Nutrient input from the litterfall in the lowland forest of Gunung Gede Pangrango National Park

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Abstract. The litterfall dynamic research has been carried out in the lowland forest of Gunung Gede Pangrango National Park aimed to determine the turnover of nutrient in the ecosystem. Plant litterfall production is crucial ecosystem process that defines the nutrient returns through the decomposition process of the forest floor. Litterfall is one of the nutrient input sources of the ecosystem. One year period of litterfall was monitored from the littertraps, and the nutrient contents were analyzed to determine the nutrient return to the ecosystem. The litter falls that have been classified as leaves, stems, reproductive parts and others were collected every month. The results showed that more nutrient litterfall components i.e. N, K, Ca, Na, Mg (except for P) returned to the soil in rainy season than in dry season. The litter fall nutrient return based on the highest to the lowest can be arranged in the following sequence Ca> N> K> Mg> Na> P; with the total values were 19.18 ± 2.42 (SE) > 18.81 ± 2.08 > 3.1 ± 0.51 > 2.98 ± 0.58 > 1.02 ± 0.24 > 0.53 ± 0.06 kg ha⁻¹, respectively. The pattern of nutrient input in each component corresponds to the component of the litterfall production.

1. Introduction
Land conversion is one of the reasons in declining of forest area and soil quality. The conversion of forests into agricultural land, plantations, and other uses has caused major impact on biomass and primary production which reduces the function of nutrient cycles in the forest areas. Therefore, the information related to nutrient input and output of litterfall in forest areas as the main source of nutrients intake needs to be examined. Forest area in Indonesia is estimated around 94.1 million ha, equivalent to 50.1% of the total land area in Indonesia, which consists of various types of ecosystems stretched out from eastern to the western part of Indonesia. The most declining forest-ecosystem area was lowland forest ecosystem in the period of 1985-1997. It was recorded around 60% forest area declination [1] mainly on the three Indonesian largest islands (Sumatra, Sulawesi and Kalimantan), followed by Java island which had been degraded decades ago due to land use change. In the period of 2000–2010, researchers have estimated forest loss in Indonesia reached 8.8 million hectares or 9.3% of the total areas. Most of the forest loss was in lowland forest, which covered an area of 7.8 million hectares or 11% compared to forest cover in 2000
The remaining lowland forests in Java are mostly in conservation areas, such as Baluran National Park (NP), Meru Betiri National Park, and Karimun Jawa. In West Java province, one of remaining lowland forest is Gunung Gede Pangrango National Park. The reduction of forest area affected the quality of the environment. Accordingly, maintaining forests and its quality becomes a necessity. As it is known, tropical natural forests have high annual productivity [3], and the nutritional cycle of tropical natural forests is important mainly to reduce nutrient loss and maintain high productivity in poor-nutrient forest soil.

Nutrient cycle has an important role for the plant growth. The nutrient which returns through the litter to the forest floor is the main pathway for transferring nutrients from plants to the soil [4-7]. Through the decomposition process of organic matter, litter will release nutrients into the soil and subsequently will be taken up by plants for producing new biomass. At the ecosystem level, nutrient cycle is important in increasing fertility and productivity of tropical forest ecosystems, which generally have low soil fertility [8].

Research on ecological studies in various Indonesian ecosystems have been carried out from Sumatra to Papua bioregion, including other islands such as Maluku and the Lesser Sunda Islands. The research revealed data collections from permanent plots as reported by Brearly et al. [9]. In addition, the studies on nutrient content from litter in lowland forest ecosystems have been carried out by Bruijnjezel in Central Java [10], in Bornean mixed dipterocarp forest [11], Jambi [12,13], and West Sumatra [14], peat swamp forests in Central Kalimantan [15,16] and Riau [17], industrial plantations in Riau [18,19], lowland forest in Jogjakarta [20,21], and in Natuna islands [22]. Meanwhile, the study of nutrient input in the forest ecosystems for tree growth and the production of new biomass have not been explored in more detail. This information is necessary to determine soil fertility conditions, especially in the poor-nutrient tropical forest soil [8]. The increasing of human population and the demand for agricultural products have driven rapid land-use change in the tropical rainforest. These forest ecosystems are rich in biodiversity and play a crucial role in the global Carbon cycle (C cycle). In addition, it also provides important ecosystem services. The ongoing land-cover change in Indonesian tropical forest in conjunction with global warming, has the potential to alter fundamental ecosystem functions such as C and nutrient cycles. The nutrient cycle has an important role in transferring nutrient to the soil thus increasing the fertility of the tropical forest.

