INTRODUCTION

The eruption of Mount Kelud (East Java) on 13 February 2014 was one in a long series of recorded eruptions and ash deposits with return times of 15-37 years (with ash deposits in intervening years as well): 1826, 1848, 1864, 1901, 1919, 1951, 1966, 1990 and a relatively minor event in 2007. Material of various particle sizes and density were expelled from the volcanic vent causing a lot of damage to agricultural lands on the lower slopes of the mountain. In the longer term, volcanic ash transforms into Andisols, known for good structure, soil organic C (C_{org}) concentrations of around 10% and soil fertility (Van Ranst, Utami, & Shamshuddin, 2002), but C_{org} has to build up from zero. Directly after the eruption the surface soil becomes dry as water infiltration is hampered by hydrophobic surface properties. Hairiah, Suprayogo, Apriyanti, Wahyudi, & Qhomariyah (2016) reported that the rate of soil infiltration slowed to an average of only 2.69 cm/hour compared to 10 cm/hour (compatible with the highest rainfall intensities during storm events) in locations free from volcanic ash. Ash deposition increases surface runoff and erosion during the rainy season so that the downstream water quality decreases, while the risk of drought conditions during dry spells increases, so that crop production declines. A common method for reducing overland flow in coffee gardens (monocultures

ARTICLE INFO

Keywords:
Coffee-based agroforestry
Decomposition
Half-life decomposition
Parasponia andersonii
Trema orientalis

Article History:
Received: November 1, 2018
Accepted: January 2, 2020

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ABSTRACT

Post eruption land reclamation consists of hoeing, mixing volcanic ash with soil, adding external organic and/or in-organic fertilizers and making infiltration-pits (‘rorak’). This study, after the 2014 eruption of Kelud volcano, aimed to evaluate: (a) soil physico-chemical fertility post eruption, (b) impact of organic inputs interacting with ash in infiltration pits on soil C and N underneath (1st experiment), (c) biomass loss (decomposition) of local biomass (Trema orientalis and Parasponia andersonii) in a coffee agroforestry system (2nd experiment). Measurements in the ash-affected (+Ash) Tulungrejo-village (Ngantang-Malang district) were contrasted with an area without recent ash deposits (-Ash) in Krisik ( Gandusari-Wlingi district). The 1st experiment (-Ash site) treatments did not lead to statistically significant influences on soil conditions just below the infiltration pits during 12 weeks of monitoring. The 2nd experiment quantified rate of biomass loss from litterbags. In +Ash location, litter half-life time (t_{50}) was 19.5 weeks for coffee or Parasponia as single biomass source to 24 weeks for Coffee+Sengon+Durian. In -Ash location decomposition was slower, with t_{50} of 24 weeks for Parasponia to 27 weeks for Coffee+Sengon+Durian biomass. Concentrations of soil NH_{4} and NO_{3} below the litterbags peaked between 4 to 8 weeks, with nitrification lagging behind on ammonium release.

ISSN: 0126-0537 Accredited First Grade by Ministry of Research, Technology and Higher Education of The Republic of Indonesia, Decree No: 30/E/KPT/2018

Cite this as: Ishaq, R. M., Saputra, D. D., Sari, R. R., Suprayogo, D., Widiyanto, Prayogo, C., & Hairiah, K. (2020). Turning volcanic ash into fertile soil: Farmers' options in coffee agroforestry after the 2014 Mount Kelud eruption. AGRIVITA Journal of Agricultural Science, 42(1), 78–91. https://doi.org/10.17503/agrivita.v42i1.2494
or simple agroforestry) is to make infiltration pits (‘rorak’) that increase infiltration and over time become organic matter rich patches of soil that stimulate root development (Young, 1989).

Earlier measurements by Hairiah, Suprayogo, Apriyanti, Wahyudi, & Qhomariyah (2016) indicated that volcanic ash from Mount Kelud is very acid with an average pH of 3.8 - 3.9, low sulphur (S) content at 0.21 mg/kg and low P availability (P-Bray 2) of 6.4 mg/kg. In general, the Cation Exchange Capacity (CEC) of volcanic ash is low, as is its soil organic matter content, increasing the risk of nutrient loss when fertilizer is applied. Kelud ash is similar to that of Mount Merapi (C. Java) which has a P content that varies between 1.6 - 47.3 P mg/kg, with S levels varying from 2 - 160 mg/kg, while the heavy metals contents Fe, Mn, Pb and Cd are below safety thresholds for cultivating agricultural crops (Rahayu et al., 2014).

