Available online at:
http://journal.unila.ac.id/index.php/tropicalsoil
DOI: 10.5400/jts.2023.v28i1.1-8

Temporal Changes in Spatial Patterns of Soil Properties During a Period of Rice Growth

Yagus Wijayanto*, Rizqi Aprilia Putri Anggreini, Ika Purnamasari and Suci Ristiyana

*Agrotechnology Study Program, Faculty of Agriculture, University of Jember, Jl. Kalimantan 37 Jember, Indonesia. *e-mail : yaguswijayanto001.faperta@unej.ac.id*

Received 05 August 2022, Revised 18 August 2022; Accepted 06 September 2022

ABSTRACT

Growing rice is complicated because of the interrelationship among production components, one of which is soil conditions. Determination of soil conditions is usually conducted by employing some soil properties. It is no doubt that soil properties have spatial and temporal characteristics. This research used two soil properties: Electrical conductivity (EC) and pH. This study aimed to use and evaluate Inverse Distance Weighted to uncover the temporal changes in pH and EC during the rice growth period. The methods used in the research were field survey, soil sampling, laboratory analysis, and data processing in Geographical Information Systems (GIS). The sample used was 30 and repeated three times under the growth period (vegetative, generative, and ripening). The results showed that there were changes in pH values of the soil in one growing season, and EC values tend to increase from the vegetative to the ripening period.

Keywords: Electrical conductivity, inverse distance weighted, rice growth, soil pH

INTRODUCTION

Rice is an essential food for Indonesia and other Asian Countries, and there have not been any changes in the consumption of 3.5 billion people for years (Widyanti et al., 2014; Gadal et al., 2019). This condition has resulted in increasing efforts to maintain stability or increase rice productivity by introducing high-yielding variety, improving irrigation techniques, and using chemicals (Mahajan et al., 2017). Growing rice is complicated due to the significant influence of other factors affecting rice production, such as climatic conditions, crop variables, farmer practices, and, more importantly, soil conditions. The utmost important factor of soils for rice production is understanding the variability in space and time. Despite the significant role of soils, their role is often neglected.

Soil properties relate to the others. This relationship could help manage soil, and only selected properties are employed. The selected one(s) then be used for managing soil properties. EC and pH are soil's two most important properties (Aimrun et al., 2007; Serrano et al., 2020; Liu et al., 2021), which have significant potential for managing soil. Najafi and Towfighi. (2013), for example, show that there is a variation in soil pH, EC varies during submergence and rice growth period. Zhang et al. (2021) show the changes in soil pH and EC after applying flue gas desulphurization gypsum in paddy fields. Aimrun et al. (2011) and Cambouris et al. (2006) provided evidence of EC for determining site-specific management zone or precision farming. These studies have clearly shown that EC and pH are two important soil properties that can be used for soil management.

Portraying spatial variability of soil properties was challenging in the past, although currently, there has been significant development in the techniques and methods used. The study of spatial variability of soil properties relates closely to the uses of GIS. Reza et al. (2017) show the importance of geostatistical methods and GIS for accurately distributing soil pH, OC, N, P, K, and Zn. Denton et al. (2017) show that geostatistical methods can be used to find the pattern of soil properties' variability (N, CEC, OC, SAR and ESP, and soil pH). These studies use geostatistical methods (kriging) for determining spatial variabilities. Indeed, other interpolation techniques can be used for characterizing soil properties spatially. This technique is IDW. IDW is a geostatistical interpolation method with the most straightforward formulation, easy to understand, and easy to implement (Ibrahim et al., 2015). Fu et al. (2021) show that kriging and IDW are comparable, meaning that there was only slightly different accuracy of both interpolation techniques. Pulatov et al. (2020) prove that interpolated soil salinity values were more accurately mapped using IDW. Therefore, both spatial interpolation techniques could potentially produce accurate estimates of soil properties. Considering this, the main aim of this research was to employ and evaluate the IDW for temporal changes in spatial patterns of soil pH and EC during rice growth.

