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Spatial Analysis of Soil Available Potassium and Plant Brix Content for Site Specific Nutrient Management in Sugarcane

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ABSTRACT

There has been a tendency of decreasing sugarcane productivity (*Saccharum officinarum* Linn) in Indonesia due to poor soil available potassium. There has also been evidence that available soil potassium relates directly to soil condition. For this reason, the management of sugarcane engaging Site Specific Nutrient Management (SSNM) must be pursued. The first and most important stage in SSNM is assessing variability, which can be used to recommend particular fertilizer. This research's main aim is to assess the variability of Potassium and Brix content for uses in the Potassium (K) fertilizer recommendation. The methodology used in this research is collecting data in the field, analyzing with Geographical Information Systems (GIS) using Kriging techniques, and developing a site-specific K prescription map. The results show that (1) spatial analysis assisted in developing a prescription map for K management in sugarcane; (2) spatially, the area can be classified into three classes (low, medium, and high) of K with the recommendation of 300 kg/ha (low), 200 kg/ha (medium) and 0 kg/ha (high) respectively. The results suggest that spatial analysis of soil available potassium and Brix content can provide a whole and specific picture of the area studied, which is beneficial for SSNM.

INTRODUCTION

Sugarcane (*Saccharum officinarum* Linn) is a type of shrub that has a plant height ranging from 2 to 4 meters from the ground and requires a balanced amount of nutrition from soils and fertilizers for optimum development and growth (Bhatt, de Oliveira, & da Silva, 2021; de Oliveira et al., 2016). Besides, fertilizer on sugarcane land must avoid adverse environmental effects because sugarcane needs significant nutrition (Kusumawati & Alam, 2021; Wang et al., 2022). However, the current practices of fertilizer recommendation for sugarcane seem to use uniform applications without considering variabilities in soil and plant needs. This practice has the consequences of providing nutrient overdose and underdose. Therefore, to maintain the productivity of sugarcane while maintaining environmental sustainability, Site Specific Nutrient Management (SSNM), also called precision agriculture, must be pursued (Kusumawati & Alam, 2021).

The implementation of SSNM in crop production, for example, paddy and maize, is not new (Li, Zhao, Wang, Sefton, & Triantafilis, 2019; Munnaf, Haesaert, & Mouazen, 2022); however, its application in sugarcane management is still in its infancy, and the integration of technologies into SSNM in sugarcane is a crucial need (Maldaner, 2021). The importance of technologies for sugarcane SSNM has been discussed elsewhere (Li, Zhao, Wang, Sefton, & Triantafilis, 2019; Sanches, Magalhães, & Franco, 2019). From these studies, the most fundamental component and the first step of any SSNM (including SSNM for sugarcane) relates to how to asses variability at the field scale. This implies that the recommendation for soil nutrient management must be conducted not uniformly but at the scale of field variability. The recommendation could be conducted based on the relationship between pertinent soil properties and sugarcane quality that can be observed. Two

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important indicators for studying sugarcane quality and quantity are potassium (K) and Brix content. K's importance in regulating sugarcane growth and development has been studied elsewhere. For example, Bhatt et al. (2021b) explain that K is the most responsible nutrient for controlling plant uptake, transport, and utilization of water and other essential nutrients. Previous studies have also demonstrated that Brix content is an important indicator of sugarcane quality, which relates to other quality indicators (purity, pol, and commercial cane sugar) and direct sugarcane cultivation and management (Bhatt et al., 2021b; Xiao, Liao, & Guo, 2017).

Former studies have shown that the main factor influencing sugarcane Brix levels is the availability of nutrients such as potassium, although some other factors may influence it (Bhatt et al., 2021a; Watanabe, Ngasan, Saensupo, & Sriroth, 2019). Brix content is one of the indicators of sugarcane quality (Rodrigues Jr, Magalhães, Franco, de Beauclair, & Cerri, 2013). One degree in Brix is defined by 1 g of sucrose in 100 g of solution, and the optimal Brix content in sugarcane stalks is between 8-16% Bx (Saetear, Saechua, & Sereenonchai, 2021). Brix content is dissolved in dry solids such as sucrose and other solids besides water. Brix content is one of the parameters that can predict sugar production (Gunnula, Kosittrakun, Righetti, Weerathaworn, & Prabpan, 2012). Potassium is one of the macronutrients needed in large quantities. The higher the potassium, the higher the Brix content in sugarcane (Ghaffar, Saleem, Fiaz, Nadeem, & Wains, 2013). The content of available K in the soil for the optimum growth of sugarcane plants is estimated to be 0.25-0.51 me/100 gram (Bhatt et al., 2021a). Therefore, a lack of potassium in sugarcane can reduce the value of sugarcane Brix levels so that the selling price of sugar cane will also decrease (Kusumawati & Alam, 2021).

