AGE03-01　　　　　　会場:213　　　　　　　　　　時間:4 月 30 日 10:00-10:15

Concentration and Potential Mobility of Trace Metals in Surface Sediment of the North Pacific Ocean By BCR Sequential

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Metals can accumulated in sediment, sludge and soil may therefore pose an environmental problem concerning possible metal transfer from sediment to the aquatic system and including them in the food chain. European Community Bureau of Reference (BCR)sequential methods commonly used to trace metals in the sediment or soil samples and can be provide information about bio-availability, mobility or toxicity which are basically depend on the chemical bonding between metals and solid phases of the samples.

Geochemical fractionation of Cadmium (Cd), Lead (Pb), Cobalt (Co), Zinc (Zn), Iron (Fe) and Manganese (Mn) in sediment of the North Pacific Ocean were determined using four-stages of modified BCR sequential extraction methods combination with ICP-MS. Also the contamination factors and risk assessment code effects on surface sediment samples are discussed.

The mean contents of the trace metals in surface sediment of the North Pacific Ocean were: Cd: 0.00; Pb: 13.94; Mn: 2732.94; Fe: 29795.10; Co: 22.16; and Zn:76.75 μg.g^{-1}, allowing to arrange the trace metals concentration from higher to lower were in the following order: Fe › Mn › Zn › Co › Pb › Cd. Pb was distributed in three fractions (acid soluble, reducible, and residual). Mn and Co were found in a group with mainly reducible fraction, while Fe and Zn were mainly in residual fraction. The high contamination factor was obtained for Mn and Co in the sediment samples, while the lowest was found for Fe. The result showed non risk for Fe, Co, Pb and Cd, while low risk is indicated for Mn and Zn at all stations.

キーワード: trace metals, BCR sequential extraction, North Pacific Ocean
Keywords: trace metals, BCR sequential extraction, North Pacific Ocean

Leaching Properties of Naturally Occurring Heavy Metals from the Soils around Abandoned Metal Mines

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The major threats to human health from heavy metals are associated with exposure to lead, cadmium, mercury, chromium, arsenic, as well as selenium, fluorine and boron. The effects of such heavy metals on human health have been extensively studies and officially reviewed by international organizations such as the WHO and heavy metal pollutions have been regulated by national environmental standards and/or laws such as the Soil Contamination Countermeasures Act in Japan.

Leaching of naturally occurring heavy metals from the soils around abandoned metal mines into surrounding water systems, either groundwater or surface water systems, is one of the major pathways of exposure. Therefore, understanding the leaching properties of toxic heavy metals from naturally polluted soils is of fundamentally importance for managing abandoned metal mines, excavated rocks discharged from tunneling and/or selecting a pertinent countermeasure against pollution when it is necessary.

In this study, soil samples taken from the surroundings of abandoned metal mines in Tochigi, Miyagi, Yamagata, Akita and Iwate prefectures in Kanto and Tohoku regions were collected and analyzed. The samples contained multiple heavy metals such as lead, arsenic and chromium. Standard leaching test and sequential leaching test considering different forms of contaminants, such as trivalent and pentavalent arsenics, and trivalent and hexavalent chromiums, together with X-ray Fluorescence Analysis (XRF), X-ray diffraction analysis (XRD) and Cation Exchange Capacity (CEC) tests were performed. This presentation illustrates the details of the above experimental study, discusses the relationships among leaching properties, and chemical and mineral compositions, indicates the difficulties associated with remediation of naturally polluted sites, and emphasizes the importance of risk-based countermeasures against naturally occurring heavy metals.

キーワード: Naturally occurring, Heavy metals, Leaching properties, Mineral composition, Bulk concentration
Keywords: Naturally occurring, Heavy metals, Leaching properties, Mineral composition, Bulk concentration

AGE03-03 　　　　　　　 会場:213 　　　　　　　　　　　　　　 時間:4 月 30 日 10:30-10:45

不飽和層の影響を考慮した透水係数推定のための自然電位分布逆解析手法の研究
Self-potential inversion for the estimation of hydraulic conductivity in the presence of unsaturated zone

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Self-potential (SP) is the electrical potential naturally generated in and on the earth. The positive electrical charge in the diffuse layer of the electrical double layer is conveyed by the groundwater flow. The electrical potential is generated when the groundwater flow through the porous medium. This electrical potential directly reflects on the Darcy velocity in the porous material, and therefore the hydraulic conductivity can be estimated from the SP data. The hydraulic conductivity has non-linear characteristics as functions of the water saturation, and so does SP. These features suggest that the effect of the unsaturated zone should be considered for much quantitative analysis of SP. However, the dependency of the SP on the water saturation makes the development of inversion difficult. We solved this problem with the adjoint state method for the calculation of the sensitivity matrix that could save the calculation time. The characteristic of water saturation in SP based on Van-Genuichen model is adapted to our inversion. We applied our inversion to a synthetic SP profile to test the performance of our inversion scheme to compare the results with and without the consideration to unsaturated zone. When the effects of the unsaturated zone are not considered, the value of estimated hydraulic conductivity is underestimated. On the other hands, more accurate image could be derived from the inversion with the consideration to the unsaturated zone. Therefore, our inversion technique would allow us to obtain the accurate hydraulic conductivity structure from SP data at the ground surface, although the SP is affected by the distribution of saturation.

キーワード: 自然電位, インバージョン, 透水係数, 不飽和層
Keywords: Self potential, Inversion, Hydraulic conductivity, Unsaturated zone

AGE03-04　　　　　　会場:213　　　　　　　　　　時間:4 月 30 日 11:00-11:25

Root Water Uptake and Soil Water Storage in a Karst Savanna on the Edwards Plateau, Texas, USA