MATERIALS AND METHODS

The research was conducted in Wirowongso Village, Ajung District, Jember Regency, from August 2021 to January 2022. Soil analysis was conducted at the Laboratory of the Biology Study Program, Faculty of Teacher Training and Education, Jember University. The materials used in this study were a map of the Jember area (1:500.000), a map of Wirowongso Village (1:25.000), satellite imagery of Wirowongso Village (1:25.000), a DEM (Digital Elevation Model) map, a topographic map, and aquadest. The tools used in this research are GPS (Global Positioning System), laptop, ArcGIS 10.5 software, shovel, plastic, stationery, soil tester, EC meter, and shaker. Workflow ofthe research can be seen in Figure 1.

The method used in this research is the preparation stage by collecting interviews and secondary data. Data from interviews include land area, fertilization carried out by farmers, and types of fertilizers applied by farmers. It made afdeling maps that overlay four basics: Wirowongso Village, satellite

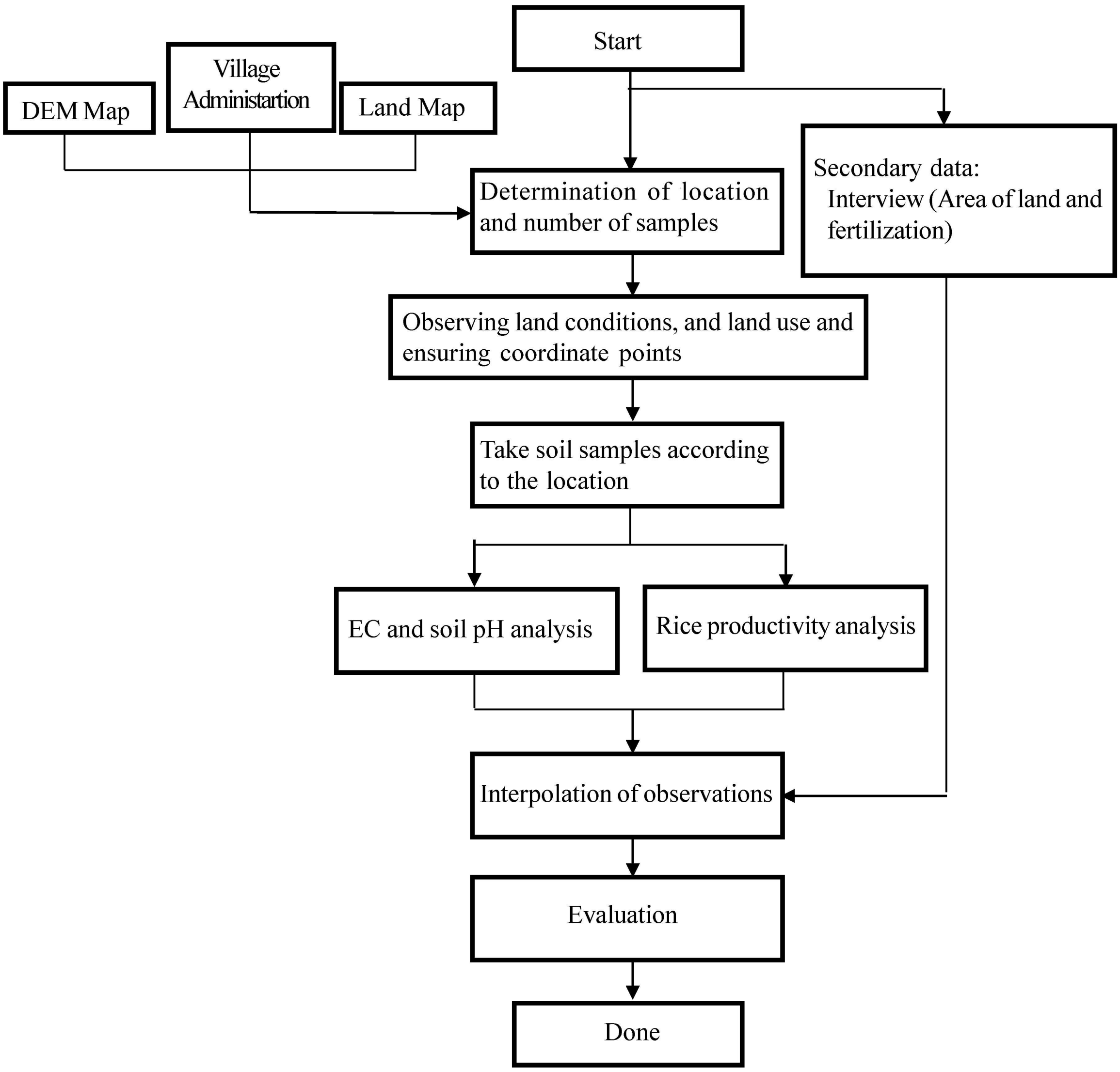

Figure 1. Workflow of the research.

image, topographic, and DEM maps. A field survey was conducted to determine the location for sampling locations. Planning for sample location points was done using GPS. Soil samples were taken using a simple random sampling method with a total sample of 30. Soil sampling was carried out three times in each phase, vegetative, generative, and ripening phases. Soil samples were taken three times to know the changes in the pH and EC values in each phase. Soil samples were taken compositely at 0-30 cm depth for soil EC analysis. Soil pH values were obtained from reading soil tester 401SP004. Data processing was carried out using interpolation analysis with the IDW method. IDW assumes a value for an attribute z at any un-sampled point as a distance-weighted average of sampled points within a defined neighborhood around that un-sampled point (Ibrahim et al., 2015). The general formula for IDW is:

$$Z\ (X_0) = \sum_{i=1}^{N} \lambda_1 . Z(X_1)$$

N = is the number of scattered observation points in the set.

$Z(X_1)$ = are values of the scattered observation points.

λ_1 = are the weights assigned to observation points.

The IDW method can produce the smallest RMSE (Root Mean Square Error) value and pro-

