that liquid limit decreases with increase in salt concentration. At very high and very low concentrations, both monovalent (Na^{+}, K^{+}) and divalent cations (Ca^{2+}, Mg^{2+}) showed similar liquid limit. However, there is a large difference in liquid limit values for monovalent and divalent cations at intermediate concentrations. Effect of concentration and valance on hydraulic conductivity of bentonite was analyzed using different concentrations of NaCl and intermediate concentrations (0.1M) of all the four cations. It was observed that both concentration and valance have little effect on hydraulic conductivity of bentonite. The results suggested that hydraulic conductivity is likely to be highly controlled by the effective porosity and effective void ratio of bentonite. The tests were run upto 100 days to investigate the effect of time on hydraulic performance of bentonite and it was observed that hydraulic conductivity does not change significantly with time.

Keywords: Bentonite, Hydraulic Conductivity, Liquid limit, Landfill leachate, Effective void ratio, Effective porosity

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Sorption of heavy metals on soil and colloidal solutions and transport facilitated by soil colloids

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Heavy metals are amongst various contaminants that are released daily in the soil environment as a result of various anthropogenic activities. Soil has the ability to immobilize contaminants like heavy metal ions and sorption is a major process for the retention of heavy metals in soils. However, mobile colloids have strong ability to sorb inorganic (heavy metals, radionuclides etc.) and organic contaminants and transport these contaminants to deeper depths or groundwater. The sorption of heavy metals on soil and colloidal solutions, and transport of heavy metals facilitated by soil colloids were investigated by batch sorption and column transport experiments respectively. Batch sorption experiments of heavy metal, (Cu), were performed on red-yellow soil and colloidal solutions ($<$1 micro meter size) generated from the red-yellow soil at natural pH and low pH conditions. The results showed that at high concentration range of Cu (10 to 200 mg/L), the sorption capacity (K_d) of Cu for the soil was greater than low concentration range (0 to 10 mg/L) and high K_d values were obtained at natural pH conditions. Similarly, sorption capacity (K_d) of Cu for colloidal solutions was greater at high concentration range of Cu and natural pH conditions. However, the K_d values for colloidal solutions were much higher; 10 to 50 fold more than for the red-yellow soil. Therefore, the colloidal solutions have greater sorption affinity for Cu than soil. In column transport experiments, the colloidal fractions played a significant role in transporting Cu and almost 76% of the total applied Cu was transported by soil colloidal fractions. The mobility caused by coarse colloidal fractions (0.2-1 micro meter size) was greater, as 85 % of the total leached Cu was associated to coarse colloidal fractions. Analysis of soil after the column leaching test indicated depth dependent phenomena of Cu distribution in the soil. Therefore, this study concludes that soil colloids play an important role in facilitating heavy metal (Cu) transport through soil which may lead to contamination of groundwater.

Keywords: Sorption, Heavy metal (Cu), Soil, Colloidal fractions, Sorption capacity, Transport

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Characterization of organic carbons orienting on the surface of water repellent soils

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Water repellency of soils has been observed in various soil types such as sandy, loamy, clayey, peaty, and volcanic ash soils. Water repellency can have a range of soil hydrological consequences such as reduction of infiltration rates, acceleration of surface runoff and erosion, and occurrence of fingering flow. Therefore, proper managements of the water repellent soils are important for optimizing sustainability and productivity of farming system. In the present study, two water repellent soils were collected from a brown forest soil in Aichi Prefecture and an allophanic volcanic ash soil in Fukushima Prefecture, and the surface orientation of organic carbons on the water repellent soils were characterized by measuring pulse saturation transfer magic angle spinning (PSTMAS) 13C nuclear magnetic resonance (NMR) and cross polarization magic angle spinning (CPMAS) 13C NMR spectra. In PSTMAS spectra, mobile portions of organic carbons are intensified when comparison is made with CPMAS spectra. This phenomenon was confirmed by measuring PSTMAS and CPMAS spectra for silica particle coated with ocdadecyl group and its mixture with dimethylsulfoxide. In the PSTMAS spectra of two repellent soil samples, it was clearly shown that the peaks at around 12 and 23 ppm were intensified, indicating that the intensified carbons are highly mobile and located on the most outer surface of the soil particles. Judging from the chemical shift values of the NMR spectra, the intensified carbons were assigned as aliphatic carbon chains, such as -(CH2)nCH3. In conclusion, at least a part of aliphatic chain would present on the most outer position of the water repellent soils, and they would prevent wetting and water penetration in the soils.