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Woody plants, especially Ashe juniper (Juniperus ashei) and honey mesquite (Prosopis glandulosa), are encroaching into a karst savanna on the Edwards Plateau in central Texas. However, their impact on hydrology is unclear because of high variability in soil depth and uncertainties about shallow and deep root contributions to water uptake in rocky soil overlying bedrock or other substrates that limit water storage capacity and root growth, and create high spatial variability in plant available water. This complex below-ground structure, while not uncommon, has of not been adequately characterized by most hydrological models. We evaluated root water uptake and water storage in the karst of the Edwards Plateau, at a typical savanna site with ~50% woody cover, mainly Ashe juniper (Juniperus ashei) and honey mesquite (Prosopis glandulosa). Water content profiles to a depth of 1.6 m were measured by neutron thermalization and time domain reflectometry at 36 locations in a 25-by-25 m grid (5 m node spacing). Bulk density profiles were measured by gamma densitometry. Temporal changes in water storage were compared with eddy covariance measurements of evapotranspiration (ET) to evaluate relative amounts of ET originating from root water uptake at various depths. Water storage capacity in the measurement grid ranged from 185 to 401 mm, and coupled with heterogeneous distribution of trees created high spatial variability in root water uptake. Water uptake was higher beneath trees than beneath grass, in part because tree roots were able to extract water from regions of the root zone with high rock density. On average, 81% of the water uptake occurred from the upper 1 m of the profile with the greatest uptake occurring at depths of 0.4 to 0.8 m. An estimated 10% of the uptake occurred from below the maximum measurement depth of 1.6 m. While this result confirms the hypothesis that trees on rocky substrates take up water from greater depths compared to similar ecosystems on soil, it also refutes the view that trees in karst regions have greater access to groundwater.

Keywords: Root water uptake, Karst, Evapotranspiration, Spatial variability

AGE03-05 　　　　　会場:213 　　　　　　　　　　時間:4 月 30 日 11:25-11:50

5 線熱パルスセンサーによる黒ボク土中の水分フラックスの推定について
Estimation of Water Flux in Andisol with a Penta-Needle Heat Pulse Probe

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The potential for using heat pulse probes for estimating soil water flux as well as soil thermal properties has received more attention this past decade. Although many studies were carried out to validate water flux estimation using heat pulse probes in sandy soils, few studies were reported for other soils. The purpose of this study was to estimate water fluxes in an aggregated Andisol using a heat pulse probe, and investigate the applicability with hydrodynamic dispersion in a soil.

The Penta-needle heat pulse probe, which has a central heater needle surrounded by two pairs of orthogonally arranged thermistors, was used to estimate two directional water flux. Steady-state saturated water flow and unit-gradient unsaturated water flow experiments were conducted in Mie Andisol. To achieve saturated conditions, the Andisol was packed in the column with a bulk density of 0.85 g/cm^3 and afterward it was saturated by applying water from column bottom. A glass filter was located at the bottom of the column. $CaCl_2$ solutions were applied from the top of the column at fixed rates using a peristaltic pump, and outflows from the bottom were measured by a scale. The flow rates were decreased stepwise from fast (around 350 cm/day) to slow rates (around 5 cm/day). Using faster flow steps, steady state saturated water flows were developed. Steady state conditions for unit-gradient - unsaturated water flow were developed by controlling suction at the column bottom, in which water contents were uniform and water flowed by gravity. At each flow steps, heat pulse measurements were conducted, and the influent solution concentrations were changed to obtain breakthrough curves (BTCs) by measuring soil electrical conductivities with four-probe salinity sensors. Water fluxes were estimated by applying an analytical solution to temperature rise data. Dispersivities were determined by applying the convection-dispersion equation to BTCs. Each experiment, including packing soil and water flow testing, were repeated a few times.

In saturated conditions, water fluxes estimated by the heat pulse probe agreed well with independently measured water fluxes in one experiment and underestimations were found in two cases. For unsaturated conditions, estimated water fluxes agreed well with actual fluxes even in the experiment with disagreement in saturated conditions. The flux estimation errors were compared with dispersivities which can be interpreted as the scale of water flow spreading from mean displacement position. Large estimation errors were found for experiments with large dispersivities ($\lambda > 1.5$ cm), while errors were relatively small for conditions with smaller dispersivities both in saturated and unsaturated water flows. Generally, dispersivity values in aggregated Andisol is larger in saturated condition than in unsaturated condition. The experimental results in this study indicates that the applicability of heat pulse probe to aggregated soils potentially results in better water flux estimation in unsaturated conditions.

キーワード: 水分フラックス, 熱パルスセンサー, 黒ボク土, 分散長
Keywords: soil water flux, heat pulse probe, Andisol, dispersivity

ボーリングコア試料より求められた熱物性値の地球統計学的補間に関する研究
Geostatistical Interpolation of Thermal Properties of Boring Core Samples

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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. Although use of GSHP systems has been rapidly increasing worldwide, environmental impacts by GSHP systems have not been fully investigated. To rigorously assess GSHP impact on the subsurface environment, instead of relying on "effective" properties, ground thermal properties including thermal conductivity and heat capacity need to be accurately characterized.

A geostatistical least-square interpolation method, known as kriging, has been used to characterize the spatial distribution of soil (or ground) physical (both hydrological and thermal) properties in one, two, and three dimensional domains. Kriging can estimate not only the values of an attribute at un-sampled locations accounting for spatial correlations between variables but also their uncertainties in terms of an error variance. Ordinary kriging (OK) which estimates unknown value as a linear combination of neighboring observations is one of the most commonly used kriging estimators. A secondary variable which is spatially cross-correlated with the primary variable can be used to reduce the estimation variance for the primary variable. Such method is known as cokriging. Ordinary cokriging (OCK) is one of the most commonly used cokriging estimator. The objective of this study was to compare OK and OCK in terms of estimating soil thermal properties along 50-m boreholes through the cross validation. Water content and sand content, which are relatively easy to measur, were used as the secondary attributes in cokriging.

In this study, undisturbed boring core samples were collected from two 50-m long boreholes at the campus of Tokyo University of Agriculture and Technology in Tokyo. Volumetric heat capacity (HC), thermal conductivity (TC), gravimetric water content (WC) and volumetric sand content (SC) were measured every 10-20 cm along the cores. The impact of sampling intensity on prediction errors were investigated by drawing random subsets of increasing size and using them to predict thermal properties at the remaining locations (jackknife approach). Then, subsets of N data were selected randomly or randomly per 10-m depth from the entire data set. For both sampling approaches, 50 different random subsets were selected to account for sampling fluctuations. Thermal properties at the remaining locations were then predicted.

This study showed that increasing the size of the subset leads to smaller mean absolute error. It was also found that kriging with random subsets per every 10-m depth yields lower mean absolute error than that with random subsets. Prediction errrors by OCK were smaller than those by OK when the sampling intensity was the same.

