Determination of chemical elements that controlling magnetic susceptibility of cacao farming soil in Koting A Sikka Nusa Tenggara Timur

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Abstract. Koting A in Sikka is one of the most popular and productive agricultural cacao areas in Nusa Tenggara Timur. The area was selected in this study with the aim of understanding the soil magnetic properties that is suitable for cocoa farming. This study assessed the magnetic susceptibility and chemical element content of cocoa farms soils. Magnetic susceptibility was measured by Bartington MS2B on 72 samples taken from 8000 m² farming area, whereas the determination of chemical elements was done by XRF test on 3 representative samples. The results showed that the magnetic susceptibility of low frequency \( \chi_L \) has a range between \((12-20) \times 10^{-6} \text{m}^3\text{kg}^{-1}\) and the soils contains some dominant elements of Fe about 37%, Al 7 – 8%, Ca 11 -12%, Si 29-32%, Ti of about 2% and nickel 3 - 4%.

1. Introduction
In the last 10 years there have been many studies utilizing geophysical methods in agriculture application [1,2,3,4]. One of the most widely studies is in the soil physical properties especially of magnetic properties [5,6,7]. Research on the magnetic properties of agricultural soils has been widely used for various purposes such as mapping [5,6,7], magnetic properties testing on farms and distinguishing between agricultural land exposed to heavy metals and those not exposed to heavy metals [8] . In this paper, the measurement of magnetic properties on plantation land aims to: (1) study the magnetic properties of the plantation yard and (2) determine the standard of magnetic properties, especially for plantation soil and discuss about the element content and magnetic susceptibility of the soil samples taken from the Cocoa plantation, Sikka Nusa Tenggara Timur.

Cocoa (Theobroma cacao L) in Nusa Tenggara Timur is a smallholder plantation that dominates family income from the agricultural sector. Facts in the field show that cocoa in Sikka district is one of the best quality cocoa. The potential is very promising and each year can produce of about 7,880 tons.

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Related to the factors that affect the quality of agricultural production, research on physical properties of the soil would be very necessary. Several studies on the measurement of the magnetic susceptibility and morphology of magnetic mineral has been conducted in some region in the world and in Indonesia we have been measured on apple plantations using magnetic susceptibility, X-Ray Fluorescence and GPR [8,9,10]. In addition, measuring of magnetic susceptibility, magnetic mineral morphology and acidity of paddy farms areas were also carried out. In this research, we carried out the initial step of evaluating the magnetic properties of cocoa plantation land.

2. Sample Preparation
Small portion of soil samples from the Cocoa plantation in Koting A is taken at 9 points with an area of 8,000 m² that has a geographical coordinate of 08°66’20.55” S and longitude 122°20’31.60” E. To see the distribution pattern of the magnetic susceptibility of the plantation soil, sampling was taken from 3 point at the rear edge, 3 points in the center and 3 points on the front edge. At each point, we taken 8 samples with variation into a depth of 10 cm. At each point obtained 8 samples so that the total sample obtained is 72 samples. The samples were subsequently prepared in the Central laboratory Universitas Negeri Malang, for magnetic susceptibility measurements using MS2B Bartington Susceptibility meter and the determination of elemental content conducted using X-ray Fluoroscenes (XRF) [9,10]. Determination of soil element content was conducted on three representative samples that selected based on the highest, medium and lowest of magnetic susceptibility.

3. Results and Discussion
The magnetic susceptibility measurement is obtained magnetic susceptibility low frequency $\chi_{lf}$ and high frequency $\chi_{hf}$ and from the two of data, we calculate the magnetic susceptibility frequency dependent $\chi_{fd}$. The $\chi_{lf}$ are in the range of $12.03 - 19.64 \times 10^{-6} \text{m}^3\text{kg}^{-1}$, and $\chi_{fd}$ in the range of 0.47% - 2.07%. Correlation of $\chi_{lf}$ and $\chi_{fd}$ shown in Fig.1., that can be seen the measurement of high and low frequency susceptibility has a high consistency, indicated by the correlation value, $R$ approaching 1. Previous research on apple plantation land done by Rizka in 2015 in Poncokusumo Malang has a range of values $\chi_{lf}$ $9.39 - 18.49 \times 10^{-6} \text{m}^3\text{kg}^{-1}$ with $\chi_{fd}$ of around 1.22% - 4.6%, while in Pujon Malang $\chi_{lf}$ 6.54 – 16.23 $\times 10^{-6} \text{m}^3\text{kg}^{-1}$ with $\chi_{fd}$ of around 1.59% - 5.38%. In addition, research conducted by Hanung 2017 on the area of paddy agricultural land in Madiun has values of $\chi_{lf}$ in the range 0.58 – 2.94 $\times 10^{-6} \text{m}^3\text{kg}^{-1}$ and $\chi_{fd}$ around 1.13 % - 2.86 %, while in Malang $\chi_{lf}$ was in the range of $0.86 - 2.1 \times 10^{-6} \text{m}^3\text{kg}^{-1}$ and $\chi_{fd}$ of around 1.51% - 1.55 %.

