Mapping of the soil phosphorus using landform approach on apple orchard in Batu, East Java Province, Indonesia

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Abstract. Soil phosphorus (P) is an essential nutrients for plant growth. A more understanding of the spatial-variability of soil phosphorus is needed to fulfill best management of P in precision farming. The mapping method of soil phosphorus variability that is widely used so far is the interpolation method. However, this method works well only if the number of samples involved is high and the distance between the sample points is tight. In consequence, it takes a lot of time, effort, and cost, which become an obstacle in the application of the precision farming concept. The aim of research was to analyze the potential usage of landforms as a basis for mapping the soil total P content in apple orchard. The study area was located on apple orchard Batu, East Java Province, Indonesia. The soil attribute was analyzed by HCl 25% ekstrakt method. Delineation of landforms was used ArcGIS 10.1 software. Stratified random sampling based on landform was the method that used to determine of sample point, at 0 to 0.5 m depth. The apple orchard is classified into nine zone with soil total phosphorus contents of soil varying from low to very high. The soil was submitted to inferential statistical by GLM Univariate 5% method with SPSS 16.0 software. The significant value (Sig.) of GLM Univariate 5% was less than 0.05. It means that the soil total P content in various zones are significantly different. It also shows that the landform influences the spatial variability of soil total P content. Therefore, the landform can be used as a efficiency basis for mapping the soil total P content of the apple plantation.

1. Introduction

The element of soil phosphorus (P) is an essential nutrient for plants that functions to stimulate root growth and the development of flower and fruit, as well as to strengthen the upright stems. A lack of this nutrient causes plants to collapse easily, slow fruit ripening process, and stunted growth. However, an excess of P content also hampers plant growth due to the occurrence of strong N-P bonds, making it difficult for plants to absorb nitrogen and it interferes the fruit ripening process [3] and [32]. Therefore, the provision of P content through fertilization must be in accordance with the plants’ needs, considering its importance for the apple plant.

The fertilization of conventional agriculture tends to ignore the spatial variability of soil P levels, as seen from the same amount of fertilizer dose for every land. In consequence, this fertilization is not in accordance with the plants' needs and tends to be wasteful. This situation happens in the apple plantations in Batu, East Java, which experienced a decrease in fruit production and soil fertility in the past few years.

The development of RSGIS nowadays has led to the emergence of precision agriculture concept. The principle of this concept is an increase of agricultural inputs by adjusting to soil phosphorus
conditions so that information on the spatial distribution of soil P levels becomes a major component of this concept application [7], [28]. The mapping method of soil phosphorus variability that is widely used so far is the interpolation method, in which the determination of the sample point uses the grid method [11], [31].

Studies on various kinds of interpolation methods have been carried out, namely kriging, spline, inverse distance weighting, and surface trend [21]. The results of various studies showed that the kriging method provides the best level of mapping accuracy [16]. However, this method works well only if the amount of samples involved is high and the spread between the sample points is tight. In consequence, it costs a lot of time, effort, and money, which becomes an obstacle in the application of the precision agriculture concept [22]. Therefore, there needs to be a research to solve these problems so as to produce new efficient methods.

The potential use of secondary variables to estimate soil properties has been carried out in this decade [7], [24]. The requirement for determining secondary variables are easy availability and low cost [25]. Secondary variables that are widely used in assessment the spatial distribution of soil characteristics is elevation [27].

Nowadays, data elevation is widely available in digital format in the form of digital elevation models (DEM) [1]. This data visualize the topographic conditions of a particular area which is quantitatively called the landform (relief). Topography is one of the forming factors of soil besides climates, parent materials, organism, and time [2] which has influencing chemical properties of soil [19], [43]. Therefore, the aim of research was to analyze the potential usage of landforms as a basis for mapping the soil total P content in apple orchard.

