

Rapid Measurement of Soil Carbon in Rice Paddy Field of Lombok Island Indonesia Using Near Infrared Technology

B H Kusumo*, S Sukartono and B Bustan

Department of Soil Science, Faculty of Agriculture, University of Mataram, JL.
Majapahit No. 62 Mataram, Lombok, Indonesia.

*bambanghk@gmail.com

Abstract. Measuring soil organic carbon (C) using conventional analysis is tedious procedure, time consuming and expensive. It is needed simple procedure which is cheap and saves time. Near infrared technology offers rapid procedure as it works based on the soil spectral reflectance and without any chemicals. The aim of this research is to test whether this technology able to rapidly measure soil organic C in rice paddy field. Soil samples were collected from rice paddy field of Lombok Island Indonesia, and the coordinates of the samples were recorded. Parts of the samples were analysed using conventional analysis (Walkley and Black) and some other parts were scanned using near infrared spectroscopy (NIRS) for soil spectral collection. Partial Least Square Regression (PLSR) Models were developed using data of soil C analysed using conventional analysis and data from soil spectral reflectance. The models were moderately successful to measure soil C in rice paddy field of Lombok Island. This shows that the NIR technology can be further used to monitor the C change in rice paddy soil.

1. Introduction

Soil organic matter (SOM) plays important roles to the fertility of soil. SOM can improve the physical, chemical and biological condition of soil [1]. It may improve the ability of soil to retain water, to improve soil structure [2], to release plant nutrients through its decomposition [3] and to increase the ability of soil in buffering contaminants [4]. Due to these roles, the adequate amount of SOM should be retained in soil and its change should be monitored.

So far, measurement of SOM is commonly conducted using conventional procedure i.e. Walkley and Black method. However this method is tedious and time consuming. It becomes expensive procedure if a large number of samples are needed to be analysed, for example, for producing a soil carbon (C) map.

Near infrared (NIR) technology, which is rapid and non-destructive technique and no chemical needed, has nowadays become an extremely important analytical technique [5]. This technology works by relating the vibration of covalent bonds of atoms such as C-H, O-H, and N-H with properties of object interest i.e. soils, minerals, and organic products. It has been reported able to measure soil C and N [6] [7] [8] [9], soil moisture content, organic matter, CEC, total C, ammonium N, nitrate N, and total N [10], root density [11, 12, 9], and biochar properties [13].



However, no information has been found on the accuracy of this technique in measuring soil C in rice paddy field of Indonesian soils. This paper reports the use of this technique to measure soil C collected from rice paddy field of Lombok Island, Indonesia.

2. Materials and Methods

2.1. Soil sample collection, analysis, scanning and spectral pre-processing

Top soil (0-10 cm depth) of 150 soil samples were collected using soil corer (2.54 cm diameter) from rice paddy field in Lombok Island, Indonesia (Figure 1). Coordinates of the samples were recorded, and the samples were shifted to the laboratory for air drying, grinding and sieving (with 0.2 mm diameter sieve). Each of the samples was divided into two parts. One part was analysed in the laboratory for total C using Walkley and Black method, and another part was scanned using ASD FieldSpec 3 V-NIR Spectrometer (Analytical Spectral Device, Boulder, CO, USA). When collecting the spectral reflectance through scanning, the sapphire window of the soil probe was touched to the soil sample which was put on a small container. The spectral data were then imported to ParLeS [14], a software that was used to transform the spectral data; transformation to $\log(1/R) - R$, wavelet detrending, and Savitzky-Golay smoothing filter. The smoothed data were then transformed into first derivative, and treated by mean centering.

