EVALUATING THE EFFECT OF AFFORESTATION ON GROUNDWATER RECHARGE USING NATURALLY-OCCURING ISOTOPES

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1. INTRODUCTION

The planting of trees is employed worldwide as a method of controlling runoff and increasing groundwater recharge. Yet the net effect of afforestation on recharge, owing to the complexity of interactions between factors such as the extent of roots, groundwater depth, and canopy density, is often difficult to determine. Additionally, the impact of trees is difficult to access experimentally, owing to their long maturation rate. One solution is to use naturally-occurring stable isotopes oxygen-18 and hydrogen-2 (deuterium) as tracers of water movement through the soil profile. The concentration of ^{18}O and ^{2}H in the soil water and groundwater allows for specific sources to be identified by comparing it to those in rainfall of various spacial and temporal distributions. Identification of seasonal recharge events in the soil moisture profile can aid in estimating the rate of permeation of water particles through a particular soil medium. The advantage of the stable isotope method is that it can be employed on existing plots and produce relatively operative results, provided historical precipitation isotope data is available for the area.

Studies employing natural isotopes as tracers of subsurface water began in earnest in the 1980's. In a widely-cited work, Allison and Hughes (1983) looked at chloride and other isotope concentrations to measure the groundwater recharge below *Eucalyptus* trees in Australia as well as on land cleared of *Eucalyptus*. A similar study by Sharma and Hughes (1985) found that water does not move uniformly through the soil matrix, instead relying on preferred pathways. Saxena and Dressie (1987) used stable and radioactive isotope techniques to assess recharge from snowmelt in Sweden, which occurs at known times of the year and has a distinct isotopic signature. The study crucially underlined the difference between the speed of movement of specific water particles and recharge. Taylor and Howard (1996) used stable isotopes to estimate recharge rates in Uganda, particularly in areas affected by deforestation. Their work correlated recharge to heavy rainfall periods, owing to the complete evaporation of light rainfall from the soil surface. Lack of site-specific precipitation isotope data was cited as a factor in this as well as other studies.

The current study also aims to access the applicability of the stable isotope method for evaluating the impact of afforestation on recharge by comparing soil moisture isotope profiles under forested and cleared areas.

2. METHODOLOGY

Over the course of 2017, soil samples were extracted from boreholes on Aobayama Campus of Tohoku University in Sendai, Japan (Fig. 1). Of the selected sites, boreholes [A], [B], [C], [D], [F], and [G] were located under mature forest cover, while [E], [H], [I], and [J] were located in areas cleared of forest several years prior, that have since returned to a natural state. Additionally, two pairs of forested and grassy sites were selected in close proximity (<100m) from each other to minimize the influence of soil variability on results. Sampling was carried out with a hand auger and a percussion sampler. After initial trials, a depth of ~4m per borehole was selected as the most practical; samples were collected every 15cm in the case of hand auger, and every 10-11cm in the case of percussion sampler. The soil was packaged in airtight vinyl-wrapped plastic bags and refrigerated for several weeks prior to additional processing.

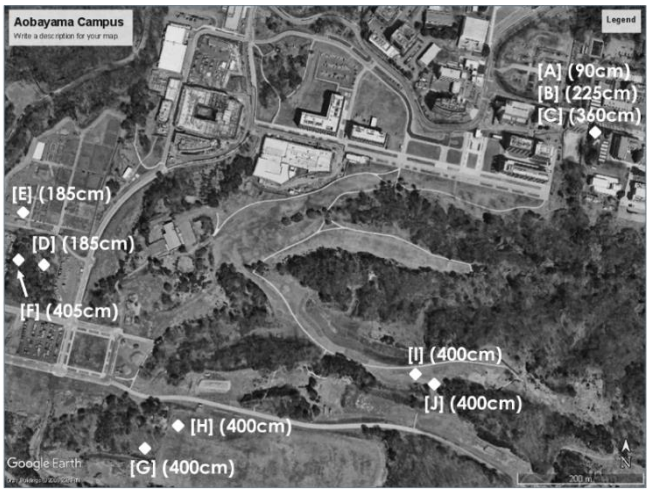

Fig. 1: Boreholes on Aobayama campus, with final depth indicated. Boreholes A-D, F, and G drilled under forest cover; boreholes E, H, I, J under grass

A total of 269 soil samples were collected. These were analyzed for soil moisture content by evaporating three ~20g subsamples for each sample at 110°C over 24 hours. Additional sub-samples were then centrifuged to extract soil water without subjecting it to processes that might result in isotopic fractionation (i.e. evaporation). Centrifugation was carried out in a Kubota 6000 centrifuge; samples in 50ml tubes were spun at 30,000 g's (35,000 g's for soil under 20% soil moisture) in batches of 6 for 30 minutes. The water separated from the soil samples by this process was then filtered using a syringe fitted with disposable 0.45 µm filters into 14-ml vials and frozen to prevent isotopic fractionation. ^{18}O and ^{2}H concentrations were determined using a Picarro water isotope analyzer (L2120-i CRDS).

