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# RELATIONSHIP BETWEEN ALLOPHANE WITH LABILE CARBON AND NITROGEN FRACTIONS OF SOIL IN ORGANIC AND CONVENTIONAL VEGETABLE FARMING SYSTEMS

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*Abstract.* Allophane is a characteristic of Andisols whose presence can absorb soil organic matter. One of soil organic matter fractions called the "labile fraction" is currently an appropriate indicator in determining soil quality. However, there is limited information concerning the relationship between allophane and the labile fraction. This study assessed the content of allophane by selective dissolution methods and calculated the labile fraction of particulate organic matter and microbial activity related to the carbon (C) and nitrogen (N) soil cycles in organic and conventional vegetable farming systems of two depths (0–25 cm and 25–50 cm). The content of the labile fractions of C and N in organic farming systems is higher than in conventional farming systems, which is also higher in the upper layer compared to the lower layer. However, the availability of allophane in the upper layer and organic system tends to be low. Therefore, allophane has a strong negative correlation with the labile fractions of carbon and nitrogen. The results of this study estimate that phosphorus (P) sorption is higher in soils containing quite high allophane. Hence, an organic farming system that has low allophane content will result in higher P availability for plants.

**Keywords:** allophane, labile fraction, farming system, organic, conventional

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## INTRODUCTION

Many conventional vegetable farming lands are turning to organic farming in these recent years. This change started from the excessive application of fertilizers, inorganic plant growth regulator (PGR), and pesticides that cause damage to the soil, the environment, and yields (Giles 2005). Thus, organic farming can be an alternative to prevent the use of synthetic inputs and restore soil quality and health (Stockdale *et al.* 2000). High market demand for organic vegetables due to competitive prices and healthy lifestyles has become a new trend leaving old patterns of life that use chemicals, such as fertilizers and pesticides. This phenomenon is considered beneficial for farmers.

In general, vegetable cultivation is centered in mountainous land with high fertility and low temperatures (<25°C), which are dominated by Andisols (Kumari *et al.* 2017). Andisols have the chemical, physical, and morphological properties that are closely related to the formation of short-range-order minerals (mainly allophane, ferrihydrite, imogolite) and Al/Fe – humus complexes (Takahashi and Dahlgren 2015). Andisols in the tropical area, such as in Indonesia, tend to have high organic matter content of around 20% (Harsh 2005). The high amount of organic matter is due to the high concentration of the organic Al complex that inhibits microbial activity to decompose soil organic matter. Even though organic material is maintained in the soil, due to high demand and crop productivity, the soil is easily leached, thereby exaggerating the depletion of decaying mineral material in the soil (Takahashi and Dahlgren 2015). The farmers in Southeast Asian countries have understood the situation as trying to combine the use of organic fertilizers with inorganic fertilizers. However, the application of manure is still too excessive, reaching around 15 to 70 $tons.ha^{-1}$ per planting season (Sharifi *et al.* 2007).

Soil organic matter is considered as the basis of the productivity of an organically managed farming system, but for farmers, there are still few indicators to evaluate the soil organic matter and soil fertility status (Marriot and Wander 2006). Short-term changes in soil organic matter are difficult to detect, so they are divided into groups of different turnover rates called "labile fraction". The labile fraction of soil in the form of particulate organic matter (POM) has a rate of change from months to several years, consisting of the results of the decomposition of some plant and animal residues, thereby providing a source of energy for microorganisms (Haynes 2005). Particulate Organic Matter Carbon (POMC) and Particulate Organic Matter Nitrogen (POMN), when correlated with input of plant residues that have just been added, will be an exact predictor of the potential presence of microbes in conventional farming systems, legume-based organics, and organic-based manure (Willson *et al.* 2001). The addition of organic matter amendment is likely to change the labile fraction faster than soil organic matter, according to the results by Fortuna *et al.* (2003) who found that the management of a farming system that only relied on compost had a 44% more POMC content than the farming system that used chemical fertilizers after four years of soil management.

However, there is still limited information about the potential of labile C and N fractions in tropical volcanic soils that are managed conventionally and organically. Meanwhile, this soil tends to be rich in organic matter strongly bound to Andisol minerals (Sharifi *et al.* 2007). In addition to the strong binding effect between Al/Fe-humus, the soil organic matter fraction of microbes contributed substantially to the gathering place of the soil organic matter in Andisols (Buurman *et al.* 2007). The labile soil fraction responds quickly to changes in land use and soil management (Lehmann *et al.* 2001) and becomes a significant indicator of changes in soil organic matter (Willson *et al.* 2001). The soil depth also determines the distribution of the labile soil fractions, considering their size that reaches 53–250 μm (Salas *et al.* 2003) so that they are not only distributed on the ground surface. Yet, some studies only use the top layer to see the responses of labile fractions to soil management and changes in land-use systems (Li *et al.* 2018).