In the direct aftermath of the eruption, forests, agroforestry systems and crops in the area were damaged by the heavy load of ash. Many crops and trees died, but part of the trees could recover after rain washed their canopies clean. Common land use systems around Mount Kelud include intensive (vegetable) agriculture, coffee agroforestry systems owned by farmers, and timber-based agroforestry owned by the Forest Agency (Perhutani), partly co-managed with farmers. The Mount Kelud eruption harmed coffee farmers because coffee bean production decreases significantly; IFRC (2014) reported that the eruption of Mount Kelud caused a financial loss of 1.2 trillion IDR with the biggest loss occurring in the agricultural sector of around 1.1 trillion IDR.

Farmers’ practice in post-eruption land reclamation consists of mixing volcanic ash with the mineral soil beneath it by hoeing and adding organic (chicken manure or crop residue) and inorganic (urea or NPK) fertilizers. However, the availability of manure or crop residues is very limited in the area; it must be purchased from surrounding areas (Blitar and Kediri), increasing production cost. Knowledge of suitability of locally available organic materials, not commonly utilized by farmers, might add options to the farmers menu of choice.

One of the most common pioneer plant species around Mount Kelud is Trema orientalis (Ind: anggrung merah) and its nodulated relative Parasponia andersonii (Ind: anggrung hijau) that, as only known plant outside the Leguminosae family, forms a symbiosis of its roots with Rhizobium bacteria able to fix N from the atmosphere (Becking, 1979; Op den Camp et al., 2012). Trema is a good provider of organic material because biomass production is fast: reaching 8.5 Mg/ha of dry weight at three years and 24.7 Mg/ha at five years of age (Styger, Fernandes, Rakotondramasy, & Rajaobelinarina, 2009). Based on commonly observed rapid organic matter decline in tropical soils of 8% per year the amount of biomass needed to maintain a C org content of 2% in the top 20 cm of soils is 8-10 Mg/ha/year (Young, 1989).

Improvement of soil fertility through the addition of plant biomass is determined by the amount and type of biomass added and its decomposition rate. Cadisch & Giller (1997) and Veen, Sundqvist, & Wardle (2015) stated that the decomposition rate of biomass and nutrient release (mineralization) is influenced by external factors (temperature, soil moisture, soil organism activity) and internal factors (the quality of biomass determined by the C/N ratio, lignin and polyphenol content). According to Palm & Sanchez (1991), rapid mineralization is expected when the added biomass is of ‘high quality’ with a C/N ratio < 25, lignin content < 15% and polyphenol < 3%. Low-quality plant biomass, however, is more useful to cover the soil surface so that the soil remains moist and does not compact under the influence of rainfall and direct exposure to the sun. As an information, in post eruption conditions, on litter decomposition rates of biomass of the pioneer trees Parasponia and Trema is not available, triggering this current research.

Aims of this study were to evaluate: (a) the impact of volcanic ash input on soil physico-chemical fertility, (b) the impact of land reclamation using local techniques on the soil C and total N content in coffee agroforestry system, (c) the rate of decomposition of various local organic materials (including Trema orientalis and Parasponia andersonii) in coffee agroforestry systems after volcanic eruption. Results of this study are discussed in terms of improving reclamation technology for coffee agroforestry systems.

MATERIALS AND METHODS

Location and Time of Experiment

The research activity was carried out in May-August 2017 (Experiment 1) and June-October
2018 (experiment 2) in simple coffee-based agroforestry land owned by farmers located in two villages: Tulung Rejo village (112°21′49″ - 112°22′28′6″E, 7°49′45″ - 7°56′03″S), sub-district Ngantang, Malang Regency in an area affected by the volcanic ash eruption of Mount Kelud and Krisik village (152°30′152 - 152°39′E, 7°66′- 8°98′S), sub-district Gandusari, Blitar Regency, that, due to the prevailing wind directions, remained free from volcanic ash in the 2014 event, even though it is close to the volcano.