The important component of spatial variability for SSNM in sugarcane has recently been studied (Bhatt et al., 2021c; Dongare, Reddy, Kharche, & Ramteke, 2022; Hovhannissian, Podwojewski, Le Troquer, Mthimkhulu, & Van Antwerpen, 2019). Bhatt et al. (2021c), for example, show that the addition of potassium affected the growth parameters (height, diameter, and internodes) and the quality (Brix, pol, purity, and extractable sugar percentage) of sugarcane both in unstressed and stressed water condition. Although this study was conducted on the scale of plots, this pattern may also occur on the scales of fields. K in sugarcane soils and Brix contents varies spatially (Dongare, Reddy, Kharche, & Ramteke, 2022; Ferraz, de P. Corrêdo, Wei, & Molin, 2019). The quantification of spatial variation is, therefore, necessary, and techniques have been available, which is often called spatial interpolation. One of the spatial interpolation methods is Kriging. Using a semivariogram model, the Kriging interpolation method in geostatistical analysis predicts an unsampled value based on the surrounding sample. Oliveira, Lima, Brasco, & Amaral (2022) show that Kriging could provide accurate estimates of soil properties while detecting anisotropy and providing an error in the prediction.

From the previous studies, it is clear that studying the relationship between the Brix content and the soil potassium in a spatial context is a significant undertaking because this is most likely to assist in the SSNM for potassium (K) fertilizer applications. This research uses kriging techniques in the environment of Geographical Information Systems to explore the spatial relationship between potassium and Brix content for site specific K management. If the relationship pattern is found, this can be used for site-specific recommendations. This research's main aim is to assess the variability of potassium and Brix content for uses in the potassium (K) fertilizer recommendation.

MATERIALS AND METHODS

The research was carried out from January 2022 to March 2022. The research location is a sugarcane plantation owned by sugarcane farmers in Tanggul Kulon Village, Tanggul District, Jember Regency. The location of the study area starts from 769202-770087(Easting) and 9095086-9096281 (Northing) with the reference EPSG: 3279–WGS 84. The projection was Universal Transverse Mercator (UTM) with a zone of 49S. The research area was 80 ha. Sugarcane varieties cultivated in the research area are BL-36. The materials used in this study were the administrative map of Tanggl Kulon Village with a scale of 1:25,000, a map of the Indonesian Geospatial Information Agency at a scale of 1:25,000, samples of sugarcane juice and alcohol, soil samples, aquadest and Ammonium acetate at pH 7.0. The research tools used are a computer, spectrophotometer, Qgis 3.16 software, UTM Geo Map, and 30% refractometer

Soil samples were analyzed at the Laboratory of Soil Fertility, Faculty of Agriculture, Universitas Jember. The determination of sample points using the grid sampling method with the number of samples 34 samples. The coordinates of samples were determined using Global Positioning Systems (GPS). The potassium content was determined using the AAS (Atomic Absorption Spectrophotometer) method, and the sugarcane Brix content was measured using a 30% Brix hand refractometer. The sugarcane Brix content was measured by taking samples on five sugarcane stalks from the bottom, middle and top segments, then the average was calculated.

The results of laboratory analysis (the content of potassium) and the reading refractometer (Brix content) were then input into Geographical Information Systems (GIS) for further analysis. Finally, Quantum GIS (QGIS) was employed for spatial analysis. In the beginning, the Moran index was employed for determining the spatial pattern of the data using the formula below (Chen, 2021):

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} wij(x_i-\bar{x})(x_j-\bar{x})}{z_x^2\sum_{i=1}^{n}\sum_{j=1}^{n} wij} \quad\text{.................................1)}$$

Where: I = Moran Index; n = number of sample; x_i = value on sample I; x_j = value on sample y; $\bar{x}$ = the average of the number of variables or value; wij = weighting element between sample i and sample y; = Variant of the sample percentage

The interpolation method used was ordinary Kriging. Ordinary Kriging was calculated by using the formula (Zhao et al., 2020):

$$\hat{z}(s) = \sum_{i=1}^{n} wi\, Z(si) \quad\text{....................................2)}$$

Where: $\hat{z}$(s) = predicted value at unsampled locations; wi = weight coefficient of $\hat{z}$(si), with $\sum_{i=1}^{n} wi$ = 1; Z(si) = value at sampled location; n = number of samples

Some trials were conducted to find the minor Root Mean Squared Error (RMSE) on the results of interpolations using the formula below (Arshad, Zhao, Khongnawang, & Triantafilis, 2021):

$$RMSE = \sqrt{\sum_{i=1}^{n}(p_i - a_i)^2} \quad\text{......................................3)}$$

Where: p_i = the value of the primary simulation results from the observation variable; a_i = the actual value of the observation variable; n = number of observations

In the end, the semivariogram model used in the analysis of available soil potassium values was exponential with a maximum distance was 300, lag(h) was 150, nugget variance (C0) was 0, sill (C0+C) was 0.025 and range (A) was 299.964. The values of RMSE were found to be 0.158, and R^2 was 0.079. on the other hand, sugarcane Brix content used a spherical semivariogram model with a maximum distance of 500 m, lag (h) 150 m, nugget variance (C0) was 9.225, Sill (C0+C) was 19.252, and range (A) was 330.372, and the value of RMSE was 3.861 and R^2 was 0.033. Spatial data analysis with semivariogram model using the following formula (de Oliveira et al., 2015):