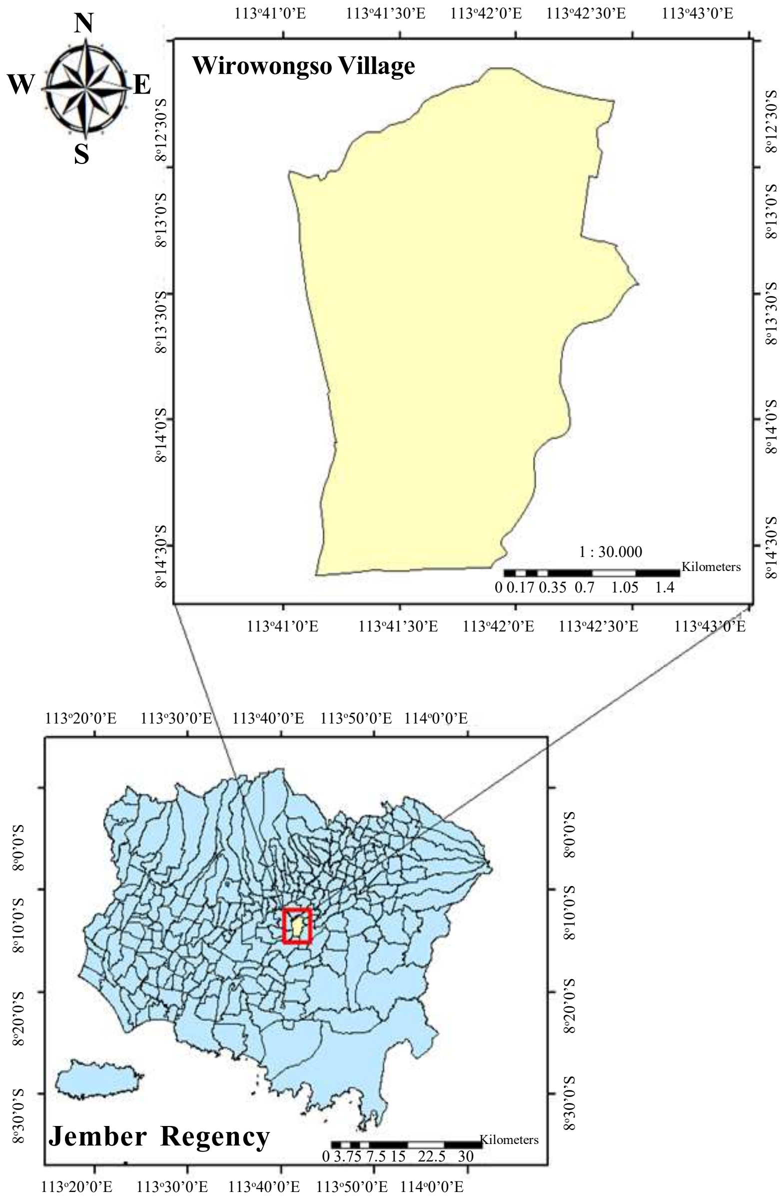

Figure 2. Research location.

vide accurate interpolation results.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(p_i - a_i)^2}{n}}$$

Description :
pi = predicted value at location i
ai = laboratory test value on i
n = number of samples

RESULTS AND DISCUSSION

Research Area Condition

Wirowongso Village is located in Ajung District, Jember Regency (Figure 2). The area of rice fields belonging to the people of Wirowongso Village reaches 505 ha. Most farmers in Wirowongso Village cultivate food crops, especially rice. The planting system used is the jajar legowo and the conventional planting system (Figure 3). Fertilization was given two to three times in one growing season. The fertilizers given were urea, Phonska, ZA, and TSP. The total fertilizers applied was 3 ku ha^{-1} in one growing season.

Soil pH Analysis

Soil pH analysis was carried out using a soil tester. The results of the soil pH analysis were then interpolated using the IDW method with a power value of 2. The results of the soil pH analysis were then divided according to the existing categories using the reclassify method in ArcGIS software. The reclassify (classification) method is used to determine the classification of soil pH values. The pH value of the soil in Wirowongso Village had a range of values from 5.4 to 6.8. The lowest soil pH value was 5.4 in the maturation phase, and the highest was 6.8 in the vegetative phase.

Table 1 shows that the soil pH category of the vegetative phase was categorized as moderately acidic, slightly acidic, and neutral. A dark blue color indicated the smallest area with a pH value range of 6.4-6.8 with an area of 20.14 ha. The yellow color had a pH value range of 6.0-6.1 and dominated the colors on the map with an area of 207.66 ha.