The two villages have similar elevation (Tulung Rejo at 870 and Krisik at 656 - 818 m above sea level (m asl)) and climate, with annual rainfall around 3000 mm/year (Fig. 1). For Tulung Rejo data suggest on average 177 rainy days per year and an average temperature of 24.6-26.8°C (BPS Kabupaten Malang, 2016) and the mean average of rainfall of 3452 mm/year; in Krisik average rainfall is recorded as 3076 mm/year with 105 rainy days per year and an average air temperature of 22.4°C, ranging from 17-24°C (BPS Kabupaten Blitar, 2015).

**Land Characteristics**

Land characteristics were observed for three land use systems (LUS) existing in the landscape i.e. secondary (natural) forest (SF), multistrata (AFM) and simple (AFS) coffee-based agroforestry systems. The diameters at breast height (DBH) of all trees (with a DBH of > 5 cm) were measured in a 20 m x 20 m sized sub-plot, with species identified. Observations were enlarged to 100 m x 20 m when for large trees with DBH > 30 cm were noticed.

**Field Experiment 1: Ash and Organic Soil Amendment Impacts on Soil Underneath Infiltration Pits**

Field experiment 1 (May - August 2017) tested change in soil physico-chemical conditions in coffee agroforestry systems by adding various types of local plant biomass to freshly made ‘infiltration pits’ (locally known as rorak). The experiment was carried out in Krisik but included various levels of fresh volcanic ash (collected in Tulung Rejo) to get direct evidence of its possible effect on decomposition.

Two factors were tested: **Factor 1.** Additional amount of volcanic ash: 0 (control), 5, 10 and 15 (kg per 0.25 m², equivalent to 0 – 6 Mg/ha); **Factor 2,** type of organic material (OM) added: without OM (as control), chicken manure, biomass of coffee, *Trema* and *Parasponia*. Treatments were assigned in a factorial design with three replications (60 plots). In each plot, an infiltration pit with a depth of 20 cm and a surface area of 50 cm x 50 cm was dug in between coffee and companion trees (Fig. 2). Air-dried volcanic ash from Mount Kelud was added into the hole according to the specified dose, followed by applying organic matter equivalent to giving 200 kg N/ha. Soil samples were taken from the 0-10 cm layer beneath the hole (20-30 cm depth layer of the original profile) at 1, 2 and 3 months after the applications. Soil samples were analysed for C_{org} and N_{tot} concentrations.

![Fig. 1. Average monthly rainfall based on 1982-2012 measurement at Krisik and Tulung Rejo (BMKG), and data for 2014-2017 for the Selorejo climate station](image-url)
Field Experiment 2: Decomposition Rates of Various Plant Biomass Sources in a Coffee-Based Agroforestry System

A decomposition study was carried out from June - October 2018 in the same plot as used for field trial 1, in coffee-based agroforestry system in Krisik Village (-Ash), but also in Tulung Rejo Village (+Ash) for comparison. Decomposition rates were measured using the litterbag technique from TSBF (Anderson & Ingram, 1993), with litterbags of 30 cm x 30 cm x 3 cm and a 7 mm mesh size. Six types of biomass were tested: coffee pruning (K), Trema (T), Parasponia (P), mix K+T, mix K+P, and mix K+S (sengon)+D (Durian); litterbags were arranged according to a Completely Randomized Design (CRD), with repeated observations at 1, 2, 4, 8 and 16 weeks after application after litter bags were placed on the soil surface in a coffee agroforestry plot. At each time of observation, each treatment was taken 5 litter bags as a repeat measurement. The biomass remaining in the litter bag was rinsed to remove adhering soil, dried in an oven at 80°C (till constant weight) and weighed. The initial amount of biomass put into a litter bag was varied with N concentration and adjusted to be equivalent to 200 kg N/ha.

As part of experiment 2 soil temperature was measured once week at 15 cm below the soil surface close to the litterbags; measurements were done between 7 and 9 am.