Semivariogram Exponential:

$$y(h) = C0 + C\left[1 - exp\left(-\frac{h}{a}\right)\right] \quad\text{..............................4)}$$

Where: h = a certain distance that separates two points; C0+C = Sill; a = range; exp = exponential

Spherical semivariogram:

$$y(h) = \begin{cases} C0 + C\left[\left(\frac{3h}{2a}\right) - \left(\frac{h}{2a}\right)^3\right], & h \geq a \\ C0 + C & , h < a \end{cases} \quad\text{.........................5)}$$

Where: h = a certain distance that separates two points; C0+C = Sill; a = range

The interpolated data were then classified according to the category and presented in the form of maps of available soil potassium, Brix content , and potassium recommendation at a scale of 1:7,000. The map of the study area is shown in Fig. 1.

RESULTS AND DISCUSSION

Table 1 show the values of soil available potassium and brix content in the research area. The distribution of available potassium value and sugarcane Brix content. As can be seen, There are 34 sample points analyzed for the value of available soil potassium at each coordinate point. The minimum value is 3.9, the maximum is 234, the mean is 65.61, the median is 46.8, the mode is 46.8, and the standard deviation is 55.61. The value of available soil potassium varied widely, ranging from 3.9-234 ppm. From the 34 samples analyzed, there are 29 samples with low criteria, 3 with medium criteria, and 2 with high criteria. Therefore, the distribution of available soil potassium values is in the low criteria with a value of <100 ppm.

The minimum, maximum, mean, median, mode, and standard deviation values of Brix content were 9, 26, 17.85, 17.9, 19, and 3.931, respectively. More significant variability was observed in potassium compared to Brix content. There are three criteria for classifying the value of sugarcane Brix content: low, medium, and high. Table 1 shows low Brix contents were observed in eleven samples, while ten were for medium and thirteen for high criteria. It indicates that the majority of samples had a high content of Brix.

Spatial Analysis of Soil Available Potassium

Fig. 2 shows a clustering analysis of soil available potassium. As can be seen, the value of the Moran Index was 0.486 (positive), showing that there was a pattern of data clustering, and this value is considered quite strong. The data shows some similarities in parts of the study area, as shown in the distribution of dot colors in Fig. 2. However, in some areas, there are differences in the values of available potassium in a category, which may be due to uneven fertilization. Referring to the p-value of 0.307 shows that despite the clustering, there is also a pattern of approaching randomness in the distribution of K.

The spatial distribution of the values of available soil potassium is most likely to relate to the farmers' cultivation practices. Farmers applied fertilizer at the time of the study was 1 t/ha of phonska fertilizer per hectare. This is still considered low compared to sugarcane plants' recommended fertilization dose. The recommended dosages are urea 300 kg/ha, TSP 300 kg/ha, and KCl 300 kg/ha, respectively (Zulkarnain et al., 2017). Phonska fertilizer contains four nutrients, namely 15% nitrogen, 15% phosphorus, 15% potassium, and 10% sulfur.

Fig. 3 shows that there are three categories of soil potassium. Red color with available soil potassium value < 100 ppm (low category), yellow color shows 100-200 ppm (medium category), and green color denotes > 200 ppm (high category). As can be seen, the low category of soil potassium shows a more extensive spatial distribution than the others. As shown in Fig. 3, polygons with green color indicate high potassium values with values > 200 ppm. In this high category, therefore, potassium is sufficient (Watanabe, Ngasan, Saensupo, & Sriroth, 2019), and no potassium is needed. On the other hand, it is necessary to add potassium fertilizer for locations with low and medium potassium. Table 2 shows the area (ha) distribution for each criterion.

