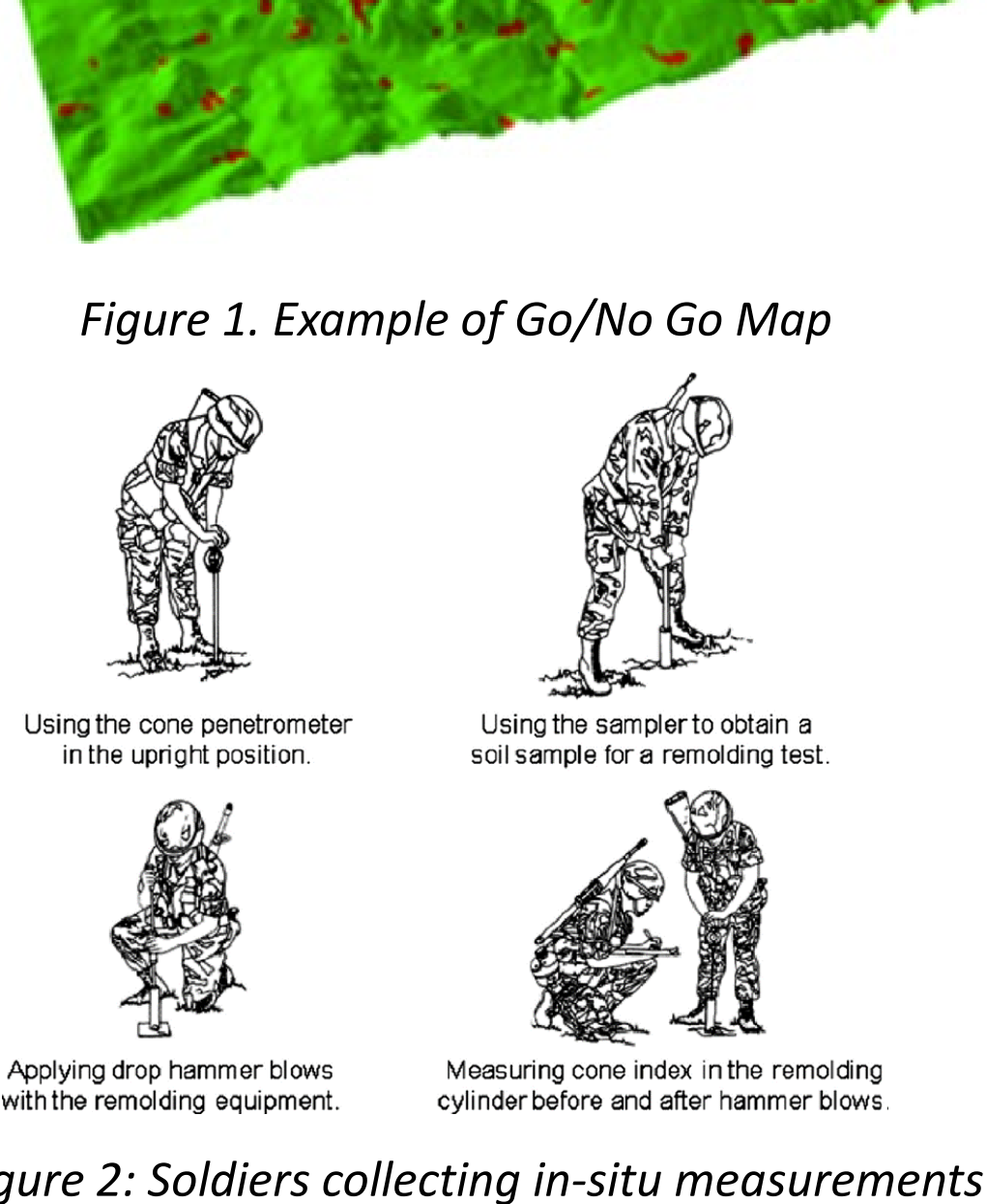


mobility under different terrain conditions.

- The output of NG-NRMM simulation is Go/No-Go maps (Figure 1).
- The NG-NRMM simulation requires terrain strength data, which is collected via in-situ measurement (Figure 2).
- The in-situ measurement places the soldiers lives in danger.