Keywords: Nuclear magnetic resonance, NMR, Water repellent soils, Surface orientation, soil organic matter, soil organic carbon

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Colloidal ferrihydrite retards the appearance of Pu on the Earth's surface

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Radioactive wastes from nuclear power plants must be disposed of safely. A large amount of Pu in the wastes is sorbed to colloidal ferrihydrite and moves in groundwater. This paper describes the behavior of Pu sorbed to colloidal ferrihydrite in nuclear waste disposal sites. When the concentration of ferrihydrite is higher than 10-5 mol Fe /L, most Pu is sorbed to the ferrihydrite. Ferrihydrite persists in groundwater as long as nitrate is present. When the filtration effect of geologic media is small, the gravity moves colloidal ferrihydrite to deep underground; the velocity is 0.12 m/year when the size of ferrihydrite is 70 nm. When the filtration effect is large, ferrihydrite is not transported further. In both the cases, ferrihydrite retards the appearance of Pu on the Earth's surface.

Keywords: colloid, ferrihydrite, plutonium, transport of radionuclides, gravity effect, sorption

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AGE04-P18 Room:Convention Hall Time:May 20 17:15-18:30

Effect of water content on the soil water repellency for Japanese and New Zealand volcanic ash soils

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Water repellency (WR) of soil can induce significant hydraulic problem such as reduced water infiltration, enhanced surface runoff and erosion and the forming of preferential flow patterns in soils. Soil water repellency is reported in many parts of the world at different climatic conditions and soil types. Although WR has been observed in many countries including Japan and New Zealand, relatively few studies evaluated WR of aggregated volcanic ash soils. In the present study, the effects of water content on the water repellency of Japanese and New Zealand volcanic ash soils at different depths were investigated. Secondly, the time dependency of the contact angle in these soils at different water contents was evaluated. The degree of water repellency of the moisture content adjusted samples was assessed with the sessile drop method (SDM), the molarity of ethanol droplet (MED) test and the water drop penetration time (WDPT) test. The degree of WR varied considerably by region and depth. For the Japanese volcanic ash soils, the contact angle increased sharply with increasing water content, reached the maximum contact angle at water contents around 0.3 cm3/cm3, and then gradually decreased to 0o at field water content. A similar pattern was found for the New Zealand volcanic ash soils. . However, the contact angle of the New Zealand volcanic ash soils was greater than 100o at field water content. Directly measured contact angles using the SDM were in good agreement with indirectly obtained contact angles using the MED test. The contact angle sharply decreased with soil-water contact time in volcanic ash soil samples at higher water contents.

Keywords: soil water repellency, volcanic ash soil, sessile drop method, water droplet penetration test, molarity of ethanol droplet test

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Evaluation of management practices in agricultural and forest lands by the multiple-frequency electromagnetic surveying

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1. Introduction

Agricultural and forest lands are the possible sources of pollutant load to aquatic environments, because those lands account for large proportion of basin areas. We had successfully evaluated pollutant load from non-point sources by sampling and analyzing river water or subsurface drainage. If a large-scale soil survey is also possible, the estimation of pollutant load could be confirmed by elucidating the processes relevant to the pollution. However, the cost in time and labor for soil survey restricts opportunities of surveying large areas. The multiple-frequency electromagnetic surveying system (MFEM) enables non-destructive measurements of soil electrical conductivity profiles. The purpose of this study is to develop a procedure for efficient soil survey with the MFEM. We applied this technique to evaluate the effects of management practices in agricultural and forest lands on the soil properties. The main test sites were at Oki-islands in Shimane Prefecture, Japan. Most of the island surfaces are covered with forests, and the forests are considered as an important watershed protection area.