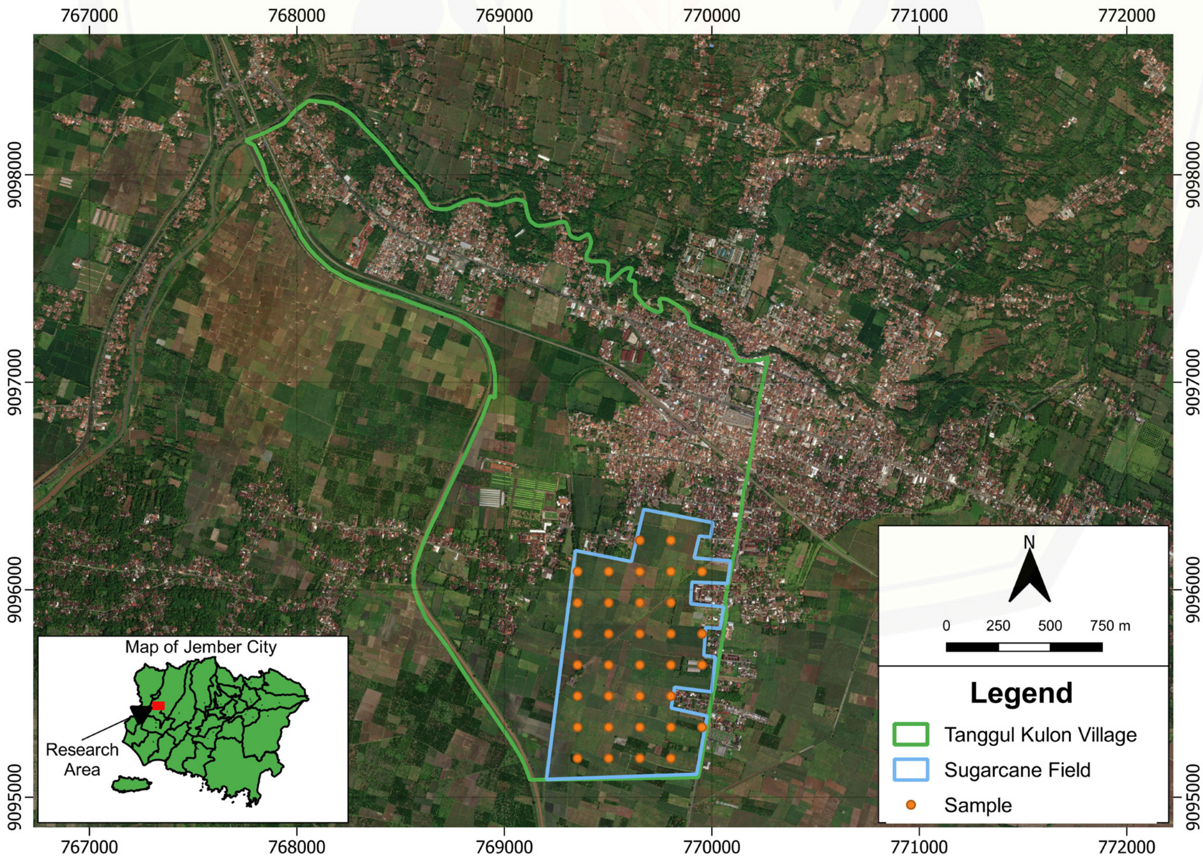

Fig. 1. The location of the research area

Table 1. The coordinate and the values of soil available potassium and sugarcane Brix content

Sample	Longitude X	Latitude Y	Available Potassium		Brix Content	
	(UTM Zone 49 S)	(UTM Zone 49 S)	(ppm)	Criteria	(%)	Criteria
1	769652,6752	9096237,5639	109.2	Medium	19	High
2	769802,5217	9096237,5639	46.8	Low	17.2	High
3	769352,6236	9096087,7180	234	High	18.2	High
4	769502,7092	9096087,5979	62.4	Low	21	High
5	769652,5556	9096087,4790	39	Low	16.9	Medium
6	769802,5217	9096087,7180	66.3	Low	22.9	High
7	769952,4877	9096087,4790	31.2	Low	16.3	Low
8	769352,6236	9095937,5730	19.5	Low	12.3	Low
9	769502,5597	9095937,5130	70.2	Low	23.8	High
10	769652,5556	9095937,5730	74.1	Low	26	High
11	769802,5516	9095937,5429	42.9	Low	17	Medium
12	769352,5339	9095787,5769	81.9	Low	19.8	High
13	769502,5448	9095787,5319	74.1	Low	25.5	High
14	769652,5407	9095787,5390	218.4	High	18.5	Medium
15	769802,5665	9095787,5390	128.7	Medium	19	Medium
16	769952,5475	9095787,5319	31.2	Low	15.8	Low
17	769352,5414	9095637,5209	15.6	Low	12	Low
18	769502,5522	9095637,5360	11.7	Low	9,5	Low
19	769652,5482	9095637,5280	3.9	Low	9	Low
20	769802,5516	9095637,5429	27.3	Low	15	Low
21	769952,6372	9095637,5429	78	Low	20	High
22	769352,5489	9095487,5179	198.9	Medium	18.5	Medium
23	769502,5448	9095487,5179	27.3	Low	15.4	Low
24	769652,5556	9095487,5329	31.2	Low	16.1	Low
25	769802,6114	9095487,5480	46.8	Low	17.2	Medium
26	769352,5339	9095337,5219	42.9	Low	17.1	Medium
27	769502,5298	9095337,5219	62.4	Low	22.8	High
28	769652,5556	9095337,5370	78	Low	20.3	High
29	769802,5488	9095337,5219	19.5	Low	14.5	Low
30	769952,5531	9095337,5199	46.8	Low	17.8	Medium
31	769352,5470	9095187,5309	19.5	Low	14.8	Low
32	769502,5503	9095187,5240	89.7	Low	19	Medium
33	769652,5514	9095187,5549	46.8	Low	18	Medium
34	769802,5492	9095187,5219	54.6	Low	21	High