Gunung Gede Pangrango National Park (TNGGP) is one of nineteen biosphere reserves in Indonesia which has a diversity of ecosystems from lowland forests to upper mountainous forests. The lowland forest in Gunung Gede Pangrango NP is an area with the range of humidity between 30-90% depending on location and altitude. Annual precipitation in the area range between 3000-4000mm. During the rainy season, the range of precipitation is around 200–400mm; while in the dry season, it is around 100mm monthly. As one of the lowland ecosystems, the sources of nutrient input in the lowland forest of Gunung Gede Pangrango are from rainfall, throughfall, stemflow, litterfall, and other resources such as tree species composition. Furthermore, these characteristics will affect the nutrient input value in the ecosystem. Some examples of tree dominant species in the lowland forest in Gunung Gede Pangrango NP are Nauclea lanceolata, Maesopsis eminii and Schima walichii; those species are shedding the leaves at the beginning and at the end of rainy or dry season [15,23]. This variation then determines the total input of litterfall which subsequently contributes to the amount of nutrients entering the ecosystem. Therefore, this site is one of interesting natural laboratories to study. However, disturbance to the biodiversity, intensive agriculture, and infrastructure development in surrounding area have caused changes in the ecosystem which contribute to several major impacts i.e biodiversity loss, floods, and landslides. These activities cause changes in ecosystem function. Research on the structure, flora composition, and litter productivity has been carried out in the low montane forest of Gunung Gede Pangrango National Park [23,24], as well as research on litterfall biomass production, and their seasonal variations in lowland forest ecosystem [15].
However, information about nutrient content of litterfall in the lowland forest area remains unstudied. Hence, the purpose of the study was to determine the input of nutrients in the lowland forests of Mount Gede Pangrango National Park.

2. Methods

2.1. Study site
The research site of this study was in lowland forest Bodogol Nature Conservation Research Center in Gunung Gede Pangrango National Park (GGPNP), Cicurug sub-district, Sukabumi district. One-hectare permanent plots were established to determine the tree structure and its composition. The altitude of the study site was 822m above sea level, with the precipitation between 3000 to 4000 mm per year, and the slope ranges from 30-50%. The permanent plot positions were located at 06°46’39.3” latitude and 106°51’30.9” longitude. The dominant species in the study site were *Maesopsis eminii* Engl., *Schima wallichii* Blume, *Dysoxylum densiflorum* (Blume) Miq., *Nauclea lanceolata* DC. Korth, and *Pterandra azurea* DC. Soil pH was in the range of 4.2-5.1, with the element content of P₂O₅ available in the soil in the range of 2-4.7 ppm, action exchange capacity of Ca, Mg, and Na were 5.53-12.4; 3.21-7.00; and 0.26-0.78 me/100 g, respectively [15].

2.2. Litterfall experiment
Twenty litter traps were randomly set up within permanent 1ha plots following a contour line in the lowland forests. The litter trap was square in shape and had a surface area of 1m². Each was placed 1m above the ground and tied to four 1m long PVC poles stuck into the soil. Litterfall was collected monthly over one year period. Litterfall was separated into (i) leaf litter; (ii) < stem 2cm diameter (twigs or woody litterfall); (iii) stem ≥2cm diameter (stem branch); (iv) reproductive parts (fruits and flowers); and (v) others i.e materials that could not be classified into leaf, twigs, stem, branch and reproductive parts. The litterfall was separated for each trap at each sampling time. These fractions were dried in an oven at 75°C for 24 hours and weighed separately. Litterfall sample was crushed and filtered with a 0.5mm size sieve and prepared for nutrient analysis at the Plant Ecology Laboratory, Research Center for Biology.

2.3. Chemicals analyses
The litterfall samples (leaf, reproductive parts, stem, twigs, and others) were homogenized using an electric grinder, and analyzed for phosphorus, calcium, potassium, and nitrogen contents. Two hundred forty samples were analysed for chemicals measurements, 0.2 g of litter materials were used for chemical analyses. The litter samples were analyzed by wet digestion method using an acid mixture of H₂SO₄, HNO₃, and HCl. Furthermore, extracts from the digestion were used to measure P content with UV-Vis spectrophotometer (Shimadzu UV mini 1240); Ca and Mg were measured by atomic absorption spectrophotometers, K and Na contents were measured by a flamephotometer (Shimadzu AA-6800). N analysis was performed with CN analyzer (Yanaco JM 1000CN). Nutrient analysis was carried out for all litterfall components: leaves, stems, twigs, reproductive parts and others.