Objective

- Determining the terrain strength properties is critical for achieving accurate mobility performance prediction as well as reliable operational planning using the NG-NRMM.
- In-situ soil measurement for strength at certain locations can be expensive, difficult, or unsafe to perform, and it only provides point data collection.
- This study is, therefore, proposing an alternate approach: Using remotely sensed thermal data, we can approximate the strength of the soil to help improve the Go/No-Go map development for the NG-NRMM.
- We also use hyperspectral remote sensing to characterize the soil based on the Unified Soil Classification System (USCS).

Data

- The five soils (Fine, Coarse, Rink, Stability, and 2NS) are from the Keweenaw Research Center mobility testing tracks, and the location is shown in figure 3.



Figure 3. KRC Field test site (Left) and Drone flying at KRC over Fine Pit (Right)

know the general composition of % sand, % gravel, and % fine particles, which will help to distinguish the 5 soil types. The rationale is that the reflectance spectrum from the soils will provide unique spectral signatures. Figure 4 displays the laboratory setup for testing, where the water content, average stiffness, albedo, thermal and hyperspectral imagery were recorded. A similar manner was applied in the field, where UAV data collection occurred in the morning and afternoon.



Figure 4. Shows the lab setup of the 5 KRC soils. The soils in order from bottom left to top right: 2NS, Stability, Rink, Coarse, and Fine. Above each bin are two 500-Watt work lights, and the middle bar is the track the hyperspectral camera is moved along.

Apparent Thermal Inertia:

Thermal inertia (TI) is calculated using the thermal conductivity (k), the density (ρ), and specific heat (C) of the soil (Equation 1). These values require in-situ measurements, so instead, we utilize the apparent thermal inertia, which is a close approximation of this value. Apparent Thermal Inertia (ATI) only requires the diurnal heating temperature change (ΔT) and the albedo (α) of the soil (Equation 2).

$$TI = \sqrt{k\rho C} \quad (1) \quad ATI = \frac{(1-\alpha)}{\Delta T} \quad (2)$$

Results

- The thermal imagery shows the change in temperature as the soil is heated by the lamp (figure 7). The ATI, in turn, will decrease as shown in figure 8, due to the temperature change increasing.
- The ATI is correlated with the stiffness (measured using GeoGauge), as seen in figure 9, for four out of the five soil types (excluding 2NS).
- Soil classification index was able to predict the % sand and % gravel (all except fine) content with an R^2 value of 0.816 and 0.989 (Figure 10).