2. Experimental methods

We investigated nine sites at Oki-islands with a MFEM system (GEM-2, Geophex, US) on 30, 31 August, 2010. The scanned data were mapped by referring location data from a GPS device. The frequencies of the MFEM measurement were 47970, 24510, 7950, 3870 and 2310 Hz. Destructive analysis on soil moisture, electrical conductivity and soil temperature were also conducted by using a soil sensor (Stevens Water Monitoring Systems, Inc., US) at several plots in each site. Total carbon content of the surface soils were also measured by the dry combustion method.

3. Results and discussion

We could distinguish the sites by referring electrical conductivity data around surface of the soils. Electrical conductivity data at surface soils obtained by the MFEM were well correlated with those by the conventional sensor. The data were not perturbed by total organic carbon of the soils. Therefore, in this study, soluble salts could be selectively measured by the MFEM system.

By considering management practices in the investigated sites, we found higher electrical conductivity at the sites with delayed tree thinning. The delayed tree thinning had reduced understory vegetation, hydraulic conductivity of surface soil, and thickness of organic layer. The reduced understory vegetation and soil permeability would have remained soluble salts at the soil surfaces. It was also found that some of the forest sites that have been used as farmlands remained greater amount of soluble salts in the soils.

4. Summary

The MFEM system could evaluate vertical and horizontal distribution of soil electrical conductivity efficiently. By comparing the mapped data, the effects of management practices and land use history on the surface soils could be found. It was confirmed that the immediacy of MFEM technique are useful in the preliminary investigation for large areas.

Keywords: Electromagnetic sounding, land management, forest

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Grain size analysis by laser diffraction particle size analyzer.

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Grain size analysis is one of the test methods of soil physical property that has been showing many research progresses. General experimental methodology of grain size analysis is determined with reference to Japanese industrial standards (JIS). But this methodology requires great effort and long time in case of carrying out many experiments. In this study, soil grain size was analyzed using laser diffraction particle size analyzer (LDPSA). Through the results, expediency of LDPSA was examined for soil grain size analysis. In the results, there were differences in the amount of fine soil grain in soil samples between JIS methodology and LDPSA methodology. Additionally, fine soil grain increased with decrease in total carbon in the soil samples. Maybe because of soil aggregate was loosed with decrease in TC. With all these factors, it was found that it was difficult form comparison of the results between JIS methodology and LDPSA methodology. However, LDPSA proved useful in transition analyses of same samples.

Keywords: Laser Diffraction Particle Size Analyzer, Grain size analysis, Soil organic matter

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Input rate of sublacustrine gas into Lake Nyos (Cameroon, West-Africa) inferred from diffuse CO2-flux measurement and hy

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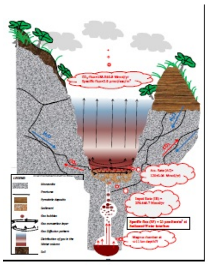
Because of its importance to understand the mechanism and the origin of the mid 1980s fatale exhalation of gas, mainly magmatic carbon dioxide (CO2) from Lake Nyos, on one hand, and on the other hand, for the sake of preventing and management of future gas explosion related hazards in Nyos area, the hydrothermal system of the lake was extensively investigated over the last quarter the century with the objective to quantify CO2 recharge rates and determine the feeding paths. More than 25 years after the catastrophe which killed 1734 people in the North-West Region of Cameroon, we revisit the question which remains of primary importance with regards with the extraordinarily high rate of gas build-up observed soon after the gas disaster. Based on results of diffuse CO2 measurement (CO2-flux) surveys we conducted in January 2009 and information on the hydrological system, input rate from hydrothermal system was estimated at 258.4 (0.7) Mmol/yr. The value estimated above using a mass balance equation CO2inp=CO2acc+CO2flux, (where CO2input CO2acc and CO2flux stand for inputs from hydrothermal system, accumulation rates and diffuse CO2 loss respectively) implies about 42.6 (0.3%) of gas supplied from beneath the lake accumulates to constitute the time bomb. If we compare the gas rate and the ground water input rate at depth below 50 m of 9 l/sec estimated from hydrological observations, the ensuing gas-