2. Methods

2.1. Study location

The research activity was conducted on March to August 2018 located in Batu, East Java Province, Indonesia (7° 52′S and 112° 31′E) (Figure 1). According to BMKG through the Köppen classification, the climate type of the research area was classified as an Am type (tropical monsoon). The total rainfall was 2179 mm per year, and the highest rainfall occurs in November. The number of rainy days in this area was 160 days per year, while the highest number of rainy days occurs in December to the number of 31 rainy days. The average air temperature in this area was 23°C and the highest air humidity was 95%.

![Figure 1. Study area on apple orchard in Batu, East Java Province, Indonesia.](image-url)

This area was geologically in the formation of ArjunaWelirang Volcano in the late Pleistocene period, which was at an altitude of 700-1900 masl having undulating to mountainous reliefs. The results of field observations showed that the soil type of this area belongs to the subgroup of Humid
Dystropepts having silt loam soil texture, sub angular blocky soil structure, 10YR3 / 2 soil color, and slightly hard on soil consistency. This research focuses on apple because this commodity has unique values becoming the identity of this area. However, low soil phosphorus level becomes a serious problem for this commodity since it reduces fruit production. One solution is to improve soil phosphorus conditions through the application of precision farming concepts. The dominant apple plant type was Ana Apples which main characteristics were thin and dominant reddish rind. In addition, the average age of these apple plants was 20 years with a spacing of 3 x 3 meters

2.2. Landform (relief) delineation
The identification of the spatial landform (relief) in this study was used DEM data of 5 meters resolution provided by the Regional Development Planning Agency (Bappeda) of Batu, East Java Province. The identification stage of landform consists of 3 main stages (Figure 2), namely the accuracy test of DEM data, spatial analysis in the form of DEM data extraction, and interpretation of landform characteristics.

Figure 2. The identification of landform on apple orchard Batu, East Java Province, Indonesia.

The accuracy of DEM data was tested using a linear error method (LE 90), which vertically examines the data accuracy known as vertical accuracy. The smaller of the LE 90 value, the lower the error level, so that the data accuracy was classified as good accuracy. The main principle of the LE 90 method is to compare the elevation value between the DEM data and the actual data in the field at the same coordinate point, which is stated in the following formula [41]:

\[ LE90 = \delta p \times 1.6449, \text{ where } \delta p: \text{ standard deviation (RMSE)} \]  

\[ (2.1) \]
The result of the LE 90 calculation was used to determine the maximum vertical accuracy using a formula of 0.5 \times \text{pixel resolution}. This advanced analysis functions as a basis to decide whether or not the data meets the accuracy criteria. If the LE 90 value is lower than the vertical maximum accuracy limit, then the DEM data meets vertical accuracy criteria [41].

The next stage was the spatial analysis of DEM data using ArcGIS 10.1 software, in which the DEM data was extracted into four spatial data namely slope maps, relief maps, drainage maps, and elevation maps [47]. The coordinate of the research area based on Universal Transverse Mercator (UTM), system datum using the WGS 84, the zone system belongs to 49 S.

The final stage of the landform delineation (relief) is an interpretation by overlapping the fourth map data. It identifies differences in relief ranging from undulating to mountainous, differences in slopes ranging from gently sloping to very steep, differences in drainage density, and differences in altitude. The final results of this stage is a landform map that divides the apple plantation into several zones.

2.3. Soil analysis and measurement
The “stratified random sampling” method was used to determine the location of soil samples based on the landform map. Each soil sample was taken at a 50 cm soil depth and approximately 60 cm distance from tree trunk. It adjusts to the root zone and to the width of the apple plant canopy. The coordinates of soil sample were logged using the “Garmin 76CSX GPS” along with the sample code. Soil samples were dried and sieved with a two millimeter diameter of sieve for the purpose of analyzing the total P, which based uses HCl 25% extraction method [13].

