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Research Article

Determination of the spatial variability of soil nitrogen content based on reliefs in an apple orchard, Batu, Indonesia

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Abstract: A better understanding of the spatial variability of soil nitrogen content is required to achieve the best management in precision agriculture. The purpose of this study was to determine the spatial variability of soil nitrogen content based on reliefs in an apple orchard. The study was conducted from March to August 2018 in a 1210 hectare of apple orchard, Batu, East Java Province, Indonesia. Soil samples were taken using the stratified random sampling method. Data were processed by the GLM Univariate 5% method with SPSS 16.0. The results of the statistical analysis showed that the Sig value and coefficient of determination were 0.000 and 0.846, respectively. This condition means that soil nitrogen content was significantly different in various reliefs. The apple orchard was divided into 10 (ten) zones with different soil nitrogen content in various reliefs. This is crucial as a basis for implementing precision agriculture in apple orchards, meaning that the determination of fertilizer dosage can be adjusted to the soil nitrogen content in the various zones. This study concluded that relief significantly affected the spatial variability of soil nitrogen content.

Keywords: *apple orchard, land management, precision agriculture, soil nutrient, topography*

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Introduction

Nitrogen (N) is one of the macro-essential nutrients because it is needed in relatively large quantities and the primary nutrients for plants. Deficiency of N results in stunted plants and root growth inhibited, whereas if an excess of N results in tissue becoming succulent, easy to fall and susceptible to plant diseases (Syekhfani, 2010). Therefore, the addition of nitrogen nutrients through fertilization must consider the soil nitrogen content so that it is precisely by the needs of the plant. Fertilizer doses on similar commodities in conventional farming systems tend to be the same for all fields. This practice shows that conventional agricultural practices have ignored the spatial variability of soil nutrient content — this practice results in fertilizers that are not by the needs of the plants and tend to be excessive. Another impact on this practice is the increase in soil chemical residues thereby reducing soil fertility and yields. This condition has occurred in the apple orchard in Batu, where a decline in apple production has occurred due to the degradation of soil fertility. This phenomenon has encouraged the emergence of a new agricultural concept is precision agriculture. The basic principle of the concept of precision agriculture is the provision of agricultural inputs by the conditions of soil fertility. Therefore, information on the spatial variability of soil nutrient content is the central element for implementing this concept (Castrignano et al., 2011). The development of remote sensing technology and geographic information systems today also contributed to the progress of the implementation of the concept of precision agriculture. Kriging interpolation is a method that is widely used to identify the spatial variability of soil nutrient content because it can produce zonation with good accuracy (Mabit et al., 2008; Debaene et al., 2014).

The Kriging method works optimum when the sample size is large, and the distance between the sample points is tight. The consequence of this method takes much time, effort, and cost. This condition is an obstacle to the application of the concept of precision agriculture (Singh et al., 2015). Therefore, this research was conducted to answer these problems. The potential utilization of secondary variables for estimating soil properties has been carried out for this decade (Sudduth et al., 1995). The conditions for selecting secondary variables are easy availability and low cost. The secondary variable that is widely used for estimating the spatial distribution of soil properties is elevation (Blackmer et al., 1995; Mulla, 1997).

Today elevation data is available in digital format in the form of digital elevation model (DEM) (Bishop and Minasny, 2006). This data visualize the topographic conditions of a region quantitatively called relief. Topography is one of the soil forming factors besides climate, parent material, organism, and time (Brady and Weil, 2002). This study aimed to determine the spatial variability of soil nitrogen content based on reliefs in an apple orchard. The results of this study are significant as a basis for implementing precision agriculture in the apple orchard.

Materials and Methods

The study was conducted in March to August 2018 and located in the apple orchards of Batu, East Java Province, Indonesia (7° 52′ S and 112° 31′ E) (Figure 1). The climate type of this region according to the Köppen classification is classified into Am type (tropical monsoon). The number of rainy days in the study area is 160 days per year, where the highest number of rainy days occurs in December with 31 rainy days. The highest rainfall in the study area occurs in November, where the total rainfall in the study area is 2,179 mm per year. The highest air humidity in this region is 95%, and the average air temperature is 23^{0}C. The elevation of the penitentiary area of 700-1900 m above sea level (asl) has complex relief. This region is geologically located in the Arjuna Welirang Volcano formation during the late Pleistocene. Field observations showed that soil types belong to the Humic Dystrudepts subgroup with silty clay of soil texture, subangular blocky soil structure, 10YR3/2 soil colour, and slightly firm soil consistency.

This study was focused on apple land use because this commodity has a unique value that characterizes the region. Today the commodity of apple has a problem in the form of a decrease in soil fertility which reduces crop yields. Improving the condition of soil fertility through the application of the concept of precision farming is the solution to these problems.