Chemical Characteristics of Organic Matter Used

Chemical characteristics of the six types of organic material tested are presented in Table 1. All are classified as ‘Low’ quality litter source according to Palm & Sanchez (1991), leading to expectation of slow N release (Cornforth & Davis, 1968). The chemical properties of the pruned coffee biomass used here differed from the natural litterfall data presented in the previous measurement (Hairiah, Suprayogo, Apriyanti, Wahyudi, & Qhomariyah, 2016) by having a much lower C/N ratio, but also a much higher lignin and polyphenol content.
Table 1. Chemical composition of plant biomass (derived as prunings of fresh biomass) used in experiments

| Organic source | Total C | Total N | Lignin (L) | Polyphenol (P) | C/N | L/N | (L+P)/N |
|----------------|---------|---------|------------|---------------|-----|-----|---------|
| K = Coffee     | 31.9    | 4.4     | 28.9       | 14.3          | 7.2 | 6.5 | 9.8     |
| P = Parasponia | 31.0    | 3.3     | 21.4       | 11.8          | 9.3 | 6.4 | 9.9     |
| T = Trema      | 30.2    | 3.9     | 24.6       | 14.3          | 7.8 | 6.3 | 10.0    |
| K + P          | 31.9    | 3.5     | 22.5       | 12.9          | 9.0 | 6.4 | 10.0    |
| K + T          | 32.9    | 3.5     | 25.3       | 13.5          | 9.5 | 7.3 | 11.2    |
| K + S(engon) + D(urian) | 36.6 | 6.5 | 32.6 | 14.2 | 5.6 | 5.0 | 7.2 |

The data of remaining biomass in the litter bag is used to calculate the rate constant of decomposition using the formula developed by Olson (1963) as follows:

\[ M_t/M_0 = \exp(k_d t) \]  \hspace{1cm} 1)

\[ k_d = -\ln (M_t/M_0)/t \]  \hspace{1cm} 2)

Where: \( k_d \) = decomposition rate (per week); \( M_0 \) = litter dry weight at the initial stage (g); \( M_t \) = litter dry weight observed at time \( t \) in weeks.

Based on the obtained data of the \( k_d \) value, the half-life (\( t_{50} \)) was calculated, indicating the time at which half of the initial litter weight has disappeared, as follow:

\[ t_{50} = -\ln (0.5)/k_d = 0.693/k_d \]  \hspace{1cm} 3)

Where: \( t_{50} \) = half-life weight loss (week). Part of the literature uses the ‘residence time’ term for \( k_d^{-1} \); results differ by a factor 0.693

RESULTS AND DISCUSSION

Characterization

Tree density, basal area (derived from DBH measurements) and relative share of the of dominant tree in each LUS is shown in Table 2, suggesting a small difference between AFS and AFM systems, but use of these terms consistent with definitions used elsewhere (with 30% of basal area and 5 tree species per standard sample as criteria as in Hairiah et al., 2006).

Calculation of Decomposition Rate

Nine species of trees i.e. robusta coffee ( Coffea canephora ), durian ( Durio zibethinus ), cocoa ( Theobroma cacao ), langsat ( Lansium domesticum ), cloves ( Syzygium aromaticum ), jabon ( Neolamarckia cadamba ) and banana ( Musa sp. ) were found in the AFM plots at the site (+Ash), with nearly 1800 trees/ha, while AFM plots in the -Ash site had 1200 trees/ha, a similar species diversity, but lower basal area. Tree diversity was lower in the AFM plots with cocoa, banana, mahogany ( Swietenia mahogani ) and calliandra ( Calliandra sp. ) as species beyond coffee, and a higher fraction of basal area belonged to coffee, but basal area and tree population were in the same range as observed in AFM. Tree population was lowest, at only 375 trees/ha in the secondary forest plots in the -Ash location and 525 trees/ha in the +Ash location.