Table 2 shows that soil pH category at the generative phase was moderately and slightly acidic. The green color dominates the colors on the map with an area of 208.60 ha and a pH value range of 6.0-6.1. The smallest area was dark blue, with an area of 25.46 ha and a pH range of 6.3-6.5.

Table 3 shows that the soil pH category of the ripening phase was strong acid, moderately acidic, and slightly acidic. The green color dominates the map with an area of 190.04 ha and a pH of 5.9-6.0. The smallest area shown in red was 38.60 ha, and the range of pH values was 5.4-5.7.

Based on Figure 4, there were several samples with decreased soil pH values. The soil pH value decreased at five sample points, 1, 3, 8, 13, and 15. The increase in soil pH value was apparent at six sample points, 5, 19, 20, 21, 24, and 30.

Figure 4 shows that each phase experienced an increase or decrease in the pH value of the soil. The decrease in the pH value of the soil can be predicted by several factors, one of which is the application of chemicals. Acidic soils can be caused by adding chemicals to the natural plant cultivation process (Hardjowigeno, 2010). The provision of chemicals was made by adding chemical fertilizers and pesticides. The application of pesticides was due to the absence of crop rotation used. Applying NPK fertilizer during the cultivation process can reduce

(a) (b)

Figure 3. Conventional planting system and jajar legowo. (a) conventional planting system, (b) row planting system legowo

Table 1. Distribution of soil pH in the vegetative phase.