Keywords: thermal conductivity, kriging, cokriging, sampling intensity, prediction error

AGE03-07　　　　　　　　　会場:213　　　　　　　　　　　　時間:4 月 30 日 12:05-12:20

Evaluation of Tangential Model Parameters with Respect to Various Soil Types

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Usage of Tangential model (Kohgo, 1995) for Soil Water Retention Curves (SWRCs) fitting requires knowing its parameters which are the numerical values of the coordinates of 3 tree points that are selected on the SWRC obtained from an experiment. Performing such an operation might be time consuming and may also lead to errors in the parameter estimation. This study aims to estimate these parameters and investigate possible relations between the parameters and some basic soil properties. SWRCs data and their corresponding hydraulic and physical properties were taken from the Unsaturated Soil Hydraulic Properties Database (UNSODA). The selected data consisted of 458 soils; among them: sand, sandy loams, loamy sands, sandy clay loams, silty loams, silty clay loams and silty clays. These SWRCs were fitted to Tangential model using nonlinear regression analysis with solver, the in-built Microsoft Excel tool. The iteration procedure, in solver, was the Generalized Reduced Gradient method. Results showed that the model performed well. The sum of the squared residuals (SSR) varied between 0.00011 and 0.2114 for sand and sandy soils, while it ranged between 0.021 and 0.00017 for all the others. Highest SSR values were noted with coarse sandy soils while the lower SSR values were noted with materials of finer structure. This suggests that this model is more adapted to fine structured soils. An attempt is being made in order to predict the Tangential model parameters, through multiple linear regression analysis, by using the soil bulk density values, saturated volumetric water content and the soil grain size distribution data.

キーワード: soil water retention curves, simulation, UNSODA, parametric model, fitting
Keywords: soil water retention curves, simulation, UNSODA, parametric model, fitting

発光バクテリアを用いたバイオアッセイによるメッキ金属に関する土壌汚染濃度の定量化
Quantification of soil pollution concentration of plating metals by bioassay using luminous bacteria

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　メッキに深く関係する物質である Cd、Cr(6+)、Pb、As、CN は土壌汚染対策法によって第二種特定有害物質として規制されているが、その他の多くのメッキ金属はこの法律の対象にはなっていない。しかしながら、第二種特定有害物質以外にも、メッキ金属として使用されている重金属類の中には、過剰に摂取すれば人体に対して有害となり得る物質もあり、第二種特定有害物質同様にリスク評価等を行う必要性があると考えられる。
　一方、有害物質に関する急性毒性評価試験のひとつに発光バクテリアによるバイオアッセイがある。急性毒性の強さと有害物質の濃度との間には通常相関関係があるため、この急性毒性影響の強さから有害物質の濃度を概算できる可能性がある。
　本研究ではメッキ金属として広く一般に使われている Fe、Ni、Cu、Zn、Ag 及び Sn に着目し、発光バクテリア（Vibrio fischeri）を用いて系統的なバイオアッセイ試験を実施した。そして、得られたデータを基に詳細な解析を行い、各メッキ金属濃度と急性毒性の強さとの相関関係の定量化を試みた。

キーワード: 土壌汚染, メッキ金属, 発光バクテリア, バイオアッセイ, 定量化
Keywords: Soil contamination, Plating metal, Bioassay, Luminous bacteria, Quantification

AGE03-P02　　　　　会場:3 階ポスター会場　　　　　時間:4 月 30 日 14:00-15:15

荒川低地海成堆積物の地下水水質に原位置長期熱負荷が与える影響
Effects of in-situ, long-term thermal loading on groundwater quality in marine sediments of Arakawa Lowland, Japan

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Subsurface temperature increase ("subsurface warming") has been documented below many large cities worldwide. The observed subsurface temperature increase has shown close relations with surface warming effects due to global warming and urbanization. Recently, ground source heat pump (GSHP) systems have become popular as a renewable energy technology for space cooling and heating. Operation of GSHP systems for space cooling discharges waste heat into the subsurface environment and, thus, induces additional subsurface temperature increase. However, any potentially negative impacts of GSHP-induced temperature increase on the subsurface environment have not been studied in detail. The objective of this study was therefore to investigate the effects of in-situ, long-term thermal loading on groundwater quality.

A GSHP system was installed in a 50-m deep borehole with a corresponding 50-m long U-tube heat exchanger at the campus of Saitama University in the Arakawa Lowland, Japan. Four groundwater monitoring wells were installed in a marine sand sediment aquifer (around 17-m depth) at 1-m (W1), 2-m (W2), 5-m (W5), and 10-m (W10) distance from the U-tube. At each monitoring well, temperature detectors were placed in 10 depths at approximately 5-m interval, and the subsurface temperature was monitored before and during thermal loading. For the thermal loading, approximately 40 ℃ water was circulated inside the U-tube heat exchanger for 13 months, and groundwater was frequently sampled from all four monitoring wells every 1 to 2 weeks. A wide spectrum of chemical properties (including pH, EC, DO, ORP "oxidation-reduction potential", dissolved gases, dissolved organic carbon, inorganic ions, and trace elements) were measured to characterize groundwater quality.

The subsurface temperature at the nearest monitoring well (W1) increased gradually with approximately 8 ℃ from 17 ℃ (baseline) to 25 ℃ during 13 months of thermal loading. In contrast, at the farthest monitoring well (W10), there was no significant change in subsurface temperature, and W10 was therefore selected as a reference (non-temperature affected) monitoring well. A number of chemical components in the groundwater, including boron and potassium, increased markedly at W1 compared to W10. Since marine sediments typically contain high concentrations of chemical components including boron and potassium, the observed increase in groundwater concentration is likely due to thermally-induced dissolution and/or desorption from the marine sediment. The possible mechanisms behind the observed concentration increases will be discussed.