3. Results
Research on nutrient cycles in lowland forests has been conducted in peat swamp [15,16], heath, alluvial, and dipterocarp forests [25] which provide information on nutrient input in these forests. In the low mountain forest area of Gunung Gede Pangrango National Park, the studies about nutrient cycle were conducted by Yamada in 1976 [23] and Rahajoe in 2006 to 2012 [15]. Therefore, these results will
complement the data and information on nutrient input and dynamics from lowland forest to low mountainous area in Gunung Gede Pangrango National Park.

3.1. Litterfall nutrient content

The results showed that most of the components of litterfall released Nitrogen (N), Potassium (K), Calcium (Ca), Magnesium (Mg), and Sodium (Na) content were higher in the rainy season than that of dry season, those were 21.47 ± 0.98; 3.78 ± 0.46; 20.23 ± 2.49; 3.36 ± 0.69; and 1.28 ± 0.32 (SE, mg g⁻¹), respectively (figure 1). This corresponds to the total number of litterfall during rainy season which was higher than dry season [15]. It was estimated that almost all plant species contribute to the high of litterfall in rainy season. Specifically for Phosphor (P), the highest concentration was recorded in the dry season, in the range of 0.66 ± 0.04 (SE, mg g⁻¹).

The nutrients returning from each type of litterfall components are varied. More specifically, the results of this study described that the highest nitrogen returned into the soil was from other components (those components can not be determined); it was recorded for 24.8 mg g⁻¹. The nitrogen return of leaf and reproductive parts were recorded to have the same tendency of 20.9 and 20.5 mg g⁻¹. The smallest concentrations were contributed by twigs and stem components with 18.3 and 17.2 mg g⁻¹ respectively. The return of phosphorus nutrient has the highest value for the reproductive part (0.9 mg g⁻¹), followed by other components with a value of 0.8 mg g⁻¹, leaves of 0.6 mg g⁻¹, while the twigs and stems of P nutrient returns were the same; accounted for 0.4 mg g⁻¹. Nutrient K return was further contributed by the reproductive part with a value of 5.4 mg g⁻¹, followed by leaf components of 3.6 mg g⁻¹, others of 3.2 mg g⁻¹, twigs of 2.7 mg g⁻¹, and the stems with the smallest nutrient K return was accounted for 2.3 mg g⁻¹.

The lowest Ca nutrient return was contributed by the reproductive component which accounted for 11.4 mg g⁻¹, while the Ca returned from the leaves, stems, and twig components were relatively similar, which accounted for 22.8; 22.6; 22.0 mg g⁻¹, respectively. The nutrient return of Mg and Na tends to be the same for all components, in the range of 3.3-3.0 mg g⁻¹ and 1.2-1.0 mg g⁻¹. This study documented that each litterfall component contributes to nutrient return in accordance with the amount of litterfall and nutrient content.

3.2. Potential nutrient return through litterfall

Litterfall is the main pathway for nutrients return from the forest canopy to maintain soil nutrient pool. Litter nutrient content varies between dominant species and ecosystem types [15, 25, 26]. Annual nutrients returned from the highest to the lowest were as follows: Ca> N> K> Mg> Na> P, the total value was recorded for 19.18 ± 2.42> 18.81 ± 2.08> 3.1 ± 0.51> 2.98 ± 0.58> 1.02 ± 0.24> 0.53 ± 0.06 kg ha⁻¹, respectively (Table 1). The order of nutrient return of each litterfall component is in accordance with the order of the production of litterfall component [15], where the leaf litterfall component has the highest value compared to the other components.

The highest N and Ca return was documented on leaf component. It was then followed by other parts such as stems, twigs and reproductive part components (Table 1). Moreover, the highest P and Mg return was recorded on leaf component, followed by other components (unidentified materials of litterfall) in the second position, while the third position was varied among the litterfall components. In the case of P and Mg return, the third position was recorded for reproductive parts and stem component, while the lowest P and Mg return was recorded for stems or twigs and reproductive part, respectively. Potassium (K) and Natrium (Na) return was recorded highly for leaf, and that was followed by reproductive parts, others and stem for K. While Na returns from the highest to the lowest were leaves > stem > others > twig and reproductive parts. The annual nutrient returns through the litterfall in the lowland forest in our study
site have a higher value than other tropical rain forests, except for the P and K elements which are smaller than in the China’s tropical forests (Table 2).