Ash and Soil Characteristics

In Krisik there were no signs of ash deposits during the 2014 eruption, but previous eruptions have formed the soil as it currently is. Textural analysis for Krisik (-Ash) and Tulung Rejo (+Ash) showed evidence of ash deposits at both sites in the sand-sized material in the upper soil layers (0-10 cm); across all Land Use systems the sand-sized fraction was slightly higher in the -Ash than in the +Ash sites, showing evidence of past eruptions (Fig. 3). Based on the texture most sampling sites were classified as ‘sandy clay’. The average soil bulk density (BD) was relatively low at 0.95 kg/dm³, with good soil porosity (average of 58% v/v). Soil pH was relatively low, ranging from 5.0-5.5. The C-organic content was 2.12% (w/w) at 0-10 cm depth, decreasing to 1.96% and 1.64% at a depth of 10-20 cm and 20-30 cm, respectively in the -Ash site and 1.70%, 1.42% and 0.40% for the same layers in the +Ash site, respectively. The difference in the top (two) layer(s) might be a direct effect of ash incorporation, but the difference in the third layer cannot be understood this way. It may indicate an older ash deposit.
Volcanic ash plays a very important role in the global carbon cycle and ensures the soil fertility of mountainous agricultural landscape in the future. The ash will sequester substantial amounts of carbon into chemically protected pools on their trajectory to become Andisols (with C\textsubscript{org} concentrations above 10\%). The primary source of such C sequestration has to be biological C turnover in the soil, based on active plant growth and/or external organic inputs. Andisols have favourable soil conditions and are used for horticulture on many of Indonesia’s mountain slopes and valleys. However, in the short term the highly acidic volcanic ash pH < 3.5 (Neild et al., 1998) damages plant tissue and most plants will die. Various types of trees planted in agroforestry system provide very significant protection to other crops growing underneath, because the tall canopy of big trees can filter tephra that enters the land, reducing damaged other plants growing underneath. Delmelle, Stix, Baxter, Garcia-Alvarez, & Barquero (2002) reported their research in the mountains of Nicaragua, the low level of damage in coffee plants that grow under the stand of \textit{Eugenia jambo}, \textit{Brosimum utile} or \textit{Clusia rosea} which are relatively resistant to the SO\textsubscript{2} gas emitted by the volcano. Open-field annual crops around Mount Kelud, unprotected by trees suffered the greatest damage to soil and plants (Hairiah, Suprayogo, Apriyanti, Wahyudi, & Qhomariyah, 2016).

Table 2. Basal area (BA) and number of trees from natural (secondary) forest (SF), multistrata agroforestry (AFM) and simple agroforestry (AFS) in areas with additional ash (+Ash) and without additional ash (-Ash) (based on 4 replicates per land use system per location)

| No. | Volcanic ash | LUS   | Number of trees/ha | No. of trees species | Total BA (m\textsuperscript{2}/ha) | BA dominant tree/total (%) |
|-----|--------------|-------|-------------------|----------------------|----------------------------------|--------------------------|
| 1   |              | SF    | 525               | 6                    | 9.5                              | 27.1                     |
| 2   | + Ash        | AFM   | 1794              | 9                    | 19.9                             | 23.8                     |
| 3   |              | AFS   | 1388              | 5                    | 11.4                             | 32.8                     |
| 4   |              | SF    | 375               | 5                    | 8.6                              | 30.1                     |
| 5   | - Ash        | AFM   | 1206              | 8                    | 14.4                             | 24.1                     |
| 6   |              | AFS   | 1275              | 4                    | 17.5                             | 30.7                     |

Remarks: +Ash = location with volcanic ash input, - Ash = location without ash input, SF = Natural (secondary) forest, AFM = multistrata agroforestry, AFS = simple agroforestry, TS = annual crops

Fig. 3. Percentage of sand, silt, and clay in a 0-10 cm soil sample of various LUS at the study sites
Beyond the directly negative effects, however, ash can be a source of plant nutrients. Achmad & Hadi (2015) reported that Mount Kelud volcanic ash entering a rubber plantation in Ngrangkah, Pawon (PTPN XII-Persero) was considered beneficial for rubber plants because the pH of volcanic ash was rather acidic (pH 5.0-6.0) which was ideal for rubber plants; chemical properties of the ash, with P-Bray1 levels of 38 mg/kg (classified as very high), Ca levels of 4.8 cmol/kg (very high), and a K level of 0.45 cmol/kg (moderate) provides for all plant needs except for N. These properties of volcanic ash indicate the driving force of the local evolution of symbiotic nitrogen fixation that the *Trema* – *Parasponia* pairing suggests; any gain in N supply by *Parasponia* is important in this volcanic ash environment, while the pioneer tree properties shared with *Trema* allow rapid seedling establishment and growth.

**Field Experiment 1. Ash and Organic Amendments in Infiltration Pits**

Three months after the treatments had been initiated, the addition of various doses of volcanic ash into the soil pit and the addition of various types of organic matter did not have a statistically significant (p > 0.05; Anova test of main factors and interactions) effect on the C$_{org}$ and N$_{tot}$ concentrations in the soil directly below the pit (20-30 cm layer of the original profile as shown in Fig. 2). On average C$_{org}$ was 1.7% and N$_{tot}$ 0.21%, matching the results for this layer in the characterisation study. The release of C and N in just 12 weeks probably was still too small to be seen during the measurements.