3. RESULTS

Soil moisture isotope concentrations of individual samples, expressed in ‰ deviation from Vienna Standard Meteoric Ocean Water (VSMOW), are plotted against sample depth in Fig. 2. $\delta^{18}O$ and $\delta^{2}H$ values for samples from boreholes [A], [B], [C], [D], [F], and [G] are displayed under "Trees", while those for [E], [H], [I], and [J] are displayed under "Grass". A curve plotted through each set of data points using a Loess function represents the overall trend of the isotope concentrations through the soil profile. The data indicates clear differences between $\delta^{18}O$ and $\delta^{2}H$ profiles under forested and grassy land cover, namely, a consistent trend towards depleted values in the forested boreholes below 2m and a notable periodic enrichment in ^{18}O and ^{2}H in boreholes under grass cover.

Relative $\delta^{18}O/\delta^{2}H$ ratios also differed significantly. On average, water samples taken from forest boreholes were more enriched in ^{2}H relative to the ^{18}O concentration than those under grass cover. Under both tree and grass cover, samples taken closer to the surface were generally more enriched in both heavy isotopes than those at greater depth. Fig. 3 provides an illustration of these trends.

Some early results can be inferred from the data at the current stage. Firstly, the periodicity seen in grass areas is likely the result of a uniform downward piston flow and indicates seasonal variation in input isotope concentrations. The lack of obvious periodicity in tree profiles could mean interference with piston flow by preferential flow and hydraulic uplift due to transpiration in the root zone. The relatively depressed trend of the grass cover samples' $\delta^{18}O/\delta^{2}H$ relationship is likely caused by evaporation from the surface; interception by the canopy of light rain events (typically more enriched in isotopes than heavier rain events) could also account for the difference. Both sets of samples evidence increased depletion at increased depth, consistent with other studies and likely approaching values in local rainfall.

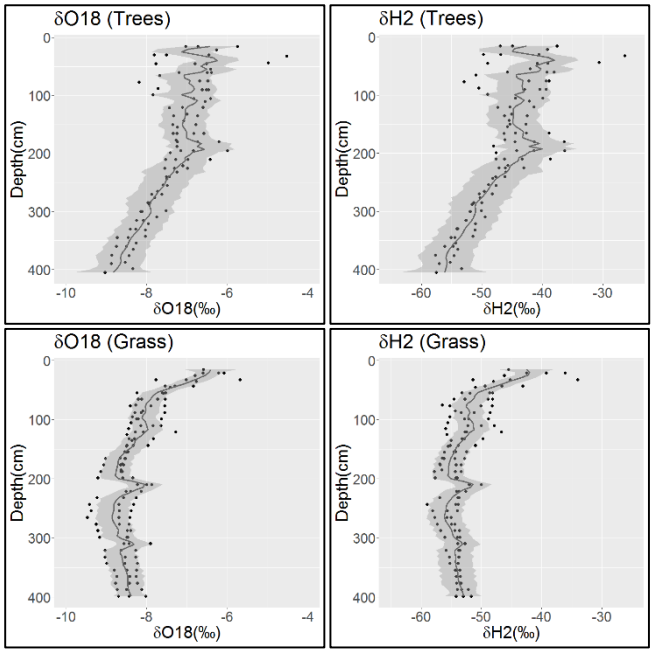

Fig. 2: $\delta^{18}O$ and $\delta^{2}H$ profiles under tree and grass cover.

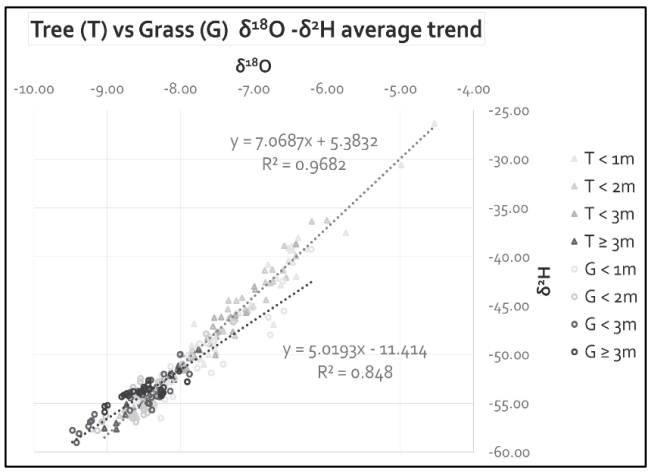

Fig. 3: $\delta^{18}O/\delta^{2}H$ relationship among samples from two kinds of land cover.

4. CONCLUSION

The results show clear differences in isotope profiles and concentrations between tree- and grass- covered areas. However, the exact factors contributing to this difference, as well as the rate of water particle movement and the volume of recharge remains obscure to the author. Subsequent work will focus on comparing the isotope profile to seasonal input from precipitation based on observed and modeled data, and estimates of recharge volume.

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