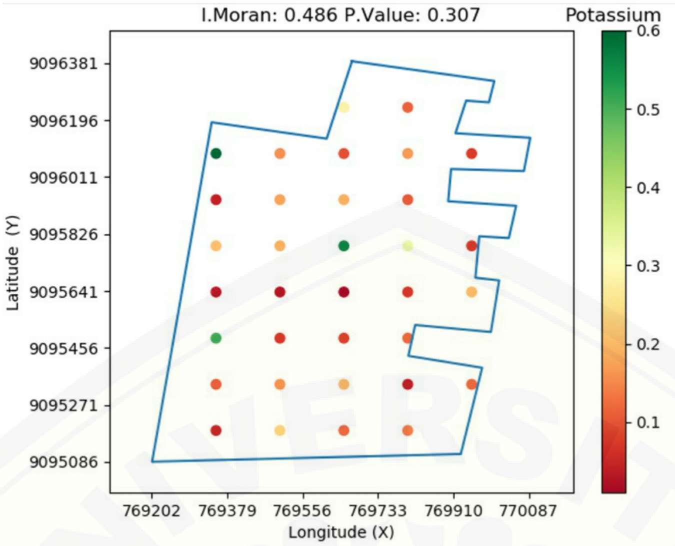

Fig. 2. Moran Index of availble potassium

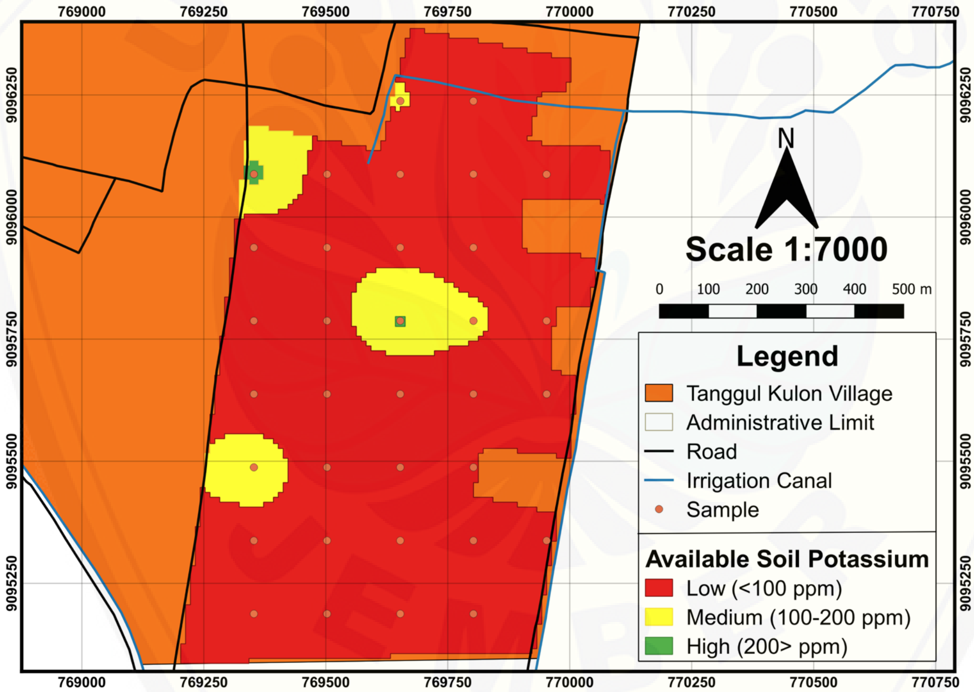

Fig. 3. Distribution map of available soil potassium in Tanggul Kulon Village, Jember Regency using the Ordinary Kriging Method

Table 2. The distribution of area for criteria of soil available potassium

Color in map	Available Potassium Value (ppm)	Criteria	Area (ha)	Percentage (%)
Red	< 100	Low	71.71826	89.59
Yellow	100-200	Medium	8.131881	10.16
Green	200 >	High	0.199801	0.25
Amount			**80.04995**	**100**

