

Mapping Indigenous Nutrient Status of Post-Eruption Soil to Support the Fertilization of Rice (*Oryza sativa*) in the Southern Area of Merapi Mountain, Indonesia

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ABSTRACT

This study aims to discuss a technique of digital soil mapping to recommend fertilization options based on the major indigenous soil nutrients. The southern slope of Merapi Mountain in Yogyakarta, Indonesia, was selected to conduct the research. Thirty-seven areas included in five sub-districts were chosen as soil sampling locations based on a stratified purposive sampling technique. The boundary of each area on the map was delineated using the kriging method. The collected soil samples were analyzed for indigenous content of available phosphorus, total potassium, and soil base saturation. The soil data were used as a basis for creating maps of available phosphorus content, total potassium content, and soil base saturation. The criteria for evaluating the level of soil nutrient content and for proposing fertilizer recommendation were developed according to criteria acknowledged by the Indonesian Soil Research Centre [ID: *Pusat Penelitian Tanah* (PPT)]. Results showed that the base saturation of the soil in the study area was dominantly classified as medium (41-60%) and high (60-80%). Phosphorus (P₂O₅) was found very highly available (>60 mg/100g of soil) and total potassium was dominantly very low (<10 mg/100g of soil) and low (10-20 mg/100g of soil). Based on this results, fertilizer need for rice cultivation in the study area is recommended to follow recommendations revealed in map 2 of potassium chloride (KCl), which for the low potassium level area is of 50 kg/ha of KCl + harvested rice straw, whereas for the medium potassium level area is of 0 kg/ha of KCl + harvested rice straw. In conclusion, the fertilization of irrigated rice plant should not be done uniformly.

1. INTRODUCTION

The Global Positioning System (GPS) has very wide adaptability in agriculture studies namely in the preparation of thematic maps such as land use, land cover, soil fertility maps, etc. The determination of the status of soil available nutrients in an area by using GPS helps formulate site-specific nutrient management and understand the status of soil fertility spatially and

temporally (Rao and Srivastava, 2000; Vadivelu, 2007). Geographical Information System (GIS) provides valuable support to handle big data, which are generated through conventional and spatial format. GPS and GIS-based soil fertility maps were elaborated for different areas of other states (Sharma et al., 2008; Muralidharudu et al., 2011; Nahak et al, 2016). In relation to the logistics of fertilizers, a map of the soil nutrient status in a region should be available. The map

of nutrient status is extremely helpful in predicting the proper amount of fertilizer needed in a region. In the research area, a map of nutrient status is required especially for phosphorus (P) and potassium (K) nutrients. Mapping the nutrient status is important to reveal specifically delineated areas and recommended dosages of fertilizers based on the homogeneity of the biophysical and socio-economic characteristics of farming activities (Dobermann et al., 2003a).

Further, Dobermann et al. (2003b) stated that the variability of soil fertility is very important to be considered as a basis for developing fertilizer recommendations. Specific Location Nutrient Management (SLNM) is one approach that can be implemented through an evaluation of the indigenous nutrient supply from the soil. This approach recommends that fertilization of irrigated paddy-fields should not be done uniformly. Recommendations on fertilization that ignore the variability of climate, soil conditions (physical, biological, and chemical properties) and plant management have a low degree of accuracy, thereby reducing efficiency in the use of input, limiting productivity and benefits of farming operations (Haefele et al., 2000).

The soil fertility level was evaluated from the composite soil samples collected from the field. Soil samples were then analyzed to determine their nutrient status. Locations of soil samples were determined by using GPS so that they could be plotted on a basic map. This is similar to the research conducted by Muralidharudu et al. (2011) in India. However, this method required a relatively high cost for soil sampling and soil fertility analysis for each new location. Producing a map of soil fertility can be used as a guiding tool for the implementation of fertilizer recommendations in any location. The digital soil mapping provided a technique for making a map of soil fertility quantitatively based on soil observation and any other supporting data.

This study aims to discuss a technique of digital soil mapping for the development of fertilizer recommendations based on data related to the major soil indigenous nutrients. This research wants to emphasize that information about the indigenous nutrient status of the soil (phosphorus and potassium) can be used to support soil fertilization recommendations. The output of this research consists of several maps of soil nutrient level and a map of fertilizer recommendation that can support fertilization of irrigated paddy-fields used for growing rice (*Oryza sativa*). The novelty of this research lies in the mixed use of spatial data showed by geographic maps and of attribute data of soil fertility. The steps followed to obtain the map include the following: mapping the demonstration plot; mapping the soil nutrient level; and mapping the fertilizer recommendations. Although these steps are time-consuming and complicated, the

fertilizer recommendation maps will be applicable and will greatly assist farmers in making the decision for the proper dosage of fertilizer for irrigated rice-fields. This research is original and has never been previously done, especially by the combination of geographic map and soil fertility map of the southern slope of Merapi Mountain in Sleman Regency, Province of the Special Region of Yogyakarta, Indonesia.