There is also limited information on the relationship between allophane minerals with the labile fractions of carbon and soil nitrogen. Saggar *et al.* (1994) showed that the labile fractions of microbial biomass would be high in soils containing high allophane (±13%) and less in soils with low allophane content (<2%). However, another study stated that incubation of volcanic soil for six days with the addition of allophane treatment showed that the availability of labile soil organic matter decreased along with the high addition of allophane content (Zakharova *et al.* 2015). Therefore, this study aimed to examine the relationship between allophane minerals with the presence of labile fractions of C and N and the soil physical-chemical properties in different farming systems using two Andisol depths.

## MATERIALS AND METHODS

### *Soil sampling and soil analysis*

The research was conducted in Semarang for organic farming systems (OF) and conventional farming systems with low organic material inputs (CL) and then in Magelang for conventional farming systems with high organic material input (CH). Each farming system was represented by three adjacent fields that were randomly selected. The altitude of the OF, CH, and CL farming system was ±1,402, 1,346, and 1,378 m.a.s.l. with an average temperature of ±23.3°C, 21.5°C, and 24.8°C, respectively. Actual temperature was based on observations at the study site during the day in July 2019. These data was taken with an average of three adjacent fields in each farming system.

In the OF farming system, farmers applied 10 $tons.ha^{-1}$ cow manure and 20 $lt.ha^{-1}$ liquid fertilizer, and the crop residues at each planting period. In the CH farming system, farmers applied 7 $tons.ha^{-1}$ cow manure, 50 $kg.ha^{-1}$ urea, 50 $kg.ha^{-1}$ NPK fertilizer and 15 $lt.ha^{-1}$ liquid fertilizer, while in the CL farming system, farmers applied 3 $tons.ha^{-1}$ chicken fertilizer, 50 $kg.ha^{-1}$ ZA fertilizer, 50 $kg.ha^{-1}$KCl fertilizer, and 50 $kg.ha^{-1}$ NPK fertilizer. The three farming systems used the intercropping system, manual tillage, and almost the same commodities, including cabbage, broccoli, beans, chili, scallion, lotus, bok choy, tobacco, and lettuce.

Soil samples were collected at the depths of 0–25 and 25–50 cm. Composite samples were divided into three parts. The first part, the samples passing <0.5 mm-filter, was analyzed for the soil chemical properties (pH $H_2O$, pH NaF, soil organic carbon, cation exchange capacity, total nitrogen, humic acid, and fulvic acid) and clay fraction of Fe, Al, and Si with three selective dissolution methods (Blakemore *et al*. 1987). The second part, the samples passing <2 mm-filter, was used for soil physical analysis (bulk density and soil texture). Meanwhile, the third part, the samples passing <250 µm-filter, was used for the analysis of the labile fraction of carbon and nitrogen. Meanwhile, organic carbon matter was determined using the dry combustion method (muffle furnace), and pH ($H_2O$ and NaF) was determined with a ratio of 1:5. The cation exchange capacity (CEC) was determined with 1 M $NH_4Cl$, total nitrogen was analyzed using the Kjeldahl method, and humic acid and fulvic acid were extracted with NaOH 0.1 mol. $L^{-1}$. The clay fractions of Fe, Al, and Si were analyzed using three selective dissolution methods, which were Dithionite citrate bicarbonate, $NH_4^+$-oxalate pH 3, and $Na^+$-pyrophosphate. Ammonium oxalate extracts the nanocrystalline (amorphous) in the inorganic form, which are $Al_o$, $Fe_o$, and $Si_o$. Dithionite citrate bicarbonate (DCB) extracts $Al_d$ and $Fe_d$ that represent fine minerals in the form of almost being crystalline, and Sodium pyrophosphate represents organic complexes in the form of $Al_p$, $Si_p$, and $Fe_p$. All extractions were calculated by using Atomic Absorption Spectrophotometry.

The amount of allophane was calculated using three selective solutions by extracting Al, Si, and Fe (Van Ranst *et al.* 2004). The amount of Si extracted with ammonium oxalate ($Si_o$) was converted to calculate the percentage of allophane by the following formula:

$$\%\ \text{allophane} = \%\ Si_o \times (100/y) \qquad (1)$$

The value of *y* is the amount of Si contained in allophane. The equation is y = 23.4 – 5.1x, in which $x = (Al_o - Al_p)/Si_o$. The calculation of allophane + imogolite was performed using the formula by Parfitt and Henmi (1982):

$$\%\ \text{allophane + imogolite} = \%Si_o \times 7.1 \qquad (2)$$

The calculation of imogolite is as follow:

Imogolite = equation (2) – equation (1) (3)

Meanwhile, ferrihydrite was calculated using the formula by Van Ranst *et al.* (2004):

$$\% \text{ ferrihydrite} = 1.7 \times Fe_o \quad (4)$$

Total amorphous materials can be calculated using the following formula:

total amorphous material = allophane + imogolite + ferrihydrite (5)

The labile carbon and nitrogen fractions consist of particulate organic matter carbon (POMC), particulate organic matter nitrogen (POMN) that were determined using the wet sieving technique through a 250-µm filter which was held by a 53-µm filter (Cambardella and Elliott 1992), microbial biomass carbon (MBC), and microbial biomass nitrogen (MBN) that were determined using chloroform fumigation incubation method (Okore *et al.* 2007).