**Field Experiment 2: Decomposition Rates Soil Temperature**

A small difference in soil temperature (at 15 cm depth below the litterbags) was noted between the +Ash and -Ash sites (Fig. 4), with means of 22 °C and 21 °C, respectively. Differences can be caused by the differences in elevation, leaf area index of the vegetation, litter presence and colour of the soil influencing albedo under direct solar radiation (Akter, Miah, Hassan, Mobin, & Baten, 2016; Nwankwo & Ogagarue, 2012).

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**Fig. 4.** Average soil temperature observed at 15 cm depth in the two study sites
Decomposition Rates

Based on the measurements of remaining biomass in the litter bag, the rate of biomass loss varied with biomass type and location of measurements. Overall the biomass loss at the +Ash location was faster than at the -Ash location (Fig. 5). The decomposition rate constant ($k_d$) in Table 3 reflects these differences.

At the +Ash location, the highest rate of biomass loss was found in coffee (K) or the Coffee + Parasponia mixture (K + P) with $k_d$ values of 0.0361 and 0.0349/week, respectively. The lowest $k_d$ estimate (a $k_d$ value of 0.0289/week) was obtained in the mixture of Coffee + Sengon + Durian biomass (K + S + D). At the -Ash location, the highest rate of mass loss occurred in P (Parasponia) biomass with a $k_d$ value = 0.0292, while the lowest rate was again obtained by the K + S + D mixture with a $k_d$ value of 0.0254/week. In terms of half-life time these $k_d$ values correspond with 19-27 weeks (Table 3).

Within the data from this study, it can be classified that the decomposition rate of each biomass type as relatively fast to decompose ($t_{50} = 19$ to 21 week), medium ($t_{50} = 22$ to 24 weeks), or slow ($t_{50} = 25$ to 27 weeks).

However, the results of this study indicated that the decomposition of all biomass types was faster than in other study using the same technique (Rachmawati, Yulistyarini, & Hairiah, 2019) of mahogany biomass (Swietenia macrophylla), angsa/narra (Pterocarpus indicus), and bungur/ crape myrtle (Lagerstroemia thorelii), undertaken in the Purwodadi Botanical Gardens.

Changes in the soil environment after eruption cause changes in litter decomposition rates. Kerfahi et al. (2017) reported that within 24 months the number of bacteria in sterile volcanic ash from Mount Sakurajima increased by a factor 10-100 from the previous year, while the release of C and N increased by a factor two. The increase in bacteria in volcanic ash depends only on the soil C-organic content, while variation in soil temperature, soil pH, soil N content, and the presence of microorganism colonies in the surrounding area were not statistically related to the on-site bacterial population in this study. The litterbag study showed that biomass decomposition was faster in soils with volcanic ash input. Faster decomposition implies earlier release of plant nutrients into soil solution, but also a decline in protective ground cover (mulch). A continuous supply of litter, as can be expected in a mixed-species agroforestry system, may be needed for maintaining soil protection throughout the year.

Remarks: K = Coffee, P = Parasponia, T = Trema, S = Sengon, D = Durian)

Fig. 5. The amount of biomass lost from the litterbag during observation: (A) location (+Ash) and (B) location (-Ash)
Table 3. Decomposition constants (k) of various local plant biomasses

| Ash   | Type of biomass | Equation         | R²      | kₜ value (per week) | 1/kₜ (week) | Half-life time (t₅₀) (week) | Category |
|-------|-----------------|------------------|---------|--------------------|-------------|----------------------------|----------|
| +Ash  | K               | y = 0.0361x - 0.0348 | 0.9767  | 0.0361             | 28          | 19                         | Fast     |
|       | P               | y = 0.0337x - 0.0284 | 0.9819  | 0.0337             | 30          | 21                         | Fast     |
|       | T               | y = 0.0287x - 0.0161 | 0.996   | 0.0287             | 35          | 24                         | Medium   |
|       | K+P             | y = 0.0349x - 0.028 | 0.9779  | 0.0349             | 29          | 20                         | Fast     |
|       | K+T             | y = 0.0306x - 0.0143 | 0.9967  | 0.0306             | 33          | 23                         | Medium   |
|       | K+S+D           | y = 0.0289x - 0.0226 | 0.982   | 0.0289             | 35          | 24                         | Medium   |
| -Ash  | K               | y = 0.0269x - 0.0231 | 0.9841  | 0.0269             | 37          | 26                         | Slow     |
|       | P               | y = 0.0292x - 0.0184 | 0.9896  | 0.0292             | 34          | 24                         | Medium   |
|       | T               | y = 0.0279x - 0.0192 | 0.9883  | 0.0279             | 36          | 25                         | Slow     |
|       | K+P             | y = 0.0275x - 0.0165 | 0.9918  | 0.0275             | 36          | 25                         | Slow     |
|       | K+T             | y = 0.027x - 0.0186 | 0.9903  | 0.027              | 37          | 26                         | Slow     |
|       | K+S+D           | y = 0.0254x - 0.0153 | 0.9942  | 0.0254             | 39          | 27                         | Slow     |