2. THEORY AND METHODOLOGY

The research was conducted in the southern area of Merapi Mountain (sub-districts of Cangkringan, Pakem, Turi, Tempel, and Seyegan) in Sleman Regency, Province of the Special Region of Yogyakarta, Indonesia from April 2015 to April 2016. The observation was done by collecting soil samples from several locations (37 stations of irrigated paddy-field) determined by using stratified purposive sampling technique. Stratified purposive sampling is different from stratified random sampling in that sample sizes are likely to be too small for generalization. Patton (2001) described these as samples within samples and suggested that purposeful samples can be stratified or nested by selecting particular units or cases that vary according to a key dimension. In this study, the irrigated paddy-field is used as the main basis for the map of soil (unit and extent). Each point of observation was plotted on the fieldwork map and their geographical position (coordinate) were determined, then they were traced in the field and a soil sample was taken by using GPS navigation.

Soil samples were analyzed in the laboratory to determine their available phosphorus and potassium content and base saturation. These three parameters were required as criteria to propose fertilizer recommendations (Makarim et al., 2003). Phosphorus content was determined by the Olsen method. The soil was extracted using NaHCO_3 0.5M pH 8.5 solution and the phosphorus content was measured by spectrophotometer using wavelength 889 nm (ISRIC, 1993). Potassium content was determined by extracting soil sample with 1M NH_4OAc pH 7 and measured for potassium content by flame-photometer. The soil extract was also measured for determining Ca, Mg, and Na content. Cation-exchange capacity (CEC, $\text{cmol}(+)/\text{kg}$) was measured by the distillation of the NH_4OAc soil extract using the N-Kjeldahl method (Burt, 2004). Base saturation (%) was calculated from the percentage of exchangeable cation (Ca, Mg, K, Na) compared to the soil CEC (Prasetyo et al., 2012).

The map of soil indigenous nutrient status was created based on data related to phosphorus content, potassium content, and base saturation of soil samples. The polygon boundary on the map was developed using the kriging method. Cressie (1990) stated that the kriging method is a method of interpolation for which

the interpolated levels are modelled by a Gaussian process governed by prior co-variances, as opposed to piecewise-polynomial spline, chosen to optimize smoothness of the fitted level. Under suitable assumptions on the priors, kriging gives the best linear unbiased prediction of the intermediate level. In addition to researching the soil, the kriging-based approach is also used by some researchers to examine soil content. Küçüker et al. (2010) applied the kriging-based estimation of the change in soil carbon stock in the coastal Black Sea region, Turkey. Mushtaq et al. (2013) researched the ordinary kriging and indicator approach on the mapping of soil micronutrients in Kashmir agricultural landscape. Shukla et al. (2015) estimated the deficient micronutrients in the soil with kriging approach in Kashi Vidyapeeth block of Varanasi District of Uttar Pradesh, India.

Fertilizer recommendations were developed based on the map of soil nutrient status according to the criteria acknowledged by the Indonesian Soil Research Centre (Makarim et al., 2003). The fertilizer recommendation criteria have been proven to be adequate for irrigated rice-field and already widely implemented in Java Island, Indonesia.

3. RESULTS AND DISCUSSION

3.1. The framework of digital soil mapping based on the major indigenous soil nutrient supply

Digital Soil Mapping (DSM) can be defined as the creation and population of spatial soil information systems by the use of field and laboratory observational methods coupled with spatial and non-spatial soil inference systems (Lagacherie and McBratney, 2007; Lagacherie, 2008). Another term used for DSM is Predictive Soil Mapping (PSM). Scull et al. (2003) explained that PSM can be defined as the development of a numerical or statistical model of the relationship among environmental variables and soil properties, which is then applied to a geographic database to create a predictive map. Predictive Soil Mapping (PSM) is made possible by geo-computational technologies developed over the past few decades. In addition, Digital Soil Mapping (DSM) can also be referred to as Quantitative Soil Survey (QSS). McKenzie and Ryan (1999) stated that QSS as conventional survey methods are efficient for medium to low-intensity surveys because they use relationships between soil properties and more readily observable environmental features as a basis for mapping. However, the implicit predictive models are qualitative, complex and rarely communicated in a clear manner. The possibility of developing an explicit analogue of conventional survey practice suited to medium to low-intensity surveys is considered. A key feature is the use of quantitative

environmental variables from digital terrain analysis and airborne gamma radiometric remote-sensing to predict the spatial distribution of soil properties (McKenzie and Ryan, 1999). DSM can be applied using two major stages in digital soil mapping based on the data regarding the major indigenous soil nutrients, i.e. (i) supply of a data set of the major indigenous soil nutrients; (ii) digital soil mapping of the status of the major indigenous soil nutrients (Bui, 2007). The conceptual framework, which also serves as a frame of reference applied in this research, is presented in Figure 1. The first stage is the supply of the data set of the soil fertility factor, consisting of various co-variants, which represent one or several factors, namely P_2O_5 , K_2O , and base saturation. The second stage includes the following actions: mapping the distribution of irrigated rice-field, digital soil mapping of the status of the major indigenous nutrient content of the soil, mapping the P_2O_5 , K_2O and base saturation status of soil, as well as the elaboration of a map with recommendations on KCl and Super Phosphate-36 fertilizer (SP-36) for the southern area of Merapi Mountain in Sleman Regency, Province of the Special Region of Yogyakarta, Indonesia. Farmers in Indonesia usually use KCl fertilizer to compensate for the deficit in K_2O in the soil and SP-36 fertilizer to adjust the quantity of P_2O_5 in the soil. SP-36 is a phosphate fertilizer with a content of 36% phosphate.

