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PLANT COMMUNITY AND SOIL RELATIONSHIP FOLLOWING WILDFIRES FROM *NUÉES ARDENTES* ON MOUNT MERAPI

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ABSTRACT

At a local scale, vegetation patterns are known to have strong relationships with edaphic factors. In the case of Mount Merapi volcanic eruption, studies on the relationships between edaphic factors and plant community composition and distribution following the *nuées ardentes*-ignited wildfires will provide valuable information on post-disturbance secondary successional processes. We collected soil and vegetation data from five different ages of *nuées ardentes* fire-affected secondary succession forests and one un-affected forest. Our results showed significant correlation of species composition and edaphic factors among sites of secondary forests. Nitrogen and soil water content were found to be the important factors in structuring species composition in the youngest site, where the N-fixing legume species such as *Calliandra callothyrsus* was found to be dominant. CCA ordination also revealed strong negative correlation between nitrogen content and legume group, while non-legume group were positively correlated with other edaphic factors such as phosphor and potassium. These findings suggested that changes in soil properties due to recovery of this system after volcanic eruption correlated with plant community composition and can be crucial factors in driving the successional trajectory. Understanding ecosystem reassembly process and trajectory of succession will improve how we approach the restoration of Mount Merapi ecosystem.

Key words: wildfires, edaphic factors, plant community, sucession, Mount Merapi

INTRODUCTION

With the destruction of most lowland forest, an intact rain forest in Java Island is seemingly only occurs on mountains (Lavigne & Gunnell 2006). However, currently mountain forests are also under serious threat whether by increasing human activities or volcanic disturbances (Whitten *et al.* 1996). Forests located in extinct volcanoes are usually severely damaged by human activities. Forest fires as an impact of land clearing or illegal logging were common in these areas. Whereas in active volcanoes, volcanic

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activities remain the biggest threats to forest vegetation (Lavigne & Gunnell 2006; Whitten *et al.* 1996). The phenomenon of Merapi-type *nuées ardentes* in Mount Merapi volcano affects its forest areas. *Nuées ardentes* are hot turbulent gas and fragmented material resulting from a collapsed lava dome that rapidly moves down the volcanic slope. Local people named this phenomenon as *Wedhus Gembel*. The intense heat (often more than 700 °C) released from *nuées ardentes* ignites wildfires. Responses to fire also initiates gradual readjustments in species composition through time and this process is known as secondary succession (Riswan & Kartawinata 1991; Walker *et al.* 2007).

One of the main objectives of community ecology, including succession topic is to untangle the hypotheses concerning the relationship between species assemblages and factors that may have influenced the composition of the community (Pan *et al.* 1998). Edaphic factors such as phosphorus and nitrogen have been known as important factors constraining the growth and distribution of plant species (del Moral 2007; Lambers *et al.* 2007; Le Brocque 1995). However, it can also be seen that temporal and spatial heterogeneity of the abiotic environment is strongly correlated with the variation and heterogeneity of the floristic assembly (Ruprecht *et al.* 2007; Walker *et al.* 2003).

The general questions of how species exist in a community and the general rule of their co-occurrence is known as assembly rules and it has been a popular topic in community ecology (Belyea & Lancaster 1999; Diamond 1975; Ruprecht *et al.* 2007). Belyea and Lancaster (1999) argued that there are three driving forces of community assembly, namely distribution limitation, environmental control (including edaphic factor) and internal dynamics. Hence, environmental constraint is one of the "filters" in community assembly.

In tropical forest, the importance of edaphic factors in affecting the floristic composition of forest ecosystem has been widely studied. However, these studies were conducted on lowland forest of Sumatra or Kalimantan Island (Brearley *et al.* 2004; Herrera & Finegan 1997; Widyatmoko & Burgman 2006). Highland rain forests, especially in Java Island, remain less studied (van Steenis 1972). When a set of species are known to be associated and if the co-occurrence of these species can be related to abiotic data such as edaphic factors in their habitat, it will offer a more convincing argument regarding the niche processes that structure the community compare than if a single species approach is taken (Widyatmoko & Burgman 2006). The objective of this study was to seek answers on whether there are significant correlations between the measured edaphic factors with plant community composition in the course of secondary succession.