Keywords: subsurface temperature, thermal pollution, long-term thermal loading, GSHP, marine sediment, groundwater quality

AGE03-P03　　　　　会場:3 階ポスター会場　　　　　時間:4 月 30 日 14:00-15:15

Characterization of water repellency parameters in soil water repellency characteristic curves for JP and NZ soils
Characterization of water repellency parameters in soil water repellency characteristic curves for JP and NZ soils

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WIJEWARDANA, Senani[1]* ; KAWAMOTO, Ken[1] ; MULLER, Karin[2] ; CLOTHIER, Brent[3] ; HIRADATE, Syuntaro[4] ; KO-MATSU, Toshiko[1] ; MOLDRUP, Per[5]

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Soil water repellency (SWR) is the phenomenon where soil does not wet when water is applied to its surface. Characterization of water repellency in natural soil is very important to understand the soil hydrological processes, surface flow and infiltration rates. Objectives of this study were (i) to characterize SWR using molarity of ethanol droplet (MED) test, sessile drop method (SDM) and water drop penetration time (WDPT) test, and (ii) to identify the relationships between the determined SWR parameters and soil organic carbon (SOC) contents. Soil samples were collected from different soil depths of representative Andosols and Cambisols in Japan (Nishigo, Hiruzen and Nikko; all sites under forest) and New Zealand (Ngahinapouri, Wahihora and Whatawhata; all sites under pasture). The soil-water contact angle was directly measured using SDM, and indirectly derived from MED and WDPT measurements. All the A horizons of the Japanese soils showed water repellency, and the New Zealand soils were also water repellent at all depths except the Ngahinapouri, B horizon. Then, soil water repellency characteristic curves (SWRCCs) were obtained for water repellent (WR) soils, i.e., soil-water contact angle / degree of WR as a function of the volumetric water content (θ). Three WR parameters were determined from the SWRCCs. They are (i) the integrated areas below a SWRCC, $S_{WR}(\theta), (ii) the soil water content at maximum (\theta_{WR-Max})$ and (iii) minimum (θ_{WR-Min}) WR. Further, WR parameters were studied with soil organic carbon (SOC) contents. These relationships were agreed well with recently published work of Kawamoto *et al*. (2007) and Karunarathna *et al*. (2010). The SOC contents of New Zealand soils varied between 1.4% (WR) to 12.1% (WR), for the Japanese soils they ranged between 2.6% (Non-WR) and 26.3% (WR). Although the Japanese soils had high SOC contents in >10 cm depths, they were not WR (for Nikko >5 cm depth-Not WR). Therefore, further studies are needed to assess SWR as affected by SOC.

キーワード: soil water repellency characteristic curve, water repellency parameters, soil organic carbon
Keywords: soil water repellency characteristic curve, water repellency parameters, soil organic carbon

AGE03-P04　　　　　　　会場:3 階ポスター会場　　　　　　　時間:4 月 30 日 14:00-15:15

福島第一原子力発電所事故後の森林土壌における Cs 移動のモニタリング事例
A result of Cs redistribution in a forest soil after FNP-I accident.

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Cesium is a large atom which does not likely to hydrate. Similar to potassium and ammonium cation it prefers to site at siloxane ditrigonal cavity of silica sheet of phyllosilicates. Cesium is strongly, almost irreversibly, captured at frayed edge site of layered clay particles. These facts may make partition coefficient of cesium to be very large. The large partition coefficient may produce larger retardation of cesium transport with percolating water. At the same time large partition coefficient may cause enhance in migration of Cs with moving colloids. A comparison of Cs content distribution of near surface soil of between cleared forestry and a forestry with 5cm litter layer in Iitate village, Fukushima suggested organic colloids could be a transporter of Cs at litter covered forest. Soil total carbon content as well as C/N ratio had relation with soil Cs content. A depth where soil had higher organic carbon and lower C/N ratio tended to show high Cs content.

キーワード: セシウム, 森林, 土壌有機物, コロイド
Keywords: Cs, forest, soil organic matter, colloids

AGE03-P05 会場:3 階ポスター会場 時間:4 月 30 日 14:00-15:15

Observation of Pore Structure for Differently Compacted Landfill Final Cover Soils Using Microfocus X-ray CT

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The final cover soil on a solid waste landfill consists of many layers of materials and is highly compacted. It is used to prevent rain/surface water infiltration in to the waste layer. On the otherhand, the landfill site has a significant emission source of greenhouse gases. Gas and mass transport in soils occurs through the soil pore network, which is highly affected by soil physical properties including compaction, particle size, moisture content and total porosity. However, there are a limited number of studies on visualization and quantification of soil pore network for highly compacted soil like final cover soil. The objectives of this study were setting of microfocus X-ray Computed tomography (CT) for scanning landfill final cover soils in conjunction with 3-D image analysis techniques and analyzing the soil pore structure parameters. In this study, soil samples were collected from landfill site in Saitama prefecture, Japan. Soil pore structure was analyzed using micro focus X-ray CT (Shimadazu inspeXio SMX-90CT, Shimadzu Corporation) for air dried final cover soil samples of particle size (d$\leq$2mm) with different dry densities 1.4, 1.55 and 1.65 gcm^{-3} by a hand compaction. The tested soil texture was silty sand. The scanned images were taken by the micro focus X-ray CT. Then, by the use of software VGStudio MAX, they were reconstructed in 3-D images. Finally, using software of EXFact analysis they were analyzed to obtain pore structure parameters such as pore size distribution, coordination number, specific area and pore-network tortuosity. For determining suitable scanned images for soil pore structure and network, several scanning conditions for the microfocus X-ray CT have been tested i.e. different combinations of voxel size (10, 30 and 50 μmm), scan number, view number, field of view(FOV), region of interest(ROI), and percent of interior pore for pore structure analysis. Base on the results from the tested conditions, we will propose a suitable condition on the microfocus X-ray CT scanning for macropore network (typically, effective pore diameter $>$100 μmm) in differently compacted final cover soils.

キーワード: Microfocus X-ray Computed Tomography (CT), Pore network and structure, Final cover soil
Keywords: Microfocus X-ray Computed Tomography (CT), Pore network and structure, Final cover soil

AGE03-P06 　　　　会場:3 階ポスター会場 　　　　時間:4 月 30 日 14:00-15:15

Consolidation characteristics of landfilling waste samples in Japan: Effects of waste compositions and various mixing pr
Consolidation characteristics of landfilling waste samples in Japan: Effects of waste compositions and various mixing pr

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Solid waste materials are highly heterogeneous depending on various waste compositions, making it difficult to understand their consolidation characteristics. The purpose of study is to find out effects of waste compositions and mixing proportions on the consolidation characteristics of compacted solid waste materials. In this study, totally 6 different waste materials, un-burnable domestic waste, un-burnable industrial waste, incineration ash, crushed concrete, organic sludge and inorganic sludge, were used as tested materials.

By using the standard proctor test, compaction curves and maximum dry bulk densities were determined for each sample. Compaction results showed that maximum dry bulk densities of the Incineration ash (1.65 g/cm3) and crushed concrete (1.45g/cm3) were higher than the inorganic sludge (0.90 g/cm3) and organic sludge (0.742 g/cm3) respectively. The maximum dry bulk densities for mixed sample of inorganic sludge, concrete and incineration ash were larger than each independent waste sample. In especial, the maximum dry bulk density for the mixed sample with ratio 1:1:1 (dry mass basis) was 1.48 times larger than that for inorganic sludge.

