Calibration and use of neutron moisture and gamma density probes in rocky soils
石礫土壌に対する中性子水分計とガンマー線密度計の校正式

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1. Introduction

Rocks may have a significant impact on soil and plant water relations by reducing volumetric water content (θ), restricting root growth, and impeding and redirecting water flow. Neutron thermalization and gamma ray scattering methods of determining θ and bulk density (ρ_b) have advantages over other methods because their measurement volumes are larger, accounting for a larger variation in rock content and rock size. These methods require insertion of cylindrical access tubes into the soil through which radioactive probes are lowered to measure θ and ρ_b. In this paper, we report on calibration of neutron moisture and gamma density probes in rocky soil, with the foam sealant around the access tubes, and show some examples of spatial and temporal variability of θ and ρ_b profiles in a karst savanna in central Texas.

2. Materials and methods

The neutron and gamma density probes were calibrated in a 60-cm diam. by 80-cm tall plastic drum. A 5.1-cm o.d. aluminum access tube was covered with a sealant, expandable polyurethane foam (Tokumoto et al., 2011). The drum was filled with dry clay loam-rock fragment mixture above a gravel layer that was at the bottom of the drum, and was packed to a ρ_b of 1.15 g cm^{-3}. Water was allowed to infiltrate in a stepwise manner from the bottom at a rate of 1 to 3 cm d^{-1} over a 2-week period to create a range of θ. Neutron and gamma counts were measured at a depth of 25 cm utilizing a 32-s count interval for the neutron probe, and a 60-s interval for the density probe. Water content in soil portion (θ_{soil}) was monitored in the drums by time domain reflectometry (TDR). Water content in the cylindrical volume containing rocks was calculated as

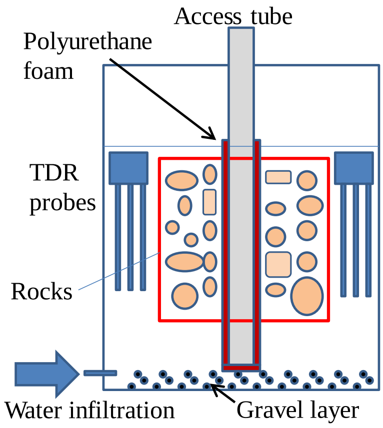

Fig.1 Schematic figure of the drum calibration technique.

$$\theta_{soil+rock} = (1-f_{rock})\ \theta_{soil} + f_{rock}\ \theta_{rock},\ (\theta_{rock} = 0.01\ m^3\ m^{-3}) \quad [1]$$

where f_{rock} is the fraction of the volume occupied by rock, and θ_{rock} is the volumetric water content in rock. On the analogy of Eq. [1], wet bulk densities for rocky soil were calculated.

3. Results and discussion

The relationship between neutron count ratio (CR_n) and θ, obtained with different fractions of rock was nonlinear and nearly identical to that obtained when rock was absent (Fig.2). This

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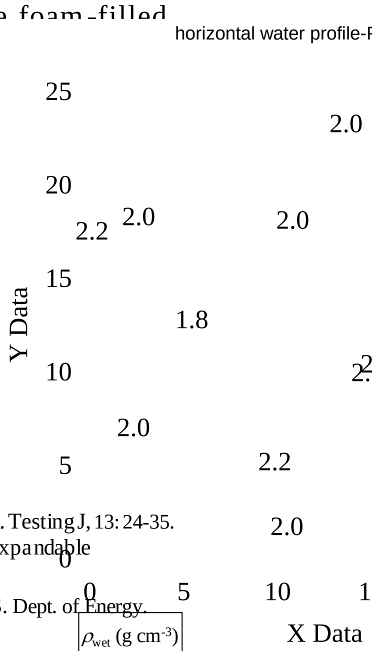
indicates that the main effect of rock on neutron thermalization was to reduce water content. We attribute the nonlinearity to changes in measurement geometry caused by the foam-filled void space. As discussed by Tokumoto et al. (2011), the measurement volume de increasing θ, so an increasingly larger fraction of the measurement volume is occ foam as θ increases. Calibration of gamma probe was found based on theo between gamma count ratio (CR_d) and wet bulk density (ρ_{wet}), proposed by Morris (1990). The CR_d we measured were larger than predicted by the theoretical curve believe the higher values were due to the foam sealant occupying a poi measurement volume, thereby reducing the density around the probe and the a gamma radiation. Using the neutron and gamma probe calibrations, ρ_b pro obtained by subtracting density of water from ρ_{wet} with 36 access tubes at experimental grid in a karst savanna (Fig.4).



