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*by* Gerald Tamuntuan 19

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# The Spatial Variation of Magnetic Susceptibility on Agricultural Soil of Volcanic Origin in Rurukan, North Sulawesi

Gerald Tamuntuan[1, a)], Wiesje Kumolontang[2)], Guntur Pasau[1)], Seni H. Tongkukut[1)], Dini Fitriani[3)], Agnes T. Mandagi[4)], Hesky Kolibu[1)], Verna Suoth[1)], As'ari As'ari[1)], Handy Mosey[1)], and Adey Tanauma[1)]

[1]*Department of Physics, Sam Ratulangi University, Manado 95115, Indonesia*
[2]*Department of Soil Science, Sam Ratulangi University, Manado 95115, Indonesia*
[3]*Department of Geophysics, Universitas Padjadjaran, Jatinangor 45363, Indonesia*
[4]*Department of Civil Engineering, Sam Ratulangi University, Manado 95115, Indonesia*

[a)] Corresponding author: gtamuntuan@gmail.com



**Abstract.** Iron is one of the elements of soil fertility where it presented in an area is influenced by natural processes and anthropogenic activities. The existence of iron in soil tends to form iron-bearing minerals which have magnetic properties, making them easier to identify physically. In this study, measurements and mapping of magnetic susceptibility were carried out on 80 ha of agricultural land in the Rurukan volcanic area, North Sulawesi in order to obtain an overview of variations in iron concentration at the studied location. Analysis of soil organic carbon was also carried out for seeing its relationship with magnetic susceptibility. The results showed that the magnetic susceptibility values on surface soil at the studied locations varied between (417.67 ± 1.85) × $10^{-8}$ $m^3kg^{-1}$ to (1208.52 ± 1.85) × $10^{-8}$ $m^3kg^{-1}$ with about 68% of the data being in the interval of 593.01 × $10^{-8}$ $m^3kg^{-1}$ until 769 × $10^{-8}$ $m^3kg^{-1}$. Compared to other areas with the same soil source, Rurukan agricultural land has the same or relatively higher magnetic susceptibility value. Based on the distribution of magnetic susceptibility values, it is interpreted that the southern and eastern parts of the study area are zones with relatively high Fe content. Several spots with significantly different susceptibility values were thought to be due to the influence of iron and C organic concentrations in the soil. In this case, the decrease in magnetic susceptibility was accompanied by an increase in the C organic content in the soil. The combination of topography and vegetation cover is thought to influence the susceptibility value at a point.

## INTRODUCTION

Recently, the rock magnetism method has been widely used to explain various conditions, phenomena, or processes that occur on the soil. The principle of this method is to study variations in magnetic properties that arise due to changes in the type of magnetic minerals, grain size, and concentration of magnetic minerals as implications of various processes in nature or due to anthropogenic activities [1]. A number of studies of magnetic properties in soils have been carried out, among others in relation to pollution [2, 3], delineating soil horizons [4], pedogenesis and soil-forming process [5], differentiating geological as well as lithological domains [6], and their use in agriculture [7, 8]. One of the parameters of the rock magnetism method that is commonly used since the measurement is relatively easy, fast, and non-destructive is magnetic susceptibility.

The Rurukan area, which is located in the eastern part of the city of Tomohon, North Sulawesi, is an area with fertile agricultural land. Besides being in a tropical area with relatively high humidity, weathering of volcanic material in this area has an impact on the formation of mineral-rich soil for various cultivated plants. One element that is an indicator of soil fertility is iron (Fe) [9]. This element is one of the essential micronutrients needed for plant growth and production [10], and is especially important in plant biochemical reactions in the photosynthesis process [9].

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Although the Rurukan area has been managed for a long time as agricultural land, studies on how the distribution of iron in topsoil spatially has never been carried out, even though this information is very useful for determining the clustering of agricultural crops which has strong implications for optimizing agricultural yields. Iron in the soil is generally found in the form of iron oxide minerals, iron oxyhydroxide, and other iron-bearing minerals that carry magnetic properties. In this study, investigations and spatial mapping of magnetic susceptibility values on agricultural land in the Rurukan area were carried out in order to obtain an overview of the distribution of magnetic properties associated with iron content in the soil.