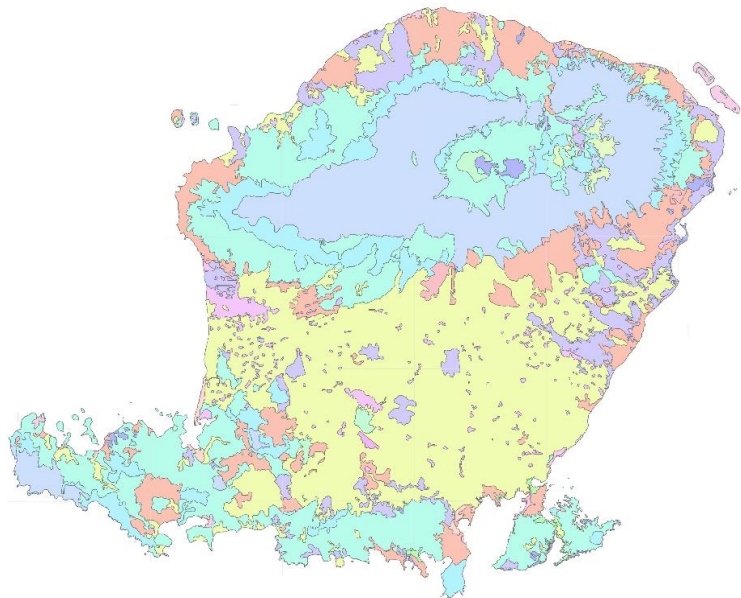


Figure 1. Location of soil sample collection in rice paddy field of Lombok Island (area with yellow colour in the map)

2.2. Developing calibration models and parameter indicating accuracy of the model

Calibration models for soil C prediction were developed using Partial Least Square Regression (PLSR) from two sources of data; pre-processed spectral data of 780 – 2500 nm and the data of soil analysis using Walkley and Black method. In order to avoid over fitting, the model was developed using the number of factors (principal components) that produce the lowest root mean square error (RMSE) [14]. The accuracy of the model was tested internally using leave-one-out cross-validation. The ability of the PLSR models to predict soil C was assessed using the following statistic: (i) RMSE (root mean square error) of measured and predicted soil C, (ii) coefficient determination (R^2), and (iii) RPD (ratio of prediction to deviation). RPD is defined by standard deviation of the reference data divided by root mean square error ($SD/RMSE$). The best model is shown by the largest RPD and R^2 , and the smallest RMSE.

3. Results and Discussion

3.1. Summary of Soil Carbon

Data of laboratory analysis of soil organic C which were analysed using Walkley and Black were present at Table 1. It can be seen that the C concentration on rice paddy field of Lombok Island varies from very low medium. Bogor Soil Research Centre (Pusat Penelitian Tanah Bogor) classifies the C-organic content into 4 categories; very low if the C-organic < 1.0%, low if the C-organic content 1.0-2%, and medium if the C-organic content 2.0-3.0%. Of all the samples, 71% samples contain very low until low C-organic, 26% samples contain medium C-organic, and only 3% samples contain high C-organic. The low concentration of soil C-organic in rice paddy field of Lombok Island is probably due to (i) low return of organic waste to the land and (ii) low input of organic fertilizer. Low C concentration in soil can also be influenced by soil cultivation. Heavily cultivated soils expose soil to the atmospheric oxygen and promote soil organic matter decomposition if soil contains less clay with coarse texture.

Table 1. Soil property

Soil property	Range		Median	Mean	Variance	Standard deviation
	Min.	Max.				
Total C-organic (%)	0.90	2.98	1.75	1.66	0.209	0.46

Soil C-organic status with various soil types of Lombok Island is presented at Table 2. Mediteran and Regosol contain C-organic varied from very low to medium. Both soils contain low average of soil C. Grumusol, Latosol and Alluvial vary from low to medium and these soils in average contain more C-organic than in Mediteran and Regosol.

Table 2. Soil C-organic status with various soil types.