2.4. Statistics analysis
Descriptive statistical analysis was used to figure the characteristics of the research variables data including average, minimum, maximum, median, range, and coefficient of variance. The data were used to calculate the “Skewness Index” and “Kurtosis Index” in order to find the data normality. The inferential statistical analysis was performed using the GLM Univariate 5% method through SPSS 16.0 software. This analysis intends to make decisions and draw conclusions on the purpose of this study, based on the significance value of the Tests of Between-Subjects Effects result [34].

3. Result and discussion
The spatial resolution of the DEM data in this study is 5 meters; so that, the further test of accuracy uses the multiplier factor of 5. Therefore, the maximum value of the vertical accuracy is 0.5 \times 5 = 2.5, meaning that the elevation data is categorized in accurate vertically if the LE90 value is less than 2.5 [33]. The further analysis results of the vertical accuracy of DEM data in this study is 1.77, meaning that this value is less than 2.5. It shows that DEM data meets the vertical accuracy criteria or elevation values in the DEM in accordance with the actual conditions in the field.

3.1. Landform (relief) characteristics
According to [38], landform is a surface configuration of land produced by natural processes. Also, [46] stated that landform is the morphology and characteristics of the land surface as a result of interaction between physical processes and crustal movements with the geology of the earth surface layer. Based on these two definitions, landform can be described as a land surface that has a typical relief due to the strong influence of the earth’s crust structure and the effects of natural processes that work on rocks in a certain space and time. Each landform is characterized by some differences in geomorphological, relief/topographic, and composing material structures and processes [17]. In the research, the main components of landform that becomes the basis of delineation are relief aspects, slope aspects, elevation aspects, and drainage density aspects [47].

The DEM data extraction produces data spatial distributions of the slope, drainage flow, elevation, and relief (Figure 3). All of the data was analyzed spatially using ArcGIS 10.1 software to produce nine zones having different landform (relief) characteristics and given codes: I, II, III, IV, V, VI, VII,
VIII, and IX. This data becomes as a basis of sample point determination using a stratified random sampling method, so the total amount of sample points were 60 samples (Figure 4)

Figure 3. The result of DEM extraction i.e a) slope map, b) relief map, c) drainage map, and d) elevation map.

Figure 4. The spatial distribution of soil sample point based on stratified random sampling on apple orchard Batu, East Java Province, Indonesia

3.2. Soil total Phosphorus content

Soil Total P Content is produced from rocks and minerals corrosion. Minerals that have high P levels are apatite, Ca10 (PO46 (F, C1, OH)2 which are abundant in igneous and sedimentary rocks. There are two kinds of P content of soil, namely P-organic and P-inorganic. The availability of P is affected by the degree of soil acidity (pH). Soil P will decrease if the soil pH is lower than 5.5 or higher than 7. While the factors that affect the soil P loss are transportation by plants, abstersion, and eruption [3], [32].

The data normality test in this study uses Skewness and Kurtosis index. The criteria of data that is categorized as normal if the Z value for Skewness and Kurtosis that ranges between -2 and 2 as presented in Table 1. The Skewness Index criterion shows the direction of data; while the Kurtosis criterion shows the level of data collapse. A data group is categorized as normal if the value of the Skewness index belongs to the Symmetrical criteria and the Kurtosis index belongs to the Mesokurtic criteria [34].