## MATERIALS AND METHODS

The research was conducted in an area of about 80 ha in the Rurukan area of Tomohon City, North Sulawesi. This area is a horticultural area located on the slopes of Mount Mahawu which is part of the Tondano Volcano System. Figure. 1 shows a location map and 180 data collection points. Magnetic susceptibility measurement was carried out using a magnetic susceptibility meter MS3 equipped with a 2B sensor. Samples were measured at a frequency of 470 Hz to obtain a low-frequency magnetic susceptibility ($\chi_{LF}$) and at a frequency of 4700 Hz to obtain a high-frequency magnetic susceptibility value ($\chi_{LF}$). The magnetic susceptibility data were then interpolated and mapped using Quantum GIS 3.16 to obtain a spatial description of the magnetic susceptibility distribution. The concentration of magnetic minerals in the superparamagnetic (SP) domain is calculated by the equation [11]:

$$\chi_{FD} = \frac{(\chi_{LF} - \chi_{HF})}{\chi_{LF}} \times 100\%$$

Measurement and analysis of soil organic carbon (SOC) were also carried out on 15 selected samples. In addition to obtaining an overview of soil quality, SOC was paired with magnetic susceptibility to see the correlation of the two parameters. The procedure for determining the SOC value uses the standard method from Walkley and Black as in previous studies [12].

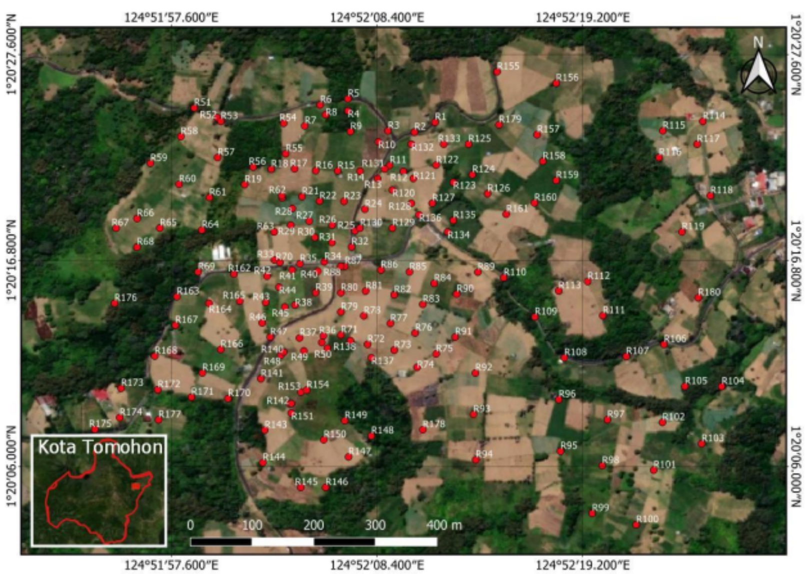


**FIGURE 1.** Research location and sampling points.

## RESULTS AND DISCUSSIONS

Figure. 2a shows the results of $\chi_{LF}$ measurements that varied between (417.67 ± 1.85) × $10^{-8}$ $m^3kg^{-1}$ to (1208.52 ± 1.85) × $10^{-8}$ $m^3kg^{-1}$. The highest frequency distribution of $\chi_{LF}$ values was in the interval 681.01 × $10^{-8}$ $m^3kg^{-1}$ to 769 × $10^{-8}$ $m^3kg^{-1}$, i.e. 68 data or 37.78% of the total data, followed by the interval 593.01 × $10^{-8}$ $m^3kg^{-1}$ to 681 × $10^{-8}$ $m^3kg^{-1}$ covering 30% of the data (Figure. 2b). About 22.22% of the data had a magnetic susceptibility value of more than 769 × $10^{-8}$ $m^3kg^{-1}$, while 10% of the data had a value equal to or less than 593 × $10^{-8}$ $m^3kg^{-1}$. The $\chi_{LF}$ values for volcanic soils in Rurukan are relatively equivalent to volcanic soils in Lembang [4], higher than volcanic soils in Lampung [13], but lower than the Massif Central, France [14]. The difference in $\chi_{LF}$ values in various regions is thought to be caused by the source of the parent material and the level of the pedogenesis process.

The calculated frequency-dependent magnetic susceptibility ($\chi_{FD}$) values varied from 1.21% to 6.82% (Figure. 3), indicating that some samples had almost no SP particles, while some samples had sizeable SP particles. Variations in $\chi_{FD}$ values are strongly influenced by the concentration of SP minerals, namely magnetic minerals less than or equal to 30 nm, having a single domain, but are unstable because they do not have magnetic remanence. The higher the $\chi_{FD}$ value, the higher the SP mineral concentration in the sample, and vice versa. The Rurukan volcanic soil has an $\chi_{FD}$ value equivalent to that of the volcanic soil in Lembang [4], but lower than the lateritic soil in Southeast Sulawesi [5]. The level of SP concentration in the soil is closely related to the level of weathering [5]. The higher the weathering level, the higher the SP mineral concentration.