*Statistical analysis*

Data collected were analyzed with analysis of variance using GenStat statistical software to determine the treatments that had a significant effect on the observed variables. Data showing significant effects between treatments were then tested using the least significant difference (LSD) test to determine the different treatments. The relationship between parameters was determined using Pearson's correlation analysis.

## RESULTS AND DISCUSSION

*Composition of amorphous from soil fractions*

The results of the study explained that the CL farming system showed the highest extraction of $NH_4^+$-oxalate compared to OF and CH farming systems (Table 1). The average $Al_o$, $Fe_o$, and $Si_o$ content in all farming systems and depths was 2.81 to 4.03% (high–very high), 1.59 to 2.13% (high–very high), and 1.52 to 3.06% (very high), respectively. Ammonium oxalate extraction is used to determine the content of amorphous materials in the soil (Parfitt 2009). The highest $Na^+$-pyrophosphate extraction was observed in OF farming systems. The average $Al_p$, $Fe_p$, and $Si_p$ content in all farming systems and depths

Table 1. The content of Al, Si and Fe in the clay fraction from different farming system*

| Vegetables farming | $Al_o$ | $Fe_o$ | $Si_o$ | $Al_p$ | $Fe_p$ | $Si_p$ | $Al_d$ | $Fe_d$ |
|---|---|---|---|---|---|---|---|---|
| | (%) | | | | | | | |
| OF farming system | | | | | | | | |
| 0–25 cm | 2.81 | 1.76 | 2.57 | 0.48 | 0.11 | 0.60 | 0.52 | 0.19 |
| 25–50 cm | 3.15 | 2.08 | 3.06 | 0.42 | 0.10 | 0.54 | 0.54 | 0.30 |
| Mean | 2.97±0.24a | 1.92±0.23a | 1.73±0.35b | 0.45±0.04a | 0.10±0.01a | 0.57±0.04a | 0.53±0.02b | 0.24±0.07b |
| CH farming system | | | | | | | | |
| 0–25 cm | 2.99 | 1.59 | 1.52 | 0.42 | 0.10 | 0.47 | 0.60 | 0.35 |
| 25–50 cm | 3.29 | 1.72 | 1.88 | 0.45 | 0.04 | 0.39 | 0.91 | 0.56 |
| Mean | 3.14±0.21a | 1.66±0.09a | 1.70±0.26b | 0.43±0.02a | 0.07±0.04a | 0.43±0.05ab | 0.76±0.22a | 0.46 ± 0.15a |
| CL farming system | | | | | | | | |
| 0–25 cm | 3.68 | 1.92 | 2.57 | 0.43 | 0.10 | 0.35 | 0.42 | 0.31 |
| 25–50 cm | 4.03 | 2.13 | 3.06 | 0.38 | 0.04 | 0.31 | 0.69 | 0.33 |
| Mean | 3.86±0.24a | 2.02±0.15a | 2.82±0.35a | 0.40±0.03a | 0.07±0.05a | 0.33±0.03b | 0.56±0.19ab | 0.32 ± 0.01ab |
| CV (%) | 17.7 | 19.7 | 15.1 | 17.4 | 79.3 | 23.9 | 23.1 | 39.5 |

a – oxalate extraction, b – pyrophosphate extraction, c – dithionite extraction

*means followed by the same letters in the same column are not significantly different according to LSD test at $p < 0.05$

was 0.38 to 0.48% (low–moderate), 0.04 to 0.11% (very low–low), and 0.31 to 0.60% (low), consecutively, explaining that the Al/Fe humus complex was absorbed higher in OF farming systems than CH and CL. Garcia-Rodeja *et al.* (2004) reported that Al/Fe from $Na^+$-pyrophosphate extraction came from the amorphous-organometal complex. The extraction of dithionate-citrate Al in the upper layer was 0.42 to 0.60% (low–moderate), while in the lower layer was 0.54 to 0.91 (moderate). Meanwhile, Fe extract from dithionate-citrate in the upper layer was 0.19 to 0.35% (very low) and in the lower layer was 0.30 to 0.56% (very low–low), in which the CH farming system showed higher value than OF and CL.

In general, the content of $Al_o$, $Fe_o$, and $Si_o$ increased with the soil depth. This result is comparable to the research of Bartoli *et al.* (2007), indicating that organic matter content supports the production of ligand complexes and blocks the production of amorphous materials. Table 2 shows the amorphous mineral content under different farming systems. In the upper layers of all farming systems, the content of allophane ranged from 10.29 to 15.18%, while in the lower layer, it ranged from 11.49 to 17.76%, indicating the upper layer absorbed organic matter higher than the lower layer (Takahashi and Dahlgren 2015). The content of imogolite in the upper layer ranged from 0.47 to 3.06%, while in the lower layer, it ranged from 1.29 to 3.98%. The ferrihydrite content in the upper layer was 2.71 to 3.26%, while in the lower layer was 2.92 to 3.63%, indicating the top layer tends to be slow in the process of crystallization to goethite and hematite minerals (Nanzyo 2002).