Table 1. Criteria for data normality based on Skewness and Kurtosis Index

| Z          | Skewness | Kurtosis |
|------------|----------|----------|
| < -2       | Right    | Leptokurtic |
| -2 < Z < 2 | Symmetrical | Mesocratic |
| > 2        | Left     | Platykurtic |
The results of descriptive statistical analysis of the soil total P content in this study were presented in Table 2. The skewness and kurtosis index value shows that the data distribution was normal because it was in the range of -2 to 2 or it belongs to the Symmetrical criteria for Skewness and Mesokurtic for Kurtosis. Soil total P level was used as an indicator of soil fertility. The criteria of soil fertility based on the total P content according to [30] are divided into 5 classes, namely very low: less than 15, low: from 15 to 20, moderate: from 21 to 40, high: from 41 to 60, and very high: more than 60. The descriptive statistical analysis results of the soil total P levels in various zones indicate that the average soil total P level varies (Table 2). The minimum soil total P value was 8,620 mg/100g located in zone VIII, while the maximum soil total P value was 284,710 mg/100g located in zone V. It shows that the spatial variability of soil total P differs between zones ranging from very low to very high classes. This indicates that the application of fertilizing every land with the same dose was not appropriate, instead, it must be in accordance with the plants’ needs and the conditions of soil fertility.

Table 2. Results of the descriptive statistical analysis of soil total P levels.

| Zone | Minimum | Maximum | Mean | Std Deviation | Variance | Skewness | Kurtosis |
|------|---------|---------|------|---------------|----------|----------|----------|
| I    | 32.500  | 118.920 | 75.033 | 34.034        | 1185.321 | -0.169   | 0.845    |
| II   | 50.320  | 196.180 | 121.241| 40.709        | 2181.702 | 0.077    | 0.794    |
| III  | 59.510  | 134.570 | 83.903 | 25.705        | 663.638  | 1.453    | 2.160    |
| IV   | 112.430 | 284.560 | 182.500| 71.544        | 5188.516 | 0.390    | 0.845    |
| V    | 59.040  | 264.710 | 144.250| 75.629        | 5716.365 | 1.483    | 3.257    |
| VI   | 13.030  | 115.070 | 47.963 | 32.670        | 1067.352 | 1.656    | 3.615    |
| VII  | 9.230   | 284.020 | 47.237 | 79.903        | 6384.529 | 3.123    | 6.611    |
| VIII | 8.620   | 95.020  | 41.902 | 29.013        | 841.731  | 1.349    | 0.845    |
| IX   | 8.390   | 65.470  | 41.483 | 24.178        | 584.598  | -0.919   | 1.014    |

3.3. Univariate analysis

The results of the significance test of the soil total P content in various zones generate a significance value of 0.000, meaning that the value was less than the significant limitations of 0.05 (see Sig. value at Landform row in Table 3). It shows that with a 95% of confidence degree, the soil total P content in various zones were significantly different. It also shows that the landform influences the spatial variability of soil total P content. Therefore, the landform can be used as a basis for mapping the soil total P content of the apple plantation.

Table 3. GLM Univariate 5% analysis of relationship between landform and soil total P

| Source       | Type III Sum of Squares | df | Mean Square | F     | Sig. |
|--------------|-------------------------|----|-------------|-------|------|
| Corrected Model | 131900.350             | 8  | 16487.544  | 5.486 | 0.000|
| Intercept    | 429707.512             | 1  | 429707.512 | 142.992 | 0.000|
| Landform     | 131900.350             | 8  | 16487.544  | 5.486 | 0.000|
| Error        | 163261.108             | 51 | 3005.120   |       |      |
| Total        | 722037.406             | 60 |             |       |      |
| Corrected Total | 285161.458             | 59 |             |       |      |

The results of a study by reference [6] and [4] showed that soil fertility was influenced by the topographic conditions in the form of slopes. Soil fertility levels of the upper and lower slopes were higher than the middle slopes, since the upper slope is less eroded than the middle, while the lower slope was a zone of sediment accumulation. Also, in reference [20] reported that topographic characteristics including altitude, slope, and drainage conditions can be a basis for mapping soil characteristics in precision farming. Furthermore, in reference [35] stated that topographic conditions...
trigger differences in soil characteristics, meaning that the topographic appearance can be applied for estimate the spatial identification of soil characteristics and fertility.