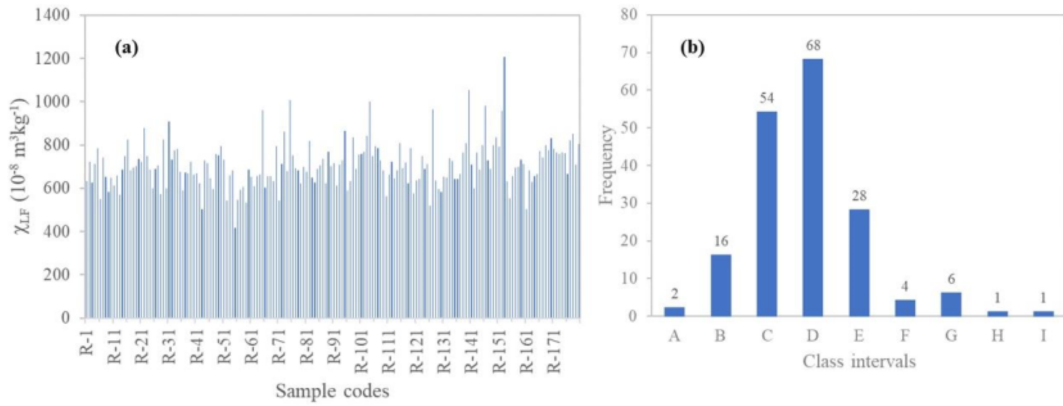


**FIGURE 2.** (a) Spectrum of magnetic susceptibility values in the Rurukan agricultural area, (b) Frequency distribution of magnetic susceptibility values. A = 417 – 505; B = 505.01 – 593; C = 593.01 – 681; D = 681.01 – 769; E = 769.01 – 857; F = 857.01 – 945; G = 945.01 – 1033; H = 1033.01 – 1121; I = 1121.01 – 1209. All values are multiplied by × $10^{-8}$ $m^3kg^{-1}$.

Figure. 4 demonstrates the spatial variation of magnetic susceptibility values from the study site. Spatially the location is dominated by the distribution of magnetic susceptibility with values of around 600 × $10^{-8}$ $m^3kg^{-1}$ to 800 × $10^{-8}$ $m^3kg^{-1}$. Magnetic susceptibility values are positively correlated with Fe content [15], so it can be said that the southern and eastern parts of the study area are zones with relatively high iron or iron oxide content.

Several spots in Figure. 4 appear to have magnetic susceptibility values in the minimum range, especially in areas that are relatively covered with vegetation. This is presumably because the soil in the area contains relatively higher organic matter or lower concentrations of ferrimagnetic minerals. Several other spots in open areas, areas that are often cultivated for agriculture, have magnetic susceptibility values in the maximum range (more than 900 × $10^{-8}$ $m^3kg^{-1}$). Identification in the field that the spot is located on a certain slope area whose lower part is bordered by a vegetated area. It is suspected that during the rainy season, magnetic material which usually has a higher density erodes and is deposited in the spot, but lighter non-magnetic materials are carried away by the flow of water and deposited at a lower level. This shows that the combination of topographic conditions and vegetation cover can affect the magnetic properties of the surface soil.

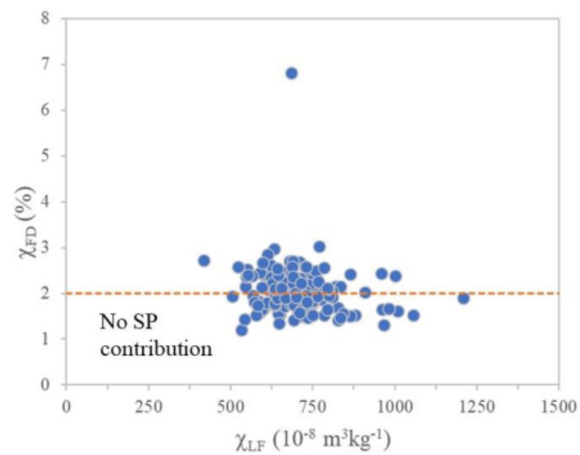


**FIGURE 3.** The $\chi_{FD}$ versus $\chi_{LF}$ plots show the relatively low contribution of superparamagnetic particles to the magnetic properties of the Rurukan agricultural soil.