Remarks: K = Coffee; P = Parasponia; T = Trema; K+P = Coffee+Parasponia; K+T = Coffee+Trema; K+S+D = Coffee+Sengon+Durian

In locations affected by volcanic ash, the application of N-rich pruned coffee biomass and the mixture of coffee biomass + Parasponia showed a faster rate of decomposition than other types of biomass, whereas in locations free of volcanic ash, Parasponia was fastest. The slow decomposition of litter biomass is influenced by internal factors (litter quality) and external factors (environment) and micro/macroorganisms. According to Cadisch & Giller (1997) and Hairiah et al. (2006) the rate of decomposition of organic matter is influenced by internal factors (C/N, lignin/N and (lignin+polyphenol)/N), decomposers, and environmental conditions. Table 4 showed that the decomposition rate (kₜ value) was, as expected, negatively correlated with the levels of lignin and polyphenol, but, surprisingly, also with N-Total. Contrary to other findings, within the research data set kₜ was positively correlated with the C/N and L/N ratios. Maybe the use of fresh prunings, rather than natural litterfall as commonly used in decomposition studies, is partly responsible for these results. Overall only about one-third of the variation in kₜ could be accounted for; however. In most studies high lignin content is a predictor of slow litter decomposition. Cadisch & Giller (1997) and Hairiah et al. (2006) suggested that high levels of lignin in biomass slow down decomposition, because lignin is a complex compound and resistant to microbiological, enzymatic, or chemical breakdown.

This study’s decomposition results can be compared (Fig. 6) with primary data of our earlier studies in the same area using the same technique i.e. cocoa (Theobroma cacao L.), sengon (Paraserianthes falcataria) and jackfruit (Artocarpus heterophyllus) on +Ash in Ngantang land directly after the ash deposition with that on an ash-free (-Ash) area in Wonosari. The comparison also included primary data points of this study using Parasponia biomass (Parasponia andersonii), anggrung (Trema orientalis), cocoa (Theobroma cacao) and sengon (Paraserianthes falcataria), in various land used that received volcanic ash input during eruptions, and data points from Purwodadi Botanical garden studied by Rachmawati, Yulistyarini, & Hairiah (2019) who compared mahogany (Swietenia macrophylla), to anggsana/narra (Pterocarpus indicus), and bungur/crape myrtle (Lagerstroemia theorellii). The figure suggests that estimating on half-life time (t₅₀) based on studies of longer duration tend to be longer – which hints at a decomposition process that has more than one phase: part of the organic input decomposes faster than the remainder, a phenomenon discussed in Cadisch & Giller (1997).
Hairiah et al. (2006) reported that residence time \(1/k_d\) of standing litter in multistrata coffee agroforestry in Sumberjaya (West Lampung) was 90 weeks (half-life time 63 weeks), whereas in simple agroforestry and monoculture coffee systems 66 or 67 weeks, respectively (half-life time 46 weeks). Relative to those studies, decomposition is rapid in the Mount Kelud area. The strongest correlation between decomposition rate constant \(k_d\) and litter quality variables was found for the total N concentration of the organic material (Table 4); relative to other studies, lignin and polyphenol concentration did not vary much between the materials and were relatively high for all materials (Table 1).