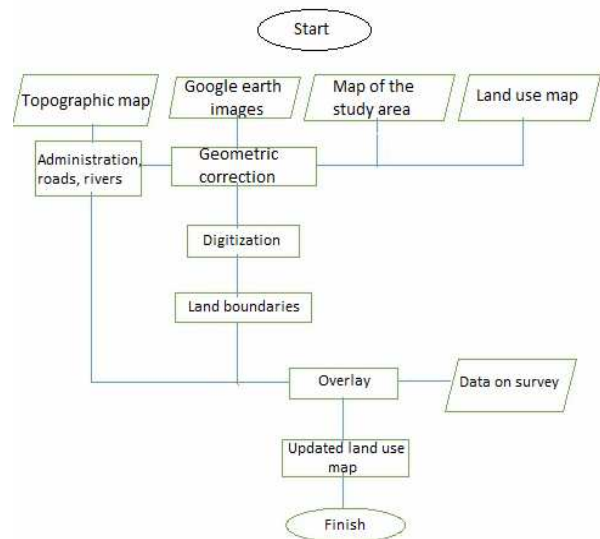


Fig. 1. Flow chart of the elaboration of the land use map.

The stages in the elaboration of land use map (distribution of irrigated rice field) are as follows:

- 1). Data collection in an analogue and digital form: Digital Topographic Map of Sleman Regency, issued by the Geospatial Information Agency; Google Earth Images of the Sleman Regency area, captured from Google Earth Inc.; Map of the Agricultural Area, issued by the Regional Development Agency of Sleman

Regency; Land Use Map, issued by the Regional Development Agency of Sleman Regency; Field Survey, carried out in 2017.

2). Geometric correction of Google Earth Images, which is a process of positioning images in accordance with the coordinates on the actual map. GIS software was used to operate corrections.

3). Digitization of the boundaries of irrigated rice fields, dry fields, and non-agricultural land.

4). Validation of digitization results by integrating data of both the map of agricultural area and the land use map.

5). After digitization, we combined the data on the Digital Topographic Map with the data from the field survey.

6). Layout creation and a map of land use was obtained (map of the distribution of irrigated rice field).

3.2. Digital soil mapping of the southern area of Merapi Mountain

Digital soil mapping was preceded by taking the coordinates of each location in the experiment stations. The 37 experiment stations were scattered in five sub-districts, namely Cangkringan, Pakem, Turi, Tempel, and Seyegan. The observation of Soil Fertility Evaluation (SFE) was done by collecting soil samples. The geographical positions of each observation point were determined, and marked on the fieldwork map; then, they were traced in the field by GPS navigator and soil samples were collected. Soil samples were analyzed in the laboratory to determine P_2O_5 , K_2O content and base saturation. The locations of soil sample collection are presented in Figure 2.