The DEM 5-meter resolution sourced from the Regional Development Planning Agency (Bappeda) of Batu, East Java Province was used to identify reliefs. The stages of relief's identification consisted of testing the accuracy of DEM data, spatial analysis, and interpretation. Test the accuracy of DEM data was made using the linear error method (LE 90). This method tests data accuracy vertically and is known as vertical accuracy. The principle of this method is the comparison of elevation values between DEM and actual location in the field at the same coordinate. The comparison forms a formula as follows (Sutanto, 2013):

$LE90 = \delta p \times 1.6449.$,

where
δp: standard deviation (RMSE)………..……eq.1)

The results of LE 90 were analyzed further to determine the maximum limit of vertical accuracy using the formula: 0.5 x pixel resolution. This further analysis serves to decide whether the data meets the criteria for accuracy or not. If the LE 90 value is lower than the maximum vertical accuracy limit, the DEM data meets the criteria of vertical accuracy (Sutanto, 2013). The next step was the spatial analysis of DEM data using ArcGIS 10.1 software. In this analysis, DEM data were extracted into four spatial data, namely slope, curvature, drainage, and elevation (van Zuidam and van Zuidam-Cancelado, 1978; Suparto et al., 2016). The coordinate system is the transverse Mercator unit (UTM), WGS 84 datum, and 49S zone. The final stage was the interpretation of reliefs based on four components, namely slope, curvature, drainage, and elevation. The relief interpretation covers the form of curvature ranging from wavy to mountainous, differences in slopes ranging from slightly tilted to steep, differences in drainage density, and differences in altitude. The final result of this phase was the relief boundary classification that divided the apple orchard into several zones. Determination of location points of soil samples used a stratified random sampling method based on relief. The depth of the soil sample adjusted the average depth of the root (50 cm) and the width of the canopy of the apple plant (50 cm from the tree trunk). Each soil sample was coded, and the coordinates of the location were recorded using the 76CSX Garmin GPS. Soil samples were dried and sieved with sieves 2 millimetres in diameter to analyze soil total N. The total N soil analysis used the Kjeldahl method (Eviati and Sulaeman, 2012), which includes three stages, namely destruction, distillation, and titration. The formula used for calculating nitrogen content is as follow:

Nitrogen (%) = (Vc-Vb) x N x 2.8 x fk;…....eq. 2)

where: Vc: ml sample titer; Vb: ml titer blank; N: normality of the standard solution of H_2SO_4; fk: water content correction factor = 100 / (100% moisture content).

Descriptive statistical analysis that included the mean, minimum, maximum, median, range, and variance coefficients was used to see the characteristics of the data. The Skewness Index and the Kolmogorov-Smirnov's Test were used to test data normality. Statistical analysis of GLM Univariate 5% was used to test the relationship between relief and soil nutrient content. All the statistical analysis processes used SPSS 16.0 software.

Results and Discussion

The total number of samples tested for vertical accuracy was 20 locations that spread evenly at the study site. The maximum limit of vertical accuracy criteria was half of the resolution of DEM data. The DEM resolution in this study was 5 meters so that the limit of the maximum vertical accuracy value was 2.5; this means that the DEM data is an accurate criterion if the LE90 value is less than 2.5. The value of further analysis tests the vertical accuracy of the DEM data in this study was 1.77 (less than 2.5). These results indicate that DEM data meet the criteria of vertical accuracy or according to actual conditions in the field.

Extraction of DEM data resulted in data on the spatial distribution of slopes, drainage flow, elevation, and curvature (Figure 1). The results of the interpretation of the four data produced 10 (ten) zones that differed in relief characteristics and were coded I, II, III, IV, V, VI, VII, VIII, IX and X. Soil samples from each zone were determined using the stratified random sampling method so that the total number of sample points in the study was 60 samples. The source of nitrogen in the soil is derived from the life activities of soil microorganisms or bacterial activity such as Rhizobium, Azotobacter, and Clostridium. Availability of nitrogen in the soil can optimize plant growth. Various factors influence the availability of soil nitrogen, namely climate, vegetation, topography, and mineral components, and profile distribution. Soil nitrogen consists of two forms namely organic and inorganic. Forms of organic nitrogen include NH_4^+, NO_3^-, N_2O, and NO, while inorganic nitrogen originates from the addition of N fertilizer (Budi and Sasmita, 2015).