MATERIALS AND METHODS

Five different ages of *nuées ardentes* fire-affected secondary succession forests and one un-affected forest were visited to sample vegetation (Fig. 1). An area of ± 2.5 ha was chosen in each site (secondary forest with different age) and circular plot was used to sample the forest vegetation. Five circular sampling units (diameter range ± 60 m) were placed systematically (with random start) in each site. In each sampling unit, three circular-nested plots (named here as sampling points, of 10, 5 and 2 meter in diameter in each circular plot) were established to measure the trees, shrubs and groundcover (Isango 2007; Supriyadi & Marsono 2001). In total, there were 30 sampling units and 90 sampling points established across the secondary forests. The position and altitude of each sampling unit were recorded using a GPS (Garmin E-Trex legend).

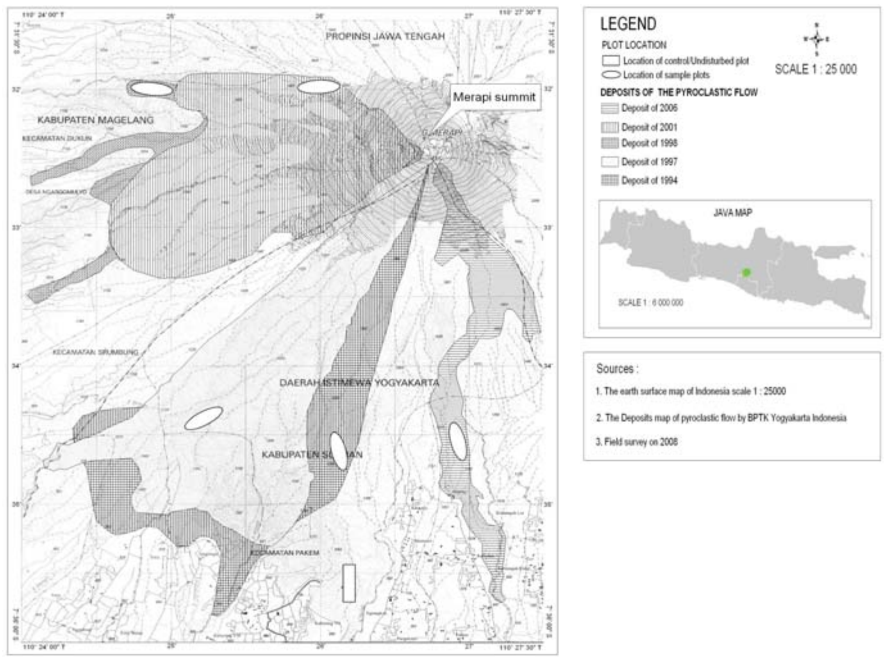

Figure 1. Map of Mount Merapi National Park's eruption deposits. Circular symbols refer to position of sampling sites in each deposit. Rectangle refers to position of an undisturbed site.

Trees (dbh ≥ 10 cm) and understorey plants species were noted and measured in their abundance (number of individual) (Kent & Coker 1992; Supriyadi & Marsono 2001). All plant species within each site were identified to species when possible. Identification was conducted at the dendrology laboratory Faculty, of Forestry, Universitas Gadjah Mada, Yogyakarta, Indonesia. Identification was done using flora books such as "the Flora of Java" (Backer & van den Brink 1963) and "Mountain flora of Java" (van Steenis 1972) and also confirming the results to a botanist at the Faculty. To assess possible interaction between edaphic factors and the species occurrence, soils were sampled from each locality in the succession forest sites and the undisturbed forest site. Three to five soil samples were collected from random points within each sampling unit. Soil samples were taken from 0-20 cm depths using an auger (5 cm diameter), bulked and sealed in a plastic bag and transferred to the laboratory. After removing stones, pebbles and large pieces of plant material, the samples were sieved by 2 mm mesh screen and used for further physicochemical analysis. Soil samples were analyzed at the soil science laboratory, Faculty of Agriculture, Universitas Gadjah Mada (UGM, Yogyakarta, Indonesia).

To match species composition and abundance patterns in each site with their soil characteristics, BIOENV method was employed (Clarke & Ainsworth 1993). BEST analysis using BIOENV method performs a rank correlation of two similarity matrices (biotic and environmental), and by successively testing for every possible combination of environmental parameters indicates which set of habitat attributes best explains the observed community patterns. Statistical significance testing on BEST-BIOENV results were done by generating global ϱ value by 999 permutations. BEST analysis was done in PRIMER v.6. program (Clarke & Gorley 2005). Furthermore, to better visualize the relationships between soil characteristics and the spatial distributions of the species, Canonical Correspondence Analyses (CCA) (ter Braak 1986) featured in CANOCO program (ter Braak and Smilauer 2002) was employed. The CANODRAW program (Smilauer 2002) was applied for the graphical presentation of the results of ordination (Palmer 2009). Environment (e.g. soil) is depicted as arrows whereas species were symbolized as dots in the CCA ordination diagram (Kim & Yu 2009).