The results of the total P content mapping was presented in Figure 6 show that the soil total P content of each apple plantation zone (from zone I to IX) were significantly different. The spatial data was a major component in implementing the concept of precision agriculture. Soil fertility improvement and fertilization to increase apple production can be appropriately performed. Agricultural inputs must be based on the soil total P content of each zone. The dose or amount of fertilizer in zone IX will be higher than in zone V, since the soil total P content in zone V is higher than in zone IX. This also applies to each zone in accordance with the needs based on the soil total P content in each zone.

In reference [26] showed that topography also influences the availability of soil nutrients through a redoximorphic process. The reference [8] and [1] stated that in wet soil conditions, Fe elements play up an significant role for the availability, absorption, and retention of P content. In anaerobic soil, P elements are not strongly bound by Fe, resulting in an increase of available P content for plants. On the contrary, in aerobic conditions, P elements are strongly bound by Fe resulting in increased P retention [14].

The reference [45] reported that topography conditions of the land in the form of landforms affected the redoximorphic atmosphere of a land so that the availability of soil P content also varied. Furthermore, the reference [12] stated that the landforms affected the spatial variabiliti of soil chemical properties including P, Ca, Mg, and CEC.

Broadly speaking, the slope position is divided into three, namely the upper, middle, and lower slope [44]. The position of the slope affects the condition of soil fertility. The middle slope undergoes more intensive erosion compared to the upper and lower slopes, where the lower slope is an accumulation zone. Therefore, the middle slope has lower soil fertility content than the upper-lower slopes [36].

The reference [44] stated that the movement and accumulation of nutrients in a land is affected by slope factors through groundwater movement. The lower slope generally has a higher pH, CEC, Ca, and Mg than the middle slope. In addition, the slope is also a major factor in the pedogenic process. The increasing of the slope angle has consequences in the addition of material translocation through the erosion process [5].

The number of samples shows that the utilization of landform (relief) variables results in more efficient soil nutrient content mapping compared to the interpolation method. The reference [15]
analyzed the level of interpolation accuracy on various sampling scales using the RMSE method. The sample determination method used is the grid method which is then processed using GS + software. The results of this study showed that the accuracy level increases in accordance with the higher number of samples and the smaller size of the grid. In this study, the number of samples involved was 961 points. Furthermore, in ref [29] reported that co-kriging generates the best accuracy of salinity mapping. This method involved 898 sample points on an area of 3375 hectares.

The reference [31] carried out a study to estimate the spatial distribution of P levels using the kriging method. The number of samples used in the study was 250 sample points. The results lay out that the spatial distribution of P levels varied in one landscape so that the application of fertilizing every land with the same dose is not appropriate.

Furthermore, the reference [18] reported that Durian orchard has spatial-variability of soil N, P, and K contents. The study involved 122 sample points on an area of 375 hectares in Durian Agrotourism, Malaysia. This result is in accordance with a study by reference [9] which showed significant differences in spatial soil fertility conditions. The number of samples used is 303 points. The results of the study showed that rice fields are divided into four different fertile zones, meaning that the management of rice land must follow the principles of precision agriculture.

The explanation of the previous studies shows that mapping soil nutrients content using interpolation methods requires a large number of sample points. In consequence, it take a lot of time, effort, and cost, so it is not efficient. The use of landform variables in mapping soil P content is more efficient because it requires less number of soil samples compared to the interpolation method.

4. Conclusion

The development of the current precision agricultural research leads to the use of secondary variables as the basis for soil fertility zoning resulting in a more efficient mapping. The landforms, as a quantification of topographic characteristics, is one of the secondary variables for mapping soil properties. The results of GLM Univariate statistical analysis shows that the significance value is less than 0.05. It means that with a 95% confidence level, the soil total P content significantly differs between zones. In other words, the landforms affect the amount of spatial-variability in the soil total P content. The division of zones I to zone IX in this study is based on landforms (relief). Therefore, it can be concluded that the landform (relief) variables can be used as a basis for mapping the total spatial characteristic of total P content of soil in apple plantations.

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