No	pH	Criteria	Surface area (ha)
1	5.7 – 6.0	Moderately Acid	71.48
2	6.0 – 6.1	Slightly Acid	207.66
3	6.1 – 6.2	Slightly Acid	155.81
4	6.2 – 6.4	Slightly Acid	50.56
5	6.4 – 6.8	Slightly Acid – Neutral	20.14
		Total	505.64

Note: *The range of pH values is based on the natural break method in ArcGIS software.

Table 2. Distribution of soil pH in the generative phase.

No	pH	Criteria	Surface area (ha)
1	5.7 – 5.9	Moderately Acid	32.87
2	5.9 – 6.0	Moderately Acid	157.77
3	6.0 – 6.1	Slightly Acid	208.60
4	6.1 – 6.3	Slightly Acid	80.94
5	6.3 – 6.5	Slightly Acid	25.46
		Total	505.65

Note: *The range of pH values is based on the natural break method in ArcGIS software.

Table 3. Distribution of soil pH in the ripening phase.

No	pH	Criteria	Surface area (ha)
1	5.4 – 5.7	Strongly Acid - Moderately Acid	38.60
2	5.7 – 5.9	Moderately Acid	100.84
3	5.9 – 6.0	Moderately Acid	190.04
4	6.0 – 6.2	Moderately Acid	136.69
5	6.2 – 6.6	Slightly Acid	39.62
		Total	505.78

Note: *The range of pH values is based on the natural break method in ArcGIS software.

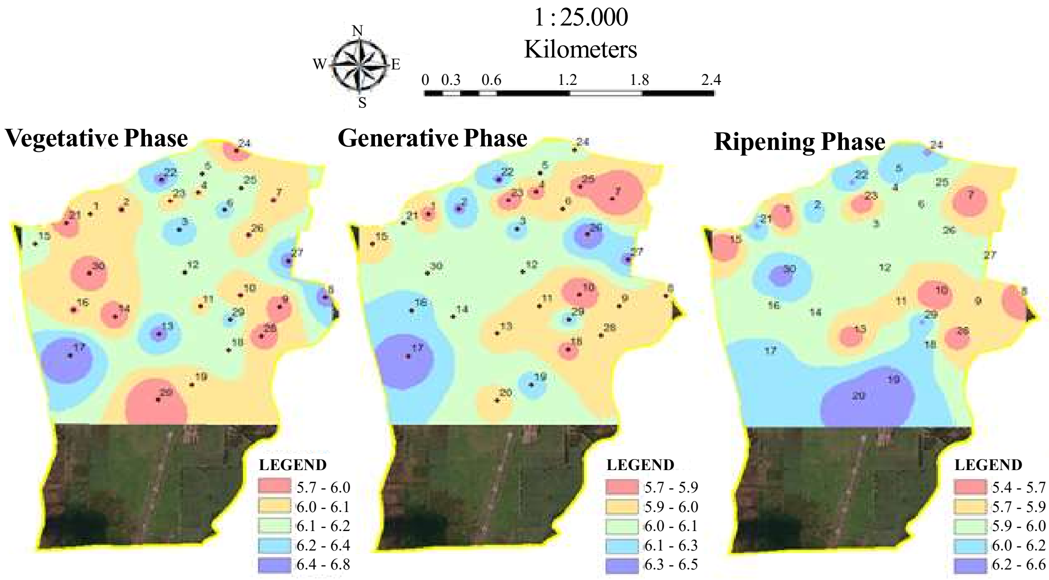

Figure 4. Interpolation of soil pH by development phase.

the pH value of the soil (Kaya, 2014). The influence of climatic factors could also affect the observed soil pH. According to Cheng et al. (2014), the soil's pH value negatively correlates with the average temperature and rainfall. Chytry et al. (2007) also stated that the pH value of the soil tends to decrease with increasing rainfall. The increase in the pH values could be due to the flooding of paddy fields during the rainy season, so the pH value changes from neutral to alkaline (Nazir et al., 2017).