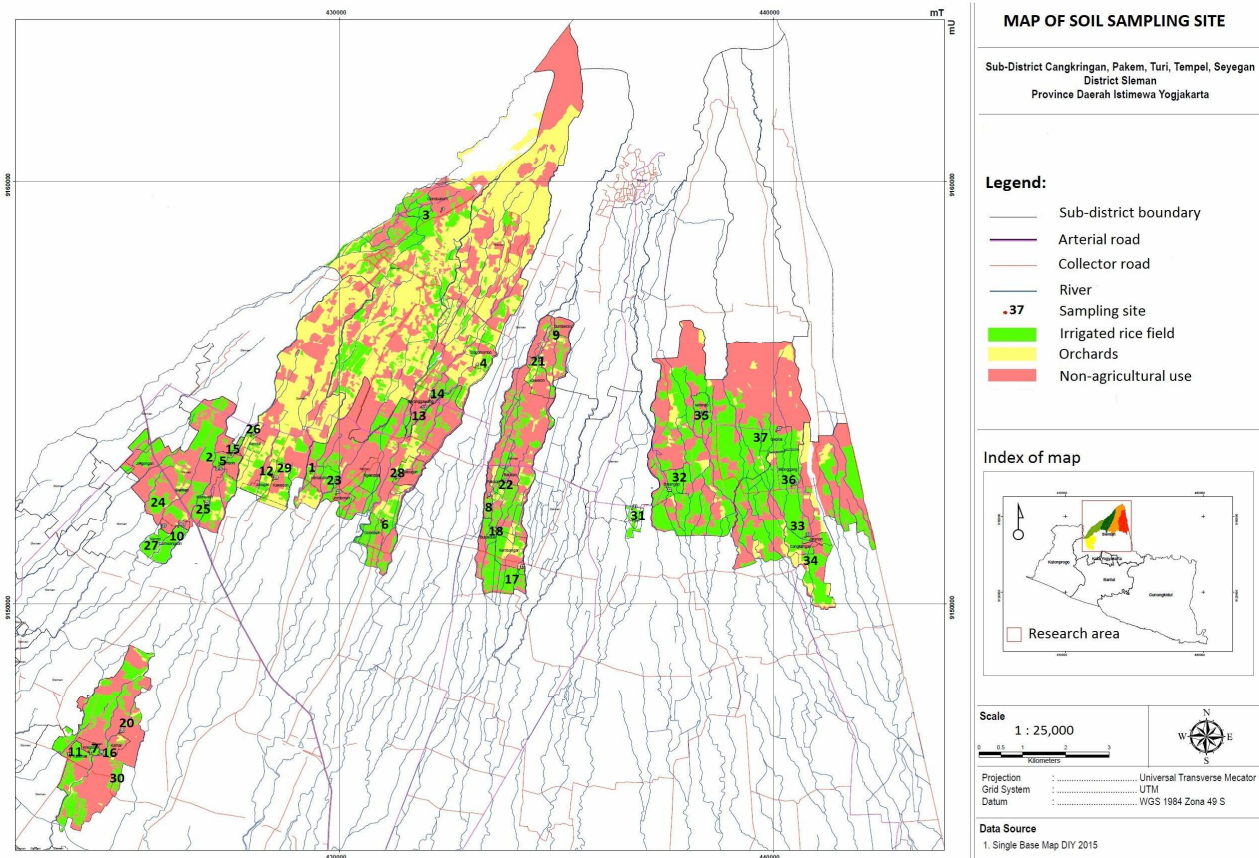


Fig. 2. The locations of soil sample collection (37 demonstration plots).

3.3. Soil nutrient level map

In soil fertility research, the study should develop of variety of models, so that the maps of soil fertility can be further selected for a better representation of the soil fertility distribution. In order to obtain the map of P_2O_5 , K_2O and base saturation level we evaluated the nutrient level based on criteria acknowledged by the Food and Agriculture Organisation (FAO, 1977) and the Indonesian Soil Research Centre (Pusat Penelitian Tanah, 1983). By

checking the location on the map of the nutrient level, users (farmers) could be informed about the nutrient status of their irrigated rice-fields.

Figure 3 shows that the P_2O_5 level along the southern area is very high (>60 mg/100g of soil). This shows that, potentially, the soil contains very high P_2O_5 . Adiningsih et al. (1989) stated that the use of phosphate in paddy-fields should be evaluated to sustain soil fertility in the long term. This is supported by several researchers in Indonesia, who stated that the P_2O_5 content in the soil in paddy-fields, which are intensively

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fertilized on Java island, tend to be high (Abdulrachman et al., 2000; Harahap et al., 2002;

Rochayati and Adiningsih, 2002).