RESULTS AND DISCUSSIONS

BIOENV analysis revealed significant correlation of species composition and edaphic factors ($\varrho = 0.61, p < 0.01$) among sites of secondary forest on Mount Merapi. Table 1 gives detailed measure of the correlation between sites and the soil characteristics. Species composition in all sites were influenced by nitrogen concentration (*Rho* = 0.35). Soil's water content correlates with species composition in most of the sites except the 1997 and 1994 with *rho* values 0.45. The highest correlation value (*Rho* = 0.61) occurs in sites 2001 and 1994, where they were strongly correlated with the phosphorus content. BIOENV selected organic carbon as the factor that more likely structured the plant community in the 1994 site (*Rho* = 0.32). Potassium was the factor that most closely associated with biotic patterns in the 2001, 1998 and 1994 sites (*Rho* = 0.55).

Table 1. Edaphic factors best constraint community composition in each site. Rank correlation method: Spearman. Sample statistic (Rho): 0.61. Significance level of sample statistic: 0.1%. Number of permutations: 999 (Random sample).

Variables	**Site selection**	**Spearman's *rho* (ϱ)**
Phosphorus	2001, 1994	0.61
Potassium	2001, 1998, 1994	0.55
Soil's water	2006, 2001, 1998, undisturbed	0.45
Nitrogen	All sites	0.35
Organic Carbon	1994	0.32

BEST-BIOENV method gave a selection of sites and their characteristics that best explain their species composition, while here CCA is more supplementary to BEST results. CCA gives clearer view of the species distribution along some environmental (edaphic) gradients. Generally, species were distributed mostly around the C, P, water and N axes (Fig. 2). The relation of some species with their edaphic variables is summarized in Table 2. The relation of species with N status could be indicated by their correlation with N arrow (Fig. 2). *Calliandra callothyrsus* had negative correlation (Spearman's *rho* = 0.25) with N arrow. This indicated that *Calliandra callothyrsus* abundance increased in a plot or site with low N content, as this species belongs to Leguminoceae family which is known to have the N-fixing ability. The strongest correlation between species-soil was shown by *Altingia excelsa* with K arrow with *rho* value = 0.62. The ecological preference for *Anaphalis javanica* was apparent from its proximity to P arrow. Positive correlation (*Rho* = 0.37) shown by *Anaphalis javanica* with P axis indicated that this species was abundant in a site with high P content.

Table 2. Correlation of certain species with edaphic factors identified from the CCA ordination diagram.

Species	**Edaphic factors**	**Spearman's correlation coefficient**
Altingia excelsa	Potassium	0.62.
Imperata cylindrica	Phosphorus	0.49
Anaphalis javanica	Phosphorus	0.37
Calliandra callothyrsus	Nitrogen	(-) 0.25
Eleusine indica	Nitrogen	(-) 0.21
Brachiaria paspaloides	Organic carbon	0.29
Eupatorium riparium	Organic carbon	(-) 0.21
Eupatorium odoratum	Soil's water content	0.17

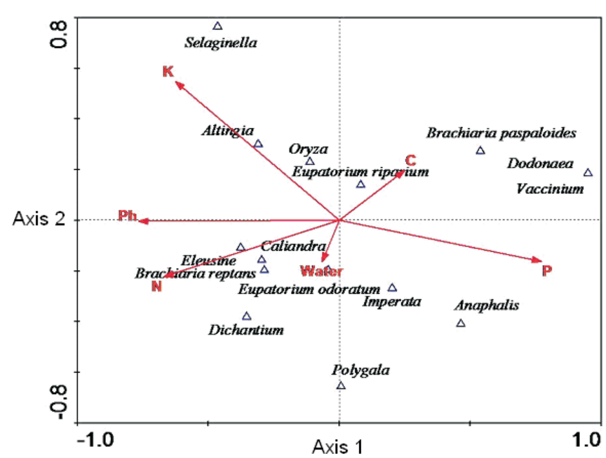

Figure 2. Biplot ordination diagram derived from Canonical Correspondence Analysis (CCA) showing distribution of selected species along the soil characteristics. Triangles correspond to the species.