![Graphs showing nutrient content](image1)

**Figure 1.** Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), and Sodium (Na) contents of 175 litterfall components in the dry and rainy seasons in Gunung Gede Pangrango NP.
Table 1. Annual nutrient return of the litterfall components in Gunung Gede Pangrango National Park.

| Litterfall Component | Nutrient | Return |
|----------------------|----------|--------|
|                      |          | N      | P      | K      | Ca     | Mg     | Na     |
| Leaf                 |          | 12.73±1.07 | 0.34±0.03 | 2.22±0.32 | 13.39±1.25 | 2.00±0.38 | 0.68±0.14 |
| Stem > 2 cm          |          | 1.31±0.26 | 0.03±0.007 | 0.16±0.07 | 1.68±0.45 | 0.21±0.05 | 0.11±0.05 |
| Twig/stem <2 cm      |          | 1.29±0.17 | 0.03±0.004 | 0.17±0.02 | 1.69±0.31 | 0.21±0.04 | 0.08±0.02 |
| Reproduction part    |          | 1.18±0.28 | 0.05±0.009 | 0.29±0.07 | 0.52±0.06 | 0.15±0.03 | 0.06±0.01 |
| Others               |          | 2.30±0.30 | 0.08±0.01 | 0.26±0.03 | 1.90±0.35 | 0.32±0.08 | 0.09±0.02 |
| TOTAL                |          | 18.81±2.08 | 0.53±0.06 | 3.1±0.51 | 19.18±2.42 | 2.98±0.58 | 1.02±0.24 |

4. Discussion
The results showed that the information from natural phenomena in lowland forest ecosystems can be very useful for forestry management in the conservation areas. Annual potential return of Ca (19.18 ± 2.42 kg ha⁻¹) was higher than those of other nutrients (N, P, K, and Mg). Based on the results of the study, it showed that most of the litterfall components provided high nutrient return during rainy season, except for the P return. The high nutrient return during rainy season was aligned to several previous studies in other tropical forest regions, such as in the teak forests of the Satpura high hill, central India, and in the broad leaf wet montane forests, China [27,28]. This is also supported by the research results from Cuevas & Lugo [29], Wood et al. [30], Paudel et al. [31], in which nutrient leaching from litter during dry season will increase the availability of plant nutrients at the beginning of the rainy season. Whereas Read and Lawrence [32], described the lack of water in the dry season reduced the absorption of nutrients from the soil. It consequently affected nutrient release and mineralization in the dry season.

The order of annual nutrient return through litterfall from the highest to the lowest is Ca> N> K> Mg> Na> P (Table 1). These nutrient sequences are the same as those conducted in tropical rain forests, China [33] and secondary lowland rainforests, Nigeria [8]. However, this sequence is different when compared to peat forests in Central Kalimantan, with the sequence Ca> Mg> K> Na> N> P [16]. The difference of the nutrient sequences of the litterfall depends on the difference of the species composition, soil nutrient content, water condition [15,16,23] and their nutrient use efficiency [26]. These are the main factors that affect the litterfall production and nutrient released in these ecosystems. The annual composition of nutrient returns from this study showed that the concentration of Ca and N were higher than those of other nutrients, 19.18 ± 2.42 and 18.81 ± 2.08 kg ha⁻¹, respectively. Calcium and Nitrogen are the main nutrients used to increase leaf area and plant growth. These two elements have close relationship in the role of plant nutrition. In addition, calcium plays a role in the absorption of nitrates and affects the growth of the plant [34].
### Table 2. Nutrient returns from the litterfall in various tropical forests (kg ha\(^{-1}\) y\(^{-1}\)).