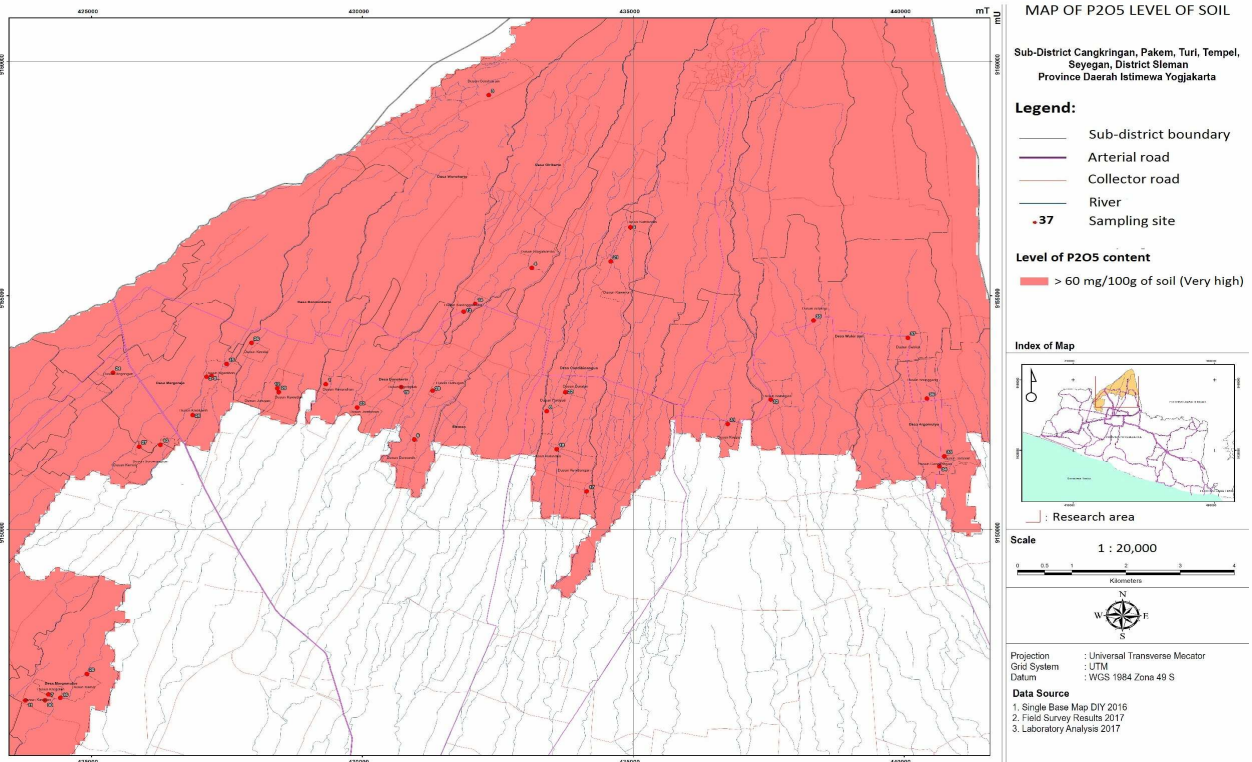


Fig. 3. Map of P₂O₅ level (mg/100g of soil) in the southern area of Merapi Mountain.

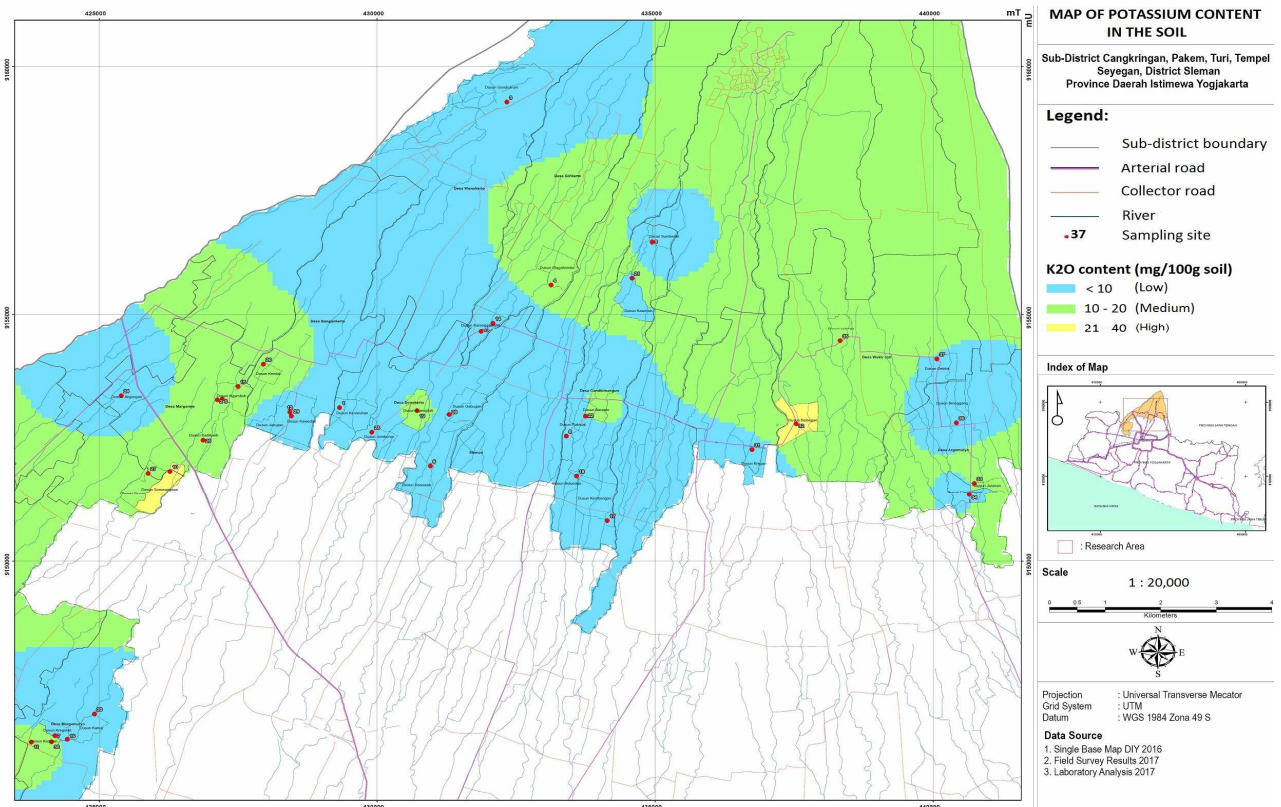


Fig. 4. Map of K₂O level (mg/100g of soil) in the southern area of Merapi Mountain.

