Mapping total Nitrogen in dryland North Lombok from soil spectral reflectance

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Abstract. Nitrogen (N) is one of the essential nutrients for plant growth, and its availability and spatial distribution in dryland need to be known for better soil and crop management. However, mapping soil N content is expensive and time consuming. The aim of this research is to test the use of soil spectral reflectance to rapidly measure and map soil total N in North Lombok dryland. About 300 soil samples, including the coordinates, were collected in Kayangan Sub-district of North Lombok, Indonesia. The samples were dried, ground, sieved (0.2 mm diameter), which then analysed for total N content using Kjeldhal method, and scanned using near infrared spectroscopy (NIRS). A calibration model was developed using partial least square regression (PLSR) from Kjeldhal-analysed N data and soil spectral data. The model was then used to predict the soil N content from the spectral data, and then soil nitrogen content was spatially mapped. The result showed that soil spectral reflectance technology was able to measure and map total N distribution in soil although the range of soil N content was from very low to medium. This shows that the technology can be used to map soil N distribution in dryland North Lombok, which may then be used for the guidance of fertiliser application.

1. Introduction
Nitrogen (N) is one of the essential nutrients for plant growth. Its availability in soil is vital for the formation of amino and nucleic acid in plant, development of plant tissue and cells, and formation of chlorophyll for the photosynthesis process [1]. The availability of N in dryland is usually low, which is associated to the small amount of plant residue, low in soil organic matter content and low input of fertilizers [2]. The loss of N from dryland may occur because of wind and water erosion, ammonia volatilization, and nitrate N accumulation beyond the root zone [2]. Application of N fertilizer is believed able to solve N deficiency and increase plant yield [3]. However, the application of N fertilizer needs information about soil N status from a soil N map [4], in order to avoid excessive addition of N fertilizers in the area of high N content, and to optimize the addition of N fertilizers in the deficient area [4,5].

Developing a soil N map is not a cheap work [6]. It is needed large number of soil samples which are then analysed in a laboratory [7,8]. This conventional analysis takes times and requires a lot of
labours [9,10]. Mapping soil N from larger area needs larger number of soil samples and makes this activity much more expensive [11]. So the conventional analysis should at least be back-up or replaced by other methods which are more efficient in terms of cost, time and labour [11,12].

Mapping soil N from soil spectral reflectance has been tried and developed in order to make the mapping process more efficient [13]. As the N soil measurement doesn’t need chemical reagents when using the reflectance technique [14], this makes the process faster and able to handle sample points with high density [11]. High sample point density will then produce a map with high resolution [13], which is very expensive when the soil analysis is carried out using conventional laboratory analysis [9].

The success of soil N mapping from soil spectral reflectance has been previously reported by other workers e.g. Kodaira and Shibushawa [13] and Witterlind et al [11]. However, limited information is found out related to the success of this technique in the dryland of tropical soil, including Indonesia. Thus, the aim of this research to test the use of soil spectral reflectance to rapidly measure and map soil total N in North Lombok dryland, Indonesia, which may be further used for the guidance of fertilizer application.

2. Material and methods

2.1. Coordinate determination, soil sample collection, analysis and spectral data pre-processing

A total of 300 coordinate positions for soil sampling were determined which cover all land uses in the study area in Kayangan Sub-District, North Lombok, Indonesia. The soil samples with 0-10 cm depth were collected from those positions using soil corer (2.54 cm diameter). The samples were then dried, ground and sieved (0.2 mm diameter), and then divided into two parts. One parts were analysed for total N using Kjeldhal method and for total carbon (C) using Walkley and Black method, and the other parts were scanned using near infrared spectroscopy (ASD FieldSpec 3 V-NIR Spectrometer, Analytical Spectral Device, Boulder, CO, USA). The spectral data were then pre-processed using ParLeS [15,16] namely: conversion to log (1/R) - R, wavelet detrending, smoothing with Savitzky-Golay filter, first derivative, and mean centering [17-19].

2.2. Development of calibration model and soil N mapping

Partial least square regression (PLSR) was used to develop the model from the Kjeldhal-analysed soil N data and the pre-processed spectral data. The robustness of the calibration model was assessed using parameters, namely coefficient determination (R²), RPD (ratio of prediction to deviation; SD/RMSE) and RMSE (root mean square error) [18,19]. The best model which produced the highest R² and RPD, and the lowest RMSE, was used to predict the soil N content from spectral reflectance.