Consolidation tests were carried out for selected pre-compacted waste samples with degree of compaction higher than 90 % after the compaction tests. For the consolidation tests, oedometer test apparatus which dimension of 10 cm diameter and 10 cm height was used for the waste materials with particle size larger than 2mm. Results of each independent sample showed that the coefficient of consolidation (Cv) for crushed concrete and incineration ash was higher than organic and inorganic sludge wastes while compressibility of un-burnable industrial waste was higher than the other materials due to a presence of compressible material. As the mixing ratio of crushed concrete in the mixed samples increased, the compression index (Cc) decreased. When the inorganic sludge and crushed concrete are mixed with the ratio 1:3, the Cc value of the mixed sample decreased up to 75% as compared to the one for only inorganic sludge. In addition, by mixing the inorganic sludge with the crushed concrete, the Cv values for mixed samples increased in the order of $10^1 \sim 10^2$. Effect of mixed proportion of the various wastes on consolidation parameters will be further investigated.

キーワード: Compaction, Consolidation, Sludge, landfill
Keywords: Compaction, Consolidation, Sludge, landfill

AGE03-P07 　　　　　会場:3 階ポスター会場 　　　　　時間:4 月 30 日 14:00-15:15

炭酸カルシウム及び有機物を用いた津波被害の塩類土壌修復に関する研究
Remediation of a Tsunami affected saline and sodic soil by calsium carbonate and rice straw

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Japanese government recommends leaching of soluble salts as well as adding calcium amendments for remediating saline and sodic soil after Tsunami by the earthquake on March 11, 2011,. Application of calcium carbonate ($CaCO_3$) is recommended for soils having pH lower than 6 and calcium sulfate ($CaSO_4$) is that for pH higher than 6. However, since $CaCO_3$ has low solubility to water, it has not been often used in reclamation of sodic soils (Shainberg et al, 1989).

Solubility of CaCO3 is controlled by CO_2-H_2O-$CaCO_3$ equilibrium in water. The concentration of calcium ion in $CaCO_3$ solution is affected by CO_2 concentration (partial pressure) of air phase. The higher partial pressure of CO_2 causes the higher concentration of Ca^{2+}. In general, addition of organic matter may enhance soil respiration and increase partial pressure of CO_2 in soil. This might potentially enhance solubility of $CaCO_3$ and increase Ca^{2+} concentration in soil solution.

Increase in Ca^{2+} concentration in soil decreases exchangeable sodium percentage (ESP) of the soil. Lower ESP may inhibit soil dispersion and help to keep aggregation. Stability of aggregates has a role on soil permeability, and it affects efficiency of leaching practice.

Objective of this study was to investigate the effect of changes in partial pressure of CO_2 by organic matter decomposition on dissolution of $CaCO_3$, and subsequent Na^+-Ca^{2+} ion exchange of a Tsunami affected soil.

Soil was collected at a former paddy field at Terashima, Miyagi, Japan, where was damaged by Tsunami at the Great East Japan Earthquake. EC (1:5) of the soil was 5.2dS m^{-1}. The soil was mixed with rice straw and/or $CaCO_3$, and then packed into plastic columns of an inner diameter of 8.5cm and 20cm-high with the bulk density of 0.95g cm^{-3}. Amount of rice straw and $CaCO_3$ application was 10t ha^{-1} and 1t ha^{-1}, respectively. The soil columns were incubated for 23 days. During the incubation, 18mm of water was supplied for each three days. The temperature inside and around the columns, and soil water pressure were continuously monitored. The CO_2 concentration in soil air phase was measured at 5-days interval.

After the incubation, the columns were leached by 4 pore volumes of 4mmol L^{-1} KCl solution with. The leachate was collected for further analysis of EC, pH and concentration of cations. After the leaching, the soil columns were separated to 3cm thick layers. Each 3cm thick soil sample was used to measure EC, pH, soluble cations, and exchangeable cations of the soil.

In average, soil CO_2 concentration inside the column was high under the rice straw treatment regardless of $CaCO_3$ application. The CO_2 concentration rose at the periodical water application, and gradually decreased with time. Rise in CO_2 concentration could be due to the enhanced organic matter decomposition and the restricted CO_2 diffusion by higher soil water content following the water application.

Exchangeable cations of the column soil were measured after the leaching. Exchangeable Ca^{2+} slightly increased at whole layer of the four treatment. Increase in exchangeable K^+ coincided with decrease in exchangeable Na^+, suggesting ion exchange between Na^+ and K^+ was a dominant reaction during the leaching.

In this experiment, the effect of organic matter and $CaCO_3$ application on remediation of the Tsunami affected saline and sodic soil was not clear. With fluctuating soil water content, soil CO_2 concentration was not always high during the column incubation experiment. It is expected that depression of soil CO_2 concentration with decrease in soil moisture after water application could not enhance dissolution of applied $CaCO_3$.

Keywords: Tsunami affected soil, saline and sodic soil, rice straw, calcium carbonate

AGE03-P08　　　　　　会場:3 階ポスター会場　　　　　　時間:4 月 30 日 14:00-15:15

人工マクロポアの輸送システムを用いた土壌表面からの放射性物質の除去促進
Enhancing Radioactive Fallout Removal from the Surface Soils by using artficial macropore transport system

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　東日本大震災による被害を受けた福島原子力発電所は、東北地方周辺に放射性物質の降下を引き起こした。降下し放射性物質は土壌表面に吸着されるため、とどまると報告されている。それゆえ表土はぎや深耕は放射性物質を取り除くために効果的である。しかしながら、これらの技術は校庭や農地などの広くて平らな土地で用いることができる。

　　多くの果樹園では降下した放射性物質はただちに土壌表万に吸着したわけではなく、交換態イオンとしてとどまり、それが植物根によって吸収され、果実に放射性物質が吸収される。それゆえこの技術は傾斜地のために放射性物物質を管理するために必要となる。