[Ref.] Morris, P.H., and Williams, D.J., 1990. Generalized calibration of a neuclear moisture/ density depth gauge. Geotech. Testing J, 13: 24-35.
Tokumoto, I., Heilman, J.L., McInnes, K.J., and Kamps, R., 2011. Sealing neutron probe access-tubes in rocky soils using expandable polyurethane foam. SSSAJ, 75: 1922-1925.

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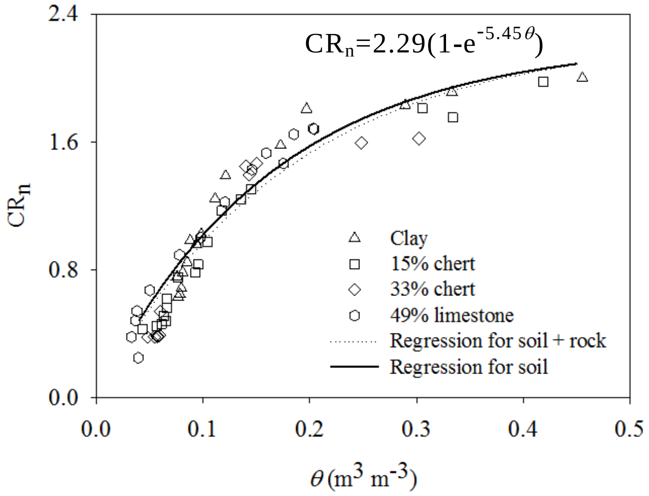

Fig.2 Neutron probe count ratios (CR_n) as a function of volumetric water content (θ) including rock fragments.

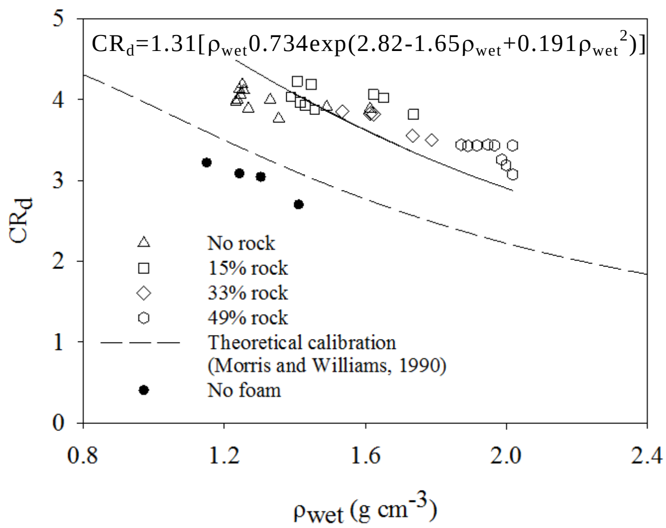

Fig.3 Gamma density probe count ratios (CR_d) as a function of wet bulk density (ρ_{wet}).

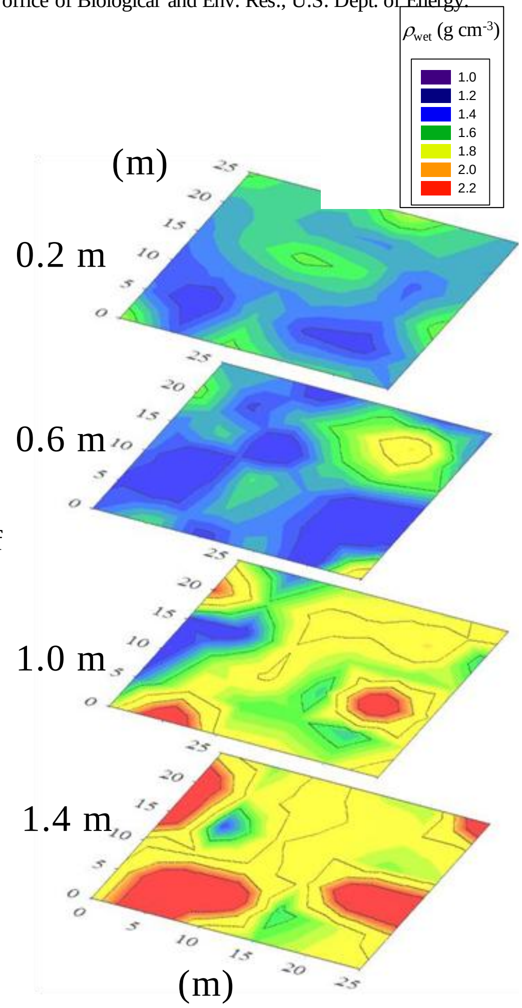

Fig.4 Spatial variability of dry bulk density (ρ_b) at 4 depths in the field. Dry bulk densities were obtained by subtracting density of water from ρ_{wet}.