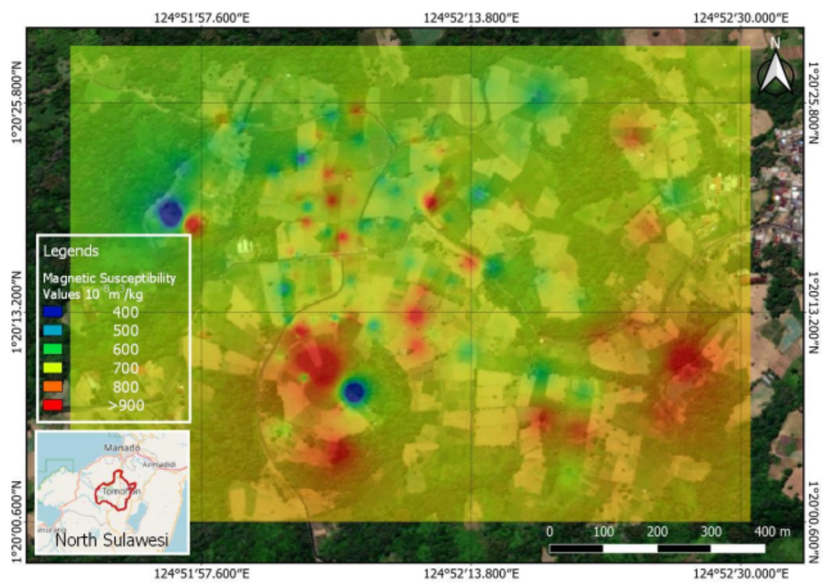


**FIGURE 4.** Spatial mapping of magnetic susceptibility in the Rurukan area. The red area is the zone with high susceptibility value, while the blue area is the zone with low magnetic susceptibility value.

Organic carbon is an element that determines the level of soil fertility. The results of soil chemical analysis on 15 selected samples of Rurukan soil showed varying SOC values in the range of 1.85% to 2.99% or were in the low to moderate category. The low content of organic matter in agricultural soils is partly due to the intensive agricultural practice [16]. The study location is an agricultural area that is managed sustainably, tends to be open, so that it has an impact on the low organic carbon content.

Several previous studies have shown a different relationship between organic matter content in soil and magnetic susceptibility. There are studies that report a positive correlation between organic matter content and magnetic susceptibility [16], but others show the contrary [17]. Figure. 5 shows the relationship between magnetic susceptibility and SOC (or C organic content of the soil) in the Rurukan area. Although the correlation is less significant, it is clear that there is a negative correlation between magnetic susceptibility and C organic content in soil samples from Rurukan. This confirms that the value of magnetic susceptibility at the study site decreased relative to the increase in organic carbon content, a non-magnetic material, in the soil.

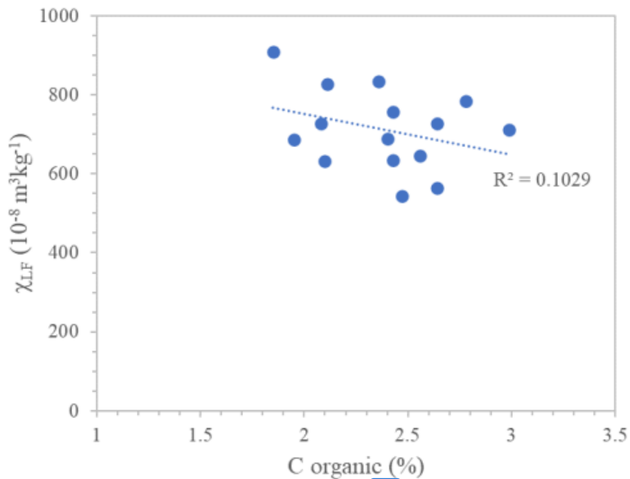


**FIGURE 5.** The relationship between magnetic susceptibility and C organic content of soil in the Rurukan area

## CONCLUSION

Agricultural soils in the Rurukan area which are generally formed from weathering of volcanic tuff have dominant magnetic susceptibility values ranging from 593.01 × $10^{-8}$ $m^3kg^{-1}$ to 769 × $10^{-8}$ $m^3kg^{-1}$ (covering about 68% of the data). The magnetic susceptibility values tend to be equivalent to areas that have the same parent material source and designation, but are relatively different when compared to areas that have different parent material sources, levels of pedogenesis, and intensity of soil management. Based on the frequency-dependent magnetic susceptibility value, the soil at the study site is still categorized as soil with a low level of weathering. Spatial mapping of magnetic susceptibility values which is associated with micronutrient Fe content was distributed relatively uniformly at the study site. However, the combination of topography and vegetation cover plays an important role in the presence of several spots with significantly different magnetic susceptibility values. The decrease in the value of magnetic susceptibility at several points is thought to be the result of an increase in the organic carbon content of the soil, which is a non-magnetic material. In the future, as a comparison, a study of magnetic susceptibility on non-agricultural volcanic soils in the area around Rurukan will be conducted, as well as a more detailed study of magnetic properties in relation to soil fertility.

## ACKNOWLEDGMENT

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