Near infrared spectroscopy of plantation forest soil in Sabah, and the potential for microsite assessment

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INTRODUCTION

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Soil is principally a medium for plant growth and the soil fertility is the underlying capacity of soil to provide essential plant nutrients in adequate amounts to ensure optimum plant productivity, including maximum economic benefit and minimum environmental degradation.[1] Knowledge of the soil status is important during the establishment of commercial forest plantations, amongst other crops such as oil palm, and the application of fertiliser during the establishment of trees in commercial forest plantations is routine to aid in initial growth and vigour.[2] Soil samples are often collected and analysed for nitrogen as the first step to understanding the fertility of the soil. However due to the labour-intensive nature of soil sampling and the frequent within-site variation that can be experienced (as is the case in Sabah) there is need for rapid, non-destructive methods of analysis. Such variation has been shown by Meder et al.[3] using nuclear magnetic resonance (NMR), NIR and mid-IR spectra of a linear transect of land-use systems through native forest, cleared pasture and re-forested pasture.Near infrared spectroscopy has been used in the forestry and wood products sector for predicting wood quality and there is a well-established knowledge of NIR spectroscopy for soil analysis since 1986[4], as reported in a review by Viscarra-Rossel et al.[5] Previous studies, such as that performed by Viscarra-Rossel et al.[5], developed global NIR calibration models for soil organic carbon (SOC) with mixed application and success. Although global models have wide ranging application, they are often subject to limited accuracy, by failing to account for local soil variability. This study describes the use of handheld NIR spectroscopy for soil characterization of total nitrogen, total organic carbon and pH, on Borneo soils, to provide analysis on soil samples after simply drying and grinding in a cost-effective and rapid manner. Furthermore, this approach can be deployed in combination with foliar analysis of nitrogen and phosphorus using the same portable NIR spectrometer to provide decision support for forest growers.

METHODOLOGY

Soil Sampling

Soil samples were collected from the A-horizon (0-10cm depth) and B-horizon (20-50 cm depth) from three sites within Sabah, Malaysia from three industrial tree plantation;

1.Acacia Forest Industries Sdn. Bhd. (AFISB)
2.Asian Forestry Company (Sabah) Sdn. Bhd. (AFCS)
3.Sabah Softwoods Berhad (SSB)

Soil Sample Preparation – Soils were air dried (ca. 30-35°C, 70-90% RH), ground to 2mm sieve and homogenised

Compositional Analysis

- **Total Organic Carbon** – Walkley- Black titration method
- **Total Nitrogen** – Kjeldahl TN determination method
- **Soil pH**

Samples were analysed at an ISO17025 certified laboratory.

Near Infrared Spectroscopy – Spectra acquired using microNIR 1700 ES (Viavi Solutions, Milpitas, CA, USA) in the spectral range 908-1676nm at 6.3nm resolution.

Spectra pre-treated using either standard normal variate (SNV) or Savitzky-Golay first derivative transformation with a 9-point window and second order polynomial fit.

Multivariate Data Analysis

1. **Principal Component Analysis (PCA)** – to confirm samples from different sites were able to be used in a single regression analysis
2. **Partial Least Squares Regression (PLSR)** – run for maximum 12 latent variables, and the optimum number of latent variables were chosen according to criteria in Unscrambler software.

Calibration and Validation & Model Performance Evaluation – Kennerd-Stone selection was used to calibration sets and validation sets from the combined spectra from all sites and both soil horizons.

Best Model Selection

RESULTS

- Based on the laboratory result (Figure 1), as expected, **Total Nitrogen (TN) and Total Organic Carbon (TOC)** from A-horizon are higher (more concentrated) than B-horizon samples across all three sites. Correlations between TOC and TN at each site are moderate to strong.
- **Principal component analysis** using raw spectra (Figure 2) from the calibration set showed that samples were not spectrally distinct for the first three principal components (Figure not shown) which together explained 99.7% of the total spectral variance.
- **Partial Least Square Regression of TOC, TN and pH using spectra from dry soil** – As shown in Table 1, results (RMSEP values) for TOC are similar to reported calibrations in geographically neighboring Papua New Guinea and in New South Wales, Australia. In the case of TN, the RMSEP values ranged from 0.02g 100g-1 (horizon-B) to 0.05g 100g-1 (horizon-A). While for soil pH (though was not validated with a test set, the RMSEC values in the range 0.14 to 0.17 pH units are comparable to other studies.