Based on CCA analysis, 32.3% of variance in plant composition was explained by CCA axis 1 and 30.2% by CCA axis 2, implying a fairly strong gradient representation (Table 3). The overall performance of the CCA ordination diagram was good, indicated by the high coefficients of species-environment correlations (1.0). Monte Carlo permutation tests confirmed the significance pattern in plant distribution on the first two axes ($p < 0.001$).

Table 3. Summary of the CCA ordination analysis.

Axes	1	2	3	4	Total inertia
Eigenvalues:	0.456	0.426	0.291	0.172	1.410
Species-environment correlations:	1.000	1.000	1.000	1.000	
Cumulative percentage variance of species data:	32.3	62.5	83.2	95.4	
of species-environment relation:	32.3	62.5	83.2	95.4	
Sum of all eigenvalues					1.410
Sum of all canonical eigenvalues					1.410

Many ecological studies have departed from the notions that ecological heterogeneity of species assemblages in communities is associated with the abiotic factors that overlapped in space and time (Pan *et al.* 1998). In line with Pan (1998), Clarke and Ainsworth (1993) stated that, some limitations are involved in the nature of the link between species and the environment. In Mount Merapi, these constraints were also observed. Nitrogen and soil water content (% moisture) were selected by BIOENV analysis as the factors structuring the species composition in the 2006 site (youngest site). Young volcanic ash origin is usually impoverished in N especially in the early stage of succession (Tan 2008). This condition then allows N-fixers species such as *Acacia decurrens* to invade the sites. N-fixing species in Mount Merapi secondary succession mainly consists of *Acacia decurrens* and *Calliandra callothyrsus*.

Influence of soil characteristics and nutrient supply on the presence of plant species in a community have been shown by both observational and experimental studies (Pan *et al.* 1998; Petr & Lepš 1991). These studies had used Canonical Correspondence Analysis to reveal the ecological preference of species with the environmental factors (Le Brocque 1995; Petr & Lepš 1991; Tsuyuzaki & del Moral 1994). The CCA ordination diagram in this study revealed the relation between N content and some N_2 fixers' species was observed in the study sites. Plant of N_2 fixer's species in the study sites were mainly consists of *Acacia decurrens* and *Calliandra callothyrsus*. According to Peet (Peet 1992), as the N content increases, N fixation will decrease. *Calliandra callothyrsus* showed negative correlation with N. This indicated that *Calliandra callothyrsus* abundance increased in a plot or site with low N content. Other species from non legume group also showed a correlation with the edaphic factors. *Altingia excelsa* is a typical tropical montane tree species in Java, showed the highest positive correlation with K, and whereas *Anaphalis javanica*, an endemic tropical montane pioneer shrub correlates best with P.

The capability of alien invasive species to change soil chemical properties remains relatively unknown (Collins & Jose 2009). However, correlation study may be the first step to understand the phenomenon. Presence of invasive species can potentially change many components of carbon (C) nitrogen (N) phosphorus (P) and water content (Collins & Jose 2009; Ehrenfeld 2003). In this study, *Imperata cylindrica* positively correlated with P, while *Eleusine indica* negatively correlated with N. When compared to native pine savanna and legumes, *I. cylindrica* seems to be a better competitor for P (Brewer & Cralle 2003). *Brachiaria paspaloides* had positive correlation with soil organic carbon while *Eupatorium riparium* showed negative correlation.

Changes in physical environment especially soil properties can be crucial factors in driving the successional trajectory. Soil processes are correlated with plant changes and expected to be associated with successional dynamics (Bautista-Cruz & del Castillo 2005). Understanding the trajectory of a succession is also important in order to achieve restoration goals. Succession and restoration are inextricably linked mainly because succession consist of changes in substrates and species as time progressed while restoration is aimed at manipulating that changes (Walker *et al.* 2007). The knowledge gained from this study will be useful for managers working in the Mount Merapi National Park as a baseline data to consider when setting up reforestation and restoration program.

CONCLUSIONS

Wildfire disturbance following Mount Merapi eruption has changed substrate properties, which associated with changes in vegetation pattern. Nitrogen, phosphor, carbon and soil water content were found to be the important edaphic factors structuring plant composition and distribution in Mount Merapi. N-fixing species were found abundant in younger deposits with low nitrogen content, while plant composition in older deposits was mainly influenced by organic carbon and soil water content. Information on changes in plant community composition and distribution along edaphic gradients can be useful to understand the trajectory of succession in Mount Merapi.

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