| Soil types                  | N   | P   | K   | Ca  | Mg  | Na  |
|-----------------------------|-----|-----|-----|-----|-----|-----|
| Total litterfall            |     |     |     |     |     |     |
| Jawa Barat\(^{a}\)          | 220.7 | 6.2 | 36.5 | 224.4 | 33.7 | 11.7 |
| Jawa Tengah\(^{b}\) Central | 3.7  | 35.0 | 144.0 | 25.0 | 3.0  |     |
| Kalimantan\(^{c+1}\) Central | 50.3 | 2.7 | 26.1 | 95.3 | 20.8 | 2.7  |
| Kalimantan\(^{c+2}\)       | 25.1 | 0.6 | 11.2 | 61.9 | 14.2 | 1.8  |
| Nigeria\(^{d}\)            | 101.8 | 4.1 | 57.4 | 103.8 | 18.0 | 8.3  |
| Malaysia\(^{e}\)           |     |     |     |     |     |     |
| Aluvial                     | 103.0 | 5.4 | 29.9 | 86.9 | 17.5 |     |
| Sandstone hill              | 47.6 | 1.3 | 11.5 | 19.6 | 11.7 |     |
| Sandstone valey             | 56.9 | 1.6 | 18.4 | 29.4 | 14.7 |     |
| Heath                       | 48.9 | 1.2 | 14.6 | 43.9 | 14.8 |     |
| Brazil\(^{f}\)             |     |     |     |     |     |     |
| Aluvial                     | 92.7 | 5.7 | 24.0 | 79.2 | 14.8 |     |
| China\(^{g}\)              | 135.9 | 8.4 | 40.4 | 145.8 | 19.6 |     |
| China\(^{h}\)              | 277.2 | 13.0 | 70.7 | 136.3 | 36.2 |     |
| China\(^{i}\)              | 144.1 | 11.9 | 56.9 | 122.4 | 15.2 |     |
| Leaf litterfall             |     |     |     |     |     |     |
| Jawa Barat\(^{a}\)          | 152.7 | 4.1 | 26.7 | 160.6 | 24.0 | 8.1  |
| Jawa Tengah\(^{b}\) Central | 62.0 | 3.0 | 26.0 | 120.0 | 21.0 | 2.5  |
| Kalimantan\(^{c+1}\) Central | 34.1 | 0.7 | 19.6 | 70.8 | 16.5 | 2.0  |
| Kalimantan\(^{c+2}\)       | 16.8 | 0.4 | 8.9  | 45.6 | 11.9 | 1.4  |
| Jambi\(^{j}\)              | 112.9 | 2.9 | 17.6 | 52.4 | 16.8 |     |
| West Sumatra\(^{k}\)       | 92.5 | 2.6 | 17.2 | 125.3 | 11.7 |     |
| Brazil\(^{l}\)             |     |     |     |     |     |     |
| Aluvial                     | 61.3 | 3.6 | 15.7 | 51.0 | 8.8  |     |
| Inseptisol                  |     |     |     |     |     |     |
| Costa Rica\(^{m}\)         |     |     |     |     |     |     |
| Highland: ultisol           | 126.0 | 5.0 | 15.0 | 65.0 | 18.0 | 4.0  |
| Ultisol slope               | 114.0 | 4.0 | 15.0 | 46.0 | 13.0 | 4.0  |
| Costa Rica\(^{n}\)         |     |     |     |     |     |     |
| Inseptisol                  | 87.9 | 7.5 | 48.3 | 118.0 | 22.0 |     |

\(^{a}\)This study; \(^{b}\)Bruijnzeel [10]; \(^{c}\)Yustinus [16]; \(^{d}\)Oziegbe et al. [8]; \(^{e}\)Dent et al. [42]; \(^{f}\)Scheer et al. [43]; \(^{g}\)Tang et al. [33]; \(^{h}\)Kotowska et al. [13]; \(^{i}\)Hermansah et al. [14]; \(^{j}\)Wood et al [37]; \(^{k}\)Celentano et al. [45].

*Lowland tropical rain forest; *seasonal climate; *\(^{m}\)manmade; 1Mixed swamp forest; 2Low pole forest.
Annual nutrient returns through litter in the Bodogol forest have higher value than other tropical rain forests (Table 2), except for the P and K elements which are smaller than China’s tropical forests [33]. The differences in annual nutrient returns in some forest ecosystems are affected by the rainfall, temperature, water, nutrient availability in the soil, composition of plant species and litter production [14,15,32,35-38]. A high nutrient return can be assumed that the nutrient availability is high in the soil. However, this also depends on the level of decomposition and the quality of the plant species, which varies among species [15,39]. From the decomposed litter, the nutrients are available for the plant to take and produce biomass.