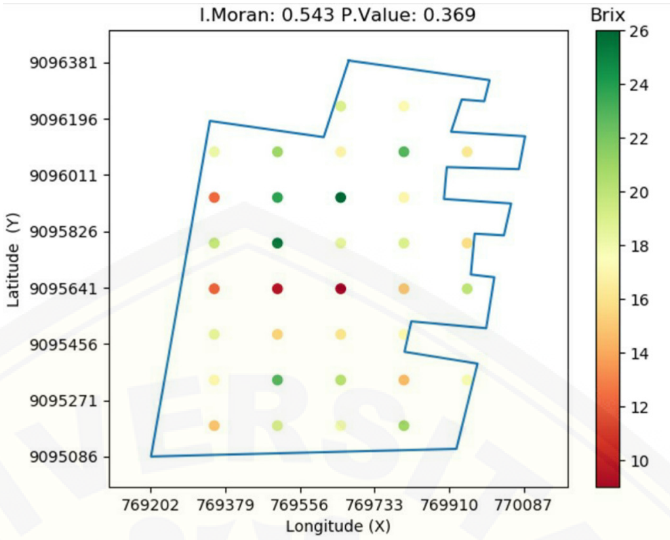

Fig. 4. Moran Index of Brix Content

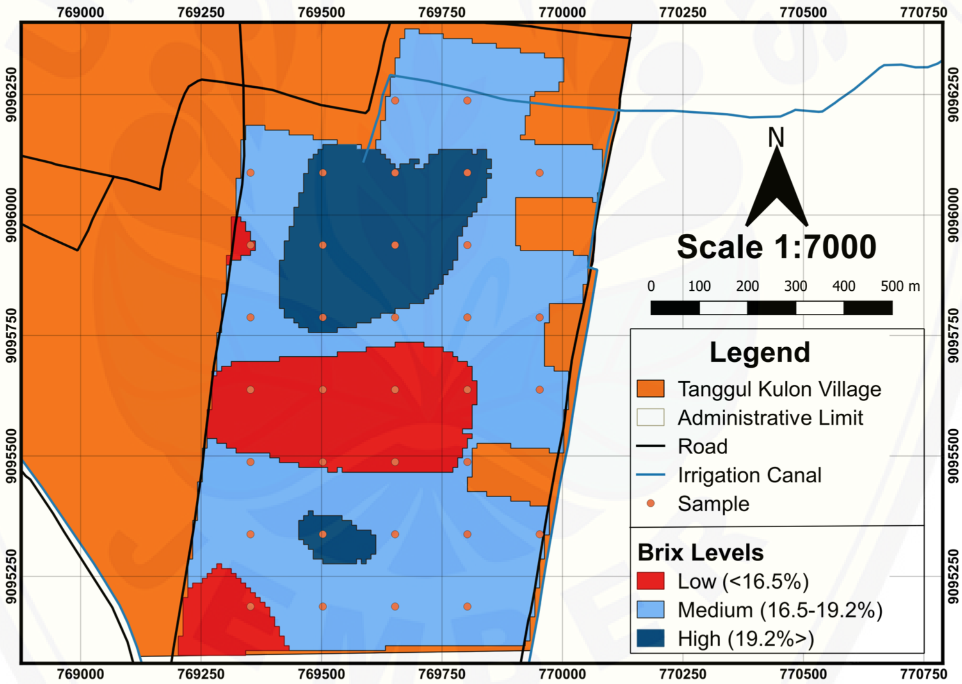

Fig. 5. Map distribution of sugarcane Brix levels in Tanggul Kulon Village, Jember Regency using the Ordinary Kriging Method

Table 3. Class area interpolation results of sugarcane Brix content values

Color	Sugarcane Brix Content Value (%)	Criteria	Area (ha)	Percentage (%)
Red	< 16.5	Low	15.49465	19.36
Light blue	16.5-19.2	Medium	51.01895	63.73
Dark blue	19.2 >	High	13.53645	16.91
Amount			**80.04995**	**100**

As seen in Table 2, 89.59% of the study area is categorized as having low available potassium with 71.71 ha, and 10.16% in the medium, with 8.13 ha. In contrast, the high criteria were only 0.25% with an area of 0.19 ha. Therefore, it indicates that most soil in the study area has been experiencing low available potassium. As seen in Fig. 3, there is a spotty pattern of soil available potassium in the study area. This pattern is most likely to relate to the fertilizer application by farmers. The interview results with the farmers provided evidence that different doses and times for fertilizer applications exist. For this reason, the remaining potassium in the soil is different from one farmer's land to the others. This pattern of farmer cultivation and the uptake of soil-available potassium by sugarcane is almost certainly responsible for the low potassium in soils.

Spatial Analysis of Brix Content

Fig. 4 shows a clustering analysis of the overall data of Brix content. Similar to Fig. 2, the clustering also occurred in the Brix content, although the Moran Index was higher than in soil available potassium. The value of the Moran Index was 0.543 (positive), showing that there does exist a pattern of clustering of data, as shown in the distribution of dot colors in Fig. 4. However, by referring to the p-value of 0.333. This indicates that there is also a pattern of being close to randomness in the distribution of Brix content.

Fig. 5 shows three categories from the interpolation results: low, medium, and high. As shown in Fig. 5, the low category (red in the map) with a Brix content value of less than 16.5%, medium (light blue in the map) with a range of 16.5-19.2% and high (dark blue in maps) with the value of more than 19.2%. It means that the areas of the medium category of Brix are more dominant than others in the study area. As seen in Fig. 4, a low category of Brix content was also observed. It is likely due to sugarcane's lack of soil nutrient requirements, especially potassium nutrients (Ahmed, Baiyeri, & Echezona, 2013). Nutrients are needed in the low and medium categories to increase sugarcane Brix levels, especially potassium. In the high category, harvesting should be carried out shortly because delaying harvesting in sugarcane plants will reduce sugarcane quality and significantly decrease sugarcane Brix content (Hagos, Mengistu, & Mequanint, 2014).