　　私たちは土壌表面から効果的に放射性物質を取り除くために人工マクロポアを用いた。人工マクロポアは土壌中に竹繊維で充填したものである。（現地では直径 1cm、長さ 50cm　実験室では直径 6mm、長さ 20cm）マクロポアの底には交換態のセシウムを吸着させるためにゼオライトを設置した。（現地では 50cm、実験室では 20cm）現地実験のためにマクロポアあり・硫酸アンモニウムあり区、マクロポアなし・硫酸ンアンモニウムなし区のような 4 つの対照区を用意した。室内実験では、安全のためカリウムを用い、400ml の人工降雨を 1 カ月降らせた。実験結果は人工マクロポアは放射性セシウムとカリウムを下層に効率的に輸送することができることを示した。室内実験では人工マクロポアは排水から放射性セシウムが検出されずに、カリウムを下方に輸送することに成功した。

キーワード: マクロポア, 土壌劣化, 放射性物質
Keywords: Macropore, Degraded Soils, Radioactive Substance

AGE03-P09　　　　　　会場:3 階ポスター会場　　　　　　時間:4 月 30 日 14:00-15:15

人工マクロポアの最適設計
A Design of Artificial Macropore for Improving Infiltration Process in Degraded Soils

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　土壌は植物や大気など地球全体において最大の炭素貯留体です。しかしながら，近年，気候変動や不十分な管理の影響によって，土は水の貯留層や栽培地としての機能することができない。今研究では，耕耘を行わず，雨水の浸透を促進することを目的として土壌中に人工マクロポアを導入した。マクロポア構造を強化するために繊維状物質を挿入した。その上，微飽和における繊維の毛管力による土壌中への表面水の導入が見られた。繊維の毛管力は鉛直輸送を行い，マクロポアは水平方向への浸透を促進する。これは空隙マクロポアよりも効果的な浸透が可能である。今実験において，人工マクロポアの最適設定が調査された。繊維状物質の充填密度を 0.2 0.3 0.5 g/cm3 のように変化させた。mた，降雨強度 2,20 mm/h の人工降雨をこのカラムに降らせた。結果として，繊維の充填物質に応じた水分特性曲線の変化が見られた。そして，密度を変化させることで毛管力を効果的に作り出すことができる。弱い雨が降ったとき，その地表水は密度の高い人工マクロポアによって効果的に集められる。そして強い雨は密度の低いマクロポアにより効果的に排水される。

キーワード: マクロポア, 土壌劣化
Keywords: macropore, soil degradation

AGE03-P10 　　　　　会場:3 階ポスター会場 　　　　　時間:4 月 30 日 14:00-15:15

劣化土壌における植物バイオマス量に人工マクロポア導入が与える影響
Artificial Macropore installation effect on organic matter storage at a degraded land.

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　排水不良地では強雨によって侵食され、土壌劣化がより早く進む。我々の先行研究では、人工マクロポアの導入によって鉛直浸透の促進と有機物量の増加に成功している。しかしながら、人工マクロポアは土壌水と同時に栄養塩と酸素を供給するために、結果的に有機物量の減少をもたらす心配があった。
　本研究では、セルロースを混ぜた砂のカラム（直径 5 ｃm、高さ 30 ｃm）を用意し、栄養塩を含んだ 210ml の人工降雨を土壌表面に滴下した。有機物の減少が促進されるよう 30 ℃の恒温室に静置した。構造による炭素量の違いを観察するために、未処理区・耕耘区・人工マクロポア導入区の 3 種を用意した。
　耕耘区では蒸発量が大きく、従来の耕耘法は水分保持で不利だと分かった。一方で人工マクロポア区は排水性の高い構造に関わらず、蒸発量は未処理区と近いものとなった。水分量の影響を受けたために、3 試験区で炭素量の鉛直分布に違いがあった。炭素量の鉛直分布の標準偏差は未処理区で小さく、耕耘区とマクロポア区で大きかった。

キーワード: 人工マクロポア, 劣化土壌
Keywords: Artificial Macropore, degraded land

AGE03-P11　　　　　　会場:3 階ポスター会場　　　　　　時間:4 月 30 日 14:00-15:15

Modelling of Critical Loads for Heavy Metals in Terrestrial Ecosystem in Slovenia
Modelling of Critical Loads for Heavy Metals in Terrestrial Ecosystem in Slovenia

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In Slovenia a modelling application of As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb and Zn critical loads in soil were performed. The calculation in the Salek Valley involved 30 research areas in the town Velenje area on a 500 x 500 m grid, where the chemical analyses of precipitation and soil were made.

The aim was application of theoretical models for determination the maximum critical levels of heavy metals in terrestrial ecosystem with empirical data. The basis for calculation was an effect-based approach, which limits are based on adverse effects on the ecosystem and the heavy metal concentrations should stay below those limits. As receptor was used a human health trough the eco toxicological risks with use of ground water for drinking water and/or consume crops that are grown on the soil. The simple model based on dynamic mass balance of heavy metals in soil was used for calculation. It was estimated that the critical time well illustrates the acute danger of soil pollution and is recommended as the draft estimation of actual condition in soil which could be valued with few data.

Two different soil conditions at the actual atmospheric input were used in calculation: unpleasant and average. The unpleasant condition was simulated for the surface soil to depth of 5 cm, and the advanced to soil depth of 20 cm and density of 1.500 kg/m3. The critical time for both conditions is calculated for As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Zn. The comparison between heavy metals indicates high accumulation of As and Hg, and thus their quit fast approach to the critical loads. In second rang of atmospheric input are Cd, Pb and Zn which are accumulated much slowly, followed by Mo, Ni, and Co, and the slowest progress make Cr. The estimated periods to reach the permitted Slovene limits in surface soil are calculated for As, Hg 100, Cd 140, Pb 230, Zn 350, Cu 830, Mo 1.700, Ni 1.800, Co 1.900, and for Cr 6.000 years.

キーワード: heavy metals, soil, contamination, modelling
Keywords: heavy metals, soil, contamination, modelling

AGE03-P12　　　　　会場:3 階ポスター会場　　　　　時間:4 月 30 日 14:00-15:15

土壌の物理的性質データベースを用いた気候変動下の農地土壌水分状態予測
Predicting soil moisture in arable land under climate change with soil-profile physical properties database

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Soil is foundation of agriculture and ecosystems. Soil physical condition such as soil moisture and temperature directly and indirectly affects yields and quality of crop production. Therefore predicting soil moisture of arable lands under climate change is important and valuable for yield prediction and adaptation under climate change. For predicting soil moisture condition of agricultural lands in arbitrary areas, use of soil database and datasets of General Circulation Model (GCM) projections should be useful since physical properties of soils and meteorological condition vary with location. Most of available GCM projections have spatial and temporal resolution of 100 km and a month. However, using GCM projections as input data for soil moisture and temperature prediction, temporal and spatial scale of the input data is favorable to be small since effective surface soil layer of agricultural production is generally shallow. In this study we investigated possibility of predicting soil moisture of arable lands in arbitrary areas with local-scale (approximately 20km×20km) daily GCM projection dataset "ELPIS-JP" (Iizumi et al., 2012) and the agricultural soil-profile physical properties database, Japan, "Solphy" (Eguchi et al., 2010).