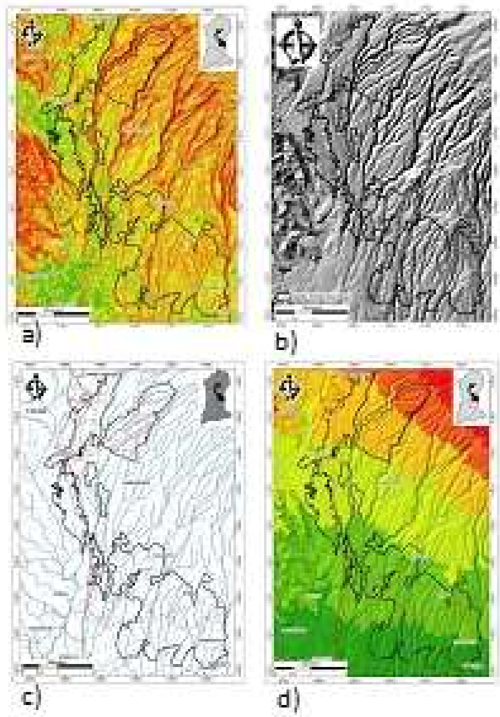

Figure 1. The result of DEM extraction, (a) slope map, (b) curvature map, (c) drainage map, and (d) elevation map

Nitrogen content is one indicator of soil fertility. The criteria for soil fertility based on nitrogen levels according to Ritung et al. (2011) are divided into 5 classes, which are very low (<0.1), low (0.1 - 0.2), moderate (0.21 - 0.5), high (0.51 - 0.75), and very high (> 0.75). The level of soil fertility from the aspect of total nitrogen content in the study site varied from low to high. The highest level of total N of soil was in the zone VII of 0.548%, while the lowest N content was in the zone V of 0.142% (Figure 2). The difference in total N levels indicates that the soil fertility rate is different so the fertilizer dosage cannot apply to the same dose. Improvement of soil fertility must pay attention to soil nitrogen content, considering that nitrogen is an essential nutrient for plants. This condition indicates that the application of fertilizing every land with the same dose is not appropriate. Instead, it must be by the plants' needs and the conditions of soil fertility. The normality test of the data in this study used the Skewness index and Kolmogorov-Smirnov's. The results of descriptive statistical analysis of soil nitrogen content are presented in Table 1. The minimum and maximum values of soil nitrogen content were 0.104% and 0.643%, respectively. The skewness index value indicated that the data distribution was reasonable because it was in the range of -2 to 2 or was symmetrical for Skewness. Likewise for the Kolmogorov-Smirnov's value produced a value of 1.318, meaning that the data distribution was classified as normal because it was more than 0.05.

Table 1. Descriptive and normality data of soil total nitrogen at 50 centimeter soil depth

Soil property	Descriptive analysis						Skewness Index
	Minimum	Maximum	Mean	Median	Std. Deviation	Variance	
N (%)	0.104	0.643	0.307	0.290	0.154	0.024	1.284*)

*) data are normally distributed

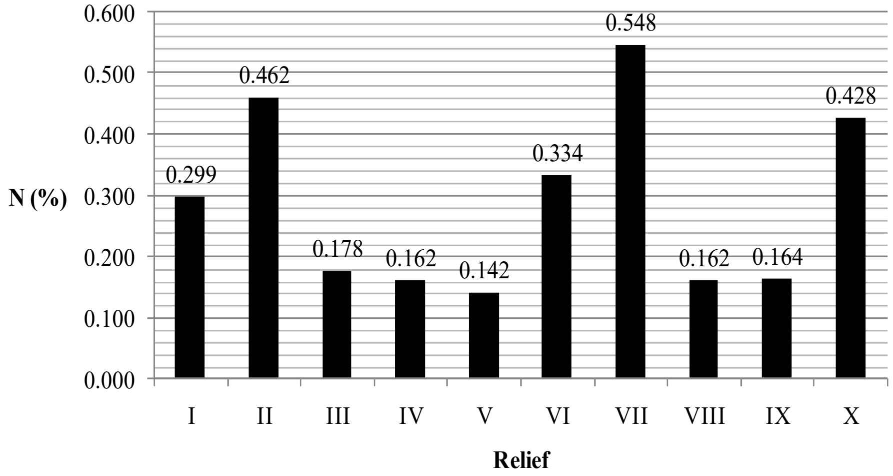

Figure 2. Total nitrogen at 50 cm depth of soil from various reliefs

The results of the test for the significance of soil nitrogen content in various relief was a significance value of 0,000, which mean that the value was less than 0.05 (Table 2). The results of these tests indicated that with a confidence level of 95% of the total N content of the soil showed a marked difference in various reliefs (zones). The effect of relief on soil nitrogen levels was very significant; the R^2 value of 0.876 indicated this. Therefore, relief can be used as a basis for mapping the soil nitrogen content in an apple orchard.