rich water would attain a concentration of 0.9 mol/l implying 136% saturation (e.g saturation level of 0.630 mol/l maximum) at system pressure (210 m depth). We believe that the high gas-rich water supply type model which was more or less accepted for past several years is incompatible with observations above because of the plumes gas oversaturated waters may generate. Instead, we advocate for a diffusional type model in which gas is supplied in the form of pure CO2 distributed throughout sediment/water interface where the specific flux would be 23 micromol/sec/m2. The view complements well the absence of horizontal anomalies (gas is evenly distributed) as suggested by several transect profiles of the lake. Else, this study permits distinguish between the recharge rate (=accumulation rate) which relates to time required for the event to repeat itself and the input rate related to activity of sublacustrine system.

Keywords: CO2-flux, Lake Nyos, gas exhalation, time bomb



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Measurement of pore velocity by using LAT-PIV, and parameter estimation of CTRW

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In recent years, the problem of soil pollution has been concerned in Japan. Soil pollution has some problems. For example, while soil pollution is close to us, but we could hardly to feel the pollution itself. Furthermore, the remediation of ground requires enormous costs and long time. This is the reason why we have to predict and take measures in early stages.

Recently CTRW (: Continuous Time Random Walk) model has been widely attempted to predict the behavior of substances in the groundwater. This model can describe the anomalous diffusion that it is difficult for ADE (Advection-Dispersion Equation) to describe. However, in the CTRW model, it is one of the most difficult problems that the model parameters cannot be fixed a priori.

In this study, we proposed a method to estimate the parameter A of CTRW by using the LAT-PIV (Laser Aided Tomography-Particle image velocimetry) method. LAT-PIV is a method that can visualize the internal structure of porous medium, and the behavior of tracers in fluid. We packed the glass beads of 2mm-5mm and 5mm-10mm in the clear plastic box (10 cm in length, 10 cm in width, 40 cm in height), and then filled the acryl box with silicone oil and tracer particles. Silicone oil is poured with the pomp at constant flow velocity, and razor sheet is irradiated to the plastic box from the side. We can hereby observe the internal behavior of porous medium. We conducted experiments and obtained the histogram of the pore velocity in the porous medium. After that, we calculated the value of A from the shape of histogram.

In this computer program which outputs pore velocity, the pore velocity is calculated by comparing two continuous visualized images. In this process, every image is divided into 1536 parts (48 by 32 parts) and the pore velocity is calculated at each grid. At this time, each grid searches the grid where tracers moved.

However, we found two problems in this process. When searching the exact grid where tracers moved, some unexpected pore velocities are calculated because the glass beads are distributed in various places. To avoid calculating these abnormal velocities, we improved this computer program. The glass points are shown by black pixels in images. We replaced these black points with red pixels that shows pore fluid. Because of this improvement, we succeed in reducing some unexpected pore velocities.

Another problem is that the zero velocity is calculated at the almost black grid (showing almost glass beads), which does not actually show the behavior of tracer particles. To make this computer program not to calculate such zero velocity, we set a certain threshold value. Because of this improvement, each grid became be able to decrease the zero velocity one tenth in comparison with the original.

As a result of analyzing the images by using improved algorism, we obtained some pore velocity distributions. From the pore velocity distribution, we estimated the value of A. When we used the glass beads of 5mm-10mm, the value of A was 0.635, and when we used the glass beads of 2mm-5mm, the values of A were 0.979 and 0.916. From this result, we found that the size of glass beads influences the value of A, on the contrary, the flow rate is not related to the value of A.