	Soil type	Range		Average	Status
		Min	Max		
C-organic	Grumusol	1.41	2.98	2.06 (medium)	Low - Medium
	Mediteran	0.85	2.73	1.56 (very low)	Very low - Medium
	Regosol	0.90	2.79	1.83 (very low)	Very low - Medium
	Latosol	1.44	2.58	2.04 (medium)	Low - Medium
	Alluvial	2.00	2.20	2.10 (medium)	Low - Medium

3.2. Soil Spectral Shape

Spectral shape of soil reflectance based on soil types is depicted at Figure 2. There are variations of soil color due to soil types which can be seen on the visible band (400-780 nm). Alluvial soil reflects highest visible bands while Regosol soil absorbs more visible bands. Very strong absorption at around 1400 and 1900 nm at Figure 2 is due to water absorption; the first overtones of the O-H bond of water and the combination of the H-O-H bend and O-H stretching, respectively [15] [16] [6]. While strong absorption at around 2200 nm is the combination of metal O-H stretch [15].

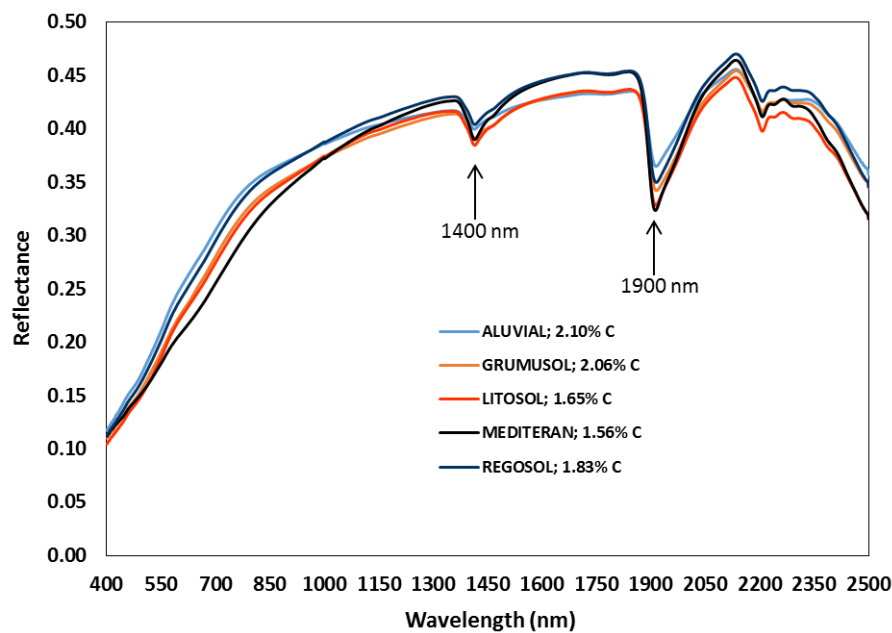


Figure 2. Soil reflectance of each soil type.

3.3. Accuracy Measurement of Soil C using NIRS

Prediction values of soil C-organic using leave-one-out cross-validation are shown at Table 3. It can be seen that NIRS technique was able to moderately predict soil C which was showed by RPD around 2.00 and R^2 0.7. Chang et. al. [17] classify the prediction values of models into moderately successful if R^2 0.5-0.8 and RPD 1.4-2.0. While, Malley et. al. [18] considered models with moderate accuracy if the R^2 0.7-0.8 and RPD 1.75-2.25. Accuracy of a model may be influenced by the accuracy of laboratory analysis and the signal to noise ratio of the soil reflectance. Soil water content, organic matter, clay and non-clay soil minerals, carbonates, iron oxides, and particle size of the soil sample [19] may also influence the model accuracy.

Table 3. Prediction values of soil C using leave-one-out cross-validation

Properties	Prediction values (leave-one-out cross-validation)		
	R^2_{CV}	$RMSE_{CV}$	RPD_{CV}
C Total	0.761	0.217	2.04

3.4. Relationship of laboratory measurement and NIR prediction

The relationship between soil C data of laboratory measurement and NIRS prediction is shown at Figure 3. Moderate accuracy of soil C prediction (R^2_{CV} 0.75; RPD_{CV} 2.04) shows that NIRS technique can be used to measure soil C-organic in rice paddy field of Lombok Island. Moderate accuracy using NIRS technique was also reported by Kusumo et. al. [6] and Chang et. al. [17] when dealing with soil C measurement.