The challenge in the future is how to convert the unavailable phosphorus into an available form

(H₂PO₄⁻, HPO₄²⁻). Continuous fertilization with SP-36 has a negative impact on soil and it is not economically

feasible. This is also confirmed by Mkhabela and Warman (2005) in their research in a Pugwash sandy loam soil in Nova Scotia and by Ming et al. (2011) in a paddy soil of subtropical China.

Figure 4 shows that the K_2O level along the southern area is dominantly low (<10 mg/100g of soil) and medium (10-20 mg/100g of soil). A number of spots on the south side record a high level (21-40 mg/100g of soil), on the east side a medium level, and on the west side, they have a low level. This is apparently caused by the fact that the east side is potentially supplied with potassium-rich material from the Merapi Mountain flowed along the Gendol river.

Figure 5 shows that the base saturation level along the southern area is dominantly medium (41-60%) and high (61-80%). There is a spot in the southern part with a very high level of base saturation (>80%). The base saturation level that tends to be high is apparently caused by the addition of new materials from the eruption of Merapi Mountain. The result of analysis shows that the base saturation of erupted Merapi Mountain mineral is 8.78%, consisting of cations of calcium 7.44 cmol(+)/kg, magnesium 0.96 cmol(+)/kg, potassium 0.17 cmol(+)/kg and sodium 0.21 cmol(+)/kg.

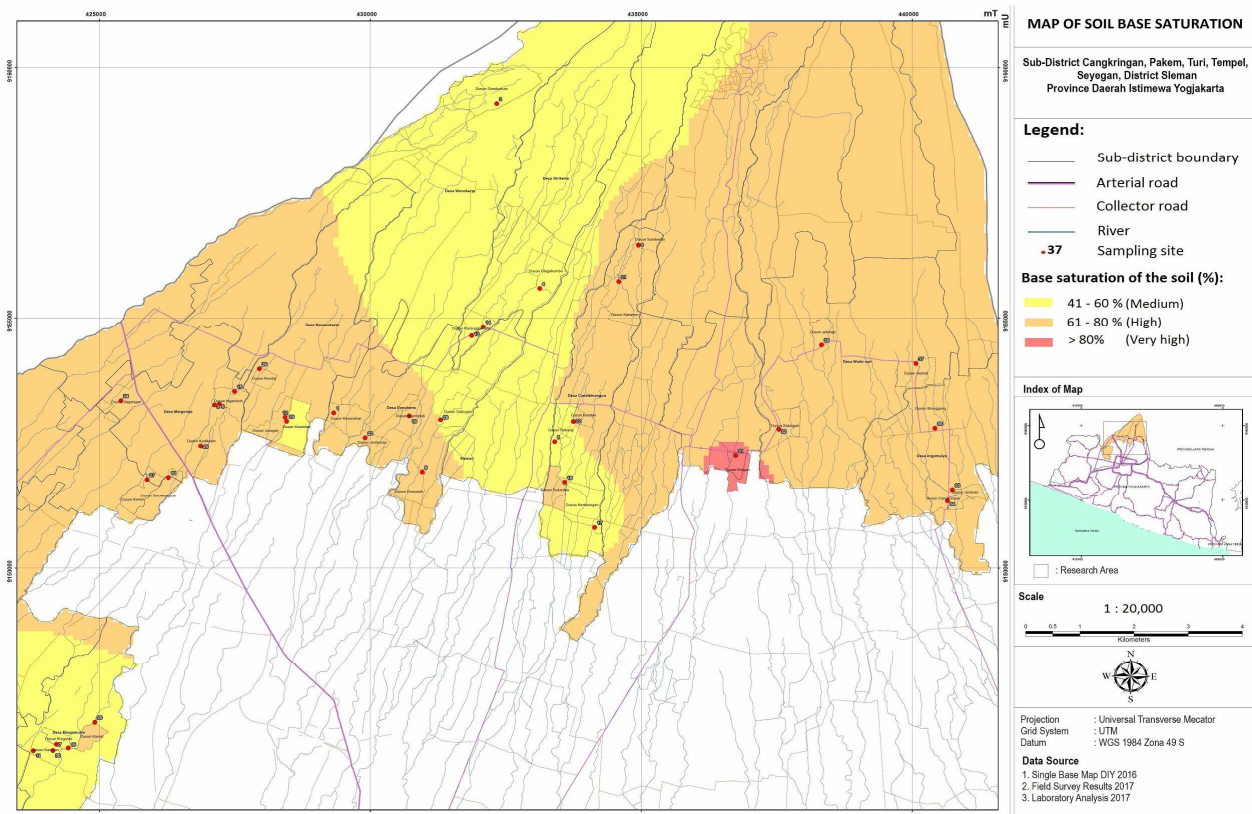


Fig. 5. Map of base saturation level (%) in the southern area of Merapi Mountain.

3.4. Map of fertilizer recommendations

Fertilizer recommendations were proposed based on the map of P_2O_5 and K_2O level. The recommended dosage of fertilizer proposed by this research is based on the criteria published by the Indonesian Rice Research Centre (Makarim et al., 2003). The recommendations were proposed by using the most popular fertilizer available in the research area, i.e. for potassium is potassium chloride (KCl) and for phosphorus is SP-36. The recommendation for potassium is provided as a recommendation map of KCl alternative-1 (using only KCl fertilizer) and alternative-2 (a combination of KCl fertilizer and rice straw) (Fig. 6), whereas for phosphorus is provided as recommendation map of SP-36 fertilizer.