Keywords: soil pollution, anomalous transport, continuous time random walk, heterogeneity, PIV, porous medium

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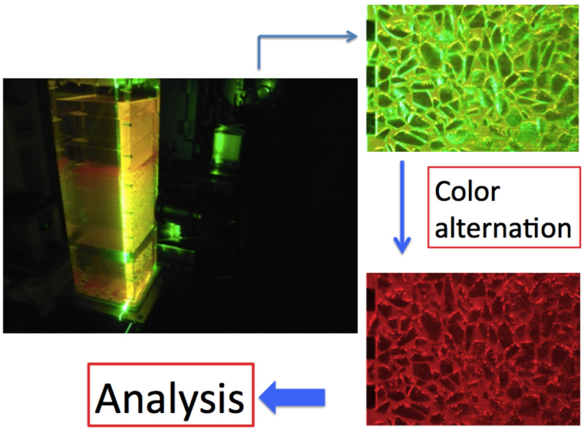

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AGE04-P23 Room:Convention Hall Time:May 20 17:15-18:30

Study of the aboveground hydrological processes in an unmanaged coniferous forest

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Through field observations we monitored the hydrological processes by measuring gross precipitation (P), throughfall (TF), stemflow (SF), transpiration (Et) and evaporation (Ef) in the Japanese cypress plantation forest floor throughout the 2011 wet season (June-October) in Karasawa Mt., Tochigi Prefecture, Japan. Previous studies have shown the different hydrological components separately. However the interaction of each and every component as a system has not been investigated in one unit. Therefore, in this study, individual components of the hydrological processes were quantified and below ground water storage was estimated by water mass balance equation. Field measurements and hydrograph analysis showed that of the 882.2 mm of cumulative gross precipitation generated by 30 rainfall events during the study period, throughfall, stemflow, and interception loss accounted about 70.6% (622.8 mm), 11.4% (100.7 mm), and 18.0% (158.7 mm), respectively. 82.0% (723.5 mm) of cumulative gross precipitation reached the forest floor, while 16.2% (152.3 mm) was lost through transpiration and 13.1% (123.1 mm) was evaporated from forest floor. According to water mass balance equation, below ground water storage was about 50.7% (447.5 mm), which composed of almost half of cumulative gross precipitation, in other words, 49.3% (434.7 mm) of gross precipitation were consumed in the unmanaged Japanese cypress forest. Daily stand transpiration varied from 0.09 to 2.53 mm day-1 with a mean value of 1.48 mm day-1, and daily evaporation loss from forest floor spread from a minimum value of 0.26 mm day-1 to a maximum value of 3.7 mm day-1 with a mean value of 1.2 mm day-1. Thus, in the unmanaged and dense Japanese cypress plantation forest, the following water loss order can be identified: canopy interception > transpiration > forest floor evaporation. This implies that through forest management and correcting the canopy density, it is possible to improve the ground water capital and water storage capacity of the entire forest watershed.

Keywords: Precipitation, Throughfall, Stemflow, Transpiration, Evaporation, Japanese cypress

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Process-based modeling of chemical weathering: A step to reduce model complexity

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Riverine export of major and minor elements to the oceans plays an important role in global biogeochemical cycles. Understanding the response of riverine export to environmental changes over various time- and spatial-scales is therefore essential for prediction of future changes in riverine chemistry including nutrients and pollutants.

Although quantification of chemical weathering rates has been recognized as one of the most important challenges to understanding the Earth system, there remain two scientific and technical problems to be resolved: a significant discrepancy between field- and laboratory-scale weathering rates and computational load for integration of process-based weathering models to large scale climate models such as general circulation models.