In this study, soybean fields of Yoshioka and Ookubo, which are located in neighbors (approximately 2 ~ 3km), in Toyama city were chosen as experimental sites and scenario studies were done for predicting soil moisture condition with HYDRUS model (Simunek et al., 2008) under climate change in the future (2071 ~ 2090). Soil physical properties of each site were determined with water retention data in the SolphyJ database by using RETC program (Yates et al., 1992). Before the scenario studies, validation of HYDRUS model and soil physical properties which are obtained with SolphyJ database was conducted by comparing observed and simulated soil moisture of the Yoshioka field. The projection of MIROC-hires 3.2 A1B scenario was chosen among 26 (10 GCMs × 3 Special Report of Emission Scenario) ELPIS-JP scenario datasets. For preparing input data for numerical simulation of soil water movement, daily ELPIS-JP datasets were temporally downscaled to hourly or minutes scale by using weather generator "CLIGEN" (Nicks et al., 1995)

Simulated results suggested that the duration of excess soil moisture condition following heavy rainfall events are more likely at Ookubo than Yoshioka even though they are located in neighbors and have similar soil textures. Increase in surface runoff fluxes is possible to be larger in Ookubo than in Yoshioka as well. These results imply that even in a small watershed it is important to consider soil spatial distribution in predicting effects of climate change on agricultural production. Also, combination of temporally downscaled GCM projection dataset and agricultural soil-profile physical properties database may be useful for predicting soil moisture in arbitrary areas.

References: Eguchi et al., 2011, Proceedings of Annual Meeting of JSDIRE, 302-303; Iizumi et al., 2012, Phil. Trans. R. Soc. A, 370, 1121-1139; Nicks et al., 1995, NSERL Report ♯10, pp.2.1-2.22.; Simunek et al., 2008, Vadose Zone J. 7, 587-600; Yates et al., 1992, Soil Sci. Soc. Am. J, 56, 347-354

キーワード: 気候変動, 土壌水分, 数値シミュレーション, SolphyJ, ELPIS-JP
Keywords: Climate change, Soil moisture, Numerical simulation, SolphyJ, ELPIS-JP

AGE03-P13   会場:3 階ポスター会場   時間:4 月 30 日 14:00-15:15

A Case Study of Combining Geophysics Prospecting Techniques to a Soil Contaminated Site

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WANG, Tzu-pin[1][*] ; CHEN, Chien-chih[1] ; DONG, Tien-hsing[4] ; CHEN, Yi-chieh[3] ; LIU, Hsin-chang[2] ; LIN, Chih-ping[5] ; HUNG, Hao-chun[6] ; HO, Ching-jen[6]

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This study utilizes a combination methods of Electrical Reisitivity Tomography (ERT), Ground Penetrating Radar (GPR), and Horizontal Loop Electromagnetic (HLEM) to examine a heavy-metal contaminated site before and after the remediation. It was a processed sludge tacking site of a smelting plant. The sludge is homogeneous red, and the main pollutants are chromium, arsenic and lead. The plant has been closed for more than twenty years. At the time when it was shut down, instead of removing the stacked sludge and underground structures (tank), the site was leveled directly and planted with lawns. Now, it is difficult to know the distribution of the sludge, the depth of its cover, and the correct location of the underground structures.

The pre-remediation investigation conducted with the application of geophysical prospecting techniques found that the HLEM could efficiently define the distribution of sludge efficiently, and ERT could be used to detect the thickness of the sludge and the location of the underground structures, but GPR results failed to meet expectations which may due to a significant attenuation of electromagnetic energy caused by the nature of the sludge. The post-remediation examination shows obvious different morphologies of the site than it was before the remediation. The results can be used to assess the effectiveness of remediation, and to check if any sludge remains.

キーワード: ERT, GPR, EM, pollution
Keywords: ERT, GPR, EM, pollution

AGE03-P14 　　　　　会場:3 階ポスター会場 　　　　　時間:4 月 30 日 14:00-15:15

飯舘村剥ぎ取り除染後農地における水稲へのCs移動性
Cs migration to rice crop from soil after stripping the contaminated top soil at Iitate Village in Fukushima Prefecture.

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　Iitate Village is at about 40 km northwest from a Fukushima Daiichi nuclear power plant. An agricultural fertile layer in agricultural fields was contaminated by radionuclides, e.g., 134-Cs, 137-Cs, and 90-Sr, just after the accident of the Fukushima Daiichi Nuclear Power Plant in 2011. The decontamination work is an important subject for villagers to return to a village and live there again. Three decontamination methods are proposed by a Ministry of Agriculture, Forestry and Fisheries. They are 1) Stripping the top soil off, 2) Removal of fine particles after soil and water mixing, and 3) Tillage reversal. By the report of the Ministry of Agriculture, Forestry, and Fishery, 90% of radioactive contaminant has been removed by the method of stripping the contaminated top soil off. In this time, we examine the Cs migration to rice crop from soil after stripping the contaminated top soil off.

　We used ~4*20 m paddy field at Iitate Village in Fukushima Prefecture. At first we decontaminated the site using the method of stripping 5 cm top soil off. After that potassium chloride (KCl) was put in all area as basal fertilizer on June 8, 2013. We comparted the area and made three kinds of treatments such as (1) mixed with rice straw that was harvested last year here, (2) only decontaminated, and (3) mixed with farmyard manure, and transplanted rice crop (rice cultivar is hitomebore) on June 9, 2013. We had sampled top soils at three points from each plot twice a month and the 134-Cs, 137-Cs, and 40-K concentration in soils were analyzed using a Ge semiconductor detector. The concentration of 134-Cs, 137-Cs, and 40-K in rice crop was analyzed by a NaI scintillation counter after harvest.