For some areas, having abundant rice straw after rice harvesting, it is highly recommended to apply the KCl recommendation alternative 2. It is very much beneficial to sequester carbon back into the soil, as well as to reduce the amount of KCl fertilizer required.

Figure 6 shows that the level of K_2O along the southern slopes of Merapi Mountain is mainly low to medium. According to Makarim et al. (2003), the fertilizer dosage recommended for the low K_2O level is 100 kg/ha of KCl, while for the medium K_2O level is of 50 kg/ha of KCl. By using this KCl recommendation map, it will be easier for the farmers to decide the appropriate amount of fertilizer required for their specific location since the different soil nutrient levels are clearly delineated on the map. Users will just plot the location of the paddy-fields on the map and then

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check for the similar colour on the map legend to get the amount of fertilizer needed.

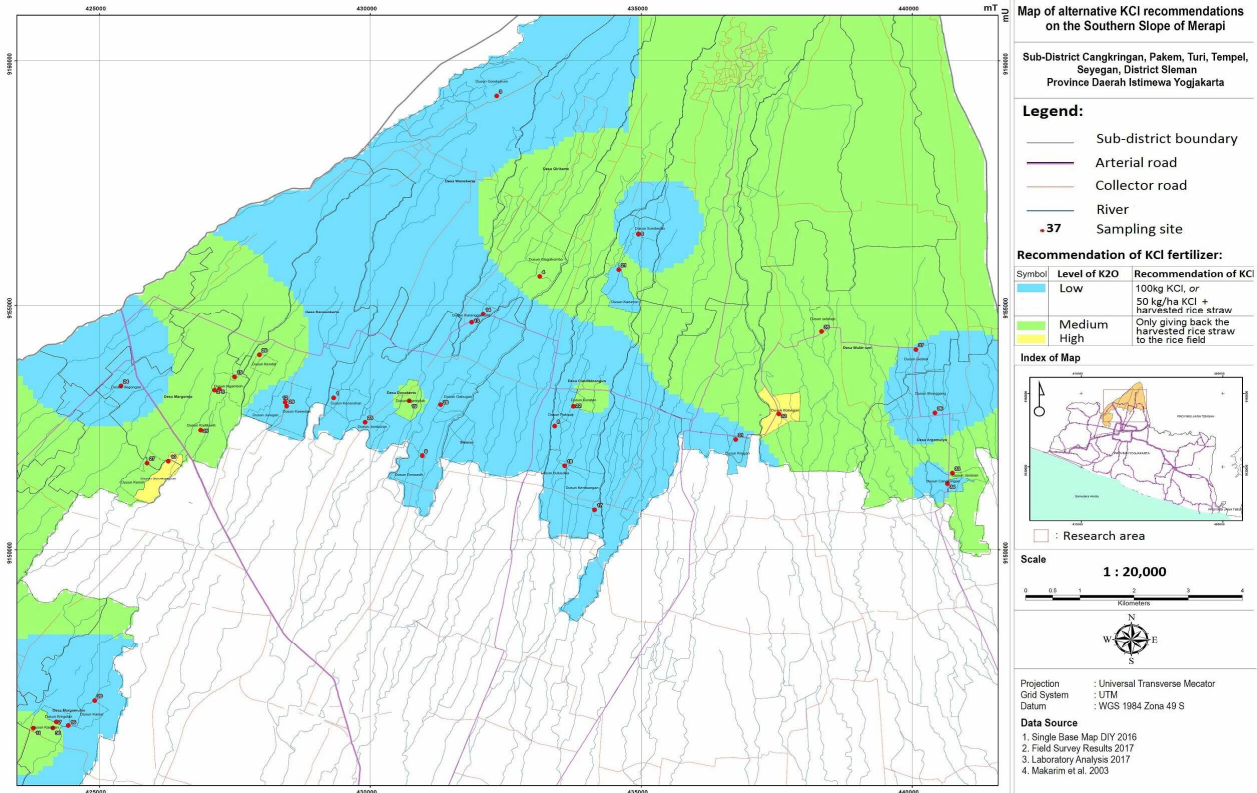


Fig. 6. Recommendation map of KCl in the southern area of Merapi Mountain.