The presence of active forms of aluminum and iron, such as oxides, oxyhydroxides, short-order silicates (allophane, imogolite), Al/Fe humus complexes, are characteristic of volcanic soils. Phosphorus fixation by iron and aluminum oxide or allophane is a limiting factor for plant growth (Takahashi and Dahlgren 2015). The high phosphorus fixation by allophane or imogolite can be evidenced by a value of pH in NaF higher than 9.4 (Soil Survey Staff 2014). Table 5 shows that the pH value of NaF in all agricultural systems was more than 9.4, but the OF farming systems have a value of pH in NaF lower than CH and CL farming systems, so that the content of allophane tends to be low. Therefore, it can be estimated that phosphorus sorption will be lower in OF farming systems and result in higher P availability for plants. On the other hand, phosphorus uptake is expected to be low in OF farming systems may be related to low aluminum extracted oxalic acid, as reported by Garcia-Rodeja *et al.* (2004) and Van Ranst *et al.* (2004).

The total amorphous content ranged from 13.48 to 21.50% in the upper layer and 16.27 to 25.36% in the lower layer (Table 2), as reported by Nanzyo (2002). The total amorphous content in the upper layer tended to be lower because it was absorbed by organic matter. The $Al_p$ and $Fe_p$ values in the OF farming system were higher than in the CH and CL farming systems, indicating the high Al/Fe humus in the farming system (Table 1), as reported by Takahashi and Dahlgren (2015). Besides, the presence of allophane is often associated with the ability to form the Al/Fe humus complex, which can slow down microbial activity in decomposition (Chevallier *et al.* 2010) as evidenced by the extraction of Na-pyrophosphate. The Al/Fe humus complex in the OF farming system was higher, but it does not indicate that the soil is non-allophanic Andisols since the pH $H_2O$ ranged from 5.11 to 5.18 (Table 5). The same result was also reported by Rodriguez *et al.* (2006) in the Canary Islands, mentioning that non-allophanic Andisols under the moisture regime of udic soils would be formed at pH < 5, and allophenic Andisols would be formed at pH 5–7 (Nanzyo 2002).

Table 2. The content of short ring order minerals under different farming system*

| Vegetables farming | Allophane | Imogolite | Ferrihydrite | Total amorphous materials |
|---|---|---|---|---|
| | OF farming system | | | |
| 0–25 cm | 10.29 | 1.51 | 3.00 | 14.79 |
| 25–50 cm | 11.49 | 1.29 | 3.54 | 16.33 |
| Mean | 10.89±0.85b | 1.40±0.15a | 3.27±0.39a | 15.55±0.19a |
| | CH farming system | | | |
| 0–25 cm | 10.30 | 0.47 | 2.71 | 13.48 |
| 25–50 cm | 12.09 | 1.25 | 2.92 | 16.27 |
| Mean | 11.20±1.26b | 0.86±0.56a | 2.82±0.15a | 14.81±1.97a |
| | CL farming system | | | |
| 0–25 cm | 15.18 | 3.06 | 3.26 | 21.50 |
| 25–50 cm | 17.76 | 3.98 | 3.63 | 25.36 |
| Mean | 16.47±1.82a | 1.35±0.65a | 3.45±0.26a | 19.09±2.73b |
| CV (%) | 15.3 | 56.5 | 19.1 | 10.1 |

*means followed by the same letters in the same column are not significantly different according to LSD test at $p < 0.05$

*Labile carbon and nitrogen fractions of the soil in the vegetable farming system*

Soil samples were filtered using a 250-µm filter and held by 53-µm filter, passing fine-sized fractions (Salas *et al.* 2003). Particulate organic matter carbon (POMC) is a fraction that is easily changed due to the addition of decomposition results of plant residues with a half-life change in weeks to months (Lehmann *et al.* 2001). The farming systems had a significant effect on the POMC content (Table 3), showing the POMC content of 209.20 $mg.kg^{-1}$ (CL farming system) to 339.37 mg.kg$^{-1}$ (OF farming system) in the upper layer. This result indicates that POMC content between the CL and OF farming systems increased by 16%. Meanwhile, the POMC content in the lower layer ranged from 282.39 mg.kg$^{-1}$ (CL farming system) to 308.27 mg.kg$^{-1}$ (OF farming system), showing an increase in POMC content of 9%. POMC concentration in OF farming systems was higher due to the C input from manure and plant residues contributing soil POM. Likewise, Li *et al.* (2018) reported that the addition of livestock manure could significantly increase the POMC content and other labile fractions in the topsoil.