Two of soil N maps were developed from soil total N data which were analysed using Kjeldhal method and predicted using spectral reflectance technique of NIRS. The digital soil maps were developed using ArcGIS software. The robustness of soil reflectance technique to produce soil N data used to map the soil N content was compared with the map produced from soil N analysed by Kjeldhal method. The R², RPD, and RMSE were used as the assessment parameters [18].

3. Results and discussion

3.1. Soil nitrogen in the study area

The soil N contents in the study area which were analyzed using Kjeldhal method were presented at Table 1. Total N concentration varies from very low to medium, with low concentration in average. The majority of low concentration of soil N in the study area may be related to the individual or combination of the following reasons: because of (i) small amount of plant residue left in soil, (ii) small amount of organic fertilizer applied to the soil [20], and/or (iii) low input of nitrogen fertilizer to the soil [20, 21].
Table 1. Soil total N in the study area.

| Soil property | Range | Median | Mean | Variance | Standard deviation | Coefficient of variation (%) |
|---------------|-------|--------|------|----------|--------------------|-----------------------------|
| Total N (%)   | Min.  | Max.   |      |          |                    |                             |
|               | 0.04  | 0.26   | 0.11 | 0.11     | 0.001              | 0.036                       | 31.70                       |

The majority of low concentration of soil N in the study area which is expected related to the concentration of organic matter in the soil is supported by the data below which show very strong correlation \((r = 0.99)\) between total N concentration and soil organic matter (SOM) content (Figure 1). As reported by Beltrán et. al. [22], the SOM derived from crop residues left in soil, such as leaves, twigs and roots of cover crops, contributes to the N content in soil.

![Figure 1. The correlation between soil organic matter content and soil total nitrogen.](image)

3.2. The accuracy of N prediction from soil spectral reflectance

The accuracy of soil reflectance technique (NIRS) to predict soil N is presented at Table 2. Soil N content can be predicted with moderate accuracy as shown by relatively high coefficient determination \((R^2 0.753)\) and ratio of prediction to deviation \((RPD 2.00)\). This accuracy is acceptable for the application of NIRS technique to the soil samples [23]. With this accuracy, rapid process of NIRS measurement, which does not need chemical reagents, may be the solution of tedious procedure of Kjeldhal method in analysing total N in soil.

Table 2. Prediction values of soil N using leave-one-out cross-validation.

| Properties | Prediction values (leave-one-out cross-validation) |
|------------|---------------------------------------------------|
|            | \(R^2_{CV}\)  | \(RMSE_{CV}\)  | \(RPD_{CV}\)    |
| N Total    | 0.753      | 0.017          | 2.00             |

The Kjeldhal-analysed N data which are plotted against the NIRS-predicted N data are presented at Figure 2, showing moderately successful of this technique in predicting soil N content. Successful prediction of soil N using NIRS was also reported previously in the tropical climate developed soils [24] and in the subtropical soils e.g. Sorenson et al. [25]. More recently, Pudelko and Chodak [26] were successful to predict the total N from mine soils using reflectance spectroscopy. Also, Sorenson et al. [27] were able to map the distribution of total N in soil profiles of boreal forest soil research plots using imaging spectroscopy.
Figure 2. Relationship between total N analysed by Kjeldhal method and NIRS.

3.3. Total N maps developed from laboratory (Kjeldhal method) and NIRS data

The maps of soil N developed from laboratory N data (Kjeldhal method) and NIRS data are presented at Figure 3. Both maps show quite similar distribution of N content in the study area. Medium N concentration, which is shown by darker colour, is located at the irrigated area which was planted 3 times a year with seasonal crops, such as rice, corn and vegetables [28]. Higher N content in the area is probably related to the more intensive planting (3 times a year) which is supported by the availability of the irrigation water. Larger amount of plant residue left below and/or above soil surface in the irrigated area may contributes to the higher organic matter content in soil [29], which then cause higher soil N content. While, lower content of soil N in the study area is shown by lighter colour (Figure 3), which is characterised by rain-fed irrigation with limited times of planting per year; mostly 1-2 times per year.

Figure 3. Soils N maps developed from (A) laboratory data (Kjeldhal method) and (B) NIRS data.
4. Conclusion
Soil total N concentration in the study area of Kayangan Sub-district North Lombok Indonesia varies from very low to medium, with the majority of low content. The N concentration is strongly correlated to the soil organic matter content. As soil reflectance technique was moderately successful to measure soil N in the study area, the soil N map developed from this technique was comparable to the soil N map produced from laboratory data (Kjeldhal method). This indicates that soil N content in the study area can be mapped using soil reflectance technique, and the map may be further used as a guidance of the fertilizer application for the precision farming.