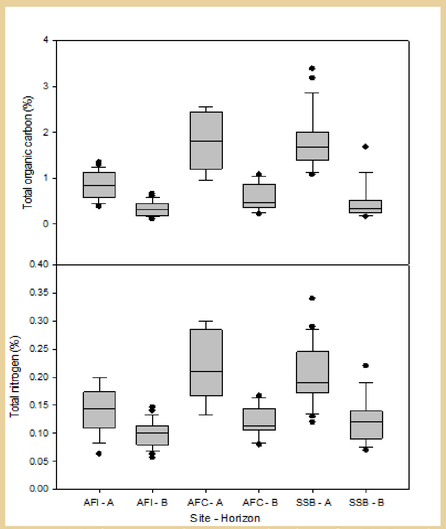

Figure 1. Laboratory-determined values for TOC and TN by site and soil horizon (A- or B-horizon) for the calibration set

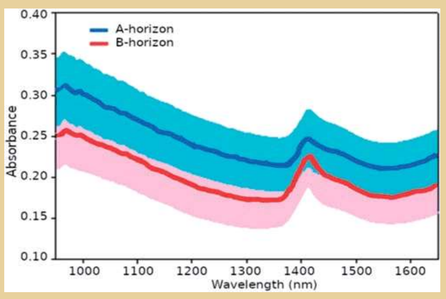

Figure 2. Mean spectra with standard deviation for NIR spectra acquired from A-horizon samples (blue) and B-horizon samples (red).

Table 1: Summary of PLS regression calibrations for the calibration set with either cross-validation or an independent validation set.

	Pre-treatment	Horizon	LV	r^2_{CV}	RMSECV (g 100·g^{-1})	RMSEP (g 100·g^{-1})
TOC (g 100g^{-1})	SNV	A	9	0.68	0.37	0.44
TN (g 100 g^{-1})	SNV	A	9	0.57	0.044	0.051
pH	1der9	A+B	2	0.81	0.15	-

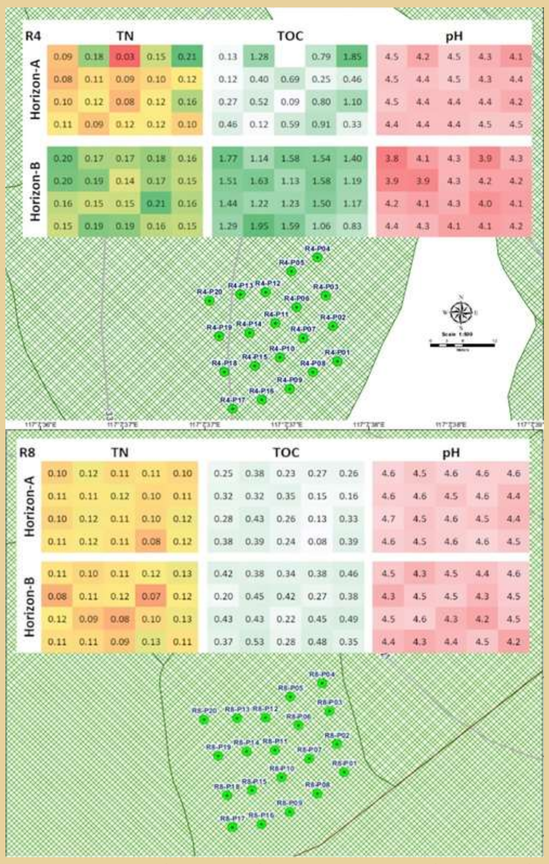

Figure 3. Top: Replicate 4 soil cores. Bottom: Replicate 8 soil cores. Shading shows relative values of analyte to aid visualization of variance

- **Using NIR spectroscopy of spatial mapping of a site**
  - Figure 3 shows NIR-predicted values of TOC, TN and pH for spectra acquired from A-horizon (0-10cm) in Replicate 4 (on slope) and 8 (on flat area) of AFI *E.pellita* progeny trial, using SNV calibration for TOC and TN and the first derivative for pH.
  - This shows the variance in Replicate 8 is lower than in Replicate 4 for both TOC and TN. By contrast Replicate 8 shows greater variance in soil pH than Replicate 4.
  - This may be explained by the fact that Replicate 4 is on a slope where nutrient loss due to rainfall run-off and leaching is very likely.
  - The results also show that the concentrations for both TOC and TN in Replicate 4 are lower in the A-horizon than the B-horizon presumably due to runoff from the A-horizon and slow percolation of nutrients into the lower depth soil where they accumulate.
  - This is in contrast to Replicate 8 where there is little observable difference between the horizons, and also different from the calibration data which was acquired in a separate series of trial plots.
  - This study shows the ability of NIR spectroscopy to provide high spatial soil data along with spatial analysis of variance of growth.

CONCLUSION

The results show the practical use of a handheld NIR spectrometer to predict total nitrogen, total organic carbon and soil pH in soils across plantation forest sites in Sabah. The results for TOC are similar to other reported calibrations as in geographically neighbouring country and acceptable for TN result. While pH was not validated with test set, the results are comparable to other recent studies.

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