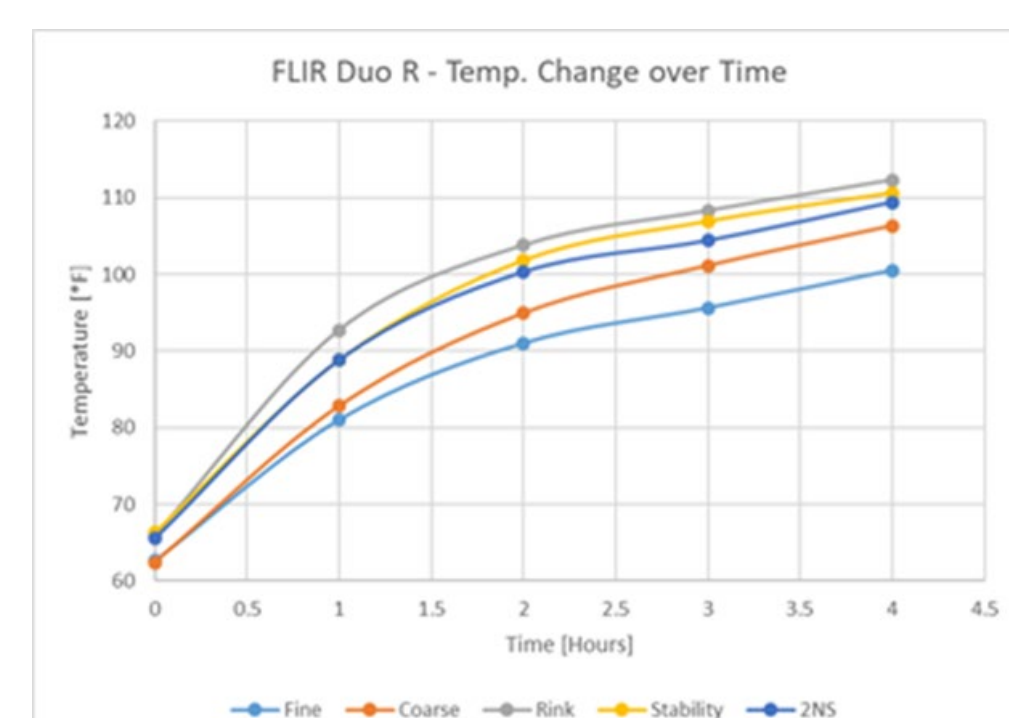


Figure 7. Plot of the change in temperature over time for lab test on 12.04.2018

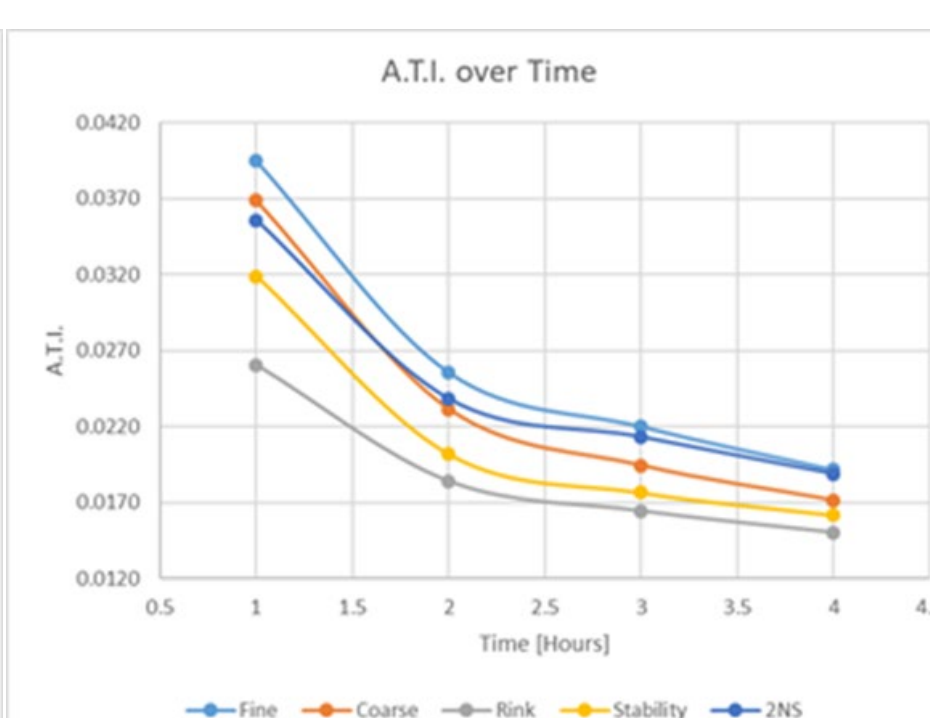


Figure 8. Plot of the change in ATI over time for lab test on 12.04.2018

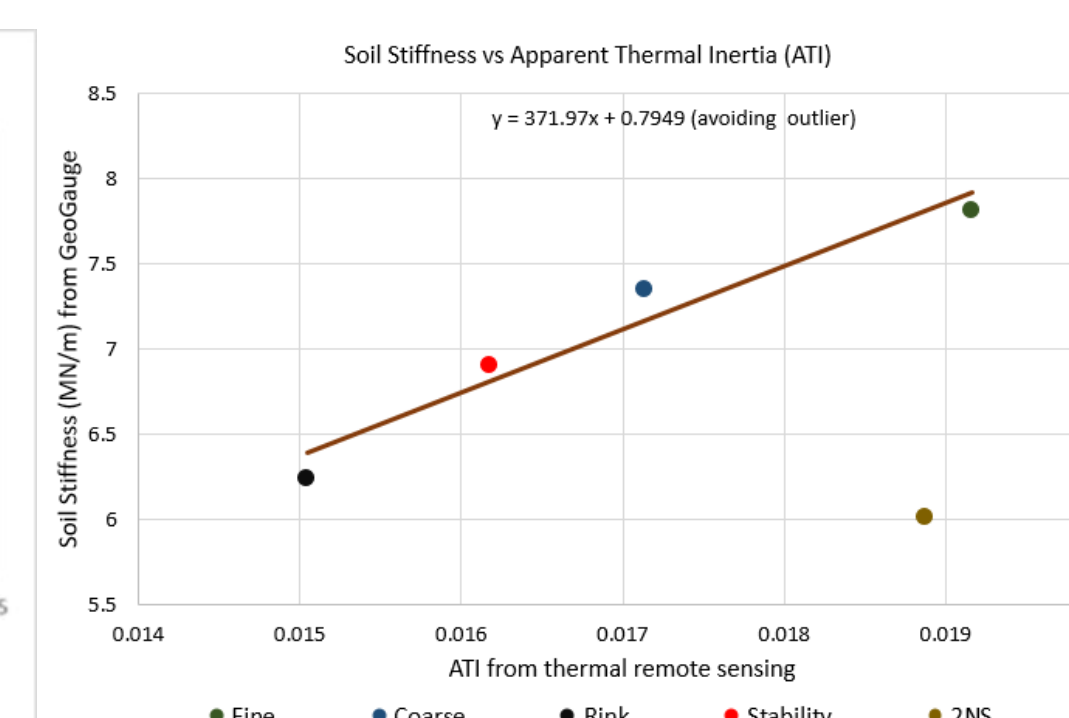


Figure 9. Plot of the ATI versus the GeoGauge stiffness for lab test on 12.04.2018

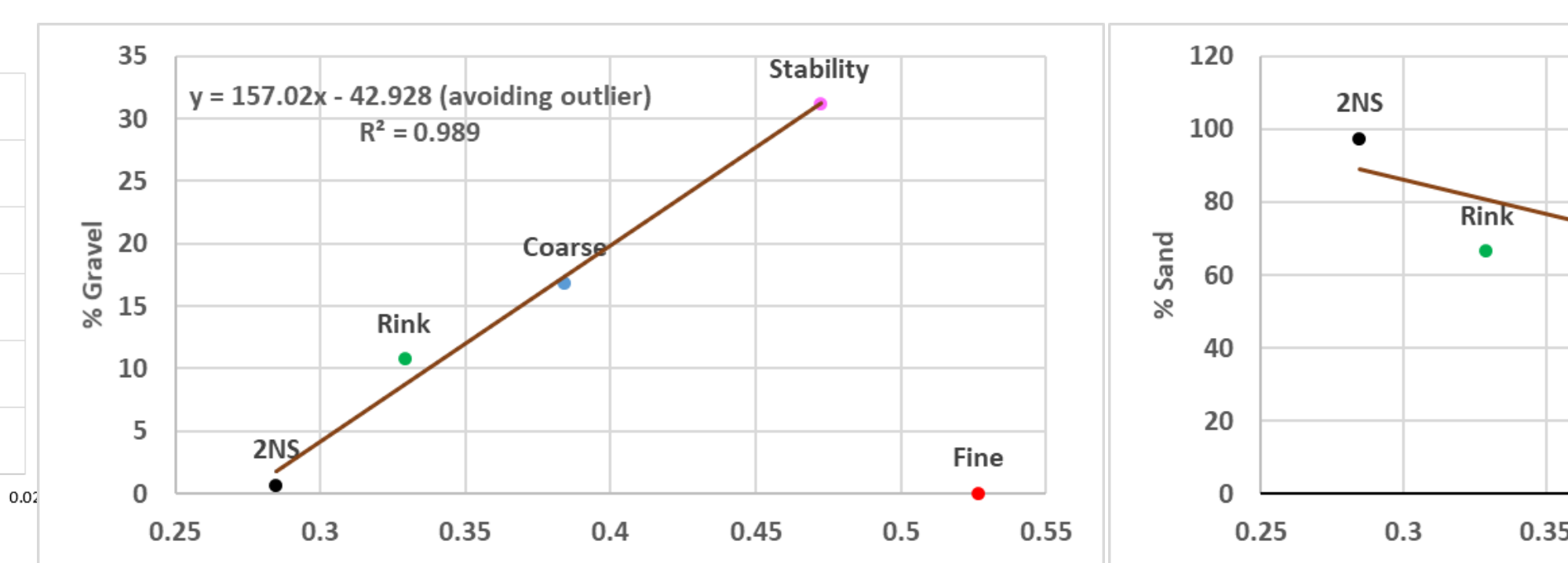


Figure 10. Soil classification index versus % Gravel (left) and % Sand (right)

Each soils reflectance spectrum is shown in figure 5. This shows the reflectance value at 650, 600, and 550 nm at different soil moisture contents to show its consistency. Even with no water up to 2000 mL of water, the SCI remains roughly constant (exception is Stability with slow increase), see figure 6.