Table 3. Labile carbon and nitrogen fraction under different farming systems*

| Vegetables Farming | POMC | POMN | MBC | MBN |
|---|---|---|---|---|
| | ........................................ (mg.kg$^{-1}$) ………………………….. | | | |
| | | OF farming system | | |
| 0–25 cm | 354.81 | 509.74 | 472.62 | 976.22 |
| 25–50 cm | 299.09 | 499.44 | 397.28 | 781.93 |
| Mean | 326.95±39.40a | 434.95±53.27a | 504.59±7.28a | 879.07±137.38a |
| | | CH farming system | | |
| 0–25 cm | 324.92 | 373.47 | 303.93 | 553.12 |
| 25–50 cm | 297.80 | 342.54 | 238.71 | 552.23 |
| Mean | 311.36±19.18ab | 271.31±46.12b | 358.01±21.87b | 552.62±0.63b |
| | | CL farming system | | |
| 0–25 cm | 273.13 | 338.14 | 265.54 | 613.95 |
| 25–50 cm | 258.59 | 306.65 | 204.75 | 373.51 |
| Mean | 265.86±10.28b | 235.14±42.98b | 322.39±22.26b | 493.73±170.02b |
| CV (%) | 11.1 | 16.5 | 25.9 | 28.7 |

*means followed by the same letters in the same column are not significantly different according to LSD test at $p < 0.05$

Also, Poirier *et al.* (2013) concluded that the application of organic fertilizer was significantly able to increase the labile carbon fractions, either directly (to be arranged in labile organic C pools) or indirectly by increasing microbial activity in the form of labile organic carbon. The labile carbon fraction is directly related to the soil quality improvement, and it supports the formation of soil aggregates that can improve soil structure for better water infiltration and storage (Skjemstad *et al.* 2006).

Particulate organic matter nitrogen (POMN) not only includes the nitrogen in living organisms, but also large amounts of nitrogen in dead organic matter such as plant residues (Okore *et al.* 2007). The OF farming system had a significantly different effect on the POMN value compared to CH and CL farming systems (Table 3). The POMN content in the upper layer ranged from 338.14 mg.kg$^{-1}$ (CL farming system) to 509.74 mg.kg$^{-1}$ (OF farming system), showing a 51% increase. Meanwhile, the POMN content in the lower layer ranged from 306.65 mg.kg$^{-1}$ (CL farming system) to 499.44 mg.kg$^{-1}$ (OF farming system), showing an increase of 63%. This result is similar to the results by Gosling *et al.* (2013), reporting a 17% increase in POMN in the British organic farming system. In addition to the input of organic matter, another factor affecting the availability of the POMN fraction is clay content (Carter *et al.* 2003). The clay content in the CL farming system was higher than in OF and CH farming systems (Table 4). However, a different result was reported by Wang *et al.* (2003), mentioning that the content of labile organic matter would increase in soils containing high clay, while our results showed that labile fraction was more available in soils with low clay content.

Table 4. Physical properties of soils under different farming system*

| Vegetables farming | BD (g.cm$^{-3}$) | Silt | Sand | Clay | Texture Class |
|---|---|---|---|---|---|
| | | ………..………..... (%) ………….............. | | | |
| OF farming system | | | | | |
| 0–25 cm | 0.91 | 25.45 | 47.17 | 30.82 | Sandy Clay Loam |
| 25–50 cm | 0.93 | 23.34 | 53.30 | 27.13 | |
| Mean | 0.92±0.02a | 24.50±1.50a | 50.00±4.33a | 29.00±2.61a | |
| CH farming system | | | | | |
| 0–25 cm | 0.95 | 22.00 | 42.99 | 31.56 | Clay Loam |
| 25–50 cm | 1.03 | 19.57 | 40.89 | 35.77 | |
| Mean | 0.99±0.05b | 20.83±1.72a | 42.00±1.48a | 33.50±2.98a | |
| CL farming system | | | | | |
| 0–25 cm | 0.96 | 20.77 | 42.53 | 36.37 | Clay Loam |
| 25–50 cm | 1.09 | 21.86 | 38.29 | 39.85 | |
| Mean | 1.03±0.09b | 21.17±0.77a | 40.50±3.00a | 38.00±2.46a | |
| CV (%) | 1.9 | 54.8 | 15.9 | 40.2 | |

*means followed by the same letters in the same column are not significantly different according to LSD test at $p < 0.05$

Soil microbial biomass carbon (MBC) is a microbial activity that produces humic substances from the degradation of organic residual biopolymers (Tavares and Nahas 2014). The farming systems had a significant effect on MBC content. The content of MBC in the upper layers ranged from 265.54 mg.kg$^{-1}$ (CL farming system) to 472.62 mg.kg$^{-1}$ (OF farming system), and in the lower layers, it ranged from 204.75 mg. kg$^{-1}$ to 397.28 mg. kg$^{-1}$, showing an increase of 78% (upper layer) and 94% (lower layer) (Table 3). The top layer (0–25 cm) contains