![Figure 1](image-url)  
*Figure 1. Correlation of Magnetic susceptibility Low Frequency $\chi_{lf}$ and Magnetic susceptibility high frequency $\chi_{hf}$ of Samples from Sikka Nusa Tenggara Timur.*
Based on the measurement results and compare to the previous research, we can conclude that the value of $\chi_{lf}$ for the cocoa plantation area is greater than that of apple and paddy farming areas in Java in particular in Malang and Madiun. Comparison of susceptibility frequency dependent, also indicates that cocoa farming areas have the smallest range. Some of samples has a percentage of $\chi_{ld}$ more than 2% that represent the presence of fine-sized magnetic minerals of ferrimagnetic with small concentrations, but the domination is still multidomain (MD) minerals [11]. Distribution of domains magnetic mineral on Cocoa farms is described in Fig. 2 and correlation between the value of magnetic susceptibility low frequency $\chi_{lf}$ with magnetic susceptibility frequency dependent $\chi_{ld}$ for the three representative samples that shows increasing of $\chi_{lf}$ will decreasing of $\chi_{ld}$ shown in Fig.3. XRF test obtained, indicating some elements are heavy metal elements in cocoa plantation. The heavy metal elements contained in the cocoa plantation land are Fe, Zn, Cu, Ni, Cr, Al Mn, Ti and Sn with percentages shown in Table 1.

Sample T3.6 which has a value of $\chi_{lf}$ about $12.03 \times 10^{-6} \text{m}^3/\text{kg}$ and XRF test (in Table 1), contains Fe element 37.1% and Ti element is 2.08%. Based on the method developed by Dearing (1999) which detected of Fe and Ti elements in the sample may contain Titanomagnetite minerals, and Ilmenite [11], [12]. Samples T3.6 are also possible to have other types of minerals such as Epidote because of Al elements of 8.1%, Ca element of 11.0% and Si element of 32.8%. Other possible magnetic minerals contained in the sample are also Ilkite which is supported by XRF test which shows a K element content of about 1.87%.

Sample T4.1 has a susceptibility value of about $19.64 \times 10^{-6} \text{m}^3/\text{kg}$ and XRF test show that contains Fe element 37.2% and Ti element of 2.18% also similar to the T3.6 which may contribute by Titanomagnetite and Ilmenite minerals.

![Figure 2](image-url)

**Figure 2.** Distribution of $\chi_{lf}$ and $\chi_{ld}$ in Cocoa plantation area Koting A, Sikka Nusa Tenggara Timur
Figure 3. $\chi_{fd}$ and $\chi_{ld}$ correlation of soil in Cocoa plantation area of Koting A, Sikka

Table 1. Magnetic susceptibility and element contain of three representative sample of soil in Cocoa plantation Koting A, Sikka

| #ID  | $\chi_{ld}$ (10^-6 m^3/kg) | Al  | Si  | Ca  | Ti  | Cr  | Mn  | Fe  | Ni  | Cu  | Zn  |
|------|----------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| T3.6 | 12.03                      | 8.1 | 32.8| 11.0| 2.08| 0.09| 0.96| 37.1| 3.53| 0.59| 0.25|
| T4.1 | 19.64                      | 7.9 | 30.3| 12.1| 2.18| 0.09| 0.88| 37.2| 3.28| 0.49| 0.26|
| T9.3 | 15.46                      | 7.2 | 29.0| 12.6| 2.07| 0.09| 1.0 | 38.3| 4.05| 0.60| 0.29|

T4.1 also possible to have other types of minerals such as Epidote because of contain of Al elements of about 7.9%, Ca element of 12.1% and Si element of 30.3%. Other possible magnetic minerals contained in the sample are Illite, which is supported by XRF test that showing the content of K elements of 1.79% and Al elements of 7.9%. Similar to the two of samples above, the mineral contained the T9.3 sample are also possible for Titanomagnetite, Ilmenite, Epidote and Illite. From the three measurable samples of XRF, it can be seen that the elemental content of Cocoa soil in Sikka looks consistent. As the consistency of measured magnetic susceptibility values, consistency of this elemental content can be used as a finger print for the cocoa plantation soil [13,14,15].

4. Conclusion
The magnetic susceptibility of the cocoa plantation soil in Sikka shows that the value tends to be higher compared to the land of apple plantation and paddy farm soil in Malang and Madiun of East Java. Magnetic mineral in cocoa plantation of Sikka is dominated by multidomain (MD) minerals. From the three representative of samples that measured of chemical elements content, shows that the higher of magnetic susceptibility of low frequency correlate to smaller of the frequency dependent magnetic susceptibility. This also means that the higher of magnetic susceptibility frequency dependent, the smaller the magnetic mineral grain size. Based on the analysis of magnetic susceptibility and XRF data, it can be assumed that the magnetic mineral content are Titanomagnetite, Ilmenite, Epidote and Illite and the key elements that controlled the magnetic susceptibility are iron (Fe), Titanium (Ti) and Silicate (Si).
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