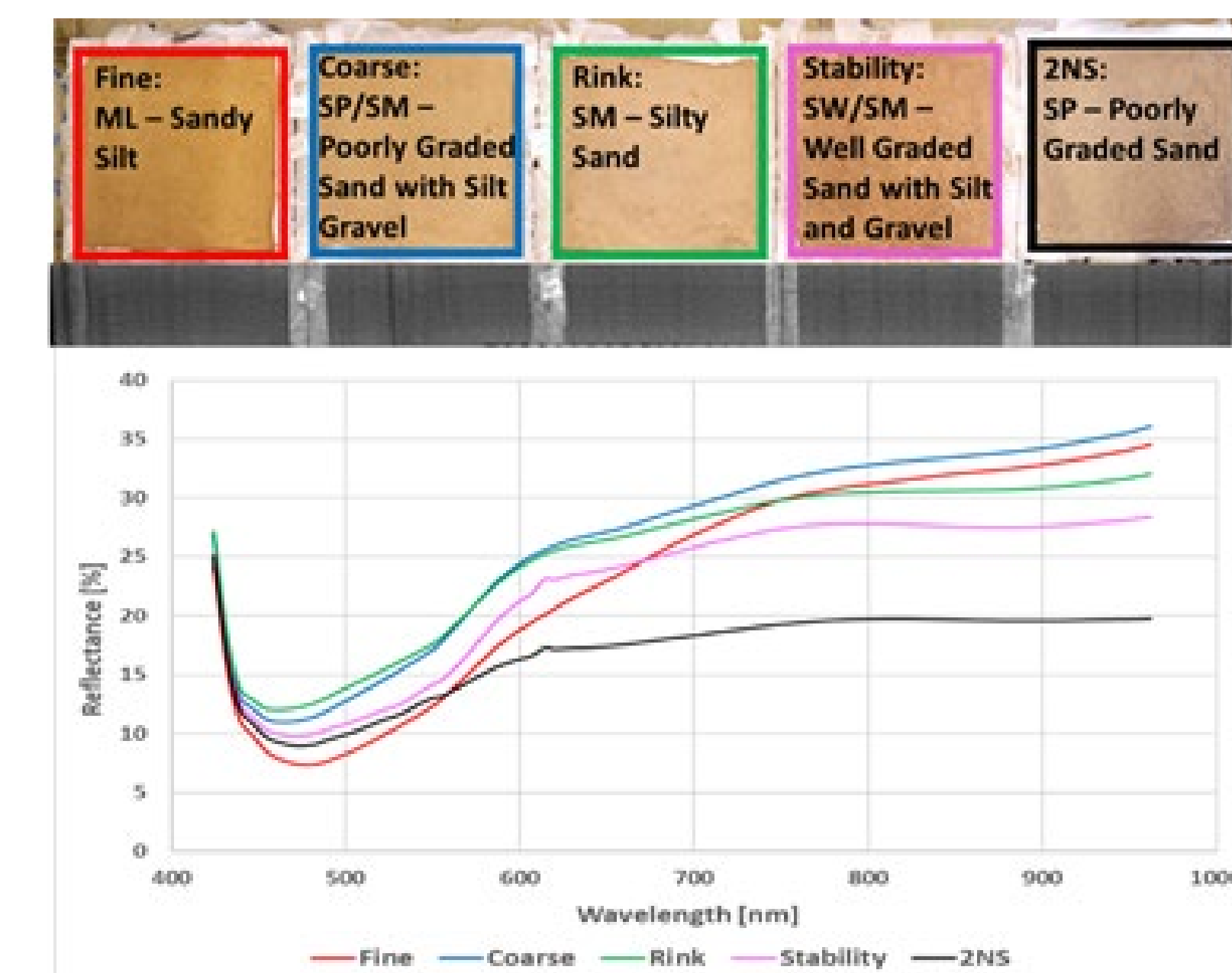


Figure 5. Shows the hyperspectral plots for each soil. Each colored box and corresponding line is a soil type. From left to right: Fine, Coarse, Rink, Stability, and 2NS. The range of the camera is from 400 to 1000 nm.