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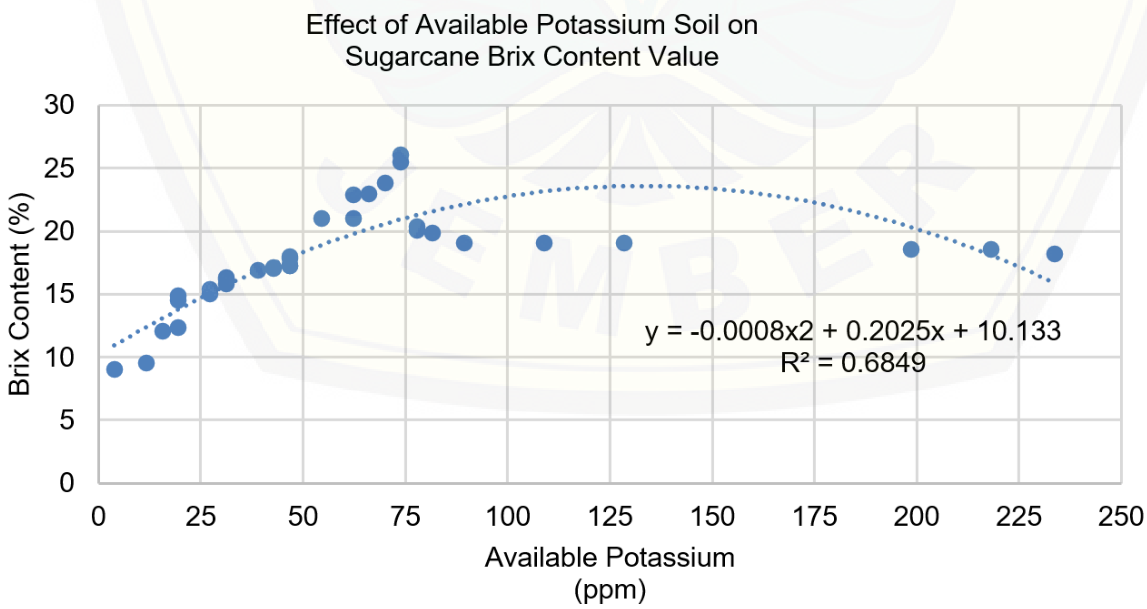

Fig. 6. Relationsip between available potassium soil and sugarcane Brix content value

Table 3 shows that the sugarcane Brix content in the medium criteria occupies about 63.73% of the total area (51.01 ha), the low criteria 19.36%(15.49 ha), and the high criteria (16.91%). This shows that most sugarcane Brix levels are in the medium.

Relationship between Soil Available Potassium and Sugarcane Brix Content

Fig. 6 shows that available soil potassium strongly influences the value of sugarcane Brix content. This is because the results of the polynomial regression equation between available soil potassium and sugarcane Brix content have an R^2 of 0.6849 or 68.49%. The value of the coefficient of determination shows that 68.49% of the sugarcane Brix content value is influenced by available soil potassium and other factors influence the rest. The following formula shows the relationship between Potassium and Brix content:

$y = -0.0008x^2 + 0.2025x + 10.133$ ....6)

Where: x = available potassium (ppm); y = Brix content (%)