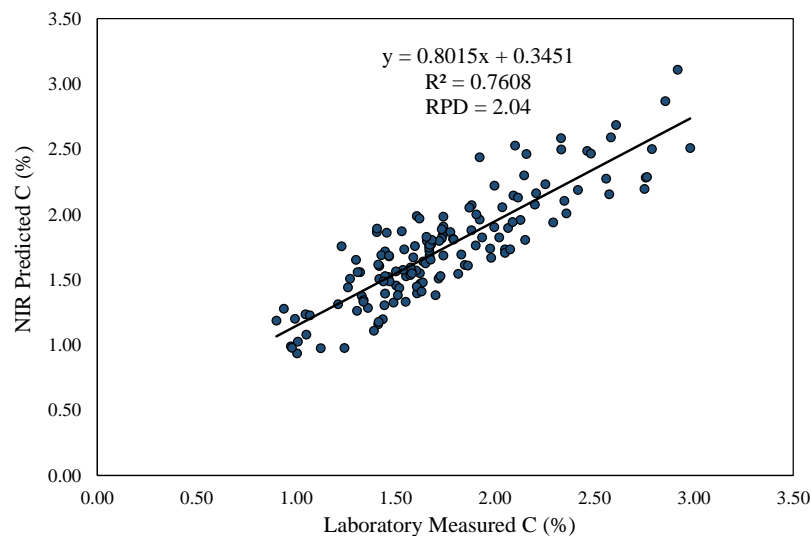


Figure 3. Relationship between soil C measured by laboratory analysis and predicted by NIRS.

3.5. Important Wavelength to the Model

Very important wavelength of soil reflectance contributing to the PLSR model is presented in Figure 4. Wavelengths with high VIP scores play more important role to the model [14]. The wavelengths around 1420 nm and most wavelengths between 2100 – 2500 nm are more important than other wavelengths in predicting soil C.

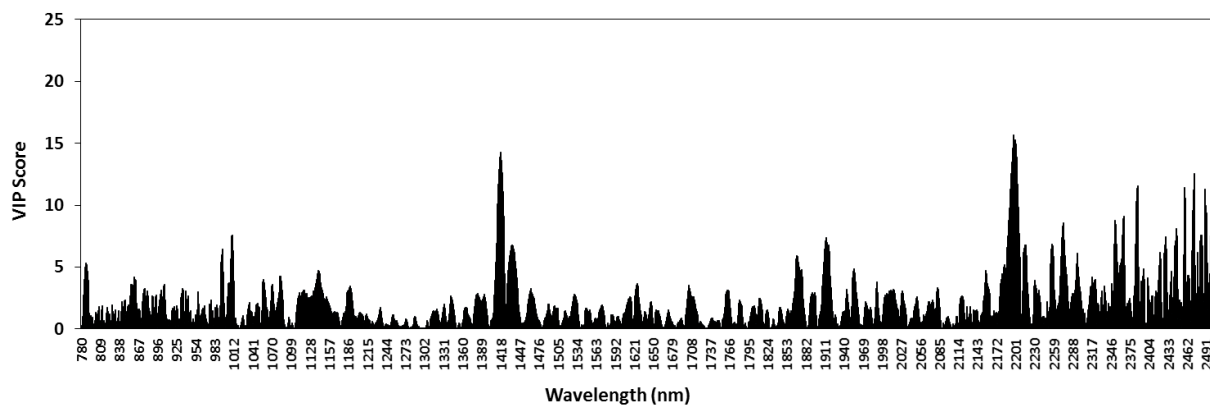


Figure 4. Very important wavelength to the model.

4. Conclusion

Soil C concentrations in rice paddy field of Lombok Island Indonesia are mostly very low to low. Some samples contain medium amount of soil C, and only small samples contain high C. This indicates that the concentration of soil C is in the critical condition. Near infrared technology was moderately successful to rapidly measure soil C in the study area. This successful measurement may give benefit for rapid monitoring of C concentration in soil which may be used as the information of the fertility status of the soil and as the information of soil C change and sequestration.

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