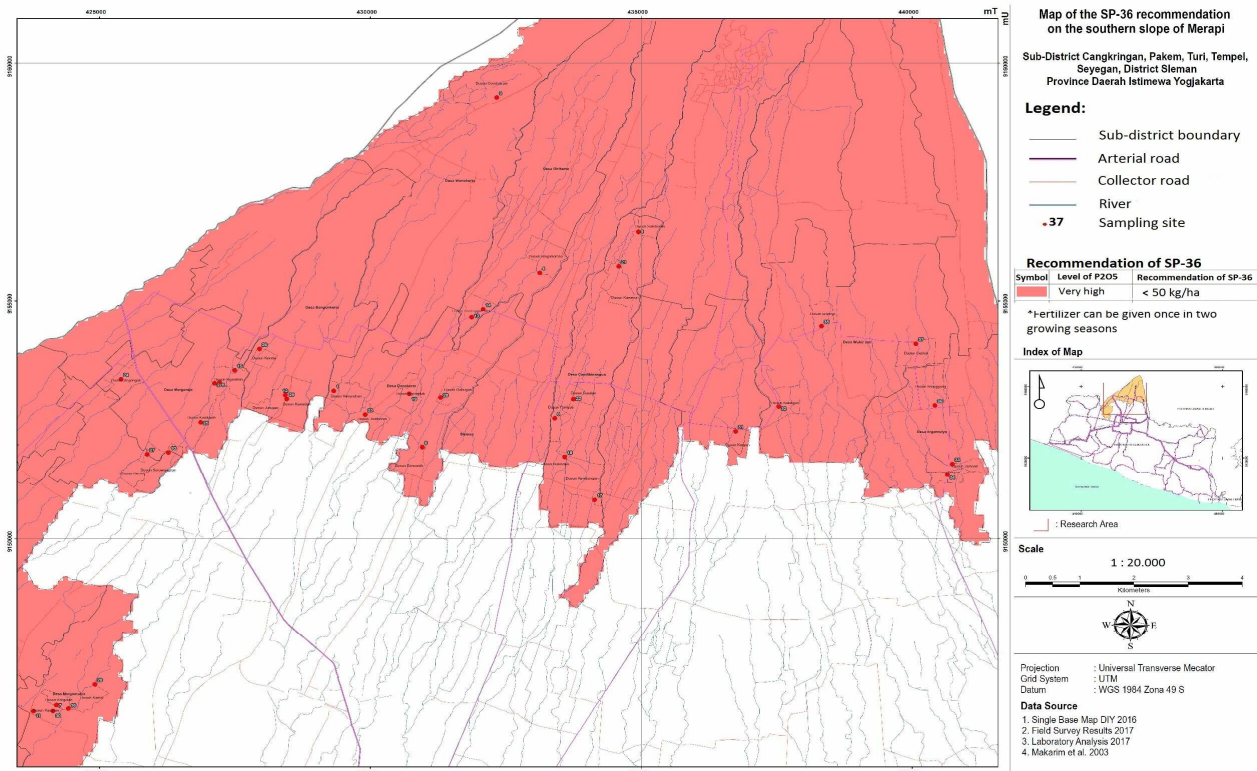


Fig. 7. Recommendation map of SP-36 in the southern area of Merapi Mountain.

Figure 6 also shows the recommendation of KCl fertilizer in combination with rice straw harvested

from the rice field. The southern area of Merapi Mountain is dominated by low to medium K₂O level.

For the low-level area, it is recommended to apply 50 kg/ha of KCl + harvested rice straw, whereas for the medium level area it is just required to give back the harvested straw to the soil and no KCl addition is needed. The use of the rice straw can economize the rice production process, especially the decrease in fertilizer expenses; it is hoped that an efficient and effective process of production will increase the farmer's income. Figure 7 shows that the southern area of Merapi Mountain is dominated by a very high soil phosphorus level (>60 mg/100g of soil) so that the fertilizer recommendation is just to replenish the phosphorus after rice-harvesting. It is recommended to apply less than 50 kg/ha of SP-36 fertilizer and only once a two rice-growing seasons. The farmer's habit to apply very intensively fertilization of the same dosage every season has caused an accumulation of phosphate in the soil and worsened the equilibrium of nutrients in the soil. The soil needs to be treated to utilize the high content of phosphate, so it could be transformed into a more available form and be absorbed by the plant.

4. CONCLUSION

An approach of digital soil mapping based on the major indigenous nutrients of the soil is extremely important in agriculture management. In broad outline, this approach covers a compilation of data, the elaboration of a soil fertility map, a distribution map of soil nutrient status and a map of fertilizer recommendations.

Results show that the base saturation status of soil along the southern area of Merapi Mountain was dominantly medium (41-60%) and high (60-80%). The P₂O₅ level in the area was very high (>60 mg/100g of soil). The K₂O level in this area was dominantly very low (<10mg/100 g of soil) and low (10-20 10mg/100 g of soil). Due to the high content of phosphorus in the soil, it is recommended to apply less than 50 kg/ha SP-36 fertilizer. For potassium, it is recommended to apply alternative 2 in the low-level area with 50 kg/ha of KCl + harvested rice straw, whereas for the medium level area just to recycle the harvested rice straws back to the soil. In addition to the investigated parameters, it is necessary to consider the chemical-physical properties of the soil.

The resulted recommendation map is highly applicable and easy to be used by farmers on providing a proper amount of fertilizer to the paddy-fields. In the case of fertilization of irrigated rice, it should be done site-specifically.

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