A new process-based chemical weathering model was developed to examine possibilities of a reduction of the computational load without losing its ability to reproduce riverine major ion concentrations. We applied the model with full complexity (i.e. vertically one-dimensional heat, moisture, gas, and solute transport and dissolution/precipitation of all minerals) to three different small watersheds to verify the model to reproduce major ion concentrations of modern streams. Then, we reduced model complexity by removing its vertical dimension and/or reducing the number of minerals to be considered. We will present sensitivity of the model results to the reductions of model complexity, and discuss how such process-based weathering models can be applied to environmental studies.

Keywords: chemical weathering, process-based modeling, stream chemistry

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Estimating soil hydraulic properties obtained from evaporation and multi-step outflow experiments

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Inverse modeling using data from transient experimental methods such as multistep outflow (MSO) method and evaporation (EVP) method are frequently used for estimating unsaturated soil hydraulic parameters. However, comparisons between different inverse results obtained from MSO and EVP methods are scarce in the literature, especially for organic-rich soils with low bulk density, e.g. Andosol. The objective of this study was to determine and compare unsaturated hydraulic properties of Andosol from data collected using both methods. Undisturbed soil core samples (5.0 cm in i.d. and 5.1 cm in height) were taken from soil at a depth of 0-5 cm. The packed soil samples were also used for the experiments. After the MSO method, the same soil core samples were saturated again for the EVP method. The MSO method yielded a set of pressure heads (h_{MSO}) or cumulative water outflow (Q_{MSO}) vs. time while the EVP method obtained a set of pressure heads (h_{EVP}) or cumulative water flux (V_{EVP}) vs. time. A one-dimensional model based on Richards' equation, HYDRUS-1D (ver.4.14), was then used to analyze data to estimate soil unsaturated hydraulic parameters. The unknown parameters were accomplished by minimizing the objective functions which described the differences between observed and estimated h_{MSO}, h_{EVP}, Q_{MSO} and V_{EVP}, respectively. The results could be important in determining the agreement of soil hydraulic parameters obtained from both experiments and provide more precise and accurate characterization of water and solute transport.

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Applicability of Ground Penetrating Radar for investigation of vadose zone in arid land

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We evaluate the applicability of Ground Penetrating Radar(GPR) for characterization of subsurface structure and groundwater in arid land, which control the transport phenomena of water and solute transport in vadose zone.

We conducted the field test in the fields of Arid Land Research Center, Tottori university, using the GPR system with shielded antennas of dominant frequencies, 100,200,400,500,900,1.5GHz. Soil type in the field is almost uniform sand, and water content of soil is around or lower then 5%. Then soil is considered to be lossless media in electric magnetic sense. Penetration depth of each antenna is deeper than values usually reported . For example penetration depth of the system with 100MHz antennas is considered to be in the range from 20 to 30m.

We visualize 3D subsurface structure using the 100 MHz antenna. The obtained image shows the distribution of ground water table and layer which seems volcanic ash seam in sand and will control water recharge process in vadose zone.

Keywords: Ground Penetrating Radar (GPR), Vadose zone, Subsurface structure, Arid land

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Predicting Soil CO_2 dynamics in the vadose zone of Andisol in Western suburb of Tokyo

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[1]University of Tokyo

Soil retains two to three times more carbon (C) than the atmosphere dose[1)]. To simulate the soil CO_2 dynamics, the effects of soil respiration on C storage, which is sensitive to soil temperature and moisture, must be evaluated quantitatively. Model investigations of soil CO_2 dynamics have been conducted mainly for forest soils. Recently, C capture and storage by soil has been recognized as a function of agricultural field, and capacity of C storage in arable land has been discussed. For example, compost application to agricultural field has been attempted to increase C storage in soil. The objective of this study is to predict soil CO_2 dynamics in the arable land using HYDRUS[2)].