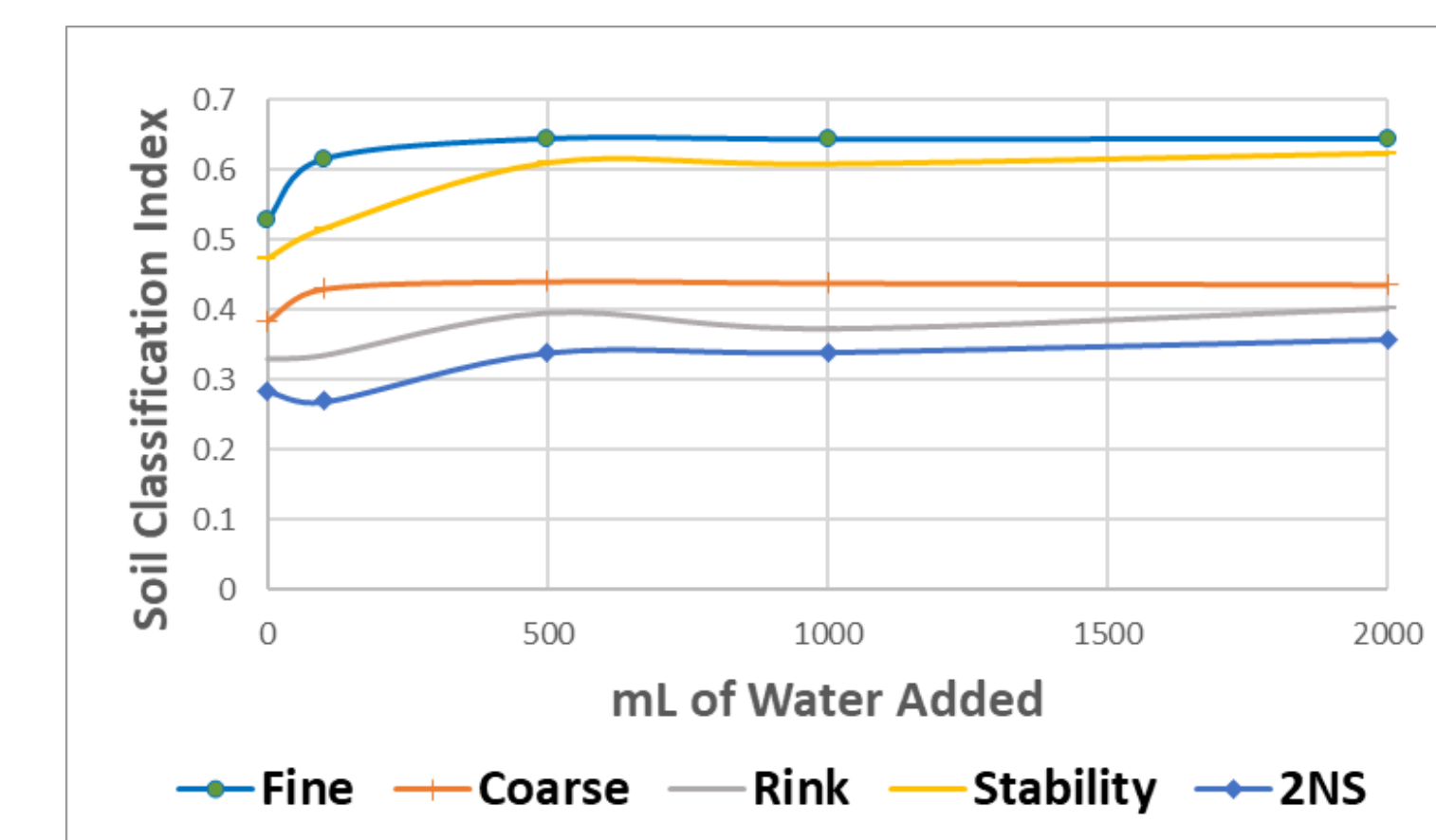


Figure 6. Soil classification index over varying water content from 0 to 4000 mL.