Table 5. Chemical and physical properties of soils under different farming systems*

| Vegetables farming | pH $H_2O$ | pH NaF | SOC | Tot-N | HA | FA | CEC | C/N |
|---|---|---|---|---|---|---|---|---|
| | | | ……….................. (%) …..........………......… | | | | (cmol.kg$^{-1}$) | |
| | | | OF farming system | | | | | |
| 0–25 cm | 5.11 | 10.80 | 6.55 | 0.38 | 0.45 | 0.44 | 24.80 | 16.88 |
| 25–50 cm | 5.18 | 10.82 | 6.34 | 0.40 | 0.31 | 0.28 | 23.42 | 17.23 |
| Mean | 5.15±0.09a | 10.81±0.02a | 6.44±0.04a | 0.39±0.01a | 0.88±0.10a | 0.61±0.12a | 24.11±0.98a | 17.06±0.24a |
| | | | CH farming system | | | | | |
| 0–25 cm | 5.34 | 10.96 | 5.86 | 0.36 | 0.53 | 0.53 | 22.57 | 16.47 |
| 25–50 cm | 5.28 | 10.96 | 5.09 | 0.39 | 0.39 | 0.49 | 21.47 | 13.32 |
| Mean | 5.31±0.04ab | 10.95±0.00b | 5.48±0.54b | 0.37±0.02a | 0.46±0.10a | 0.52±0.03a | 22.02±0.78b | 14.90±2.23ab |
| | | | CL farming system | | | | | |
| 0–25 cm | 5.43 | 10.98 | 4.20 | 0.34 | 0.95 | 0.63 | 20.24 | 12.27 |
| 25–50 cm | 5.49 | 11.00 | 4.14 | 0.37 | 0.82 | 0.57 | 19.39 | 11.47 |
| Mean | 5.46±0.04b | 10.98±0.02b | 4.17±0.15c | 0.35±0.02a | 0.38±0.09a | 0.36±0.04a | 19.81±0.60c | 11.87±0.56b |
| CV (%) | 4.5 | 0.3 | 7 | 17.2 | 59.6 | 31.4 | 5.9 | 14.9 |

*means followed by the same letters in the same column are not significantly different according to LSD test at $p < 0.05$

a lot of MBC because the upper layer has high organic C content (Table 5). As reported by Melero *et al.* (2011), such conditions favor microbes to decompose organic matter and produce enzymes that can increase the labile carbon fraction of the soil. The use of organic material in OF farming systems, in the long run, will increase the MBC fraction by 30–40% compared to conventional farming systems (Marriot and Wander 2006). In addition, according to Furtak and Gałązka (2019), the use of organic farming systems had a positive impact on the structure of microorganism communities and soil biological activities.

Although soil microbial biomass represents a few percent of the total soil organic C and N, it can play an important role in the C and N cycling, because of fast turnover (Li *et al*. 2018). The farming system significantly affected the MBC content, showing a value ranging from 613.95 mg.kg$^{-1}$ (CL farming system) to 976.22 mg.kg$^{-1}$ (OF farming system) in the upper layer and 373.51 mg.kg$^{-1}$to 781.93 mg.kg$^{-1}$ in the lower layer (Table 3). Likewise, Lehmann *et al.* (2001) mention that the topsoil contains a lot of MBN, indicating the accumulation of organic C that will be used as an energy source for soil microbes. The MBC content in CL farming systems is lower than OF and CH because, according to Six *et al*. (1999), the slow decomposition of plant residues at the soil surface in conventional farming systems and without tillage is caused by low input of organic matter, thereby reducing microbial activity. Based on the observations of various labile fractions, it can be concluded that those variables can be used as indicators to determine the right soil quality due to differences in the use of vegetable farming systems in a short period, as has been conducted by Plaza-Bonilla *et al.* (2014).

*Effects of farming system on the soil physical and chemical properties*

The farming systems had a significant effect on the soil bulk density (Table 4) with values varying from 0.91 g.cm$^{-3}$ to 0.93 g.cm$^{-3}$ (OF farming system), from 0.95 g.cm$^{-3}$ to 1.03 g.cm$^{-3}$ (CH farming system), and from 0.96 g.cm$^{-3}$ to 1.09 g.cm$^{-3}$ (CL farming systems). These results are in contrast to the findings of Bartoli *et al.* (2007), who found that Andisol bulk density ranged from 0.33 to 0.85 g.cm$^{-3}$ in Europe. The OF farming system showed the lowest bulk density value due to the input of organic material and the absence of chemical fertilizers, as reported by Zhang *et al.* (2016), high organic fertilizer inputs significantly reduced the formation of large soil macroaggregates (>2 mm), thereby increasing soil pores. The bulk density value in the lower layer (25–50 cm) of all farming systems tended to be higher than in the top layer (0–25 cm), indicating the strength of the soil that is weak against pressure (Nanzyo 2002). The low bulk density value and the high macro-pores of the top layer (0–30 cm) provide a good medium for penetration of the roots of vegetable plants where the root hair can elongate relatively freely in search of nutrients and water in the soil with good aeration (Msanya *et al.* 2016).