### Table 4. Relationship between decomposition rate and litter quality variables

| Relationship between variables | Correlation (r) | Equation | \(R^2\) |
|--------------------------------|-----------------|----------|----------|
| \(k_d\) value vs Lignin        | -0.5656         | \(y = -1257.4x + 63.248\) | 0.32 |
| \(k_d\) value vs Polifenol     | -0.5719         | \(y = -309.06x + 22.697\) | 0.33 |
| \(k_d\) value vs N-Tot         | -0.6105         | \(y = -392.92x + 15.88\) | 0.37 |
| \(k_d\) value vs C-Org         | -0.5788         | \(y = -687.74x + 52.884\) | 0.34 |
| \(k_d\) value vs C/N           | 0.526           | \(y = 419.36x - 4.398\) | 0.28 |
| \(k_d\) value vs L/N           | 0.4397          | \(y = 174.92x + 1.1162\) | 0.19 |

**Remarks:** The number follows the plant species is the mean of \(t_{50}\)

**Fig. 6.** Distribution of half-life \(t_{50}\) decomposition of various biomass sources measured after the eruption of Mount Kelud

Hairiah et al. (2006) reported that residence time \(1/k_d\) of standing litter in multistrata coffee agroforestry in Sumberjaya (West Lampung) was 90 weeks (half-life time 63 weeks), whereas in simple agroforestry and monoculture coffee systems 66 or 67 weeks, respectively (half-life time 46 weeks). Relative to those studies, decomposition is rapid in the Mount Kelud area. The strongest correlation between decomposition rate constant \(k_d\) and litter quality variables was found for the total N concentration of the organic material (Table 4); relative to other studies, lignin and polyphenol concentration did not vary much between the materials and were relatively high for all materials (Table 1).

**Mineral Soil N (Concentration of \(\text{NH}_4^+\) and \(\text{NO}_3^-\))**

The concentration of soil mineral N under the litterbags peaked between 4 and 8 weeks, depending on litter source and location (Fig. 7). Across all measurements 66% of mineral N was in ammonium form. The nitrate fraction was highest in the coffee+Trema (K+T) treatment and at 16 weeks, and lowest in the coffee+Parasponia (K+P) treatment and at 8 weeks. This indicates that nitrification lags behind on primary mineralization (in ammonium form), indicating relatively slow nitrification, as expected at low soil pH.

**Soil Organic C**

The C\(_{org}\) of soil below the litterbags at 6 weeks after application was not significantly different
between litter types (p > 0.05), but significantly different (p < 0.05) between locations (+Ash) and (-Ash) (Fig. 8). The results so far suggest that a number of local biomass sources, including the local N\textsubscript{2} fixing tree Parasponia, can contribute to the need of organic material to help in restoring infiltration capacity of the soils covered by ash and after mixing ash with surface soil. For the longer term organic inputs will be needed for the ash to sequester carbon on its way to become an Andisol. Farmers’ practice of constructing infiltration pits (rorak) addresses the immediate need for better infiltration, but decomposition of organic material in the pits will only in the longer term contribute to soil change in the layers beneath. Diversity of plant biomass can help in meeting the multiple and partly conflicting demands on rapid and slow decomposition in agroforestry ecosystems subjected to episodic ash inputs.

**Fig. 7.** Concentration of mineral soil N under the litterbags in two different locations at 1 - 16 weeks after application

Remarks: K= Coffee, P= Parasponia, T= Trema, K+P= coffee+Parasponia, K+T= coffee+Trema, K+S+D= Coffee+Sengon+Durian
CONCLUSION

The decomposition rates in the +Ash location varied with half-life time ($t_{50}$) of 19.5 weeks for coffee or Parasponia andersonii to 24 weeks for mixed coffee+sengon+durian biomass. In the -Ash location decomposition, $t_{50}$ of 24 weeks for P. andersonii to 27 weeks for mixed coffee+sengon+durian biomass. The concentrations of soil NH$_4$ and NO$_3$ below the litterbags peaked between 4–8 weeks, with nitrification lagging behind on ammonium release. No consistent effects on C$_{org}$ or N$_{tot}$ were noticed within the observation period.

ACKNOWLEDGEMENT

This research was funded by the Directorate of Higher Education-Rector of Brawijaya University through Program of Higher Education Leading Research (PUPT), FY 2017 and non-tax revenue (PNBP-UB) 2018. The role of the community in Tulungrejo and Krisik villages is very important to facilitate the implementation of this research, their support is highly appreciated. We acknowledge the valuable criticism and input from Prof. Meine van Noordwijk (ICRAF, Nairobi-Kenya) that improved this paper.

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