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References
[1] Barker A V and Pilbeam D J (Eds.) 2015 Handbook of plant nutrition (CRC press)
[2] Li S X, Wang Z H, Hu T T, Gao Y J and Stewart B A 2009 Advances in Agronomy 101 123-181
[3] Omara P, Aula L and Raun W R 2019 International Journal of Agronomy 2019 1-6
[4] Smith A P, Beale P, Fulkerson B J and Eckard R J 2019 Agricultural Systems 176 102677
[5] Laird D, Rogovska N and Chiou C P 2019 Iowa State University Research Foundation (ISURF) Soil nitrate sensing system for precision management of nitrogen fertilizer applications US Patent Application 16/415,634
[6] Chi Y, Zhao M, Sun J, Xie Z and Wang E 2019 Geoderma 339 70-84
[7] Wang S, Zhuang Q, Wang Q, Jin X and Han C 2017 Geoderma 305 250-263
[8] Kusumo B H 2018 IOP Conference Series: Materials Science and Engineering 434(1) 012235
[9] Stenberg B, Viscarra Rossel R A, Mouazen A M and Wetterlind J 2010 Advances in Agronomy 107 163-215
[10] Calvelo Pereira R, Hedley M, Camps Arbestain M, Wisnubroto E, Green S, Saggar S, Kusumo B H and Mahmud A F 2016 GCB Bioenergy 8(3) 600-615
[11] Wetterlind J, Stenberg B and Söderström M 2010 Geoderma 156(3-4) 152-160
[12] Stafford A D, Kusumo B H, Jeyakumar P, Hedley M J and Anderson C W 2018 Geoderma regional 13 26-34
[13] Kodaira M and Shibusawa S 2013 Geoderma 199 64-79
[14] Kusumo B H 2009 Development of field techniques to predict soil carbon, soil nitrogen and root density from soil spectral reflectance (Unpublished doctoral thesis Massey University Palmerston North New Zealand)
[15] Kusumo B H, Arbestain M C, Mahmud A F, Hedley M J, Hedley C B, Pereira R C, Wang T and Singh B P 2014 Journal of Near Infrared Spectroscopy 22(5) 313-328
[16] Viscarra Rossel R A 2008 Chemometrics and Intelligent Laboratory Systems 90 pp 72-83
[17] Kusumo B H, Sukartono S and Bustan B 2018 IOP Conference Series: Materials Science and Engineering 306(1) 012014
[18] Kusumo B H 2018 IOP Conference Series: Earth and Environmental Science 129(1) 012023
[19] Kusumo B H, Sukartono S, Bustan B and Purwanto Y A 2019 Journal of Physics: Conference Series 1402(2) 022096
[20] Córdova S C, Olk D C, Dietzel R N, Mueller K E, Archontoulis S V and Castellano M J 2018 Soil Biology and Biochemistry 125 115-124
[21] Hijbeek R, Ten Berge H F M, Whitmore A P, Barkusky D, Schröder J J and Van Ittersum M K 2018 Nutrient cycling in agroecosystems 110(1) 105-115
[22] Beltrán M J, Sainz-Rozas H, Galantini J A, Romaniuk R I and Barbieri P 2018 Environmental Earth Sciences 77(12) 428
[23] Malley D F, Martin P D and Ben-Dor E 2004 Application in analysis of soils. Near-Infrared Spectroscopy in Agriculture, Agronomy Monograph no. 44. ed Barbarick K A, Roberts C A, Dick W A et al (Madison, Wisconsin, USA: American Society of Agronomy, Inc., Crop Science Society of America, Inc., Soil Science Society of America, Inc.)

[24] Barthès B G, Kouakoua E, Clairotte M, Lallemand J, Chapuis-Lardy L, Rabenarivo M and Roussel S 2019 Geoderma 338 422-429

[25] Sorenson P T, Quideau S A and Rivard B 2018 Geoderma 315 170-177

[26] Pudełko A and Chodak M 2020 Geoderma 368 114306

[27] Sorenson P T, Quideau S A, Rivard B and Dyck M 2020 Geoderma 359 113982

[28] Kusumo B H, Purwanto A, Idris H, Sukartono, Susilowati L E and Bustan 2020 Soil Organic Matter in Various Land Uses and Management, and Its Accuracy Measurement using Near Infrared Technology Under process of publishing in IOP Conference Series, IOP Publishing

[29] Dong L, Yu D, Zhang H, Zhang M, Jin W, Liu Y and Shi X 2015 Soil and Tillage Research 145 148-156