For model validation, continuous monitoring has conducted at Institute for Sustainable Agro-ecosystem Services of the University of Tokyo (ISAS) in western suburb of Tokyo. The soil of 0 to 35 cm under the surface was Kuroboku andisol, and below it to 100cm, Tachikawa loam andisol was distributed. A 10 m square bare area was prepared for study site. Soil moisture and temperature at eight depths and soil CO_2 concentration at three depths were measured every 20 minutes from Jul. 2010 to Sept. 2011. CO_2 efflux from the surface was measured with closed chamber method in both summer and winter. Meteorological data was obtained from ISAS and AMeDAS station located in Fuchu city, near the field.

In the simulation, considering the vertical distribution of dry bulk density and soil texture, simulation area was divided in three layers i.e. cultivated, hardpan and Tachikawa loam layer, respectively. Durner-Mualem model[3)] was employed for soil hydraulic function and parameters were determined by inverse analysis with evaporation method[4)]. Volumetric water content at saturation Q_s is an important parameter to predict diffusion of CO_2 through air filled pores in a variably saturated soil. In this study, porosity of the field soil was employed asQs. Chung and Horton[4)] model was used for soil thermal conductivity. Parameters for CO_2 production were referred to Buchner et al.[5)].

Simulation of soil CO_2 dynamics, including CO_2 production and transport, was conducted using HYDRUS-1D from 1st Jan. 2010 to 30th Sept., 2011. In the model, since CO_2 production rate is affected by soil moisture and temperature, HYDRUS first simulates the soil water and heat transport and then production and transport of CO_2 are predicted.

Initial conditions (I.C.s) were determined with preliminary calculation from 1st Jan. to 31st Dec., 2010. Boundary conditions (B.C.s) for water movement were hourly observed rainfall and daily evaporation rate which had been calculated with meteorological sub model of HYDRUS. Separately calculated soil surface temperature using meteorological data and energy balance equations were given for thermal B.C.. Atmospheric CO_2 concentration was applied for B.C. of CO_2. The final results of the preliminary calculation were employed as I.C.s for exact numerical simulation. Then simulated values were compared with monitored data for model validation.

The model could describe well the daily and seasonal variation of soil moisture, temperature and CO_2 concentration. Predicted CO_2 concentration at the hardpan layer was higher than other layers because of the small diffusivity of dense hardpan layer. This phenomenon had been observed in other field where hardpan layer existed[6)]. Predicted cumulative CO_2 flux for a year was also comparable to the value which was estimated with observed data. HYDRUS could simulate the soil CO_2 dynamics in arable land well.

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Keywords: Soil CO_2 dynamics, Field monitoring, Numerical simulation

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Ecosystem Modeling for a Temperate Grassland Wind-Erosion Scheme

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Temperate grasslands are significant or potentially significant source for dust emission; however, detailed relationships among dust emission and characteristics of grasslands, in particular the special roles of vegetation and grazing are not well documented. Moreover, existing dust models do not have sufficient capability in modeling vegetation growth and decay, which play a major role in temperate grassland aeolian processes. In this study, we assessed the grassland ecosystem model (DAYCENT) for its capability to provide estimations of vegetation dynamics under different grazing conditions in order to incorporate into a temperate grassland wind-erosion scheme. DAYCENT model was parameterized with the field experiment data (soil physical/chemical properties, vegetation and grazing) at the Bayan Unjuul (BU) site in 2010-2011. BU is located in north of the most frequent dust outbreak region in Mongolia. The results from the model have been validated 8-years (2003-2010) plant phytomass (Live, dead, and litter) and species, and soil data obtained at the grazed and un-grazed areas at the BU. Generally, the model performed reasonably well in simulating seasonal and interannual variations in the observed plant production. However, some discrepancies may be due to the fact that the model does not consider year-to-year changes in plant species composition. It is important to note that the model could simulate realistically the effect of grazing on grasslands and vegetation memory, which suppressed dust outbreaks. Therefore, this model will provide a useful tool for dust emission study in temperate grasslands.

Keywords: Temperate grasslands, Ecosystem modeling, Integrated Wind-Erosion Scheme, Dust emission, Vegetation