If the soil pH analysis results are adjusted to the category, then the pH value of the soil in Wirowongso Village is included in the pH of acidic soil. The appropriate soil pH value for rice plants is 5.5-7.0 (Peraturan Menteri Pertanian, 2013). This is in line with the pH value of the soil in Wirowongso Village.

Soil EC Analysis

Soil EC analysis was used to see the pattern of distribution of EC values on the soil in Wirowongso Village. The results of the soil EC analysis were then interpolated using the IDW method with a power value of 2, then categorized by the natural break method. The natural break method is a class division according to the data that has been obtained. This method can also provide a visual description of the value of the data obtained (Grinderud et al., 2009).

Soil EC values in each phase were different. The EC value of the soil in the vegetative phase had a value range of 0.05-0.64, the generative phase had a range of soil EC values from 0.06-0.64, while the ripening phase had a range of soil EC values from 0.07-0.65. The lowest EC value in the vegetative phase was 0.05, and the highest EC value in the ripening phase was 0.65.

Table 4 shows that the EC category of the vegetative phase was included in the non-saline soil category. The light green color dominates the map with an area of 262.29 ha. The smallest area shown in red is 5.67 ha.

Table 5 shows that the EC category of the generative phase is included in the non-saline soil category. The dominant color is light green, with an area of 241.76 ha. The smallest area shown in red is 6.72 ha.

Table 6 shows that the EC category of the soil in the ripening phase is included in the non-saline soil category. The dominant color in this phase is light green, with an area of 222.97 ha. The smallest area is shown in red, with an area of 6.28 ha.

Figure 5 shows several sample points experiencing an increase in the EC value. The increase in the EC value was visible at eight sample points, at points 4, 6, 8, 9, 10, 13, 21, and 23. As for the decrease in soil pH value, it was seen at point 25.

Table 4. Distribution of EC soil vegetative phase.

No	EC	Criteria	Surface area (ha)
1	0.05 – 0.13	Non Saline	155.12
2	0.13 – 0.19	Non Saline	262.29
3	0.19 – 0.28	Non Saline	69.56
4	0.28 – 0.43	Non Saline	12.91
5	0.43 – 0.64	Non Saline	5.67
	Total		505.55

Note: *The range of EC values is based on the natural break method in ArcGIS software.

Table 5. Distribution of EC soil generative phase.

No	EC	Criteria	Surface area (ha)
1	0.06 – 0.15	Non Saline	146.79
2	0.15 – 0.20	Non Saline	241.76
3	0.20 – 0.28	Non Saline	92.05
4	0.28 – 0.42	Non Saline	18.21
5	0.42 – 0.64	Non Saline	6.72
	Total		505.53

Note: *The range of EC values is based on the natural break method in ArcGIS software.

Table 6. EC distribution of ripening phase soil.

No	EC	Criteria	Surface area (ha)
1	0.07 – 0.18	Non Saline	140.99
2	0.18 – 0.23	Non Saline	222.97
3	0.23 – 0.31	Non Saline	107.65
4	0.31 – 0.45	Non Saline	27.60
5	0.45 – 0.65	Non Saline	6.28
	Total		505.50

Note: *The range of EC values is based on the natural break method in ArcGIS software.