Phosphorus nutrient content in lowland forests is lower than the other macro nutrients (Table 2), low P nutrient returns indicates that the P is a limiting factor for plant growth both in the tropic and sub-tropical regions [7,40]. This subsequently affects the low P soil availability [41]. Annual P nutrient returns through litterfall in this study are in the same range as in Sepilok lowland tropical rainforest in Malaysia and in the secondary tropical rainforest in Salto Morato Nature Reserve, Brazil [42,43].

The leaf component is the biggest contributor to annual nutrient returns. This is positively correlated to litterfall production. Leaf litter production in the lowland forests of Gunung Gede Pangrango NP is greater than other litter components, which was recorded for 78% [15]. Some research also reveals that leaf litter is the largest contributor in the return of nutrients to the soil in various types of ecosystems; the leaf litterfall was in the range of 55-78% [10,16,23,25,28,31,40,43,44].

In this study, Nitrogen return through leaf litterfall was 152.7 kg ha\(^{-1}\)y\(^{-1}\), which is higher than the research in the wet tropical forest of La Selva Biological Station, Costa Rica, Harapan lowlands and Bukit forests Dua Belas, Jambi with successive values of 114-133 and 112.9 kg ha\(^{-1}\)y\(^{-1}\) [13,37]. The high N content in the litterfall is related to the nitrogen content in the leaf litterfall which is about 12.73 kg ha\(^{-1}\). Moreover, the high leaf litterfall was recorded for 72.5% of the total litterfall in this lowland forest [15]. Mg nutrient is recorded at 24 kg ha\(^{-1}\)y\(^{-1}\); the value is close to the results of the research in Pringombo lowland forests, Central Java and secondary tropical rain forests in Costa Rica which is around 21-22 kg ha\(^{-1}\)y\(^{-1}\) [10,45]. The K element from the results of this study also has similar range as the results of research in the lowland forests of Pringombo, Central Java and the wet tropical forests of La Selva Biological Station on insepticol soil, Costa Rica with values ranging from 23.0-26.7 kg ha\(^{-1}\)y\(^{-1}\) [10,37].

P nutrient return through leaf litter was recorded at 4.1 kg ha\(^{-1}\)y\(^{-1}\). This value is higher compared to Pringombo lowland forest area (Central Java), tropical rain forest Pinang-Pinang (West Sumatra), successional secondary tropical alluvial tropical rain forest, old vegetation Salto Morato Nature Reserve (Brazil), Harapan lowland forest, and Bukit Dua Belas (Jambi) with value of 3, 2.6, 3.6 and 2.9 kg ha\(^{-1}\)y\(^{-1}\), respectively [10,13,14,43]. The high P content in the litterfall related to the P content in the leaf litterfall which was about 0.34 kg ha\(^{-1}\). The high leaf litterfall was recorded for 72.5% of the total litterfall [15]. However, P nutrient return from this study is equal or lower than those in the wet tropical forest of La Selva Biological Station, Costa Rica which is 4-6 kg ha\(^{-1}\)y\(^{-1}\) [37]. Whereas, the return of Ca and Na nutrients is higher than other lowland locations [10,13,14,37,43,45]. Phosphorus returns have little value in most tropical forests (lowland and montane). In tropical forests, phosphorus is recycled efficiently. However, the high P concentrations in this study show low P use efficiency [43,46].

The location is a forest with a slope variation between 30-50%, and in this study we use the total value of litterfall. A study on the effect of slope on nutrient input information was conducted in timber forests in central New York and found that litter and nutrient intake were greatest on foot slopes [47]. This trend is also likely to occur in this low montane forest. Meanwhile, another study described the dynamics of annual litter and different nutrient deposition with respect to altitude and land use on Mt. Kilimanjaro [48], soil fertility in the Sepilok Forest Reserve (SFR) Sabah [42], as well as the disturbance in tropical mountain forests [31], and in evergreen hardwood forests in Central Taiwan [44].
5. Conclusion
Research on nutrient dynamics in the lowland forests of Gunung Gede Pangrango National Park showed high nutrient returns which occurred during the rainy season, except for P. In regard to the leaf litter components, leaves are the main source of nutrients return to the soil. Successive nutrient return from the highest to the lowest order is Ca > N > K > Mg > P > Na. These nutrient returns are lower than other forest ecosystems in tropical rain forests and sub-tropical plantation forests. The lowest nutrient return P indicates that P is a limiting factor for plant growth.

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