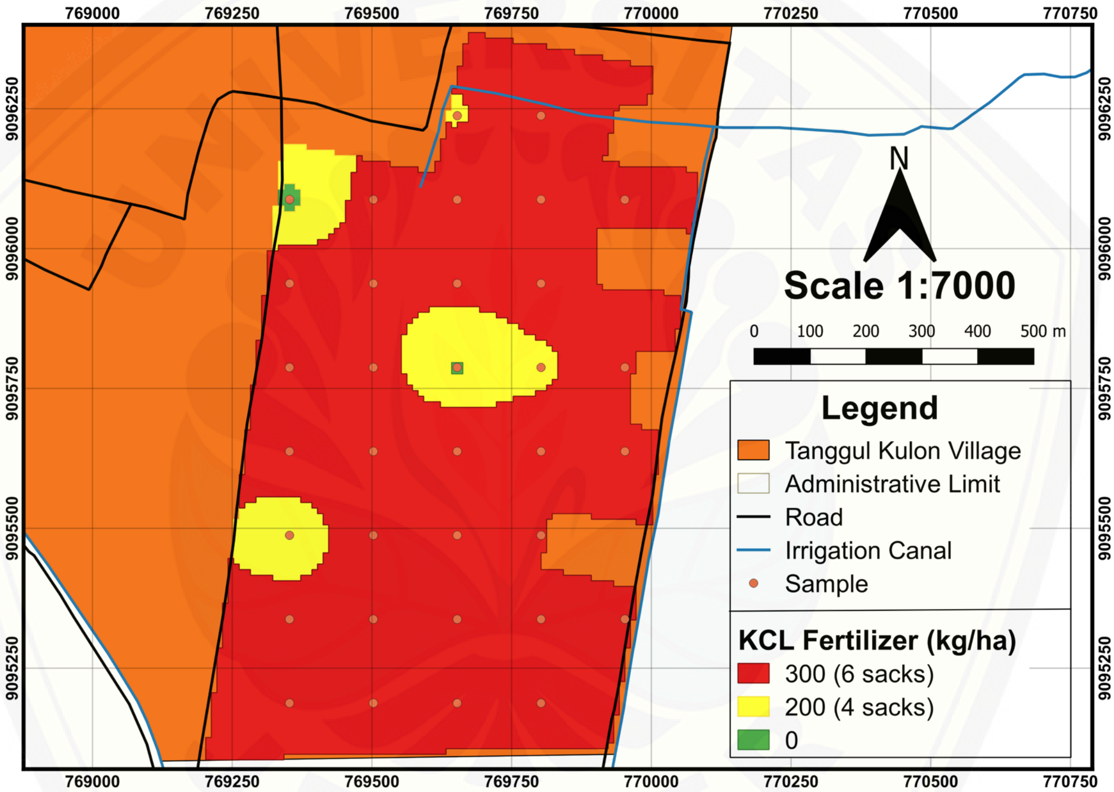

Fig. 7. Recommendations for KCl fertilization (60% K_2O) in the study area

Table 4. Recommendations for potassium fertilization (K_2O) in the study area

Criteria	K_2O Fertilization Recommendation (kg/ha)	Recommendations for Fertilizing K_2O with KCl Fertilizer 65% K_2O (kg/ha)	Area (Ha)
Low	180	300	71.71826
Medium	120	200	8.131881
High	0	0	0.199801
Total			**80.04995**

Fig. 6 shows that the higher the soil available potassium, the higher the sugarcane Brix content. However, this is only to a certain extent. Too high a soil's potassium value can reduce the sugarcane Brix content (de Almeida et al., 2015). As seen in Fig. 6, the effect of available potassium on Brix levels is very significant under conditions where soil available potassium is low. Therefore, it seems to agree with the study by Watanabe, Ngasan, Saensupo, & Sriroth (2019), claiming that maintaining a potassium level would maintain the sugarcane quality (Brix content). This is evidence that to achieve the quality of sugarcane, the addition of potassium must align with the needs of the sugarcane plant. However, this does not mean providing excessive potassium into soils. For this reason, to perform appropriate K fertilizer management, knowledge of the K status of each sugarcane field is necessary. Therefore, site-specific recommendations for fertilizing potassium nutrients are needed in maintaining high sugarcane Brix levels.

Potassium Fertilization Recommendations

Table 4 shows the doses for recommending fertilizing potassium (K_2O) in sugarcane. This table is used for fertilizer recommendation in this study, and the recommendation map is shown in Fig. 7. Table 4 shows that for the low criteria, it is necessary to add 180 kg/ha of K_2O fertilizer, the moderate criteria for adding 120 kg/ha of K_2O fertilizer, and the high criteria do not require the addition of fertilizer (Watanabe, Ngasan, Saensupo, & Sriroth, 2019). Therefore, fertilization recommendations use KCl fertilizer with a K_2O content of 60.

Fig. 7 shows the prescription map for KCl recommendation. In low criteria, adding 300 kg/ha of KCl fertilizer or equivalent to 6 sacks (1 sack equal to 50 kg) per hectare is necessary. Areas with the middle criteria require the addition of 200 kg/ha of KCl fertilizer (equivalent to 4 sacks per hectare), whereas no addition of fertilizer for high criteria. Overall, the total need for KCl fertilizer for fertilization in the study area is 500 kg/Ha. Therefore, adding KCl fertilizer was mostly recommended in the low and medium criteria. In the high criteria, no additional potassium is needed because the availability of potassium for plants is considered sufficient and avoids excessive fertilization because it affects nutrient poisoning (Balaganesh, Vasudevan, Suneethkumar, Shahir, & Natarajan, 2020). The addition of potassium aims to improve Brix levels because potassium strongly influences sugarcane Brix levels, based on Fig. 7 Sufficient potassium needs in sugarcane also affect the other qualities of sugarcane crops, such as pollination. Besides, the sufficiency of potassium can support the growth and development of sugarcane plants (Kumar, Babar, Mohan, & Bansal, 2019). These recommendations ultimately aim to make it easier for farmers to add KCl fertilizers. Meeting the need for potassium in sugarcane plants can also increase economic benefits for farmers because the quality of sugarcane yields is getting better, and the selling price of sugar cane increases.

The results of this study proved that the farmers' application of potassium fertilizer at Tanggul Kulon Village was not conducted based on the soil condition and plant needs because the farmers are likely to apply fertilizer uniformly over the whole area. The results of this study also show that varying degrees of doses and time of application would lead to the different soil available K and then Brix content. It means that part of the study area would experience a lack of K, whereas the others would show excessive K. The critical finding of this research is that although the uniform recommendation has been the basis for the application for a long time, SSNM recommendation would improve fertilizer use efficiency due to its consideration of spatial variability. If spatial variability is encountered, then it will guide fertilization. This research provided evidence of the importance of discovering spatial variability for K recommendation in sugarcane.

CONCLUSION AND SUGGESTION

The recognition of spatial variability of soil properties is the most pertinent characteristic of SSNM. The results of this study have proven that a more efficient input of fertilizer could be achieved if the spatial variability of soil available potassium is considered. Likewise, this study's results ascertain that better nutrient management in sugarcane could be achieved if the different pattern of available soil K is acknowledged in precise locations. The suggestion for further work is that a study on different nutrients other than K in the study area can be conducted to find their spatial patterns for SSNM.

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