The soil at the study site had varied soil textures and was classified as sandy clay loam (OF farming system) and clay loam (CH and CL farming system) (Table 4). In general, according to Batjes (1995), the pH $H_2O$ is classified as strongly acidic between 4.0 to 5.5. In this study, the pH $H_2O$ of soils varied from 5.11 to 5.18 in the OF farming system, from 5.34 to 5.28 in the CH farming system and 5.43 to 5.46 in the CL farming system (Table 5). In the organic farming system, the acidity of the soil is suspected to be due to the humic and fulvic acids released by organic fertilizer and plant residues, while in the conventional systems, one of the causes is due to the application of urea and NPK fertilizers. These conditions, according to Gentili *et al.* (2018), cause the released nutrients to be low due to the optimal conditions for plants to absorb nutrients and for root growth, which is in the medium/sub-acid pH range (7–6). The pH value of NaF in this study ranged from 10.80 to 10.98 in the upper layer and 10.82 to 11.00 in the lower layer (Table 5). A pH of NaF $\geq$ 9.4 is a strong indicator that amorphous material dominates the soil exchange complex, and it shows the presence of allophane and non-allophane complexes (Soil Survey Staff 2014).

The content of soil organic carbon (SOC) in the soil was classified as very high in OF and CH farming systems, ranging between 6.34% to 6.55% and 5.09% to 5.86%, respectively (Table 5). Meanwhile, the SOC content in CL farming systems was classified as high, ranging from 4.14% to 4.20%. The total N content in all farming systems and depths was classified as moderate, ranging from 0.34% to 0.40%. The OF farming system showed a very high SOC content due to the considerable input of organic matter (manure and plant residues). This result is in accordance with the results by Nath *et al.* (2015). Meanwhile, the top layer had high SOC concentration due to the low levels of allophane concentration at the surface of the soil (Takahashi and Dahlgren 2015). The high increase in total organic carbon at the surface of the soil is also caused by the accumulation of organic material derived from root biomass (Nath *et al.* 2015).

Cation exchange capacity (CEC) in all farming systems and soil depths was categorized in the medium scale. The CEC values in the OF, CH, and CL farming systems were 23.42 to 24.80 $cmol.kg^{-1}$, 21.47 to 22.57 $cmol.kg^{-1}$, and 19.39 to 20.24 $cmol.kg^{-1}$, respectively (Table 5). This result proved that the CEC decreased with the increasing soil depth, likely due to higher organic matter to surface soil, which is similar to the results obtained by Adugna and Abegaz (2015). The C/N ratio in the upper layer ranged from 12.27 to 16.88 (moderate-high) and in the lower layer ranged from 11.47 to 17.23 (moderate-high). The higher C and N content in the upper layer is due to the high content of organic matter that is derived from the decomposition of plants and animal residues. In the lower layer, the level of organic C tends to decrease because the amount of accumulation of organic matter derived from root biomass and soil microorganisms is much less than in the upper layer (Nath *et al.* 2015).

The content of humic acid (HA) in all farming systems ranged from 0.45 to 0.63% in the upper layer and 0.31 to 0.39% in the lower layer (Table 5). The highest content was in the OF farming system, and the lowest was in the CL farming system (Table 4). The provision of high organic matter in OF farming systems is thought to cause high levels of humic acid in both the upper and lower layers, as reported by Zhang *et al.* (2017) who found that the application of manure could increase the content of SOC and HA in the soil. In addition, the content of humic acid also depends on the type of soil, in which the soils with relatively high organic C content will contain higher humic acid than mineral soils. Valladares *et al.* (2007) found that humic acid in Brazilian Histosol soils ranged from 12.5 $g.kg^{-1}$ to 208.4 $g.kg^{-1}$ when the organic C content was 38.0 $g.kg^{-1}$ to 528.1 $g.kg^{-1}$. The fulvic acid (FA) content in all farming systems ranged from 0.45 to 0.95% in the upper layer (0–25 cm) and from 0.31 to 0.82% in the lower layer (25–50 cm). The surface layer of the soil is larger due to the humification because the level of the air at the surface of the soil is greater (aerobic) than at the lower layer so that the development of soil biological activity is more intensive (Yang *et al*. 2013).

*Relationship between allophane, physical-chemical properties, and labile fractions in the OF, CH, and CL farming systems*

A negative and significant relationship between allophane and SOC ($r$ = –0.74**) in this study is similar to the result reported by Bartoli *et al.* (2007). This relationship indicates that the content of allophane influences the availability of SOC, which had previously been observed by Celik (2005) in a Turkish vegetable farm. High soil organic matter accumulation is a characteristic of Andisols (Parfitt 2009). Organic matter can be easily bound to the surface area of allophane to form an organo-mineral complex (Rumpel *et al.* 2012), which, in turn, will influence the microbial activity in decomposing soil organic matter. A negative and insignificant relationship occurred between allophane and MBC ($r$ = –0.63**) and MBN (r = –0.52*), as reported by Chevallier *et al.* (2010), showing the effect of allophane content on soil microbial biomass. In addition, other considerations that pH $H_2O$ is negatively correlated with MBC ($r$ = –0.50*) and MBN ($r = -0.39^{ns}$) are similar to the results of Takahashi *et al.* (2006), mentioning that the acidic farming systems cause low microbial activity, which then leads to the accumulation of soil humus compounds. There is a positive and significant correlation between SOC with MBC ($r$ = 0.70**) and MBN ($r$ = 0.58*) so that it can be concluded that the provision of organic matter inputs can still increase the content of soil microbial biomass in all farming systems, as reported by Li *et al.* (2018) who claimed that the use of organic or fertilizer combined manure-mineral fertilizer application significantly increased MBC concentrations compared to mineral fertilizers or the unfertilized control in a wheat-maize rotation system in the North China Plain.