The results of the study by Clemen et al. (2010) and Bui et al. (2017) showed that the level of soil fertility is influenced by topographical conditions in the form of slopes. The soil on the upper slope and the lower slope is more fertile than the soil on the middle slope. This situation is because the upper slope is less eroded from the centre, while the lower slope is a zone of sediment accumulation making it more fertile. Kumhálová and Vitězlav (2014) reported that topographic characteristics including altitude, slope, relief, and drainage conditions could be used for mapping soil characteristics in precision agriculture. Furthermore, Sewerniak et al. (2017) stated that topographic conditions trigger differences in soil characteristics. This condition means that the appearance of the topography in the form of relief can be used to estimate the spatial distribution of soil fertility.

Spatially, the nutrient content of N total soil is presented in Figure 3. Based on the map, it can be seen that each zone in apple orchard had a significantly different total N nutrient content in the zone I to X. These spatial data are the main components in implementing the concept of precision agriculture. Improvement of soil fertility and fertilization to increase apple production can be made on target. Agricultural inputs are given by the level of total N nutrients in each zone. The dosage or amount of fertilizer in zone V should be more than zone VII because the nutrient content of the total N of soil in zone V was lower than in zone VII. This also applied to all zones as needed based on nutrient levels of N total soil in the various zone.

Table 2. GLM Univariate 5% data of the relationship between relief and soil total nitrogen

Source	Type III Sum of Square	df	Mean square	F	Sig.
Corrected Model	1.186	9	0.132	30.568	0.000
Intercept	4.333	1	4.333	1005.044	0.000
Relief	1.186	9	0.132	30.568	0.000*)
Error	0.216	50	0.004		
Total	7.073	60			
Corrected Total	1.402	59			

R Squared = 0.846
*) Significance value

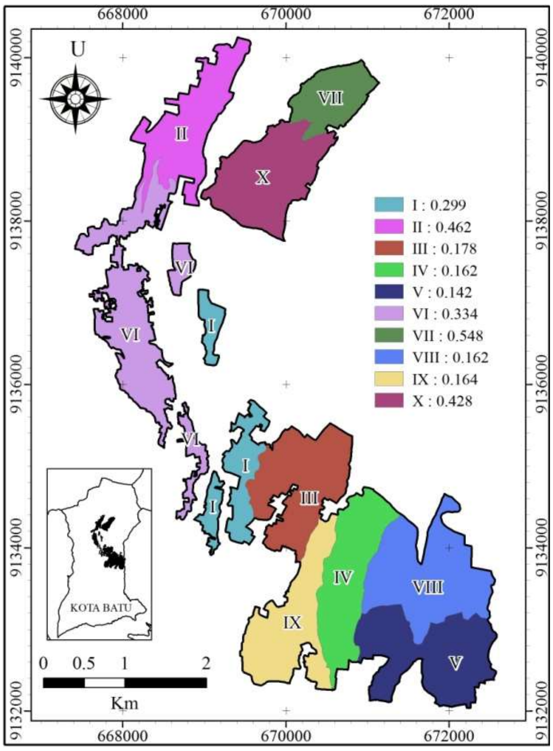

Figure 3. The map of total N content at 50 cm soil depth on an apple orchard in Batu City, East Java Province, Indonesia

Moser et al. (2001) reported that the topography of the land in the form of relief affects the redoximorphic atmosphere of land so that the availability of nutrients in the soil also varies. Furthermore, de Souza et al. (2006) stated that relief affects the spatial distribution of soil chemical properties including N, P, K, Ca, Mg, and CEC. Tsui et al. (2004) stated that slope factors influence the movement and accumulation of nutrients in the land through groundwater movement. The lower slope generally has a higher pH, CEC, and N than the middle slope. In addition, the slope is also a significant factor in pedogenic processes. The higher the slope angle, the material translocation through the erosion process also increases (Buol, 1997). The slope position can be divided into three, namely the upper, middle, and lower slopes (Arsyad, 2010). The slope position affects the condition of soil fertility. Relief characteristics affect the position of the slope. The middle slope undergoes a more intensive erosion process compared to the upper and lower slopes, where the lower slope is the accumulated zone. Therefore, the middle slope has lower soil fertility when compared to the upper and lower slopes (Shaoliang et al., 2016).

Conclusion

The results of GLM Univariate 5% analysis showed that the Sig value and coefficient of determination were 0,000 and 0,876, respectively. It means that soil nitrogen content was significantly different in various reliefs. The apple orchard was divided into 10 (ten) zones with different soil nitrogen content in various reliefs. The values of soil nitrogen content in various zones were 0.299% for Zone I, 0.462% for Zone II, 0.178% for Zone III, 0.162% for Zone IV, 0.142% for Zone V, 0.334% for Zone VI, 0.548% for Zone VII, 0.162% for Zone VIII, 0.164% for Zone IX, and 0.428% for Zone X. This is important as a basis for implementing precision agriculture in apple orchards, meaning that the determination of fertilizer dosage can be adjusted to the soil nitrogen content in the various zone. This study concluded that relief significantly affected the spatial variability of soil nitrogen content.

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