　As a result, 134-Cs is about half of 137-Cs. Since the half-life of 34-Cs is two years, it has become approximately a half. Changes of Cs and K concentrations in soil were not observed during a rice cultivation period. The concentrations of radionuclides in mixed rice crop were 572.93±8.05 Bq/kg-dry / Cs-134, 1089.35±11.41 Bq/kg-dry/ Cs-137, and 127.29±27.59 Bq/kg-dry/ K-40. Although these values were comparatively high, soil did not show the high dose. The reason of that would be the volume of mixed rice straw was small and migration of caesium from the rice straw to the soil was hardly happened. The soil dose mixed with manure had been high through the whole cropping period. It might be the original manure dose was high, but the analysis of the manure has not completed yet. The concentration of radionuclides in rice crop below a detection limit of the NaI scintillation counter and it is below the regulation value defined in our country.

キーワード: 剥ぎ取り除染, 水稲, セシウム
Keywords: stripping top soil off, rice crop, caesium

Nitrogen removal and effect of chemical oxygen demand on removal of nitrogen in Coir Fiber Biofilm Treatment System
Nitrogen removal and effect of chemical oxygen demand on removal of nitrogen in Coir Fiber Biofilm Treatment System

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Biological treatment is the most useful process to remove nitrogen from water and wastewater. In this process, ammonium is first oxidized to nitrate by aerobic autotrophic nitrifying microorganisms. Nitrate is then reduced to nitrogen gas by heterotrophic denitrifying bacteria under anoxic conditions. Oxygen and organic carbon must be supplied to act as electron acceptor in nitrification and electron donor in denitrification. This study has carried out microcosm experiments in the laboratory for evaluating wastewater treatment mechanism and efficiency in the Coir Fiber Biofilm Treatment System (COTS). Coconut fiber was used to encourage the development of contaminant-degrading biofilms. A string of coconut-fiber (0.2-m length) was used as a biofilm support media and experiments were carried out using synthetic wastewater. The string of coconut-fiber was put inside the treatment container (0.012-m3 volume) with two conditions: low fiber density (LFD; single string per a container) and high fiber density (HFD; two strings per a container). As a control condition, a blank container without a coconut-fiber string was also used in the experiment. The flow rate is about 870 cm3/day (two-weeks retention time)

The inflow ammonium nitrogen concentration was 500 mg/l- 640 mg/l and the average nitrate nitrogen concentration in influent was 5.9 mg/l- 6.5 mg/l (low nitrate nitrogen loading rate). Dissolved Oxygen (DO) value of the treatment tanks were range between 0-0.3 mg/l. DO concentration in LFD and HFD treatment tanks were slightly lower than the inflow and blank tank during the whole experimental period. The maximum ammonium nitrogen removal efficiency was recorded in the 14 days of startup. It was approximately 45% and 30% in HFD and LFD treatment tank respectively. After that, ammonium nitrogen removal efficiency shows the slightly decreasing trend over the time. The maximum nitrate nitrogen removal was observed for 70 days of operation. It was around 90% and 72% in HFD and LFD tank respectively. Over the duration of the experiment, very low concentrations of Nitrite Nitrogen were observed and it was below 1 mg/l. low nitrite nitrogen is evident that the oxygen limited anaerobic nitrification-denitrification process leads to removal of ammonium nitrogen in this system. This process involves two-step as partial nitrification and Anammox. One of the most critical parameters of the nitrification process is the influent chemical oxygen demand (COD), because it directly influences the growth competition between autotrophic and heterotrophic microorganism population. The average inflow COD concentration in influent was 18300 mg/l- 19800 mg/l. Ammonium nitrogen removal efficiency decreased with the increasing of COD removal efficiency in both LFD and HFD treatment tanks. So there is a negative relationship between organic carbon concentration and biological ammonia removal. High organic loading can result in decreased nitrification due to faster growing heterotrophic bacteria dominating the surface of the biofilm, and leads to oxygen limitations for the nitrifying bacteria growing deeper inside the biofilm. As considering the results obtained from the microcosm system it can be conclude that partial nitrification and the subsequent anaerobic ammonium oxidation (Anammox) are the major process associated with the removal of ammonium nitrogen. This process is a shortcut biological nitrogen removal without increasing nitrite and nitrate concentration in the system. At the same time treatment tank with HFD always tend to eliminate significant amount of ammonium nitrogen than the LFD tank. Difference between results in HFD and LFD treatment tank indicating that surface provided for growth of biofilms is a major factor for improving biodegradation rates. COTS has effect on remove nitrate nitrogen effectively at low nitrate loading rate from the wastewater.

キーワード: Coir Fiber, Biofilm, Nitrogen removal, Chemical Oxygen Demand
Keywords: Coir Fiber, Biofilm, Nitrogen removal, Chemical Oxygen Demand

鉱物-水界面と水-空気界面の電気二重層相互作用に基づく地質媒体中の水膜厚さの評価
Estimation of water film thickness in geological media based on electric double layer interactions

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Water film plays an important role in mineral-water interactions and mass transport in geological media under water-unsaturated conditions (Nishiyama and Yokoyama, 2013, Geochim. Cosmochim. Acta). To quantify such reactive-transport in water film, the understanding of the properties of water film is essential. Water film is retained on grain surfaces due to the action of electric double layer force associated with the compression of diffuse layers developed from mineral-water and water-air interfaces. In this study, we focused on the thickness of water film and developed a model to estimate the thickness taking into consideration the effect of ion concentration, pH, and electric double layers overlapping.

The surface charge density and electric potential at mineral-water and water-air interfaces depend on the amount of adsorption-desorption of proton and ions. When two diffuse layers developed from the opposite interfaces overlap, the concentration of ions in diffuse layers changes and consequently the adsorption-desorption reactions at the interfaces achieve a new equilibrium state. To take into account this process, we used a triple-layer model and a double-layer model to numerically solve the Poisson-Boltzmann equation describing the ion distribution in diffuse layer between the interfaces. We considered water film on quartz grains and calculated water film thickness as a function of pH and ion concentration. The results show that water film thickens with decreasing ion concentration and increasing pH. The model presented in this study allows film thickness to be estimated as a function of mineral type, ion concentration, and pH. Such model would be useful for considering the reactive-transport under unsaturated conditions including the geological storage of carbon dioxide and soil formation.

キーワード: 水膜, 電気二重層, 不飽和帯
Keywords: water film, electric double layer, unsaturated zone