Table 6. Correlation between allophane with labile fractions and physical-chemical properties in the different farming systems

| Variables | pH $H_2O$ | Clay | SOC | Fulvic | Humic | Allop | POMC | MBC | POMN |
|---|---|---|---|---|---|---|---|---|---|
| Clay | $0.44^{ns}$ | - | - | - | - | - | - | - | - |
| SOC | $-0.46^{ns}$ | $-0.22^{ns}$ | - | - | - | - | - | - | - |
| Fulvic | $-0.47^{ns}$ | $-0.31^{ns}$ | $0.49^{*}$ | - | - | - | - | - | - |
| Humic | $-0.24^{ns}$ | $-0.39^{ns}$ | $0.55^{*}$ | $0.44^{ns}$ | - | - | - | - | - |
| Allop | $0.33^{ns}$ | $0.05^{ns}$ | $-0.74^{**}$ | $-0.37^{ns}$ | $-0.53^{*}$ | - | - | - | - |
| POMC | $-0.44^{ns}$ | $-0.15^{ns}$ | $0.60^{**}$ | $0.24^{ns}$ | $0.57^{*}$ | $-0.50^{*}$ | - | - | - |
| MBC | $-0.50^{*}$ | $0.01^{ns}$ | $0.69^{**}$ | $0.45^{ns}$ | $0.23^{ns}$ | $-0.63^{**}$ | $0.42^{ns}$ | - | - |
| POMN | $-0.34^{ns}$ | $-0.26^{ns}$ | $0.77^{**}$ | $0.58^{*}$ | $0.54^{*}$ | $-0.58^{*}$ | $0.41^{ns}$ | $0.66^{**}$ | - |
| MBN | $-0.39^{ns}$ | $-0.16^{ns}$ | $0.58^{*}$ | $0.32^{ns}$ | $0.33^{ns}$ | $-0.52^{*}$ | $0.55^{*}$ | $0.70^{**}$ | $0.62^{**}$ |

* – $p < 0.05$; ** – $p < 0.01$; ns – non significant

A negative and significant relationship was observed between allophane with POMC ($r$ = –0.50*) and POMN ($r$ = –0.58*), indicating that allophane formation would be inhibited by the presence of labile fractions with a particulate size of 53–250 µm. This result is presumably because allophane, with a high absorption surface area, absorbs strong organic material both from the soil and compost input (Parfitt 2009). Particulate organic matter (POM) is part of soil organic matter with a size of 53–250 µm so that there is a positive and significant relationship between SOC with POMC ($r$ = 0.60**) and POMN ($r$ = 0.77**). Accordingly, the labile fraction can be one of the factors determining the presence of allophane. A negative and significant relationship also occurred between allophane with MBC ($r$ = –0.63**) and MBN ($r$ = –0.52*) (Table 4). These results illustrate the impact of labile biological properties on allophane synthesis that can be used as a sentimental parameter for changes in farming systems. Likewise, Tavares and Nahas (2014) reported that the observation parameters of soil biological properties could be sensitive parameters to the soil ecosystem observations.

The negative and insignificant relationship between allophane and fulvic acid ($r = -0.37^{ns}$) is thought to be due to the functional group of fulvic acid interacting with allophane that has a positive charge from organo-minerals, which can bind the negative charge of fulvic acid (Takahashi and Dahlgren 2015). Meanwhile, allophane and humic acid have a negative and significant relationship ($r$ = –0.53*) because humic acid can reduce the formation of allophane minerals in various ways according to the distribution of molecular weight and acidic properties (Mora and Canales 1995). Besides, a positive and significant relationship between the availability of humic acid and SOC ($r$ = 0.55*) shows that humic acid is one of the stable organic carbon fractions (Haynes 2005).

## CONCLUSIONS

1. Farming systems have a significant effect on the soil physical (bulk density) and chemical pH ($H_2O$ and NaF), SOC, CEC, and C/N) properties as well as on the availability of labile carbon and nitrogen fractions of the soil (POMC, POMN, MBC, and MBN).
2. Allophane is negatively correlated with the labile carbon and nitrogen fractions of the soil. Soil organic carbon appears to play a major role in this correlation.
3. The results of this study can estimate that the phosphorus (P) sorption is higher in soils containing quite high allophane. Thus, organic farming systems that have low allophane content will result in higher availability of phosphorus for plants.

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