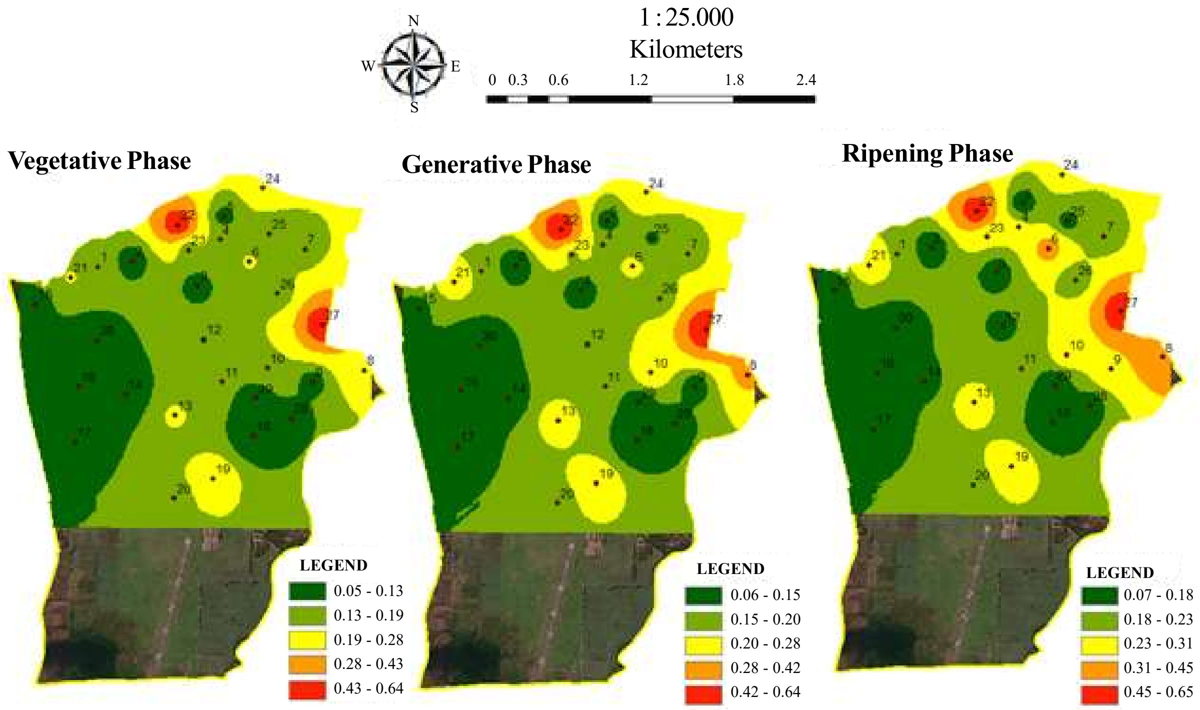

Figure 5. Interpolation of soil EC by development phase.

The results of the EC value based on the phase during one growing season showed that the EC values of the soil tended to increase. This increase was most likely related to higher rainfall at the ripening phase (November). The measurement of EC of the soil could increase with the abundance of soil water content (Zhou et al., 2015). These results indicate that the time of soil sampling can significantly affect the evaluation of soil properties, particularly soil EC (Lee et al., 2018). Overall, the EC value of the soil in Wirowongso Village was included in the non-saline soil type. The soil salinity value suitable for rice plants is < 2 dS m-1 (Peraturan Menteri Pertanian, 2013).

CONCLUSIONS

Soil pH in the study area are divided into four classes which are strong acid, moderate acid, slightly acidic, and neutral. The lowest soil pH value was 5.4 in the ripening phase, while the highest was 6.8 in the vegetative phase. There was an increase in soil pH value at six sample points and a decrease in soil pH value at five sample points. Most soil EC in Wirowongso Village was categorized as non-saline soil types. The lowest soil EC value was 0.05 in the vegetative phase, while the highest EC value was 0.65 in the ripening phase. Eight soil samples showed increased EC values, whereas only one showed a decreasing value. The results showed that IDW technique applied to soil properties (EC and pH) at different times, could be a valuable tool for exploring changes. The result certainly has consequences on soil management.

ACKNOWLEDGMENTS

The authors thank the Laboratory staff of Biology Study Program, Faculty of Teacher Training and Education, University of Jember for their assistance, and GAPOKTAN Wirowongso Village, Ajung District, Jember Regency, in providing land for this research.

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